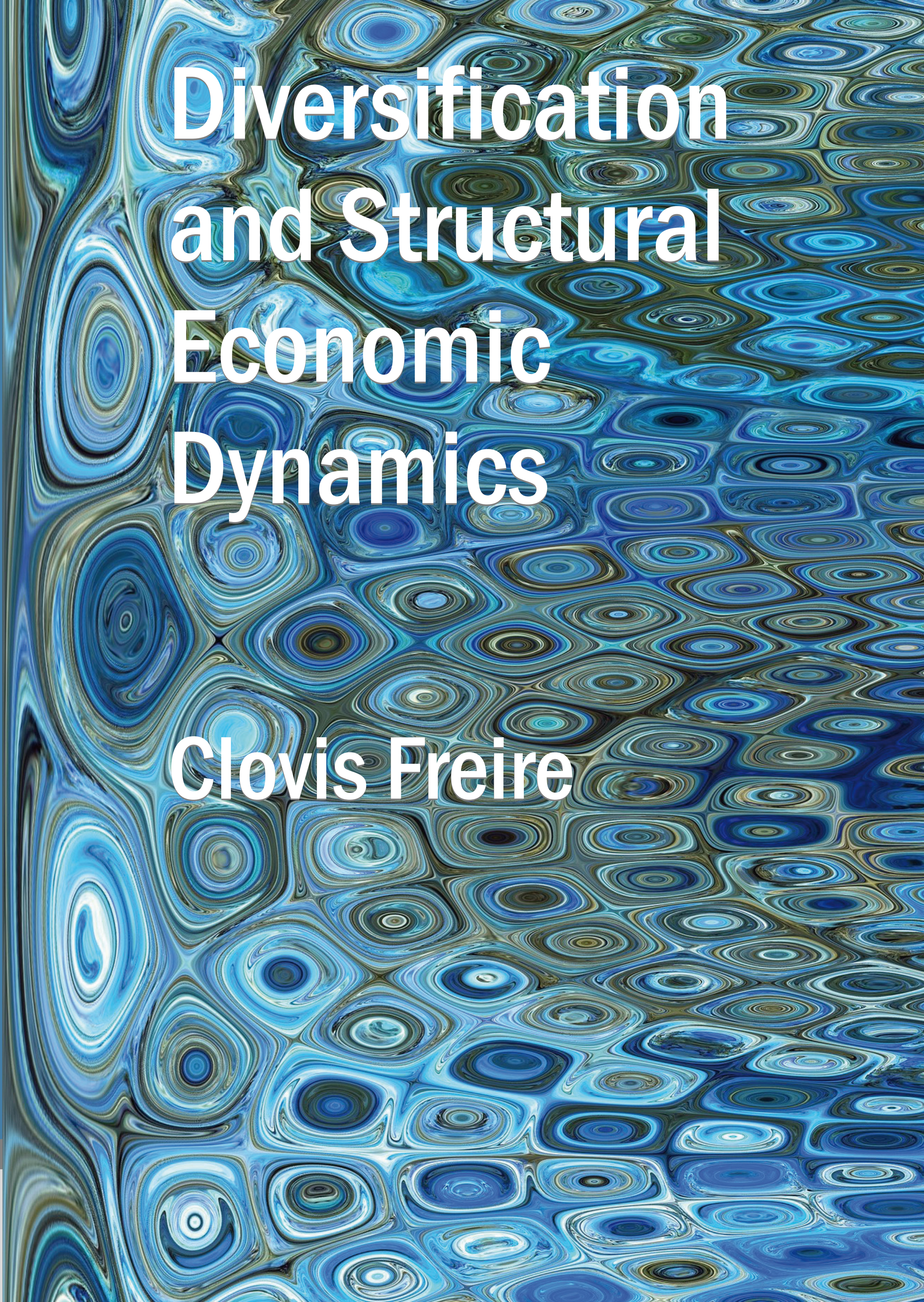

Diversification and Structural Economic Dynamics

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DISSERTATION

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by

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I dedicate this book to my father.

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Symbols

N_k	total population in country *k*
L_k	total labour available for production sectors in country *k*
$l_{j,k}$	labour coefficient (labour input per unit of output) to produce commodity *j* in country *k*
$c_{j,k}$	coefficient of consumption per capita of commodity *j* in country *k*
$MK_{j,h,k}$	proportional markup added to the price of commodity *j* produced in country *k* and consumed in country *h*
w_k	nominal wage rate in country *k*
$p_{j,h,k}$	price of commodity *j* produced in country *k* and consumed in country *h*
$c_{j,h,k}$	coefficient of consumption per capita in country *h* of commodity *j* produced in country *k*
$Q_{j,k}$	quantity of commodity *j* produced in country *k*
$E_{j,k}$	employment in sector *j* in country *k*
E_k	total employment in country *k*
$Y_{j,k}$	output of sector *j* in country *k*
Y_k	total output in country *k*
y_k	output per capita in country *k*
$Exp_{j,k}$	household expenditure in sector *j* in country *k*
Exp_k	total household expenditure in country *k*
exp_k	per-capita household expenditure in country *k*
$X_{j,k}$	exports of sector *j* in country *k*
X_k	total exports of country *k*
$M_{j,k}$	imports of products produced by sector *j* in country *k*
M_k	total imports of country *k*
$BOP_{j,k}$	balance of payments related to trade of product *j* in country *k*
BOP_k	balance payments of country *k*

1

Introduction

1.1 Diversification and development

The main topic of this thesis is the perennial quest for the nature and causes of the wealth of nations. Why are some nations rich and are others poor? What can unleash development in poorer nations? Or what is holding them back? These are the questions that are at the core of this work.

In the library of human knowledge, the room reserved to this topic is already full of well-crafted studies. At the centre of it, stands the shelf dedicated to innovation and technology change. It contains countless books that contribute to our knowledge on the importance of innovation to development and how factors such as education, health, governance and institutions contribute to innovation capacity and technological change.

This work focuses on one aspect of innovation and development that has been less explored: the diversification of economic activities. This is a quintessential characteristic of development. The more developed the society, the more diversified its economy. In the words of Adam Smith:

"Though in a rude society there is a good deal of variety in the occupations of every individual, there is not a great deal in those of the whole society.... In a civilized state, on the contrary, though there is little variety in the occupations of the greater part of

individuals, there is an almost infinite variety in those of the whole society." (Smith, 1776, p.430).

As pointed out by Saviotti and Pyka (2004a), the importance of the study of the association between diversification and development depends on whether diversification is only a result of growth or whether diversification is a determinant of future growth. This dissertation tries to contribute to a better understanding of these linkages.

Economic diversification, ultimately, is the result of innovation. Each new economic activity, producing a new good or service, generates a novelty. That novelty is the result of the innovation process and technology change. Therefore, it should not be surprising that a more developed economy is also more diversified; it contains the result of innovation which is the driver of progress.

In the context of developing countries, economic diversification is usually associated with the introduction of a product that is new to the country but not to the world. Such emulation[1] of more productive activities, which were the result of previous innovation in more developed countries, has long been recognized as an important way for poorer economies to catch up. For example, Gerschenkron (1962) notes the importance of borrowed technology in the rapid development of backward economies in their early stages of industrialization. Abramovitz (1986, 1989) argues that the emulation of best-practice technology from the United States was a key element for the rapid growth rates in Europe and Japan in the post-war period. Reinert (2007) argues that the process of emulation is the way that rich countries got rich. Lin (2012) suggests that a common feature of diversification strategies adopted by countries that were successful in catching up was that they targeted mature industries in countries not far away in terms of income per capita. Emulation is also at the core of the "Flying Geese Model" pattern of economic development, in which economies grow by starting production in sectors that were once traditional in more developed economies, such as garments, but were phased out in those countries when they introduced new sectors at the technology frontier (Akamatsu, 1962).

However, emulation requires the innovative process of absorbing and adapting technologies to country's context. Streams of the literature related to catching up and technology gap have explored the factors and conditions that facilitate or hinder that process (Abramovitz, 1986, 1989; Lall, 1992; Verspagen, 1993; Fagerberg, 1994; Los and Verspagen, 2006). Moreover, diversification is a path-dependent process and possibilities for emulation are not equally available at

[1] In the literature on technology change, 'emulation' is usually referred to as 'imitation'. In this dissertation, I prefer to use 'emulation' because I believe that, for those that are not aware of that literature, the term imitation somehow gives the false idea that such process entails merely copying the production processes that are in place in more advanced economies.

any given point in time (Gerschenkron, 1962; Dosi, 1982, 1988; Hausmann and Klinger, 2007; Hidalgo and Hausmann, 2009). Products that are produced in a country today affect the products that will be produced in that country in the future. Hausmann and Rodrik (2006) argue that path-dependence in the process of diversification is created because new activities tend to exploit the productive capacities that were previously developed for other activities. Therefore, the industries that are more likely to be emulated are those that require a set of technologies that largely overlaps with the set required by the existing industries in the economy. On the other hand, the incentives for creation and combination of technologies are shaped by economic institutions and the expected demand for the new products.

Therefore, the question for policymakers in developing countries is how to foster the emergence of more productive industries given the technological level of the current production base and the domestic and global demand for potential new products.

1.2 Motivations for the dissertation

There are two main motivations for this dissertation. The first is the relevance of economic diversification for poorer developing countries to create jobs and foster structural transformation and economic development. That need has been recognized in key internationally agreed development goals including the 2030 Agenda for Sustainable Development,[2] the Programme of Action for the Least Developed Countries for the Decade 2011-2020 (Istanbul Programme of Action),[3] the Vienna Programme of Action for Landlocked Developing Countries for the Decade 2014-2024,[4] and the Small Island Developing States Accelerated Modalities of Action (Samoa Pathway).[5]

I first became interested in the topic of economic diversification in 2011 when I was tasked, as part of my work as Economic Affairs Officer at the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), to prepare a chapter of the Economic and Social Survey of Asia and the Pacific on the theme of building productive capacities in Asia-Pacific least developed countries. That is a critical theme for these countries and it is the first priority for action listed in the Istanbul Programme of Action.

A recurrent theme in the discourse for building productive capacities is its importance in creating the conditions for economic diversification. That is critical

[2] United Nations A/RES/70/1.

[3] United Nations A/CONF.219/3.

[4] United Nations A/CONF.225/L.1.

[5] United Nations A/CONF.223/10.

for many poorer developing countries and least developed countries in particular. These economies are very reliant on the production and export of few agricultural commodities or manufactured goods from low-wage and low-productivity industries, which makes them exposed to price and exchange rate volatilities in the international markets. Most of these countries are also challenged by high unemployment and under-employment, and their populations would benefit from a more diversified economy that could support more jobs.

My initial approach for that research was to find ways to quantify productive capacities, to be able to study how they have evolved and which policies were in place to foster the development of those capabilities. The literature on technology change and growth emphasize that productive capacities are related to technology and consist of very specific knowledge, skills and processes that require effort to learn and master (e.g. Dosi, 1982; Perez and Soete, 1988; Verspagen, 1993). Empirical streams consistent with that literature have proposed methods to estimate the capabilities associated with different industries (e.g. Michaely, 1984; Lall, Weiss and Zhang, 2005). I saw the method of reflections proposed by Hidalgo and Hausmann (2009) to quantify economic complexity as one of such empirical methods that could be used as a way to estimate the productive capacities of least developed countries. In their definition of economic complexity, a more complex economy would have a more diverse set of non-tradable capabilities required for the production, and that includes such elements as "property rights, regulation, infrastructure, specific labour skills, etc." Therefore, a country with more productive capacities is a more complex economy. In addition to the productive capacity, or economic complexity, of countries, the method also estimates the set of capabilities required to produce each product exported, also called product complexity (e.g. Felipe, Kumar, Abdon and Bacate, 2012).

The three key assumptions behind that method make a direct link between productive capacities and economic diversification. First, the assumption that products require a specific set of non-tradable capabilities to be produced. Second, countries have a set of those capabilities but not all of them. Third, countries produce the goods and services for which they have the capabilities required to produce.

The method of reflections had to be modified to be applicable to least developed countries. The main issue is that the method uses export data as proxy for production, but exports from poorer and less populous countries are very volatile. I had to modify the method and develop a new dataset to be able to estimate the levels of productive capacities of those countries. That work is presented in the first part of this dissertation.

I had the opportunity and privilege to present and discuss that work with policymakers and practitioners in conferences, seminars and workshops organized by ESCAP as part of its programme on countries with special needs. In those interactions, it became clear that more important than being able to estimate and track the evolution of productive capacities was the possibility to identify potential new products for diversification based on the existing productive capacities of countries.

I saw the possibility of identifying these products by combining the method of reflections with a method to map the network of products connected to each other ('product space'), which has been proposed by Hidalgo, Klinger, Barabasi and Hausmann (2007). That paper found that the product space has particular characteristics with certain products, such as computers, electronics or cars, connected to many other products, while products such as oil, vegetables or leather, are connected to only a few. A key assumption in that stream of literature is that countries diversify by expanding their production to products that are close to their existing production in the product space.

My proposal was to identify the potential products for diversification that are also more complex than the average product in the economy. The hypothesis is that diversification following that path would result in an increase in the productive capacities of the economy over time. Early in that research, I was reminded to take into consideration not only the supply capacity of countries, in terms of what they are able to export, but also the demand incentives that producers face. I developed a method to estimate these demand incentives both in terms of exports as well as import replacement. I then developed a methodology to identify potential new products for diversification combining these methods.

Working for ESCAP, I had the chance to apply that methodology in the context of least developed, landlocked developing and small Island developing countries and report the results in several meetings and publications. That work is presented in the second part of the dissertation.

The second motivation for the dissertation is exactly the fact that many of the scientific results that have informed the political debate, which to some extent resulted in the emphasis on diversification in internationally agreed goals mentioned above, are a product of the literature concerned with economic complexity. That stream of literature has uncovered several stylized facts about the pattern of diversification of economies, but the development of explanations for those patterns in general has been only loosely associated with the literatures on growth, trade, technology change and structural transformation. There is, therefore, an opportunity for exploring ways to link these literatures in order to expand our knowledge about the relationship between diversification and economic development. A better understanding of these relations is of great interest to policymakers in developing countries in designing and implementing policies and strategies for promoting inclusive growth and catch up with developed economies.

An effort in that direction is presented in the third part of the dissertation. The model presented in this book is an initial attempt to incorporate diversification within a multi-country multi-sectoral structural economic dynamics framework considering trade. As any model, it makes many simplifications. One of them I would like to address at the outset. The model considers that all goods produced are final consumption goods and therefore it does not consider trade in tasks or activities, in which different stages of production of a final product are allocated to countries with different characteristics. That is indeed a very important feature of global trade and a following step to this thesis, discussed in the final chapter, would be to consider the formulation of the model within an input-output framework.

1.3 Objective and research questions

The objective of this study is to verify the relation between economic diversification, structural change and economic growth to identify strategies that facilitate the emergence of productive activities in poorer economies and promote economic catch up.

From the discussion in the previous sections, a critical element of any such strategy would involve the identification of potential new products for diversification. Therefore, a key research question of the dissertation is: which new economic activities are more likely to emerge given the level of diversification of the current production base and the domestic and global demand for potential new products?

The investigative questions that have guided the research are: What is the relationship between economic diversification, structural change and economic growth? How does the level of economic diversification affect the number of possible opportunities for future diversification? Which strategies could governments in developing countries follow to facilitate the emergence of more productive economic activities?

1.4 Research outline

The dissertation is structured in three parts: empirical regularities, methodology to identify products for diversification, and modelling of diversification and structural economic dynamics. The first part is comprised of Chapters Two to Four and focuses on empirical regularities related to diversification.

Chapter Two presents a review of the literature about economic complexity and its main results. That stream of literature has contributed with stylized facts, such as those related to the relationship between diversification and growth, and by highlighting the importance of not only how diversified an economy is but also which products the economy produce. The chapter also presents and discusses the terminology introduced in that literature, which will be used in the dissertation and includes terms such as 'ubiquity', 'economic complexity', 'product complexity', 'product space' and 'productive capacities'.

The third chapter presents the datasets and the methodology used to estimate the diversification and level of productive capacity of economies and the level of complexity of products exported. The datasets used are based on trade data disaggregated at 5 and 6 digit levels and cover 220 to 240 countries and the period from 1984 to 2013. The data is further disaggregated by unit value range, which results in datasets with 30,000 to over 44,000 products. The methodology presented is based on the method of reflections, which is revised to allow the analysis of diversification, productive capacities and product complexity of least developed countries. The chapter also presents the methodology to build the product space, which is used to assess possible diversification paths based on existing export patterns.

The fourth chapter presents the results of the replication of the stylized facts of the literature on economic complexity using the datasets and the methodologies presented in Chapter Three. The chapter also presents new stylized facts related to the evolution of diversification, productive capacities and distribution of complexity of products of countries. The chapter shows: 1) a positive association between the export diversification of a country and its total GDP, 2) a negative association between diversification and the average number of countries that can export a similar basket of products, 3) that opportunities for caching up in terms of diversification are not equally distributed and less diversified countries tend to fall behind, 4) that development is associated with the expansion of exports towards products of higher complexity, and 5) that countries are more likely to diversify towards products that are near in the product space and that have similar levels of product complexity.

The second part of the dissertation is comprised of Chapters Five and Six and focuses on the presentation and application of a methodology to identify potential new products for diversification.

Based on the analysis of the network of products exported in the world, the fifth chapter discusses whether governments should play an active role through industrial policies to foster structural transformation and economic diversification, or whether markets incentives would be sufficient to drive this process of catching up.

Chapter Six presents a methodology to identify potential products for diversification. The methodology combines the analyses of product complexity and of the structure of the product space of a country, with the analysis of the export and import replacement opportunities. The objective is to identify sectors that would maximize the opportunities for countries to build their productive capacities and promote structural transformation through the emulation of the productive structure of more developed countries. The analysis focuses on the group of 36 least developed, landlocked developing and small Island developing countries in the Asia-Pacific region. For each of these countries, the chapter presents the top five sectors with highest percentage of potential new products, and the potential new sectors with highest export and import replacement opportunities. The chapter also identifies export opportunities in agro-based processing activities that could potentially be linked to the existing agricultural production in Asia-Pacific least developed countries. The application of that methodology could assist governments and the private sector to identify potential new sectors for consideration in the design of industrial and investment policies.

The third part of the dissertation is comprised of Chapters Seven to Twelve. It proposes and discusses a model of structural economic dynamics with economic diversification. The objective of the model is to allow for testing changes in policies that could facilitate the process of catch up through economic diversification.

Chapter Seven presents a literature review of the models that have been proposed to explain the stylized facts uncovered in the literature on economic complexity. It then discusses how models of other economic traditions have treated economic diversification and what is the modelling strategy adopted in the dissertation to link the empirical results of the economic complexity literature with the formalism of economic dynamics of the literature on structural and technology change.

Chapter Eight explores the role of diversification within the framework of structural economic dynamics proposed by Pasinetti (1993). It adopts the assumptions of the literature on economic complexity related to the links between countries, capabilities and products. The chapter contributes to the literature by analysing the impact of diversification on technological unemployment and long term growth.

Chapters Nine and Ten present the main model proposed in this thesis, which combines diversification, structural change and international trade. Chapter Nine describes the model without the use of mathematical formulas. The objective is to give the reader a sense of the functioning of the model by presenting the sectors that comprise an economy, how they are interlinked, how countries trade with each other, what is exogenous and what is endogenous to the model, and how the model works in the short- and long-term. The formal description of the model is presented in Chapter Ten.

Chapter Eleven presents the functioning of the model without diversification. The objective is to describe the pattern of trade and export specialization given a fixed set of goods produced. The chapter discusses the model by presenting a set of results of computer simulations.

Chapter Twelve presents the analysis of the model with economic diversification by exploring different sets of parameters through computer simulations. The focus is on the dynamics of the model that regulate the emergence of new products and how these products affect the demand and production of existing products. The chapter also presents the results of computer simulations that show how the model replicates the stylized facts discussed in Chapter Four. The chapter explores policy-oriented questions such as those related to the effects of targeted strategies for diversification to facilitate the process of catch up. It considers ways in which less diversified countries could move ahead, which links back to the issues raised in the preceding chapters related to opportunities for diversification in least developed countries.

The final chapter presents the conclusions and a discussion on how the dissertation is placed in relation to the literature. The chapter also discusses possible directions for future research.

2

Literature review

This chapter presents a review of a stream of the empirical literature on economic complexity and discusses stylized facts related to diversification that result from that body of work. That literature advances the principle that what a country produces and exports matters more for long term economic development than the value that it gets out of that production. The reason is that what a country is capable to produce in the present affects what that country would be able to produce in the future. That stream of literature is in great part the result of the collaboration between development economists and physicists, and uses and adapts methods and measurements of network analysis. The discussion in this chapter provides the basis upon which the relevance and novelty of contributions of this dissertation could be assessed.

2.1 Diversification and the empirical literature on economic complexity

The literature on economic complexity covers several topics related to economic diversification such as varieties of products (e.g. Page, 2001; Content and Frenken, 2016), the role of proximity and relatedness of different industries, sectors, products and technologies in the process of innovation and diversification (e.g. Boschma, 2005; Hidalgo et al., 2007; Arthur, 2009; Neffke and Henning, 2013; Balland, Boschma and Frenken, 2015), and indices of the complexity of countries and products that are based on measures of diversification (e.g. Hidalgo and Hausmann, 2009; Zaccaria, Cristelli, Kupers, Tacchella and Pietronero, 2016), to name a few.

The stream of the literature discussed in this chapter, and in which the first two parts of this dissertation are based, is a subset of that literature that, to a large extent, is associated to the methods, indices and results presented in Hidalgo et al. (2007) and Hidalgo and Hausmann (2009). That literature covers two main complementary areas. First is the creation of quantitative indices that are used to estimate the complexity of economies and products. That area of research initially aimed at analysing the association of these indices with measures of income of countries to estimate future growth. The second main area is the analysis of the network of countries connected to products that they export and of the network of products connected to other products that are jointly exported. That line of research focuses on mapping the diversification paths of countries, studying the association between industries and uncovering new stylized facts regarding patterns of trade specialization.

A seminal study in that literature is Hausmann, Hwang, and Rodrik (2007). In that paper the authors argue that what a country exports matters for its current and future levels of wealth. That paper contributes to the literature on patterns of trade specialization by changing the focus away from the fundamentals such as country's endowments or quality of institutions, and emphasizing instead the role of entrepreneurs, which could be incentivised to emulate the production of more developed economies. The argument is based on the idea well accepted by early development economists (for example Rosenstein-Rodan, 1943; Hirschman, 1958; Prebisch, 1959) that products differ in terms of their consequences for the economic performance of the countries that produce them. As a result, for the long-term growth of countries, specialization in some products is more beneficial than specializing in others. However, a key element in this framework is that entrepreneurs face discovery costs that are not completely internalized (Hausmann and Rodrik, 2006). They have to adapt the production of the industry that they emulate to the realities of the economy of their country.[1] Once an entrepreneur successfully emulates that production, other entrepreneurs would know that such a good can be produced in the country and would enter in that sector. That would increase the export performance of the country in the short-term but would also reduce the innovation rents of the incumbents, which has an impact on their incentives to emulate in the first place.

A key contribution of that paper is the proposed framework for ordering products based on their association with higher productivity levels. The authors propose two new empirical measures: *PRODY* and *EXPY*. The first is used to estimate the level of income or productivity associated with a product. The index is created as a weighted average of the GDP per capita of the countries that export that product, using as weight the revealed comparative advantage (RCA) of each country in exporting that product. The second index, *EXPY*, is a measure of productivity level associated with the pattern of specialization of a country and is constructed as the average of the *PRODY* of the products exported by that country weighted by the share of exports. The authors show that *EXPY* is strongly correlated with the level of GDP per capita of countries and put forward the hypothesis that deviations from that association can predict subsequent economic growth.

At least two other indices similar to *PRODY* had been proposed at the time of the publication of Hausmann, Hwang, and Rodrik (2005), which was acknowledge in that paper. Similar to *PRODY*, they are calculated as a weighted average of the income per capita of the countries that export the product. The difference between these measures was in the weighting scheme adopted. The index proposed in Michaely (1984), called "income level of exports", predates *PRODY* in using the average income per capita of countries that exports a product to measure the level of income associated with the product. The weighting scheme adopted in Michaely's index uses the market share of countries in global exports of the relevant product, as opposed to the weighing scheme adopted in the construction of *PRODY* that uses the revealed comparative advantage of countries exporting the product. The second index was proposed by Lall et al. (2005) as a measure of the level of sophistication of exports. That index uses country's share of world exports as weights in their calculation. The definition of export sophistication used by the authors is that "an export is more sophisticated the higher the average income of its exporter", and it reflects export "characteristics that allow high wage producers to compete in world markets." They argue that these characteristics include technology, marketing, logistics and proximity, divisibility of the production process, information and familiarity, natural resources, infrastructure, value chain organization, in addition to policy such as trade restrictions and subsidies, trading

[1] This is an idea also present in the literature on technology change (for example see Lall, 1992).

blocs and trade preferences, among others. Similar to the idea of the index *EXPY*, Lall et al. (2005) also present a measure of sophistication by country and region calculated as the average sophistication of the exports weighted by the share of each product in the country or region total exports.

Hausmann and Klinger (2006) present an analysis of the determinants of the evolution of the level of sophistication of products exported by countries. The paper, in a way, presents a dynamic view of the study of economic complexity and product sophistication presented in Hausmann, Hwang, and Rodrik (2005). Echoing arguments of the literature on technology change (e.g. Lall, 1992), the authors emphasize that the production of new products, either products that are new to the world or new to the country, is a process that is very different from the production of existing products. The firm that start the production of that new product should figure out how to combine all the required nontradable capabilities:

"*For example, they will not find workers with experience in the product in question or suppliers who regularly furnish that industry. Specific infrastructure needs such as cold storage transportation systems may be non-existent, regulatory services such as product approval and phytosanitary permits may be underprovided, research and development capabilities related to that industry may not be there, and so on. In short, changing products is problematic and the difficulties it involves may adversely affect the process of development.*" (Hausmann and Klinger, 2006)

A key argument of the paper is that the capabilities required to produce one good are different from those required to produce another good, but the level of product specificity vary. Using their own example, the capabilities required to produce trousers are closer to those required to produce shirts than those to produce computers. Therefore, the probability that a country will develop the capabilities to produce a specific new product is higher if the country already produces other goods for which existing required capabilities can be more easily adapted.

Based on that idea, Hausmann and Klinger propose the concept of a product space - a network in which products are connected to each other based on a measure of similarity (distance) between two products, which is calculated as the probability that countries export both products. The authors illustrate that idea with a metaphor of products being trees and firms being monkeys whose livelihood is based in exploiting the trees that they occupy, and the product space being a forest comprised of those trees. The forest can be homogenous with trees equality distant from each other, or heterogeneous with some parts of the forest with trees close to each other and other parts that have trees far from each other. The homogenous forest increases the probability of monkeys jumping from one tree to the other.

Hausmann and Klinger (2006) also propose a measure of density of a product in the product space, which is the average distance between a potential new product and all products that the country already exports. That measure indicates the likelihood of a potential new product to be produced. If the density of that product is high, it is close to many products that the country already exports and may require capabilities that can be more easily adapted from the capabilities already in existence.

Hausmann and Klinger uses the measure *PRODY* proposed by Hausmann, Hwang, and Rodrik (2005) to estimate the 'implied productivity' of each product. The idea is that products with higher *PRODY* values are associated with countries with higher income per capita, which are more productive. Therefore, these products have higher 'implied productivity'. They then argue that the process of structural transformation involves firms moving from the poorer parts of the product space, comprised of products with low values of *PRODY*, to the richer parts (higher values of *PRODY*). However, the probability of a country undergoing structural transformation would depend on the structure of the product space – how close to the richer part of the product space are the products already produced? A key contribution of that research is to emphasize the differences in the ability of firms to emulate production depending on the distance of the country's current production to the potential new products, and to show empirically that the product space is heterogeneous.

In 2007, Hausmann and Klinger presented a shortened and revised version of their 2006 working paper, which further emphasizes the role of the structure of the product space in driving the process of structural transformation. One of the main revisions was the removal of the analysis that included the index *PRODY* to verify if structural transformation involved the shift towards parts of the product space that have products associated with higher productivity (higher *PRODY*). Instead, the paper focused on presenting the stylized fact that changes in the revealed comparative advantage of countries are directed by the pattern of relatedness of products at the global level – the product space. Hausmann and Klinger (2007) also show that the stylized fact is only partly explained by other measures of similarity proposed in Leamer (1984), based on factor intensity, and in Lall (2000), which is based on the technology class associated with a good, suggesting that the product space reflects elements of similarity that are more product-specific than broad factor or technology intensity.

The increased emphasis of Hausmann and Klinger (2007) on the structure of the product space as determinant of paths of structural transformation was followed by more rigorous research of network structure employing tools of network analysis. In doing that, Hausmann and Klinger teamed up with Albert-László Barabási, well-known for his work in the research of network theory, and his PhD student at that time, Cesar Hidalgo. In Hidalgo et al. (2007), they present the measures of proximity and density that were introduced in Hausmann and Klinger (2006) and add a set of visualizations of the product space of different countries and their evolution over time. In these visualizations, products are nodes in a network and are connected to each other by links whose colour represents the proximity between two products. These visualizations show the product space as characterized by a core and a periphery.[2] Its core is composed by products that are closely connected and are mainly from the industries of metal products, machinery and chemicals. In its periphery, which is formed by the other product classes, the products are less connected and more distant from each other in terms of the likelihood of being jointly exported.

They also simulate the evolution of product structure of countries when assuming that firms in a country move to the production of goods that are within a given distance to the existing products exported by the country. The results show that when firms are assumed to jump longer distances from one product to the other, both more and less connected developing countries are able to catch up with the production pattern of more developed countries, although countries that have their exports in more densely connected parts of the product space are able to catch up in a shorter period of time. On the other hand, when firms are assumed to move only to products that are at a closer distance, some countries are not able to diversify their production and get stuck in less dense parts of the product space. The policy implication is that some countries may require more strategic intervention to diversify their economies to products that are very distant from their current production in the product space. The authors acknowledge that policies that promote such large jumps are more challenging but they argue that they are required to generate subsequent structural transformation and growth.

The authors also included supplementary material that presents various stylized facts. They show that the product space is composed by few links that represent short distances between products, which they called strong links, and many links representing longer distances – weak links. The distribution of the proximity value of the links is shown to follow approximately a log-normal distribution. The authors show that the structure of the product space is in broad agreement with the classification of products presented in Leamer (1984) in the sense that the average proximity of the products in the clusters according to Leamer's classification is always higher than the proximity for products of different clusters. They also present an analysis of the value of the sophistication of each product (measured by *PRODY*) as a function of the proximity between products. The results suggest that if structural transformation only moves production to more sophisticated products, in some cases a local maximum may trap countries. In other words, countries may reach some sophisticated products (i.e. high *PRODY*), but these may be isolated in the product space, without possible paths to other even more sophisticated products. That is the case of cereals and animal agriculture products that were located in the periphery of the products

[2] This is an analogy that has clear resonance with the Latin American Structuralist literature (e.g. Prebisch, 1959).

space but have relatively large values of *PRODY*. The authors also show that the structure of the product space is relatively stable over a period of 10 years. They analyse the structural transformation of countries over time and show that countries move to new products that are close to the existing products already exported. They show that the closest the proximity between a potential new product and an existing product, the higher is the probability of the country to diversify its exports to include that new product.

The indices and results of Hausmann, Hwang, and Rodrik (2007) and subsequent research discussed above have received much attention. Many in the academic community and practitioners in the development community have used the indices to analyse the evolution of productivity of countries and estimate their potential for future growth (e.g. Di Maio and Tamagni, 2008; Jankowska, Nagengast and Perea, 2012; Anand, Mishra and Spatafora, 2012; Felipe et al., 2012). However, that research has also received criticisms related to the way that the indices were created and the implications for the predictions of potential subsequent growth (e.g. Harrison and Rodríguez-Clare, 2009; Wang, Wei and Wong, 2010). One of the criticisms was that products produced by richer countries invariably would have a higher value for the index *PRODY* given that the measure uses in its calculation the GDP per capita of countries that export that product. The result was considered a tautology with rich country's products being exported by richer countries.

In a way, the response to that criticism was presented in another very influential paper, Hidalgo and Hausmann (2009). In this paper, the authors develop measures of capabilities that are not associated with the level of incomes of countries. They present the so called "method of reflections" to estimate the economic complexity of countries. The method interprets trade data as a bipartite network in which countries are connected to products that they export. The authors base their argument on the endogenous growth theory (Romer, 1990 and Grossman and Helpman, 1991) to suggest that "wealth and development are related to the complexity that emerges from the interactions between the increasing number of individual activities that conform an economy." The authors, put forward the hypothesis that productivity of a country is linked to the diversity of nontradable capabilities and that "differences in income can be explained by differences in economic complexity, as measured by the diversity of capabilities present in a country and their interactions." The core of their argument is that in a global market for inputs and outputs with opportunities to exploit division of labour at global scale, a possible explanation for differences in income between countries is differences in nontradable capabilities such as policies, regulations, infrastructure, or specific knowledge and skills related to the production activities.

Although not mentioned by Hausmann and Hidalgo, a similar argument in terms of capabilities from the point of view of innovation and development is found in Lall (1992) and Bell and Pavitt (1995). For example, Lall (1992) proposed a framework for explaining growth in the capabilities of a country based on the interrelations between capabilities, incentives and institutions. In that framework, capabilities are composed broadly of physical investment, human capital and technological effort.

Hidalgo and Hausmann illustrate their method to estimate the number of nontradable capabilities in the country, which they called economic complexity, by using an analogy with Lego pieces. Each country has the equivalent to a bucket of those pieces and we see what each country can produce with them. Each Lego model requires a specific set of Lego pieces to be assembled. A country with a bucket with more pieces would be able to produce more Lego models. Therefore, by looking at the Lego models that a country is able to produce we can infer the Lego pieces that it has in its bucket. Similarly, they assume that:

1- Products require a specific set of nontradable capabilities to be produced;

2- Countries have a set of those capabilities but not all; and

3- Countries produce the products for which they have the required capabilities to produce.

The method of reflections is proposed to assess the capabilities in a country. The method is based on the analyses of the network of countries connected to products that they export. That network is built empirically using trade data. The method generates a series of successive measures of diversification of countries and ubiquity of the products exported. Ubiquity in this literature means the number for countries that export that product. They argue that the higher order of those measures is able to reflect the set of capabilities available in the economy and they use that measure to rank countries in terms of economic complexity. The authors also put forward many results that were later further explored in the literature, including the negative association between diversification and ubiquity and the positive association between economic complexity and income.

In a 2009 working paper, Hidalgo (2009) shows that the new measures of diversification and ubiquity are correlated with the indices *PRODY* and *EXPY* proposed by Hausmann, Hwang, and Rodrik (2007). He also shows that more than the GDP per capita of the countries, those indices reflect the structure of the network connecting countries to products. In that same paper, Hidalgo presents the evolution of economic complexity of a set of countries between 1963 and 2005. Focusing on the trajectory of the countries that were able to transform their productive structure, he shows that China already had a more complex economy throughout that period and argues that the hardships that the country suffered during the 1950s and 1960s were related to the poor incentive structure and not from the lack of capabilities, which were unleashed when the country reformed its economy. In that regard, he cautions about the reliance on the same set of reforms in other countries that do not have an already more complex economy.

Hidalgo (2009) also presents an analysis of the evolution of the product sophistication as measured by *PRODY* and shows that, despite some variation, the relative sophistication of products remains constant in the period from 1985 to 2000. He also shows that the change in the structure of the product space of countries is driven mainly by the structural transformation of those countries, which move production with relative comparative advantage from one product to the other, instead of being driven by changes in the sophistication of the products and their position within the product space, which remained relatively constant throughout the period.

Hausmann and Hidalgo (2010, 2011) continue to explore the properties of the network connecting countries to the products that they export. They present four stylized facts related to that network: the negative relationship between the diversification of a country and the average ubiquity of its exports, and the non-normal distributions for product ubiquity, country diversification and product co-export. They propose a model, called the binomial model, which adopts the same assumptions as in Hidalgo and Hausmann (2009): products require many nontradable capabilities, and countries have some of those capabilities but not all. They further assume that the probability that a country has a capability and that a product requires a capability are constant and they solve the model calibrated to the empirical data related to the network connecting countries and products. They report results that suggest that the binomial model is able to replicate all stylized facts except for the non-normal distribution of country diversification. They argue that the result gives evidence of the large heterogeneity in the distribution of capabilities across countries. They also show that the model implies that less diversified countries, which have fewer capabilities, would have to accumulate a large number of capabilities to be able to diversify their economies, as opposed to countries that are more diversified and that would expect higher increase of diversification from the accumulation of a small number of capabilities.

2.2 Subsequent areas of research

The literature presented above has motivated several areas of research. One of them is the study of the properties and structure of the network that connects countries to products that they export, or the country product matrix, and of the product space. For example, Bustos, Gomez, Hausmann and Hidalgo (2012) show that the matrix of countries and products that they export, when ordered from the most to the least diversified country and from the most to the least ubiquitous export, has the characteristic of being nested. This means that, for any country, the set of products that it exports is well approximated by a subset of the products exported by the country that is immediately more diversified. They argue that this property can be used to predict the appearance and disappearance of exports.

Bahar, Hausmann and Hidalgo (2012, 2014) study the relationship between product spaces of neighbouring countries to assess if the production in one country affects the diversification in the other. They report that the probability of a country to diversify to a particular product is 65% larger if that same product is exported with revealed comparative advantage by a neighbouring country. They interpret that result is evidence of the international intra-industry diffusion of knowledge.

Another line of literature is related to the development of measures of diversification, product complexity and proximity in the product space. For example, Anand et al. (2012) calculate *EXPY* and *PRODY* measures adding 10 service export categories to obtain a dataset that combines products and services. Felipe et al. (2012) use the method of reflections to calculate the complexity of countries and products, with alternative cut-offs for the revealed comparative advantage of countries. The authors compare the results with other measures of technological capabilities finding a high rank correlation.[3]

Felipe, Kumar and Abdon (2010) develop an "index of opportunities" to assess the capabilities of 130 countries to undergo structural transformation. The index is comprised of seven indicators and their residuals obtained from cross-country regressions of each of the indicators on the level of GDP per capita. The indicators are based on the *EXPY* and *PRODY* measures, measures of diversification and ubiquity, as well as measures of proximity and opportunities for diversification in the product space.

Freitas and Salvado (2008) propose an alternative to the method proposed by Hausmann and Klinger (2007) to measure the relatedness of two products in product space. The method results in a measure called Revealed Relatedness Indexes (RRI) and estimates the relatedness of two products using a probit regression model that assesses if the probability of a country having a revealed comparative advantage in one product is dependent on having the RCA in another product. The use of this method reduces the number of links in the product space and produces links with positive and negative values, which reflects the possibility that the production of one product indicates unfavourable conditions for production of another (e.g. the climate for production of bananas may not be ideal to produce wine). Tacchella, Cristelli, Caldarelli, Gabrielli and Pietronero (2012) argue that, while Hidalgo and Hausmann (2009) is a first attempt to measure economic complexity, their measures of diversification and ubiquity suffer from conceptual and practical problems. They agree with Hidalgo and Hausmann (2009) that the average complexity of products is an appropriate measure for the complexity of an economy, but they argue that a measure of complexity of products has to consider the fact that being exported by a diversified country does

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[3] The measures considered were the UNDP's Technological Achievement Index by Archibugi and Coco (2004) and Desai, Fukuda-Parr, Johansson, and Sagasti (2002), the OECD high-tech product classification by Hatzichronoglou (1997), and the measures proposed in Lall and Albaladejo (2002) and Wagner, Brahmakulam, Brian, Jackson and Wong (2001).

not give much information, whereas being exported by a less diversified country indicates that the product requires few capabilities to be produced. That asymmetry implies that the measure of product complexity has to be non-linear, which was initially suggested by Caldarelli et al. (2011). The authors define new metrics for product complexity and economic complexity (called country fitness), which are calculated through several iterations similar to the framework proposed in Hidalgo and Hausmann (2009) but with an additional step in the calculation of product complexity that adds more weight to the information that a product is exported by a less diversified country. They discuss several properties of these measures and contrast with the results in the framework by Hidalgo and Hausmann to argue that their measures are more appropriate to estimate the complexity of countries and products. I, in principle, agree with the point raised by Tacchella et al. (2012) that there is an asymmetry in the information when considering a product exported by a diversified or a less diversified country, and I believe it is relevant to further study whether the solution that they have adopted properly addresses that issue. Nevertheless, in the analysis that follows this chapter, I use a method that is based on the method of reflections, which has been more widely applied in the literature.

Another line of research is related to verifying the effect of economic complexity of a country on its level and growth of wealth. That area of work is to some extent motivated by the claim in Hidalgo and Hausmann (2009) that the level of economic complexity of a country is a good predictor of future economic growth. Hausmann and Hidalgo (2013) applies that idea to estimate the expected GDP growth of 128 countries in the period until 2020.

Some studies have found similar results in terms of the relationship between economic complexity and growth. For example, Anand et al. (2012) found that, after controlling for financial development, human capital, and external liberalization, the initial level of product sophistication of both goods and services exported by a country is correlated with subsequent output growth. Conversely, Wang et al. (2010a) did not find any strong or robust effect in an econometric study to assess the effect on economic growth of increasing the sophistication of country's exports.

That line of work has used regression analysis to uncover the effect of economic complexity on future growth. A different approach was adopted by Cristelli, Tacchella and Pietronero (2015), in which they observe that the dynamics of the relationship between country fitness, as proposed by Tacchella et al. (2012), and GDP per capita presents strong heterogeneous patterns of evolution. They argue that, in such a framework, regressions are not the proper tool to assess the association in the fitness-income plane, and suggest the use of strategies borrowed from the theory of dynamic systems. They propose and start to document a new data driven method, which they call the "selective predictability scheme" to forecast future economic growth of countries based on existing levels of country fitness.

In parallel to the approaches highlighted above, and based on the research of John Sutton on firms investing to build capabilities to produce quality products, Sutton and Trefler (2016) study theoretically and empirically the relation between a country's income and the mix of products it exports. They argue that these are simultaneously determined by country's productivity and quality levels in the production of each good, which they define as country's capabilities. Their framework assumes that some goods are produced by fewer high-quality producers/countries and that imperfect competition allows high- and low-quality producers to coexist. The result is an inverted-U relationship between a country's export mix and its GDP per capita, for which they found empirical support.

Another area of research is the use of methods developed in the literature of economic complexity to estimate the economic complexity of countries and product complexity of exports and to find new stylized facts. For example, Anand et al. (2012) found that the sophistication of exports has increased in all countries covered in their analysis but that move was less pronounced in low income countries, and in particular in those in Sub-Saharan Africa. Abdon and Felipe (2011) also use the product space to study the evolution of productive structure of countries in Sub-Sharan Africa. Felipe et al. (2012) use the method of reflections to compute measures of product and country complexity for 124 countries and 5,107 products. They found that export shares of more complex products increase with country's income and those of less complex products decrease with income. Using the indices *PRODY* and *EXPY*, Freitas and Salvado (2008) study the evolution of the sophistication of products in Portugal; Di Maio and Tamagni (2008) assess the evolution of sophistication of Italy's exports since 1980; and Neves (2012) studies the specialization pattern and evolution of product sophistication in China and India. Jankowska et al. (2012) study the evolution of product complexity and the product space of Brazil, Mexico and the Republic of Korea and discuss the contribution of such line of analysis for the debate regarding the middle-income trap. Hausmann and Hidalgo (2013) presents an atlas of economic complexity with the analysis of the complexity of production and evolution of product space of 128 countries with populations above 1.2 million people and annul exports of over USD 1 billion.

Badibanga, Diao, Roe and Somwaru. (2009), based on Hausmann and Klinger (2006), propose a new measure called "density gravity center" that is calculated as the distance between a country's existing exports and a group of products that the country does not produce. They use their proposed measure of distance in the product space to analyse the evolution of the production structure of China, Malaysia and Ghana in the period from 1962 to 2000. They note that the rapid transformation of China's economy is characterized by high proximity of their exports to capital goods, consumer durable goods and intermediate inputs. They found that Malaysia's economy had followed a similar but less extensive change in the product space and that Ghana's economy was mainly unchanged over time.

Zaccaria et al. (2016) use the measures of country fitness and product complexity proposed in Tacchella et al. (2012) to assess the evolution of the competitiveness of the Netherlands. Their results confirm the high level of diversification and complexity of that economy, which has remained stable through the years. However, they found that in some sectors, such as Chemicals, complexity has declined.

The literature presented above has motivated the discussion of the role of governments in fostering the process of structural transformation. For example, Anand et al. (2012) analyse the impact of exchange rate policy in contributing to increasing export sophistication, and suggest that overvaluation has a negative impact but undervaluation has no effect.

Based on the assumptions and key models of that literature, the product space shows the potential new products that require similar capabilities to those already exported by a country. That can serve as a map to assist countries in designing and implementing industrial policies. For example, Hausmann and Klinger (2008) identify potential new exports for Colombia by considering products that are near to the existing exports of the country in the product space. Similarly, Vitola and Davidsons (2008) identify the products with higher potential for diversification in Latvia. De La Cruz and Riker (2012) uses the product space to predict the products in which Brazil would gain comparative advantage within the following decade and compare with the results when considering only the product space of the country's exports to the United Sates.

Hausmann and Hidalgo (2013) identify new categories of products for diversification with above country's average complexity in 128 countries, also taking into consideration the proportion of global trade for each category of product. Felipe and Hidalgo (2015) apply the methods of reflections and the analysis of product space to assess and discuss the implications of economic diversification for Kazakhstan. Using the alternative measure of proximity in the product space proposed by Freitas and Salvado (2008), Freitas, Salvado, Nunes and Neves (2013) and Neves (2012) identify products for diversification with higher than country's average sophistication in Portugal and in China and India, respectively.

A potential emerging area of research is the link between the measures of economic complexity and other concepts relevant to economic development. For example, Hartman, Guevara, Jara-Figueroa, Aistaran and Hidalgo (2015) study the relationship between economic complexity and inequality through the combination of econometric and network science methods. They found that countries exporting more complex products have lower income inequality than countries exporting less complex ones. They also found that increases in economic complexity are associated with the reduction of income inequality. They report that their results are robust when controlling for income levels, institutions and human capital. A policy-relevant conclusion is that social policies alone may not be enough to reduce inequality in the absence of changes in the economic structure of countries.

2.3 Discussion

The empirical literature on economic complexity emphasizes the importance of the products that a country exports for its long-term development. That literature aligns with and echoes the work of early development economists and also expands it in many ways.[4] For example, it gives support to the importance of poorer countries diversifying towards manufacturing, which was a key element in the theory of forward and backward linkages of Hirschman (1958) or the 'big push' of Rosenstein-Rodan (1943). It shows that many trade product categories related to manufacturing are in denser parts at the centre of the product space, which facilitates future diversification. In addition, it shows that these products are also associated with the production of wealthier and more diversified countries. Moreover, that literature goes beyond the advice provided by those early development economists because it also provides a product map that shows the proximity between products and allows the identification of products for diversification that are not restricted to manufacturing. However, methods developed in that literature have used data with cut-offs for the population size and values of annual exports of countries that keep out of the analysis the less populated and poorest economies. As consequence, least developed countries, as well as Small Island developing States that have small populations and low income, have not benefited from that analysis that identifies potential products for the diversification of countries.

In terms of new stylized facts, the empirical literature on economic complexity supports results of other recent empirical studies. For example, the study of the network of countries connected to products that they export reveals the empirical fact that diversification is positively associated with total GDP. That result is in line with other empirical results that show that richer countries export not only a higher output, as compared with poorer countries, but they also export a broader variety of types of products (e.g. Schott, 2004; Hummels and Klenow, 2005).

Conversely, some of the new stylized facts highlighted in the empirical literature of economic complexity are not predicted by traditional theory. For example, that literature uncovered the negative relationship between diversification of countries and the average ubiquity of its products in the matrix of

[4] Although these streams of literature highlight different economic mechanisms responsible for diversification.

countries connected to their exports. As discussed in Hausmann and Hidalgo (2010, 2011), the two main approaches to trade specialization in the literature do not account for that regularity. Classical trade theories of the Ricardian or the Heckscher-Ohlin type, which determine specialization based on comparative advantage, do not predict the number of products that a country will export or how many countries will export each product. In fact, they usually have to rely on trade costs to replicate the empirical fact that in international trade there is no full specialization, with only one country – for example the one that produces with the lower price – exporting a given type of product.[5] The new trade theory addresses that fact assuming that products come in different varieties that are imperfect substitutes, which gives firms competing in the same category of product some market power (e.g. Krugman, 1979). Competition drives prices down by reducing profits while economies of scale reduce costs. Intra-industry specialization is explained by assuming that there are scale economies in product development. The new trade theory, however, does not predict which country will specialize in which product because it uses the Dixit-Stiglitz model (Dixit and Stiglitz, 1977) that assumes a continuum of symmetric products. Therefore, empirical facts discovered by the literature on economic complexity highlight the need for further theoretical research on patterns of trade specialization.

2.3.1 Note on the assumptions in using trade data

This section discusses the assumptions in using trade data as a proxy for production, which is a common approach in the stream of the empirical literation on economic complexity presented in this chapter. The motivation for that is the same behind the proposition of product taxonomies based on sophistication of products such as *PRODY* (Hausmann, Hwang, and Rodrik, 2007), Michaely's (1984) index, and sophistication score (Lall et al., 2005), that is to be able to classify products with a higher level of granularity than what is possible using industry-level data.

As discussed in Lall et al. (2005), the challenge in using the industry-level classifications for analysis of capabilities is the lack of granularity. Production data are available as an aggregated measure for the economy in a given period of time, usually by year. Datasets such as the Industrial Commodity Statistics Dataset of the United Nations Statistics Division would present the production in value and

[5] Another possible mechanism to replicate the lack of full specialization is the consideration of the limit of the availability of labour, or other non-tradable factor, required for the production in a country (e.g. Duchin, 2005). Countries with comparative advantage in many products but not enough labour to produce the amount required to meet the global demand would have to share the market with other countries.

quantity for items such as “T-shirt, singlets and other vests, knitted or crocheted”, but that information would not allow us to infer if the country produces the low- or the high-end products, or both, and all the intermediate products in between. Such information is crucial for the classification of a sector given that it would permit us to differentiate between the set of technologies that is required to produce the commodity of each sector.

Production data are aggregated at relatively larger sectors even when its coverage is limited to developed countries and large developing economies. At a higher level of aggregation, most countries can produce most products; it is difficult to assess the different capabilities between countries based on an assessment using that level of aggregation.

In addition, country coverage is somewhat limited. That is not a problem if the interest is in conducting cross country analysis without any specific requirement regarding a particular country that has to be included. As long as a large enough set of countries is included in the dataset, the results could be statistically sound and conclusions could be drawn about that set of countries. However, if the interest is in conducting country specific analysis, covering particularly the least developed countries and the less diversified economies, the question of country coverage of the dataset becomes very relevant.

An alternative is to use trade data. One can find much disaggregated datasets, for a large number of economies and covering many years. Most importantly, the availability of bilateral trade data, showing what country *A* has exported to country *B*, allows us to grasp the production of different commodities within the same broad product category, for example, low-end and high-end men’s t-shirts.

Note that we still have to make an assumption: that one country exports to the other only one type of commodity, either the low-end or the high-end t-shirt. This is not ideal and other methods to identify the sectors that comprise an economy ought to be explored to try to circumvent that problem.

We should also note that the focus on the composition of the export basket is a stronger version of the stylized fact that economic development is associated with the diversification of the production base. While a more diversified export basket implies a more diversified production, an economy could diversify production focusing on efficient import replacement without at the same time being able to diversify the export basket. Therefore, the risk in the analysis is to identify countries as less diversified than they actually are.

One disadvantage in using trade data is that they cover only tradable goods without considering tradable services. Some studies have tried to incorporate services in the analysis (see for example Anand et al., 2012) but their findings do not contradict the results reported in studies that use only trade in goods. It is also interesting to note that a considerable number of tradable services emerged in many countries in association with existing industries, as services for those local industries that over time started also to be exported. Examples are engineering and financing services in New York, London, Paris, and Hong Kong. Some small Island States offering financial services should be considered as exceptions.

Another issue in using trade data is that there is the risk that some re-exports are included in the analysis. For example, the dataset may show that a given country is exporting a highly-sophisticated construction machine when in fact it is the re-export of the machine that was initially imported to the country by a foreign construction company. The solution of that is to remove re-exports from the dataset, which is possible given that UN Comtrade keeps track of trade flows and identifies re-exports in the dataset. That procedure is followed in the treatment of datasets used in the analysis in this thesis.

An important issue in using trade data is how to handle production in global value chains. There is no doubt that a country seldom produces all parts that constitute a product. Many firms in developing countries export - with minor value addition – products that they have just imported. This is a real downside of this approach of using gross trade data. Future research to address this issue may benefit from the recent literature that has aimed at developing an accounting framework that breaks country's gross trade data into value-added components (e.g. Koopman, Wang and Wei, 2014).

2.4 Summary

A key message of the seminal work in the empirical literature on economic complexity is that what a country exports matters for its current and future levels of wealth. That research has made contributions to the literature on patterns of trade specialization and to the literature addressing the degree of similarity between products or sectors. Important methods proposed are related to measurement of complexity of countries and products, as well as to the concept of a product space - a network of products connected to each other based on measures of similarity. Underlining assumptions of that research is that products require a specific set of non-tradable capabilities to be produced, countries have a set of those capabilities but not all, and countries produce the products for which they have the required capabilities to produce.

That literature has motivated several areas of research, including: the study of the properties and structure of the country-product matrix and of the product space; the development of measures of diversification, product complexity and proximity in the product space; the study of the effect of economic complexity of a country on its level and growth of wealth; the assessment of the economic complexity of countries and product complexity of exports to find new stylized facts; the discussion of the role of governments in fostering the process of structural transformation; and the study of the link between measures of economic complexity and other concepts relevant to economic development, such as inequality.

However, methods developed in that literature have not been applied to the analysis of potential new exports of least developed countries, the economies of which need to diversify to address the challenges posed by the fact that they rely in few commodities for exports. In addition, stylized facts highlighted in that literature suggest the need for further theoretical research on diversification and patterns of trade specialization.

The next chapter presents and discusses in detail some of the main methodologies and data used in the empirical literature on economic complexity. The chapter also presents the specific modifications to these methods, indices and data that are proposed in this dissertation to address the gaps in the empirical study of complexity of poorer economies.

3

Data and methodology: Introduction to the method of reflections, measures of productive capacity, product complexity, proximity and methodology to classify products[1]

This chapter presents the method of reflections proposed by Hidalgo and Hausmann (2009), a workhorse method used by most studies in the empirical

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[1] This chapter presents and discusses methodologies and datasets that were initially introduced, applied and discussed in Freire (2011) and in Chapter 4 of ESCAP (2011) titled "Building the productive capacity of the least developed countries", which I authored.

literature on economic complexity, and discusses how to revise it to allow the analysis of diversification, productive capacities and product complexity of least developed countries. A methodology to create more disaggregated datasets is also introduced, which uses trade data and further disaggregates it by classifying products according to their unit values. The chapter also presents the methodology proposed by Hidalgo et al. (2007) to calculate the proximity between products, which is used to build the product space. These data and methods will be used in the analysis presented in the following three chapters.

3.1 Introduction

As discussed in Chapter One, a motivation for this dissertation is to apply methods of the empirical literature on economic complexity to inform national development policies and strategies of poorer nations, including least developed countries and Small Island developing States. This chapter presents the method of reflections (Hidalgo and Hausmann, 2009) and the method to calculate the proximity between products in the product space (Hidalgo et al., 2007), which are extensively used in the literature. That stream of research, however, has not particularly focused on that subset of countries and many studies have applied a cut-off for population size and volume of trade that result in the exclusion of smaller economies.

Table 3.1 lists selected studies in the literature and presents the cut-offs when they were applied, which in the papers listed vary from 1.2 million to 3.5 million people. The reasons for the use of cut-offs are usually not explicitly stated in those papers,[2] but they are subsumed to be applied to exclude outliers in regression analysis and to focus on countries that are considered to have better data. Some studies have presented a broader coverage, with 200 economies included (e.g. Tacchella et al., 2012; and Cristelli et al., 2015).

The table also highlights the use of trade data in the empirical literature on economic complexity. It shows that both Standard International Trade Classification (SITC) and Harmonized System (HS) trade classifications are used in empirical analysis, and data disaggregation varies from 4- and 6- to the 10-digit level of detail. Trade data is usually obtained from the United Nations Comtrade Database, a repository of official trade statistics,[3] but also from datasets based on

[2] Many studies that apply population cut-offs do not present clear justification for its use or why do they matter for the results (e.g. Hausmann and Klinger, 2006, 2007; and Hidalgo, 2009; Sutton and Trefler, 2016).

[3] The UN Comtrade is maintained by the Statistics Division of the Department of Economic and Social Affairs of the United Nations. Data is available at: http://comtrade.un.org/

Comtrade data, such as Feenstra, Lipsey, Deng, Ma and Mo (2005), in which data consistency methods were applied to the dataset.

In this chapter, I argue that the method of reflections should be slightly revised to allow for the inclusion of the poorest countries in the analysis of the network connecting countries to products that they export. In addition, such revision calls for more disaggregated datasets to allow for more detailed differentiation of product structure across countries. Here I present a method that considers the distribution of unit values of bilateral trade flows to create more disaggregated datasets. The chapter also presents the measures of productive capacities, product complexity and product proximity that will be used in the analysis in the following chapters.

Table 3.1. Coverage of countries and products in the empirical literature on economic complexity, selected studies

Study	Dataset	Number of economies	Number of products
Lall et al. (2005)	SITC Rev 2 for 1990 and 2000	30	237 (3-digit) 766 (4-digit)
Hausmann, Hwang, and Rodrik (2005, 2007)	HS 6-digit level for 1992 to 2003	113	5,000
Hausmann and Klinger (2006, 2007)	SITC 4-digit level for 1962 to 2000 (Feenstra et al., 2005)	106 to 112 countries. Population larger than 2 million	1,006
Hidalgo et al. (2007)	SITC 4-digit level for 1962 to 2000 (Feenstra et al., 2005)	-	775
Freitas and Salvado (2008, 2009), Neves (2012), Freitas et al. (2013)	SITC 4-digit level	93 countries. Population larger than 2 million	1,245
Hidalgo (2009)	SITC 4-digit level for 1963 to 2000 (Feenstra et al., 2005)	84 countries. Population larger than 3.5 million	

Study	Dataset	Number of economies	Number of products
Tacchella et al. (2012)	HS 6-digit level	200	1,200
Bahar et al. (2012), Hausmann and Hidalgo (2013)	Feenstra et al., 2005	128 countries. Population larger than 1.2 million and total trade above USD $1 billion in 2008	1,005
Felipe et al. (2012)	HS 6-digit from 2001 to 2007	176	5,132
Cristelli et al. (2015)	HS 2007 6-digit from 1995 to 2010	200	1,131
Zaccaria et al. (2016)	HS2007 4-digit from 1995 to 2010	146 to 148	1,131
Sutton and Trefler (2016)	SITC 4-digit, HS 1996 rev. 6-digit, HS 10-digit (USA import data)	94 countries. Population larger than 2 million	

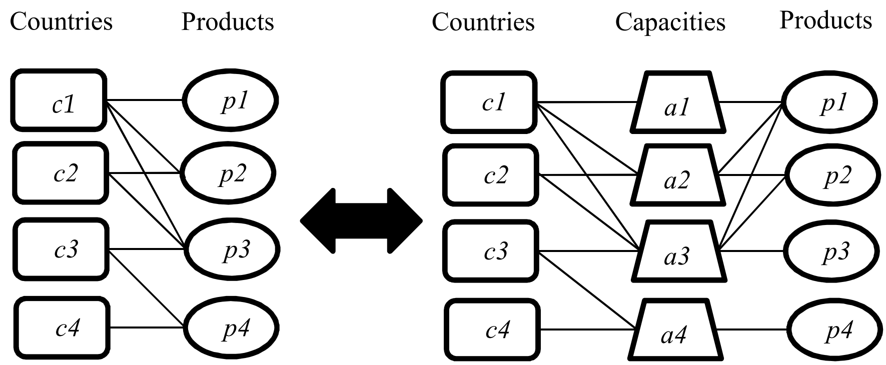
3.2 Method of reflections

The method of reflections proposed by Hidalgo and Hausmann (2009) is based on the following assumptions:

1) Products require a specific set of non-tradable capabilities to be produced;
2) Countries have some of these capabilities available but not all of them; and
3) A country produces the goods for which the required set of capabilities is available in that country.

The three assumptions of the method of reflections are illustrated in Figure 3.1. The figure shows a bipartite network that connects countries (*c*) to products that they produce (*p*), and interprets that network as the result of the tripartite network that connects countries (*c*) to the productive capacities (*a*) that they have, and products (*p*) to the capabilities required for their production.[4] We should note that what is observable from the empirical data is not the tripartite but the bipartite network of countries and products. Such a network can easily be constructed using trade datasets highlighted in the previous section by listing all economies and products that they exported in a given period.

Figure 3.1. Tripartite network connecting countries, productive capacities and products



Source: Based on Hidalgo and Hausmann (2009).

The method of reflections represents such a bipartite network connecting countries to products using the adjacency matrix M_{cp}, where:

$$M_{cp} = \begin{cases} 1 & if \;\; RCA_{cp} \geq threshold \\ 0 & otherwise \end{cases} \tag{III.1}$$

The Revealed Comparative Advantage (*RCA*) of country *c* in exporting product p is defined as the ratio of the share of product p in country $c's$ exports and the share of product p in the global market. Formally:

$$RCA_{cp} = \frac{\left(\frac{x_{cp}}{\sum_k x_{ck}}\right)}{\left(\frac{\sum_j x_{jp}}{\sum_j \sum_k x_{jk}}\right)} \tag{III.2}$$

[4] Capabilities and capacities are synonymous and are used interchangeably in this dissertation.

Where x_{cp} is the value of exports of product p by country c, and j and k are indices that represent countries and products, respectively.

The threshold in (III.1) is taken as 1 ($RCA_{cp} \geq 1$) by Hidalgo and Hausmann (2009), but other values could be used. For example, if one wants to create the adjacency matrix M_{cp} only with products that countries export in proportions much higher than the average export of that product in the global market, a value higher than 1 for the threshold could be adopted. On the other hand, if one would like to create the adjacency matrix M_{cp} with all products exported by each country, the value of the threshold should be set to zero.

To illustrate the application of equation (III.1), the following is the adjacency matrix M_{cp} that represents the network of countries and exports presented in Figure 3.1:

$$M_{cp} = \begin{vmatrix} 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

In this matrix, we consider the threshold of RCA as zero. Each row is associated to a country listed from country c_1 in the first row to country c_4 in the fourth, while each column is associated with one product listed from p_1 in the first column to p_4 in column four.

The method of reflections uses this bipartite network of countries and products that they produce and iteratively calculates measures of diversification and ubiquity that are generalized as follows:

$$k_{c,N} = \frac{1}{K_{c,0}} \sum_p M_{cp} k_{p,N-1} \quad \text{(III.3)}$$

$$k_{p,N} = \frac{1}{K_{p,0}} \sum_c M_{cp} k_{c,N-1} \quad \text{(III.4)}$$

for $N > 0$

In equations III.3 and III.4, $k_{c,0}$ represents the number of products exported by country c and $k_{p,0}$ represents the number of countries that export product p. Formally:

$$k_{c,0} = \sum_p M_{cp} \quad \text{(III.5)}$$

$$k_{p,0} = \sum_c M_{cp} \quad \text{(III.6)}$$

Therefore, the method of reflections produces, for each country c, an ordered list of N real numbers ($k_{c,0}$, $k_{c,1}$, $k_{c,2}$, … , $k_{c,N}$), where N is the number of iterations of the method of reflections.

Intuitively, equations III.3 and III.4 can be seen as simultaneous equations. The former estimates the capabilities of countries as an average of the complexity of the products exported, while the latter estimates the complexity of a country's exports as a function of the capabilities of the countries that export the products. The calculation of one equation changes the results of the other in the next iteration. The method of reflections is an iterative procedure to find estimates of the capabilities of countries and the complexity of product that are consistent with each other.

Table 3.2 illustrates how the method of reflections can be used to rank countries c_1, c_2, c_3 and c_4, shown in Figure 3.1, in terms of the capabilities that are available within these countries. Based on the first variable ($k_{c,0}$), which represents the number of products exported by country c, the most diversified economy is c_1 and, therefore, based on the assumptions listed in the beginning of this section, it can be seen as the country that has more productive capacities available to it. Conversely, c_4 is the least diversified and hence the country with potentially the lower number of capabilities. This first approximation ($k_{c,0}$), however, cannot differentiate between c_2 and c_3 given that both are equally diversified - exporting two products.

We can turn to the second variable ($k_{c,1}$), representing the average ubiquity of the products exported by country c, to try to rank c_2 and c_3. Under the assumption mentioned above regarding countries, products and productive capacities, a relatively low value of average ubiquity means that few countries can produce that product-mix, which in turn implies that a higher number of capabilities are required for its production. Based only on the 2-tuple ($k_{c,0}$, $k_{c,1}$), however, it is still not possible to differentiate between c_2 and c_3 since the product-mix of each of these countries has the same average ubiquity ($k_{c,1} = 2.5$).

Table 3.2. Example of the use of the method of reflections

Country	Measures of diversification		
	$k_{c,0}$	$k_{c,1}$	$k_{c,2}$
c_1	3	2	2.6
c_2	2	2.5	2.4
c_3	2	2.5	1.9
c_4	1	2	1.5

We should then move to the next iteration of the method which produces $k_{c,2}$, representing the average diversification of the countries with an export basket similar to country c. A higher value of this variable indicates that the product-mix of country c is associated with countries that are diversified and therefore are assumed to have more productive capacities, from which we infer that country c as well should have more capabilities. At that iteration of the method, the differences between c_2 and c_3 become visible: $k_{c,2}$ for c_2 is 2.4, while it is 1.9 for c_3.

Therefore, the results in Table 3.2, combining the interpretation of $k_{c,0}$, $k_{c,1}$ *and* $k_{c,2}$, show that, in terms of productive capacities available to these countries, the ranking from the highest to the lowest is c_1, c_2, c_3 and c_4.

As shown in Figure 3.1, both c_2 and c_3 have in fact two capabilities available to each of them: a_2 and a_3 are available in c_2 while a_3 and a_4 are available in c_3. Therefore, is not only the number of capabilities available to the countries that determines the ranking, but it is also the information regarding the other countries to which those capabilities are available. The method of reflections is used to generate additional information about the capabilities available to the countries based on the network connecting countries to products.

The method of reflections also produces, for each product *p*, a vector representing each product in terms of its ubiquity and the diversification of the countries that produce that product, which can be identified with an ordered list of *N* real numbers ($k_{p,o}$, $k_{p,1}$, $K_{p,2}$, …, $k_{p,N}$). The measure $k_{p,o}$ represents the number of countries that export product *p*, or in other words, the ubiquity of product *p*. The next iteration of equation (III.4) results in $k_{p,1}$, which represents the average diversification of countries that export product *p*, whereas the next measure ($k_{p,2}$) is the average ubiquity of the products exported by the countries that *export* product *p*, and so on and so forth.

To illustrate that idea, take the example of two products: low-priced women's dresses made of synthetic fibres and low-priced bars of alloy steel. Both were exported by 100 economies in 2009, but the average diversification of the countries that exported women's dresses was 3,357 products while the average diversification of countries that exported the bars of alloy steel was 3,505 products.[5] If a product is exported by countries that have higher diversification, it is assumed that this product requires more capabilities to be produced. Therefore, a bar of alloy steel is assumed to require more capabilities to be produced than women's dresses. The analysis continues to identify how common the product-mix of the countries that export each product is – a more exclusive product-mix indicates that the relevant countries have more capabilities available to them.

As the number of iterations of the method increases, however, it becomes difficult to grasp the meaning of the variables produced. For example, the interpretation of $k_{c,3}$ is the average ubiquity of the products exported by the countries with an export basket similar to country *c*, while $k_{p,4}$ is the average diversification of countries that export a basket of products similar to the countries with an export basket similar to that exported by countries that export product *p*.

[5] Source: Comtrade data HS 2002.

Such tongue twisters become larger and larger with higher order of reflections (Table 3.3).

Table 3.3. Successive measures obtained by the method of reflections

Measure	Interpretation
$k_{c,0}$	Diversification: Number of products exported by country *c*
$k_{p,0}$	Ubiquity: Number of countries that export product *p*
$k_{c,1}$	Average ubiquity of products exported by country *c*
$k_{p,1}$	Average diversification of countries that export product *p*
$k_{c,2}$	Average diversification of countries that export a basket of products similar to country *c*
$k_{p,2}$	Average ubiquity of products exported by countries that export product *p*
$k_{c,3}$	Average ubiquity of the products exported by the countries with an export basket similar to country *c*
$k_{p,3}$	Average diversification of countries that export a basket of products similar to that exported by countries that export product *p*
$k_{c,4}$	Average diversification of countries that export a basket of products similar to countries with an export basket similar to country c
$k_{p,4}$	Average ubiquity of the products exported by the countries with an export basket similar to that exported by countries that export product *p*
$k_{c,5}$	Average ubiquity of the products exported by the countries with an export basket similar to that exported by countries with an export basket similar to country c
$k_{p,5}$	Average diversification of countries that export a basket of products similar to the countries with an export basket similar to that exported by countries that export product *p*

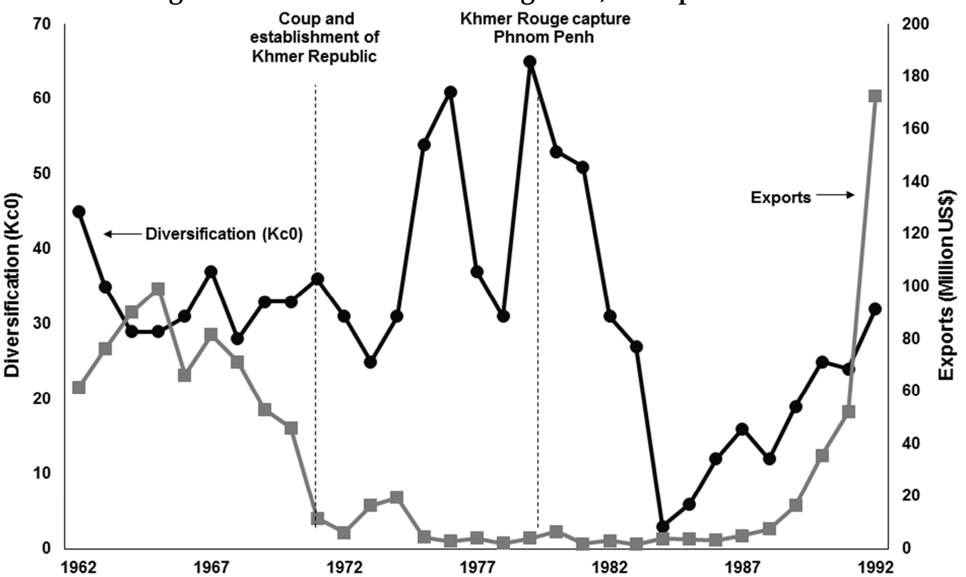
Source: Based on Hidalgo and Hausmann (2009).

3.2.1 *The use of revealed comparative advantage*

One element of the method of reflections makes it particularly problematic to be applied to poorer economies such as the least developed countries. That element is the use of RCA in the creation of the adjacency matrix M_{cp} in equation (III.1). The problem is that the RCA_{cp} is affected by changes in the volume of trade and it is particularly inconsistent when used for smaller economies. Any changes in quantities traded, such as those caused by supply constraints or even disruptions caused by internal conflicts, natural disasters, or changes in prices of commodities in the global market, which are facts rather recurrent in some of the least developed countries, could make the number of products with $RCA_{cp} > 1$ change more easily than in larger economies where the total trade is large.

For example, Cambodia experienced a decline in exports during the period of the Khmer Rouge. During those years, there was a great amount of volatility of the corresponding diversification measure calculated using $RCA_{cp} > 1$ (Figure 3.2). If that threshold is used, we may find that the diversification of Cambodian export had peaked by the time that the Khmer Rouge was capturing Phnom Penh, which of course is not true. What in reality happened is that when the Cambodian exports collapsed, the *RCA* of some of the few products that Cambodia was still exporting went up. If we use one of the reflections as the measure of productive capacity of the country, the analysis using RCA_{cp} equal to 1 as the threshold would suggest that the Cambodia's productive capacity increased during the Khmer Rouge years, which clearly is not the case.

Figure 3.2. Diversification using RCA, example of Cambodia



Source: Author based on COMTRADE data.

Hidalgo and Hausmann (2009) justify the use of RCA in the method of reflections as a way to identify products for which a country is a significant exporter. The underlying supposition seems to be that only products for which a country is a significant exporter could provide information about its productive capacity. However, that notion may be at odds with the core basic assumptions that products require specific capabilities to be produced and that countries have some of them but not all. These basic assumptions do not require exports from country c of product p to have $RCA_{cp} > 0$. In fact, the assumptions are not related to any measure of the volume of exports, but only to the empirical evidence of exporting the product or not.

Consider, for example, exports of garments by Bangladesh and USA, more specifically, the SITC rev.2 4-digit product category 8424 "men's jackets, blazers and the like". In 2000, Bangladesh's export value for that category represented 0.16% of its total exports, which was 4 times the share of the global export value of that category (0.04%). On the other hand, the USA's export value for the same category represented 0.0039% of its exports ($RCA_{US\ 8424} = 0.09$). If in applying the method of reflections the threshold for the RCA_{cp} is set to any value higher than 0.09, then the fact that USA does produce "men's jackets, blazers and the like" is not considered, as if the set of productive capacities required to produce that category of product are not available in the country, which clearly is not the case. Therefore, the use of RCA may even undermine the objective of the method of reflections, which is to create an indirect measure of capabilities based on assumptions of the framework connecting countries, capabilities and products.

A more practical reason for the use of RCA, however, is that it helps to differentiate the production structure of industrialized countries when using trade data at higher levels of aggregation. For example, Hidalgo and Hausmann (2009), in the supplementary material to that paper, assess the diversification of countries (given by $k_{c,0}$) as a function of the threshold of RCA in equation (III.1) and found that, for values of the threshold lower than 1 and tending to zero, industrialized countries export products in almost all SITC 4-digit categories.

Therefore, the predicament is the following: if RCA and a threshold are used then the method of reflections may sometimes overestimate the capacities of poorest and less populous countries, such as many of the least development countries. Conversely, if RCA is not used then the method may not differentiate the capabilities of industrialized countries when using more aggregated trade data.

The solution adopted in this dissertation to address those issues is twofold. First, I use the method of reflections without considering the RCA, by setting the threshold in equation (III.1) to zero. That solution implies that all links in the network of countries connected to their exports are counted. Second, I created and use a more disaggregated dataset to be able to differentiate the productive structure of countries at a very granular level.[6] The last section of this chapter presents and discusses the methodology to create that dataset.

Before we discuss the dataset, the next sections present how the measures derived from the method of reflections are used to create measures of productive capacity of countries and complexity of products.

[6] As discussed in Fontagné, Gaulier and Zignago (2008), the similarity of the export baskets of countries is a matter of aggregation level.

3.3 Productive capacities

The level of productive capacities has been calculated in the literature as one of the measures $k_{c,2N}$ that result from the method of reflections. For each country c, a higher order reflection ($K_{c,2N}$ with $N \geq 1$) provides information regarding product-mix ubiquity and diversification of production of other countries in the network connecting countries and products, which is used to infer the productive capacities available in the country c.

As the number N of iterations of the method increases, the ranking of countries based on the higher measures of diversification stabilizes. For example, if in table 3.2 we continue to calculate the values of $k_{c,4}$ we would find the values {2.47, 2.41, 2.01, 1.70} for countries c_1 to c_4, which would make the ranking of countries remain the same. There is, therefore, a limit in the number of iterations that result in relevant values to differentiate the productive capacities of countries. The value of such a limit number (N_L) depends on the structure of the network (i.e. the number of countries, products, and how they are connected).

A strategy used by Hidalgo and Hausmann (2009) and by Hidalgo (2009) is to iterate the method enough times that the ranking of the higher variables appears to remain unchanged, which in these studies resulted in 18 iterations (N_L=18). Hidalgo and Hausmann (2009), therefore, use $k_{c,18}$ as the measure of country's productive capacity and $K_{c,19}$ as the measure of product complexity.[7] Felipe et al. (2012) uses $k_{c,16}$ as the measure of country's productive capacity and $k_{c,17}$ as the measure of product complexity.

Such a strategy, however, may fail to provide useful information in some specific cases when it is applied to poorer economies that export a small number of products. In some cases, the export-oriented production, usually as part of foreign direct investment, of few relatively sophisticated products is captured by the higher order reflection as highly complex. For example, I found that Greenland and Gibraltar were the first and the fourteenth most complex economies in 1966 when only $K_{c,18}$ is considered.[8]

In this thesis, I use a measure of productive capacities that considers all the information in the n-tuple that result from the method of reflections. The measure is directly proportional to the generalized measures of the diversification ($k_{c,2N}$ with $N \geq 0$) and inversely proportional to the generalized measures of ubiquity of

[7] Which they called product sophistication echoing Lall et al. (2005).

[8] Using data from Freenstra et al. (2005). The result might well be the result of the nature of the data, in particular of the so-called XX-classes used in the product classification. Nevertheless, the measure of productive capacity proposed in this section is able to account for that by considering the other measures of diversification.

product-mix ($k_{c,2N+1}$ with $N \geq 0$). That formulation is based on assumptions that the higher the diversification the higher the number of capabilities available in the country and the range of capabilities available will be lower the higher the number of countries that export a similar product-mix. Formally, productive capacity ($PCAP$) of a given economy is here defined as:

$$PCAP = \frac{k_{c,0} \times k_{c,2} \times k_{c,4} \times k_{c,6} \times k_{c,8} \times k_{c,10} \times k_{c,12} \times k_{c,14} \times k_{c,16} \times k_{c,18}}{k_{c,1} \times k_{c,3} \times k_{c,5} \times k_{c,7} \times k_{c,9} \times k_{c,11} \times k_{c,13} \times k_{c,15} \times k_{c,17} \times k_{c,19}} \tag{III.7}$$

I use 19 iterations of the method of reflections as used by Hidalgo and Hausmann (2009) because the raking of the higher variables remain unchanged in further iterations and to allow for comparisons between the measure of productive capacity proposed and the measure that those authors use.

Let me explain the intuition behind equation III.7 using an example. Suppose we would like to estimate the capabilities of two countries (A and B). Country A produces 100 products and country B produces 50. Based on the assumption that each product requires a specific set of capabilities to be produced and a country would produce the products for which it has the required set of capabilities, then we would consider that the productive capacity of country A is higher than of country B. Therefore, an initial measure of the productive capacity ($PCAP'$) is directly proportional to the diversification ($k_{c,o}$).

$$PCAP' = f(k_{c,0}) \tag{III.8}$$

Now suppose that a country C has the same diversification level as country A. To differentiate between these two countries in terms of productive capacities, we could use the information regarding the average ubiquity of their exports. The assumption is that more ubiquitous products require capabilities that are more easily found in many countries. A country with higher average ubiquity of exports would have a lower level of productive capacity than a country with a lower average ubiquity. Hence, a more refined measure of productive capacity ($PCAP''$) is inversely proportional to the average ubiquity of exports ($k_{c,1}$).

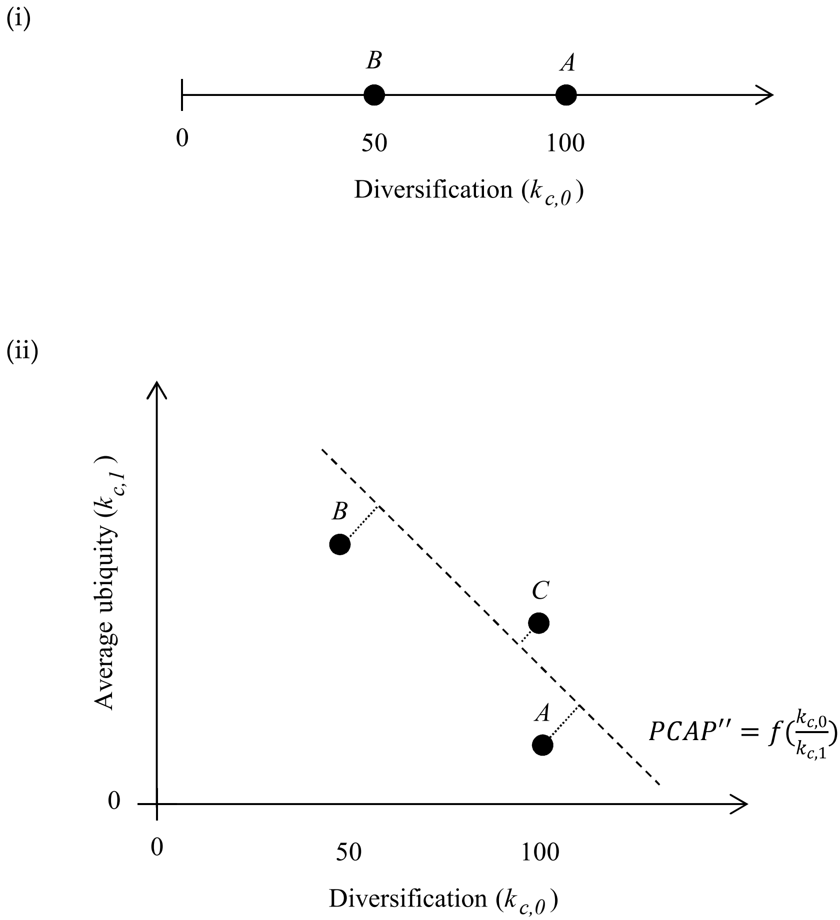
$$PCAP'' = f(\frac{k_{c,0}}{k_{c,1}}) \tag{III.9}$$

Let us move one step further and consider that a country D has the same level of diversification and average ubiquity of exports as country A. In that case, we are not able to differentiate these two countries in terms of productive capacities based only on the values of $k_{c,0}$ and $k_{c,1}$. However, we can use the information related to $k_{c,2}$, which for any country j represents the average diversification of countries that export a basket of products similar to that country. The strategy is to look at that group of "similar" countries in terms of exports and, based on their level of diversification, estimate the level of capabilities of the country in question. The assumption is that a higher value on that indicator is associated with higher capabilities of the countries that are "similar" in terms of exports. Therefore, we could refine equation III.9 to make the productive capacity directly proportional to $k_{c,2}$.

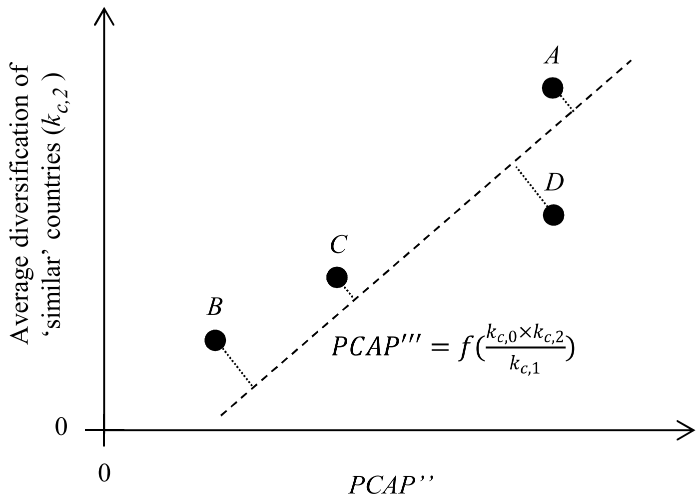
$$PCAP''' = f\left(\frac{k_{c,0} \times k_{c,2}}{k_{c,1}}\right) \tag{III.10}$$

The steps described above are illustrated in Figure 3.3.

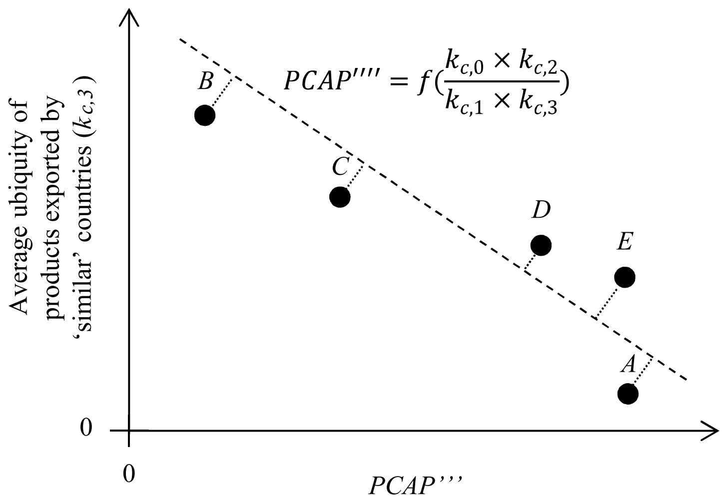
Figure 3.3. Graphic illustration of the construction of a measure of productive capacity



(iii)


Average diversification of 'similar' countries ($k_{c,2}$)
A
D
C
B
$PCAP''' = f(\frac{k_{c,0} \times k_{c,2}}{k_{c,1}})$
0
0
PCAP''

(iv)


Average ubiquity of products exported by 'similar' countries ($k_{c,3}$)
$PCAP'''' = f(\frac{k_{c,0} \times k_{c,2}}{k_{c,1} \times k_{c,3}})$
B
C
D
E
A
0
0
PCAP'''

The method described above could then be extended to continue differentiating countries in terms of productive capacities. If a country E has the same values of country A for the indicators $k_{c,0}$, $k_{c,1}$ and $k_{c,2}$, the next step is to consider $k_{c,3}$, which represents the average ubiquity of the products exported by the countries with an export basket similar to the country in question. The assumption is that a higher average ubiquity of the exports of the countries that are similar in terms of exports would indicate a lower level of productive capacity. The measure of productive capacities is therefore inversely proportional to the measure $k_{c,3}$.

$$PCAP'''' = f(\frac{k_{c,0} \times k_{c,2}}{k_{c,1} \times k_{c,3}}) \qquad \text{(III.11)}$$

If we continue with that procedure, the result is that productive capacities are directly proportional to the measures of diversification with even indices and inversely proportional to the measures of average ubiquity of exports (odd indices). If we consider 19 iterations of the method of reflections, the measure of productive capacity would become the measure $PCAP$ as given by equation III.7.

Summary statistics of the measures of diversification and ubiquity as well as of the index of productive capacity ($PCAP$) are presented in Annex III.1, considering two datasets as examples (HS and SITC trade data classifications further disaggregated by unit value as described in section 3.6).

The reduction of the variables ($k_{c,o}$, $k_{c,1}$, $k_{c,2}$, … , $k_{c,N}$) into a single measure could also be carried out using principal component analysis, a statistical technique used for data reduction. The result of the analysis of the first component using the STATA command *pca* shows that it explains .9948 of the variance of the set of variables and it is 0.87 inversely correlated with $PCAP$ measure (see Annex III.2 for the results of analysis). The inverse correlation is a statistical construct and only changes the way that one should interpret the resulting measure: higher values would indicate economies with a more limited set of technologies, and vice versa. For simplicity, equation (III.7) is initially used to calculate $PCAP$.

The final index ($PCAP_{norm}$) is taken as a normalized value of the $PCAP$ value (using z-score and considering $\overline{PCAP}$ the average of $PCAP$ and σ as the standard deviation of the distribution). Formally:

$$PCAP_{norm} = \frac{PCAP - \overline{PCAP}}{\sigma} \qquad \text{(III.12)}$$

3.4 Product complexity

Similar to the calculation of productive capacities, the product complexity of countries is calculated in the literature as one of the $k_{p,2N+1}$ measures that result from the method of reflections. Such interactive analysis is carried out until no further information is obtainable from this method. In the case of the datasets used in this thesis, no additional information is obtained after the fifth iteration. In other words, the ranking of products based on the measure $k_{p,2N+1}$ remain unchanged for iterations higher than five. Therefore $k_{p,5}$ is used to assess product complexity.

The measure of the set of capabilities in a given sector is here called product complexity (*PCOMP*) and is taken as the normalized value of the k_p value of the fifth iteration of the method of reflections. Formally:

$$PCOMP = \frac{k_{p,5} - \overline{k_{p,5}}}{\sigma} \tag{III.13}$$

Where $\overline{k_{p,5}}$ is the mean and σ is the standard deviation of the distribution of $k_{p,5}$.

We should note that, different from the case of the measure of productive capacities of the whole economy, for the assessment of the set of capacities related to each product, we use only one of the measures ($k_{p,5}$) that result from the method of reflection, instead of the information of the whole set of generalized measures of ubiquity. The reason lies in the different way in which the assumptions concerning diversification (countries) and ubiquity (products) work. In the case of diversification, the more diversified the country the larger the set of capabilities in the economy. Similarly with all other measures of diversification ($k_{c,2}$, … , $k_{c,2N}$), the higher the measure, the higher the number of capabilities in the set.

In the case of ubiquity, however, the larger the number of countries that export the commodity, the smaller the set of capabilities required for the production, but the opposite is not always true. If a commodity is exported by few countries, we cannot assume that the reason is because it requires a large set of capabilities. Other factors may be at play. It may be the case that the commodity is a primary resource that is only found and extracted or harvested on few countries. Even if the set of capabilities required to produce that commodity is not large, the commodity will not be ubiquitous. What that example shows is that we cannot rely on the initial measure of ubiquity ($k_{p,0}$) to assess the set of capabilities of a given sector. But as we run more iterations of the method of reflections, each odd measure related to products ($k_{p,2N+1}$) captures the average diversification of the countries that export the commodity in study, and that average is what we take as a proxy to assess the set of capabilities required to produce that commodity.

Therefore, instead of using the same methodology explained in the previous section that uses measures of diversification ($k_{c,2N}$) and average ubiquity of exports ($k_{c,2N+1}$) of countries, we use only one of the measures related to products but we look at the average diversification of countries that export that product. In fact, we use a higher iteration of the measure ($k_{p,5}$), which, as listed in Table 3.3, represents the "average diversification of countries that export a basket of products similar to the countries with an export basket similar to that exported by countries that export product *p*".

Now let us verify how that measure applies to the case of a primary resources *p* that is exported by few countries. If most of these countries that export this product have export baskets similar to very diversified countries, then the measure will indicate that the complexity of that product is high (it requires many capabilities to be produced). On the other hand, if the product is mainly exported by countries that are more similar, in terms of exports, to less diversified countries, than the calculation of the measure will indicate that the complexity of that product is low.

That method, however, has unavoidable limitations. As discussed in Tacchella et al. (2012), there is an asymmetry in the information that can be obtained when considering a product exported by a diversified or a less diversified country. For example, suppose a primary resource is extracted only in one country that happens to be very diversified. The complexity of that product would be considered to be high, even if it would require few capabilities to be produced. If, on the other hand, the product was only produced and exported by a country that was less diversified, than its complexity would be low, which is likely to reflect the actual low capabilities available in the country for that production. Therefore, the measure of complexity of products has its limits particularly when applied to products exported by few countries that are diversified.

3.5 Proximity between products

The measure of proximity between products *A* and *B* (Φ_{AB}) in the product space is calculated through the method proposed by Hidalgo et al. (2007), as the minimum value between the conditional probability $P(A|B)$ of a country producing *A* given that it produces *B* and the conditional probability $P(B|A)$ of a country producing *B* given that it produces *A*:

$$\Phi_{AB} = \Phi_{BA} = min(P(A|B), P(B|A)) \tag{III.14}$$

The proximity between two products, therefore, ranges from 0%, in the case in which no country produces both products, to 100% in the case in which all countries that produce one good also produces the other.

3.6 Method to classify products

This section presents a methodology to classify products based on trade data. The motivation is the creation of a product classification that could be used in the analysis of the productive capacities of least developed countries. As emphasized in Lall et al. (2005) "empirical economics relies heavily on product classification", which are proposed to apply and test theories. What we are interested in is to measure the level of productive capacities of countries.

As discussed in the previous sections, the assumptions of the empirical literature on economic complexity are that products require a specific set of capabilities to be produced, countries have a subset of these capabilities and they produce the commodities for which they have the required capabilities. These assumptions describe a much-disaggregated dataset of production. We should be able to differentiate, for example, between a low-priced men's t-shirt made with easily available technology and a few hours of training and a high-end men's t-shirt that was cut using laser technology and has a whole set of technologies involved in creating a well recognizable and valuable brand. The former uses a set of capabilities that is different of that used to produce the latter.

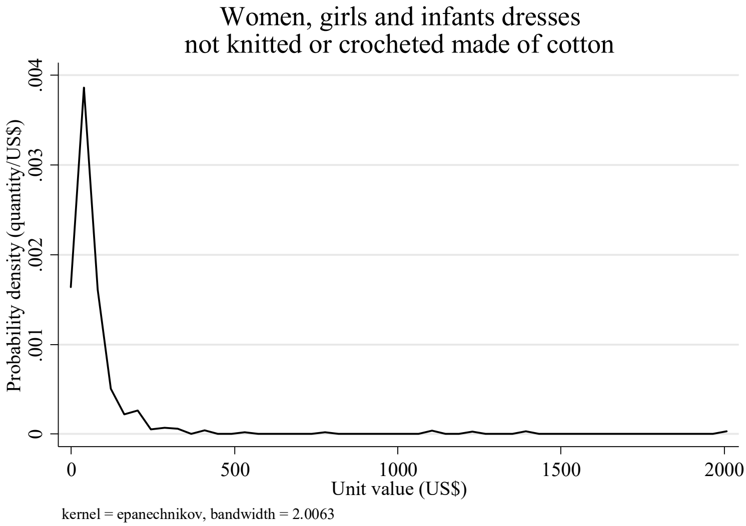
The empirical literature on the impact of quality on trade specialization has used the information regarding the unit value of trade flows to infer those differences between products within the same product category (e.g. Schott, 2003, 2004; Hummels and Klenow, 2005; Fontagné et al., 2008; and Sutton and Trefler, 2016). Unit value is calculated by dividing the trade value by the quantity traded, where quantity traded is specified in a particular way (e.g. number of items, weight in kilograms, and volume in litres) depending on the product.

As I mentioned in the previous chapter, the use of unit value of trade to classify products has to assume that one country exports to another only one type of commodity. If a country *A* exports both high- and low-unit value products to country *B*, this would not be obvious in the gross trade data. By dividing the total trade value by the total quantity of that product exported from *A* to *B*, the result may be a mid-range unit value. This is an inherent limitation of the use of unit value of trade information due the way that gross trade data is accounted.

Keeping that in mind, differences in unit values are what one finds when looking at the data. Not only the unit values follow a distribution from low to high, the distribution of the unit values of products classified using the same 5-digit (SITC) or 6-digit (HS) code is fat-tailed – there are outliers that are many standard deviations away from the mean. That fact is illustrated in Figure 3.4, which presents the distribution of unit values of bilateral trade flows of product number 84332 using SITC rev2 5-digit classification (Women, girls and infant's dresses not knitted or crocheted made of cotton, which quantity is measured by number of items). The figure shows in the vertical axis the shares of the worldwide export flows of this product measured in quantities per US$ 1, and the area below the line equals one. As the figure shows, the unit value of one item is generally lower than US$ 250 but it can go over US$ 2,000. [9]

[9] The top three trade flows related to the high unit value dresses in that year were two dresses exported from Kuwait to the United Kingdom with average unit value

Figure 3.4. Example of fat tail distribution of unit values



Source: Based on data from UN Comtrade.
Note: SITC rev 2 code 84332 for the year 2010.

Other examples of fat-tailed distributions of unit values of tradable goods are presented in Figure 3.5. The examples (i.e. bovine meat and natural rubber latex) were selected because they may be perceived as commodities - each one with basically a single price in the international market - and nevertheless they present fat-tailed distributions.

Setting the possibility of errors in the reporting of the trade, the existence of such outliers may be due to either sizeable differences in the quality of similar products that are reflected in their unit values or the existence of totally different products classified under the same 5-digit or 6-digit code. Both these reasons justify the assumption that similar products at different unit values are different products.

The method proposed in this dissertation to create a more disaggregated dataset for analysis uses the information about the distribution of unit value of trade flows illustrated above. The trade data used is from UN Comtrade, with two datasets used for different analysis. Whenever a long time period is required, this thesis uses the dataset based on the SITC rev2 (5-digit level) trade classification covering 240 economies in the period from 1984 to 2012. If a shorter period of time

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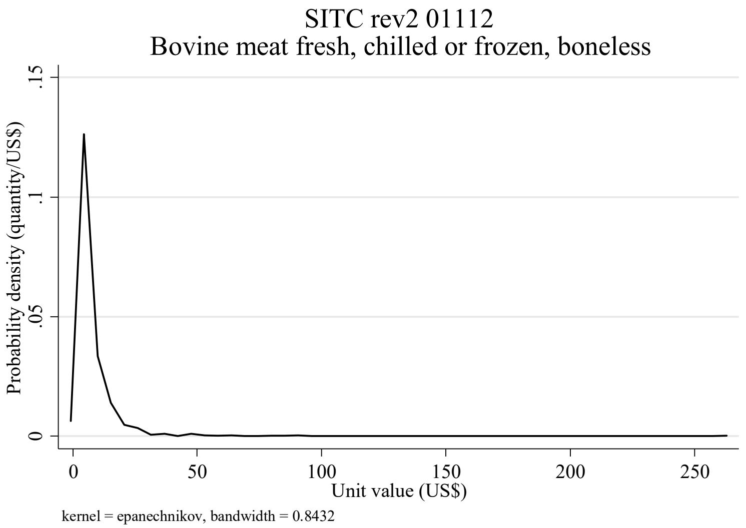
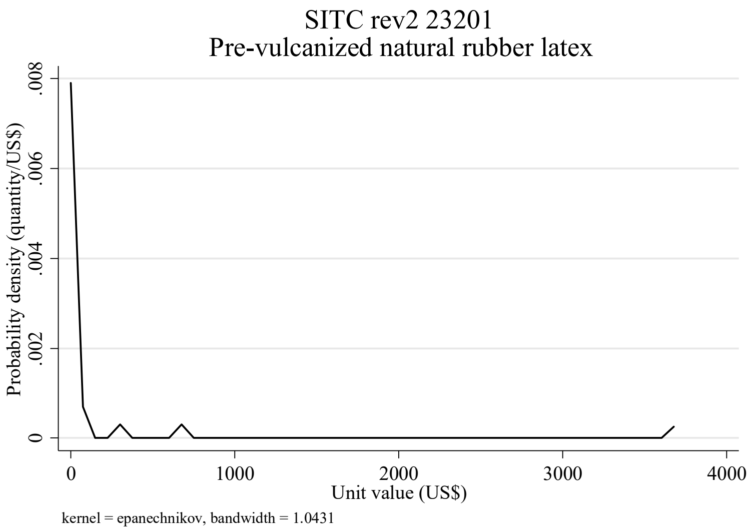
of US$ 1,975; two dresses exported from Lebanon to Romania with average unit value of US$ 1,992; and one dress exported from Russia to Italy with the value of US$ 2,005.

is involved in the analysis, a more disaggregated dataset is used: the Harmonized System code (HS 2002) at 6-digit level trade dataset covering around 220 economies in the period from 2005 to 2013.

Figure 3.5. Examples of distribution of unit values of tradable goods





Source: Based on data from UN Comtrade.

Those datasets contain bilateral trade data. That data is reported by the exporter, by the importer or both. Countries tend to report imports better than exports. Import data also contains more observations of exports from the least developed countries and other small developing economies, many of which do not systematically report export data. Therefore, following usual practice in the literature, import data is used in the analysis to estimate exports. For example, the export basket of India is estimated by combining the data from countries who report imports from India.

Only the part of the dataset that includes quantities of imports is used in the analysis, since this information is used to estimate the unit value of the products traded. The SITC dataset contains data from 1960 but data before 1984 do not have information on the quantity of the product traded and cannot be used to estimate the unit value of products (see Annex III.3 for summary statistics on the share of trade flows by country that do not have information on quantity).

The method to differentiate products according to differences in unit values follows a simple classification procedure, which is described below using as example the HS 2002 6-digit code classification:

1) The bilateral trade is initially sorted by the unit used to measure the quantity of the trade; such unit codes are part of the UN Comtrade dataset and are based on the standards of quantity recommended by the World Customs Organization (WCO) (e.g. weight in kilograms, length in meters and volume in cubic meters). The quantity unit code is added to the 6-digit classification to create an "artificial" 7-digit classification. My assumption is that if the products under the same 6-digit code are registered using different quantity unit codes then they may have different characteristics and could be classified as different products.[10]

2) The bilateral trade flow in the same 7-digit classification is sorted by the unit value of the trade. The distribution of unit value (x) for the same 7-digit product is then divided into up to nine groups. The first 3 groups are:

- Group 1 if $x < q1(x)$
- Group 2 if $q1(x) \leq x \leq q3(x)$ (III.15)
- Group 3 if $q3(x) < x \leq q3(x) + (1.5\ (q3(x) - q1(x)))$

[10] In the trade datasets provided by UN Comtrade, in addition to a field with the 6-digit code of a product, there is another field that indicates the quantity units. The codes and unities of measurement used are the following: 1 - No Quantity; 2 - (m^2) Area in square metres; 3 - (1000 kWh) Electrical energy in thousands of kilowatt-hours; 4 - (m) Length in metres; 5 - (u) Number of items; 6 - (2u) Number of pairs; 7 - (l) Volume in liters; 8 - (kg) Weight in kilograms; 9 - (1000u) Thousands of items; 10 -U (jeu/pack) Number of packages; 11 - (12u) Dozen of items; 12 (m^3) Volume in cubic meters; 13 - (carat) Weight in carats.

Where q1 and q3 are the first and the third quartiles of the distribution, respectively.[11]

For $y > q3(x) + 1.5\ (q3(x) - q1(x))$, the distribution of the unit value (y) above this threshold is further divided into 4 quartiles and 3 more groups are created:

- Group 4 if $y < q1(y)$
- Group 5 if $q1(y) \le y \le q3(y)$ (III.16)
- Group 6 if $q3(y) < y \le q3(y) + (1.5\ (q3(y) - q1(y)))$

Again, for $z > q3(y) + 1.5\ (q3(y) - q1(y))$, the distribution of the unit value (z) above this threshold is further divided into 4 quartiles and 3 more groups are created:

- Group 7 if $z < q1(z)$
- Group 8 if $q1(z) \le z \le q3(z)$ (III.17)
- Group 9 if $q3(z) < z \le q3(z) + (1.5\ (q3(z) - q1(z)))$

The group number is added to the 7-digit classification to create an "artificial" 8-digit classification. At the end of this procedure, each product is represented by such 8-digit classification code in which the first six digits correspond to the 6-digit HS 2002 code, the seventh digit corresponds to the quantity unit code of the product and the eighth digit represents the unit value group that includes the unit value of the product.

Table 3.4 shows the summary statistics of the dataset created using the method described above based on trade data using HS 6-digit classification and covering the period from 2005 to 2013. The level of disaggregation is such that for each year over 42,000 products were identified. For comparison, the dataset of U.S. import and export data using HS at 10-digit level disaggregation has approximately 40,000 products per month (Mandel, 2010). The coverage of economies and products is, therefore, much broader than that found in the literature, as illustrated by the selected studies listed in Table 3.1.

One last note on the method to classify products and the index of productive capacities: trade data has distinct classification codes for products and for the parts of products. The method proposed in this chapter uses that information to differentiate the productive capacities available, for example, in a developing country that exports an assembled product (say computer) using sophisticated parts and components, from the productive capacities of a more developed country that exports those parts and components. Different products require different capabilities to be produced. Since the final product exported by the developing country (computer) is different from the product exported by the developed country (micro-processor), the analysis considers that the capabilities available in

[11] The use of 1.5 times the interquartile range follows the usual procedure for detection of outliers as proposed by Tukey (1977).

the developing country to produce computers are different of the capabilities available in the developed country to produce micro-processors.

Table 3.4. Number of economies and products in the dataset based on HS classification

	Economies	Products
2005	229	44,664
2006	230	44,725
2007	230	44,411
2008	230	43,896
2009	230	43,309
2010	230	43,293
2011	232	43,373
2012	233	43,044
2013	233	42,583

The analysis conducted in this thesis is also able to differentiate the commodities in case that both developed and developing countries exports the same product (e.g. computers), but with different unit values. As mentioned previously, the literature on trade and quality has shown empirically that, when exporting the same product to a same country, the higher-income country will systematically export the higher unit value product while the lower-income country will systematically export the lower unit value product (Schott, 2004; Fontagné et al. 2008). Given that in the analysis we consider computers of different prices as different products, the capabilities available in these countries to produce these products will be considered inherently different.

However, the method is not able to differentiate the capabilities of two countries that export the same product for the same unit value, but one assembles the product using complex imported components (as part of a Global Value Chain) and the other produces these components and the final product domestically. Their capabilities will be the same as measured by the approach proposed in this chapter, which is not necessarily the case. This is an unavoidable limitation of the method.

3.6.1 Example of the application of the method

To illustrate the application of the method, let us consider the same distribution of unit values shown in Figure 3.4 related to the bilateral trade flow in the year 2010 of product 84332 in the SITC rev.2 classification, which correspond to dresses for women, girls and infants made of cotton. There are 4,277 bilateral trade flows of that product in 2010 and the unit value ranges from US$ 0.076, which is related to 64,000 units exported from Viet Nam to the Philippines totalling

US$4,861, to the maximum unit value of US$ 2,005 related to one item exported from the Russian Federation to Italy.

The initial step is to identify in the distribution the first (US$ 13.5) and third (US$ 29.5) quartiles. The interquartile range is the difference between those two quartiles (US$ 16). The cut-off for the outliers of that distribution is the third quartile plus 1.5 times the interquartile range, which result in US$ 53.5.

The result is that the first group of the classification is related to 1,069 bilateral trade flows in which the unit value is lower than US$ 13.5, the second group is related to 2,138 bilateral trade flows in which the unit values are in the range from US$ 13.5 to US$ 29.5, and the third group correspond to 426 trade flows in which the unit values are higher than US$ 29.5 and lower than US$ 53.5.

That same procedure is applied for the distribution of unit values higher than US$ 53.5 to classify products into groups 4 to 6, and then, once again, the method is applied to the outliers of the second distribution to classify products into groups 7 to 9. The result is shown in Table 3.5.

Table 3.5. Example of application of the method

Distribution	Limits	Unit value (US$)	Group	Unit value range (US$)	Number of trade flows
1	min	0.076	1	0.076 - 13.5	1,069
	p1	13.5			
	p3	29.5	2	13.5 - 29.5	2,138
	max	2,005.0	3	29.5 - 53.5	426
	cut-off	53.5			
2	min	53.5	4	53.5 - 71	161
	p1	71.0			
	p3	172.0	5	71 - 172	321
	max	2,005.0	6	172 - 223	61
	cut-off	223.0			
3	min	223.0	7	223 - 260.5	26
	p1	260.5			
	p3	688.0	8	260.5 - 688	52
	max	2,005.0	9	688 -2,005	25

Note: Distributions refer to product SITC rev 2 code 84332 for the year 2010.

One limitation of this method is that by construction the “middle” groups (2, 5 and 8) always contain around twice as many trade flows as the “low” groups (1, 4 and 7). Trade flows do not relate one-to-one with countries (a country could be the source of many trade flows), but the unequal numbers of trade flows affect the ubiquity estimates. The measure of product complexity is less affected because it uses the fifth iteration of the method of reflections, which includes information related to the diversification of countries that export the product. However, analysis of the dataset shows that the products in the "middle" groups are more likely to have a lower complexity than the products in the "low" groups. That tendency is stronger in relation to groups 4 and 5. Future research could explore ways to address this limitation; for example, by dividing the "middle" groups by the median of each distribution.

3.6.2 Relation with other classifications in the literature

Other methods have been proposed in the literature to classify products according to the unit value of trade flows. For example, Fontagné et al. (2008) classify products into three quality segments (low, medium or high). They use the BACI world trade database at 6-digit disaggregation to calculate the unit values of varieties of products exported.[12] They classify each bilateral trade flow in either low and medium ranges, medium range only, or medium and higher ranges. That procedure is used to account for the fact that each flow aggregates the trade of several firms throughout the year and to avoid a threshold effect in which small variations in unit values changes the price segment. For each trade flow, they calculate the ratio between the unit value and a weighted average of unit values of that type of product over all trade flows in the world. If the ratio is lower than one then the product is classified both in the low and medium ranges; products with a ratio higher than one are classified in the medium and high segments, and equal to one in the medium range. The authors also test a simpler procedure of dividing the unit values by percentiles in each year (down-market under the 33th percentile, up-market above the 67th percentile and middle-market in between) and found that their conclusions are robust to that change. Mulder, Paillacar and Zignago (2009) use the same procedure to classify products into three quality segments (low, medium or high) and add the technology-content classification of Lall (2000) to investigate trade flows by price segments.

The method proposed here is similar to those used in the studies mentioned above in terms of dividing the distribution of unit value of products into ranges.

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[12] BACI is a database for international trade analysis developed by the French research center CEPII. The name is the French acronym for "Base pour l'Analyse du Commerce International". The database was developed based on HS 6-digit data from Comtrade. It reconciles bilateral trade flow information, and estimates CIF (cost, insurance and freight) to compute FOB (free on board) import values. BACI is available with versions 1992, 1996 and 2002 of the Harmonized System (HS) with 6-digit disaggregation. Source:
http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=1.

However, the method that I propose also considers the fact that the distribution is fat-tailed, with high priced varieties that are many standard deviations above the average unit value. A classification in three segments risks aggregating different varieties within the higher-range segment.

Esposito and Vicarelli (2011) also classify products into low, medium and high quality based on unit values of products, but they acknowledge the existence of outliers. They use that product classification to study whether the contraction of trade during the 2008 global financial crises was related to changes in preferences of consumers towards lower quality goods. They consider the distribution of unit values and classify products with unit value 15% below the mean as of low quality, 15% above the mean as high quality and the rest as medium quality. Outliers in the distribution of unit value are considered different products and are not included in the classification. In the method proposed in this dissertation, the outliers are also considered and classified as different products.

The approach followed here is in the spirit of Mandel (2010), who considers the distribution of prices of imports and exports to evaluate the specialization of countries in terms of quality differentiation. He used price information from U.S. import HS data disaggregated at 10-digit level[13] and found that the distribution of prices of highly differentiated products is consistent with a power law-type distribution (i.e. fat-tailed) with a right skewed shape comprised by outliers that have high unit values.[14] Mandel also found that some products of industries associated with lower differentiation such as wood or mineral have price distribution with outliers with low unit value (i.e. skewed to the left), but overall the skewedness of the distributions was to the right. The methodology proposed in this chapter goes beyond the identification of the skewedness to the distribution to use that information to develop a classification of products differentiated by unit values.

The literature mentioned above associates different unit values with products of different quality. Khandelwal (2010) takes a different approach by considering both price and quantity information to infer the quality of varieties of a same type of product. Varieties with a higher market share conditional on price are considered to have higher quality. The assumption is that if a higher-priced variety has a low market share then it implies that people's preferences in buying that variety are driven by horizontal attributes of that variety (e.g. colour, size or style) rather than by the quality of the good. The empirical application of that method of classification shows that developed countries export varieties of higher quality when compared with developing countries. A key result is the measurement of the

[13] Data collected by the International Price Program (IPP) of the Bureau of Labor Statistics.

[14] In that study, outliners were defined as distant from the mean by one standard deviation.

different widths of the quality range of different types of products, which can be used to identify sectors in which competition can be avoided by moving up in the quality ladder.

The strong association between price and quality is questioned in the literature (e.g. Hallak and Schott, 2011) on the grounds that the other factors also affect prices, including exchange rates and differences in production costs. Nevertheless, an underlying assumption of that literature is that when countries export products of the same type but with different unit values, these are considered to be different varieties of products.[15] The methodology to classify products proposed here makes the same assumption.

Another approach is used in Kaplinsky and Santos Paulino (2004), who consider changes in the unit value over time to measure the level of innovativeness of products. The assumption is that more innovative products have rising prices while non-innovative products have declining prices. As noted in Lall et al. (2005), that approach assumes that the change in prices is driven mainly by the level of innovation in the products, which they argue may not be always justifiable given that prices can also change due to various other factors such as demand changes, trade barriers, changes in the configuration of value chains, etc. The methodology presented in this chapter is different because we use the unit value ranges in a given period of time instead of the change over a period. In addition, the methodology does not make any assumption regarding the level of technology or innovation in a product.

In summary, similar to the literature surveyed above, the methodology proposed in this dissertation considers the distribution of unit values of different bilateral trade flows and uses that information to classify products. An innovation of the method is that it takes into consideration the fact that, for many of the product categories in the usual trade classification, the distribution of unit values is fat-tailed. That information is used to divide a product category of the original trade classification in up to nine sub-classifications, which allows for a finer detail in the product classification.

3.7 Summary

This chapter presents methods in the empirical literature on economic complexity that are used in this dissertation to explore empirical regularities

[15] This relates to the difference in the literature between varieties of products that are horizontally differentiated (e.g. green versus yellow T-shirts), which are assumed to provide similar utility to consumers, and varieties that are vertically differentiated by quality, which are considered to be by all effects different types of products providing different levels of utility (Mandel, 2010).

related to diversification and to inform national development strategies. It highlights the use of trade data in that literature and the usual application of data cut-offs based on the population size or volume of trade, which reduces the usefulness of those methods for the analysis in the productive capacities of poorer countries.

The chapter presents the method of reflections proposed by Hidalgo and Hausmann (2009), which is extensively used in the literature. I argue that the use of revealed comparative advantage in the method is at odds with its basic assumptions and may create problems when applied to the analysis of less diversified economies, such as the least developed countries. A practical reason for its use is to differentiate the trade flows of industrialized countries when using trade data at higher levels of aggregation. To allow the use of the method for the analysis of poorer economies without compromising its application in the study of industrialized countries, I propose to use the method of reflections without considering the revealed comparative advantage, while using a more disaggregated dataset to be able to differentiate trade flows at very granular level.

The chapter presents the measures of productive capacity of countries and product complexity used in this dissertation. Similar to other studies in the literature, they are derived from measures of diversification and ubiquity that result from the method of reflections. The chapter also presents the measure of proximity between products that is calculated through the method proposed by Hidalgo et al. (2007).

The final part of the chapter presents a methodology to classify products that could be used in the analysis of the productive capacities of least developed countries. The method proposed follows other studies in the literature and considers the distribution of unit values of different bilateral trade flows to classify products. The novelty of the method is that it takes into consideration the fact that the distribution of unit values is fat-tailed, which results in finer detail in the product classification. The chapter also discusses the assumptions in using trade data as a proxy for production.

Annex

III.1. Summary statistics

Table 3.6. Summary statistics of measures from the method of reflection and index of productive capacity (*PCAP*), HS 6-dig (2013)

Variable	Obs	Mean	Std. Dev.	Min	Max
$k_{c,0}$	233	5199.73	6658.64	33.00	28627.00
$k_{c,1}$	233	83.52	18.58	39.00	119.33
$k_{c,2}$	233	11665.99	1630.23	9347.87	16366.42
$k_{c,3}$	233	65.81	3.65	56.44	71.46
$k_{c,4}$	233	13251.16	356.94	12722.86	14218.90
$k_{c,5}$	233	62.28	0.75	60.31	63.41
$k_{c,6}$	233	13597.14	75.76	13484.24	13798.53
$k_{c,7}$	233	61.55	0.16	61.14	61.79
$k_{c,8}$	233	13670.50	15.93	13646.72	13712.58
$k_{c,9}$	233	61.40	0.03	61.31	61.45
$k_{c,10}$	233	13685.92	3.34	13680.94	13694.73
$k_{c,11}$	233	61.37	0.01	61.35	61.38
$k_{c,12}$	233	13689.16	0.70	13688.11	13691.00
$k_{c,13}$	233	61.36	0.00	61.36	61.36
$k_{c,14}$	233	13689.83	0.15	13689.62	13690.22
$k_{c,15}$	233	61.36	0.00	61.36	61.36
$k_{c,16}$	233	13689.98	0.03	13689.93	13690.06
$k_{c,17}$	233	61.36	0.00	61.36	61.36
$k_{c,18}$	233	13690.01	0.01	13690.00	13690.02
$k_{c,19}$	233	61.36	0.00	61.36	61.36
PCAP	233	1.31E+23	2.43E+23	2.52E+20	1.40E+24

Source: Author based on data from UN Comtrade for the year 2013.

Notes: Products are originally classified using 6-digit HS (2002) classification further disaggregated by the methodology using unit values as presented in section 3.6.

Table 3.7. Summary statistics of measures from the method of reflection and index of productive capacity (*PCAP*), SITC rev2. 5-digit (2012)

Variable	Obs	Mean	Std. Dev.	Min	Max
$k_{c,0}$	233	1955.68	2159.90	3.00	8808.00
$k_{c,1}$	233	95.08	20.78	47.37	149.67
$k_{c,2}$	233	3802.23	490.62	2877.53	5146.21
$k_{c,3}$	233	77.61	3.89	67.79	85.27
$k_{c,4}$	233	4221.73	101.81	4028.63	4490.19
$k_{c,5}$	233	74.29	0.78	72.29	75.77
$k_{c,6}$	233	4308.68	20.73	4269.33	4362.76
$k_{c,7}$	233	73.63	0.16	73.22	73.93
$k_{c,8}$	233	4326.39	4.20	4318.41	4337.31
$k_{c,9}$	233	73.49	0.03	73.41	73.55
$k_{c,10}$	233	4329.98	0.85	4328.36	4332.18
$k_{c,11}$	233	73.47	0.01	73.45	73.48
$k_{c,12}$	233	4330.70	0.17	4330.38	4331.15
$k_{c,13}$	233	73.46	0.00	73.46	73.46
$k_{c,14}$	233	4330.85	0.03	4330.78	4330.94
$k_{c,15}$	233	73.46	0.00	73.46	73.46
$k_{c,16}$	233	4330.88	0.01	4330.87	4330.90
$k_{c,17}$	233	73.46	0.00	73.46	73.46
$k_{c,18}$	233	4330.88	0.00	4330.88	4330.89
$k_{c,19}$	233	73.46	0.00	73.46	73.46
PCAP	233	2.56E+17	4.13E+17	8.68E+13	2.20E+18

Source: Author based on data from UN Comtrade for the year 2012.

Notes: Products are originally classified using 5-digit SITC rev2 classification further disaggregated by the methodology using unit values as presented in section 3.6.

III.2. Principal component analysis

This section presents the results of principal component analysis considering the measures obtained using the method of reflections ($k_{c,0}$, $k_{c,1}$, $k_{c,2}$, …, $k_{c,19}$), based on data from UN Comtrade for the year 2013 originally classified using 6-digit HS (2002) classification further disaggregated by the methodology using unit values as presented in section 3.6.

Table 3.8 presents the eigenvalue of the first eight components. The table shows that the first component is able to explain 99.48% of the variation across all measures of diversification and ubiquity.

Table 3.9 presents the eigenvectors that result from the analysis. The table shows that all measures ($k_{c,0}$, $k_{c,1}$, $k_{c,2}$, …, $k_{c,19}$) contribute to the first component. They have similar loadings in terms of absolute value meaning that each variable is equally important. It is also noticeable that the measures of diversification ($k_{c,2N}$) have a positive sign (an increase in these variables increase the value of the first component) and the measures of ubiquity ($k_{c,2N+1}$) have a negative sign (an increase in these variables decrease the value of the first component).

Figure 3.6 presents the relationship between the index of productive capacities (*PCAP*) and the first component of the primary component analysis.

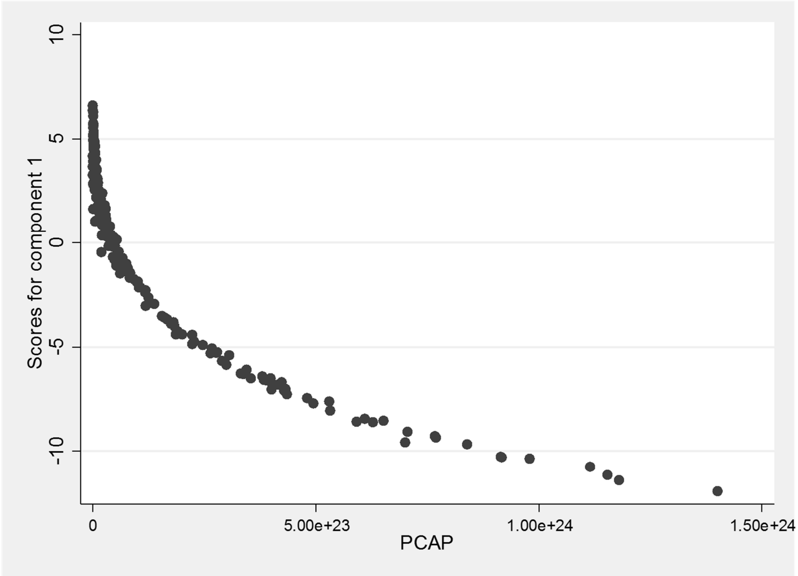
Table 3.8. Principal component analysis, eigenvalue

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	19.8966	19.8141	0.9948	0.9948
Comp2	0.082491	0.070374	0.0041	0.999
Comp3	0.012118	0.006068	0.0006	0.9996
Comp4	0.00605	0.004304	0.0003	0.9999
Comp5	0.001746	0.001133	0.0001	1
Comp6	0.000613	0.000373	0	1
Comp7	0.00024	0.000159	0	1
Comp8	8.1E-05	6.97E-05	0	1

Table 3.9. Principal component analysis, eigenvectors

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8	Unexplained
$k_{c,0}$	-0.216	0.924	-0.227	-0.057	0.026	-0.209	-0.008	0.011	0
$k_{c,1}$	0.222	0.297	0.911	0.117	-0.054	0.042	0.024	-0.023	0
$k_{c,2}$	-0.224	0.143	-0.070	0.044	-0.100	0.850	0.010	-0.041	0
$k_{c,3}$	0.224	0.096	0.027	-0.049	0.034	0.263	-0.089	0.119	0
$k_{c,4}$	-0.224	0.008	0.023	0.062	-0.076	0.301	0.044	-0.068	0
$k_{c,5}$	0.224	0.057	-0.064	-0.067	0.053	0.150	-0.082	0.088	0
$k_{c,6}$	-0.224	-0.027	0.054	0.067	-0.065	0.063	0.062	-0.074	0
$k_{c,7}$	0.224	0.047	-0.071	-0.068	0.057	0.093	-0.076	0.080	0
$k_{c,8}$	-0.224	-0.038	0.065	0.068	-0.061	-0.021	0.069	-0.076	0
$k_{c,9}$	0.224	0.044	-0.070	-0.068	0.059	0.073	-0.074	0.078	0
$k_{c,10}$	-0.224	-0.041	0.068	0.068	-0.060	-0.049	0.071	-0.077	0
$k_{c,11}$	0.224	0.043	-0.070	-0.068	0.059	0.066	-0.072	0.078	0
$k_{c,12}$	-0.224	-0.042	0.069	0.069	-0.060	-0.057	0.074	-0.077	0
$k_{c,13}$	0.224	0.043	-0.070	-0.068	0.056	0.068	-0.070	0.072	0
$k_{c,14}$	-0.224	-0.043	0.069	0.069	-0.058	-0.072	0.084	-0.061	0
$k_{c,15}$	0.224	0.045	-0.069	-0.067	0.046	0.062	-0.060	0.047	0
$k_{c,16}$	-0.224	-0.043	0.072	0.074	-0.073	-0.021	0.107	0.958	0
$k_{c,17}$	0.224	0.046	-0.079	-0.077	0.114	0.056	0.958	-0.030	0
$k_{c,18}$	-0.224	-0.033	0.112	0.070	0.962	0.065	-0.048	0.012	0
$k_{c,19}$	0.224	0.059	-0.195	0.953	0.009	-0.016	0.005	-0.004	0

Figure 3.6. Relationship between the index of productive capacities (*PCAP*) and the first component of the primary component analysis



III.3. Share of data without information on quantity

This section presents the summary statistics regarding the share of the data by country that do not have information related to quantity traded in the datasets used in this dissertation. That information is important because the quantity traded is used to calculate the unit value that is used in the product classification. If one country has quantity data for the entire spectrum of its trade, and another country only for half of its trade, the analysis could be distorted in a significant way.

Table 3.10 shows the statistics related to the dataset that uses the HS classification covering the years from 2005 to 2013. For each year, the table shows the average proportion of trade flows by country for which quantity information is not available. For each country and year, this share is calculated dividing the number of trade flows without quantity information by the number of all trade flows originating from that country. For example, an average 4.85% of the trade flows of 2005 do not have that information; the country with the lower share of missing data has 1.67% of the trade flows missing the quantity information, while the country with the higher share has 10.26% of the trade flows without quantity information. On average, 10.22% of the trade flows by country have missing data on quantity.

The average for the data based on SITC classification is lower (8.59%), but the early years in that dataset (1984 to 1987) is more problematic (Table 3.11). Higher shares of missing data vary from 75% to 90% in that period.

Table 3.10. Summary statistics of the share of the data by country that do not have information on quantity, HS data

year	mean	sd	min	max
2005	4.85	1.69	1.67	10.26
2006	5.00	1.55	2.12	9.73
2007	10.38	2.98	3.84	19.71
2008	11.07	3.44	3.84	25.43
2009	10.96	3.40	3.80	20.90
2010	10.74	3.36	4.18	25.71
2011	10.56	3.71	3.38	28.16
2012	17.25	4.62	8.03	33.33
2013	11.15	3.58	2.17	26.14
Mean	10.22			

Table 3.11. Summary statistics of the share of the data by country that do not have information on quantity, SITC data

year	mean	sd	min	max
1984	19.06	12.53	2.01	80.00
1985	13.41	10.21	2.46	75.56
1986	14.17	11.46	1.96	79.41
1987	14.33	10.96	1.47	90.91
1988	11.55	6.11	2.22	39.29
1989	13.31	7.68	2.83	75.00
1990	14.28	6.64	3.22	46.67
1991	12.10	6.37	1.99	44.44
1992	10.97	5.84	2.08	33.33
1993	10.12	5.58	2.11	38.46
1994	9.67	6.36	1.49	53.33
1995	8.32	5.38	0.92	36.36
1996	7.32	5.14	0.84	28.23
1997	6.76	4.26	1.48	34.78
1998	6.88	4.75	0.51	33.33
1999	8.29	4.34	2.63	33.23
2000	6.23	3.27	1.52	20.00
2001	6.23	3.74	0.21	21.45
2002	4.87	3.72	0.70	30.77
2003	4.57	3.81	0.82	31.43
2004	2.32	1.88	0.16	16.14
2005	1.96	1.90	0.29	21.81
2006	1.70	1.48	0.25	16.43
2007	5.06	2.37	0.95	23.20
2008	5.59	2.47	1.53	21.98
2009	5.36	1.91	1.93	12.62
2010	5.63	2.10	1.40	14.97
2011	5.05	2.09	0.73	20.00
2012	13.99	4.55	6.04	32.50
Mean	8.59			

4

Empirical evidence[1]

Using the datasets and methods presented in the previous chapter, this chapter replicates some of the empirical regularities found in the literature on economic complexity and presents new stylized facts related to diversification, productive capacities and the complexity distribution of exports of countries. The empirical regularities highlighted are used as basis for the analysis presented in the following two parts of the dissertation. First, there is a positive association between the export diversification of a country and its total GDP. Second, there is a negative association between diversification and the average ubiquity of exports. Third, the opportunities for caching up in terms of diversification have not been equally distributed and less diversified countries have fallen behind. Fourth, development is associated with the expansion of exports towards products of higher complexity. Fifth, for a given country, the potential new products that emerge with high probability are those nearby in the product space and in terms of the level of product complexity.

[1] This chapter presents and discusses empirical regularities that were first shown in Freire (2012a, 2013c) and in the Chapter 3 of ESCAP (2012), which I authored.

4.1 Diversification within and across product classification

This section presents and discusses empirical regularities of trade data related to the classification of goods within and across product classifications. The analysis shown here is based on datasets built using the method to classify products that was presented in the previous chapter. The method is applied to two bilateral trade datasets, one using the SITC revision 2 (5-digit) classification and the other using the HS 2002 (6-digit) classification. The method disaggregates bilateral trade flows into unit value ranges, which are identified by considering the distribution of unit values of all trade flows of a particular product in a given year. Most of the empirical regularities presented in this section are illustrated by results using both datasets.[2]

The empirical regularity presented in this section is that diversification within and across product categories are not mutually exclusive, but occur simultaneously. This stylized fact is illustrated in Figure 4.1, which shows two graphs: one based on SITC data for 230 economies in the year 2009 (graph *a*) and the other on HS data for 180 economies in the year 2013 (graph *b*). In both graphs, dots represent economies. The horizontal axis shows the number of product categories exported and the vertical axis shows the average number of unit value classes per category of product exported.[3] Countries that export goods within a broader range of product categories (horizontal diversification) also export these goods within a broader range of unit values (vertical diversification).

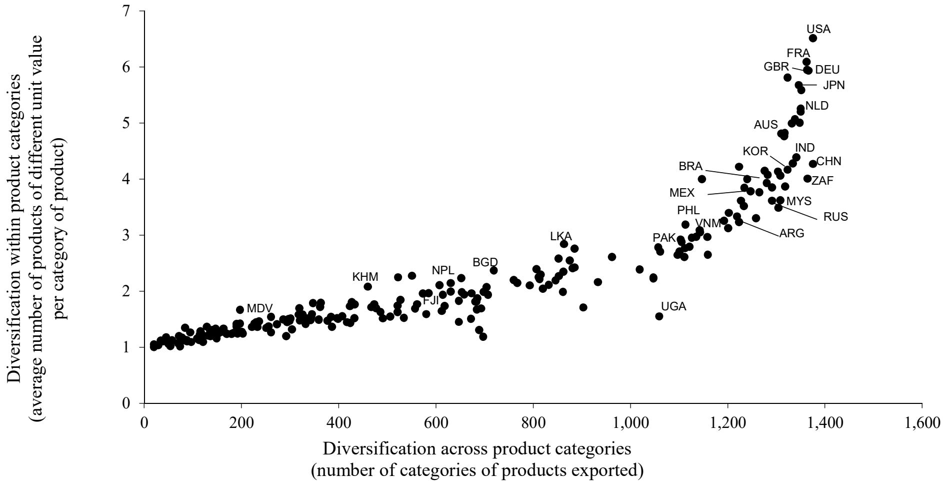
Therefore, it seems that the two forms of diversification go hand in hand. This stylized fact is in line with the view that sectors require a set of capabilities to produce goods and services, and some of those capabilities have been built initially for very different economic activities, not for previous activities in the same product category. For instance, a firm may require the use of laser cutting and engraving machines to enter the high-end garment segment. This may in turn require employing people skilled in the use of specialized software such as AutoCAD, who are more likely to be available if there are already other activities in the economy employing people with that type of skill.

[2] In addition, I have applied the method using SITC rev.2 4-digit classification and the dataset created by Feenstra et al. (2005), and also have applied the method by considering all outliers of the unit value distribution as part of a single unit value range. The results of the analysis using those datasets are similar to those presented in this section.

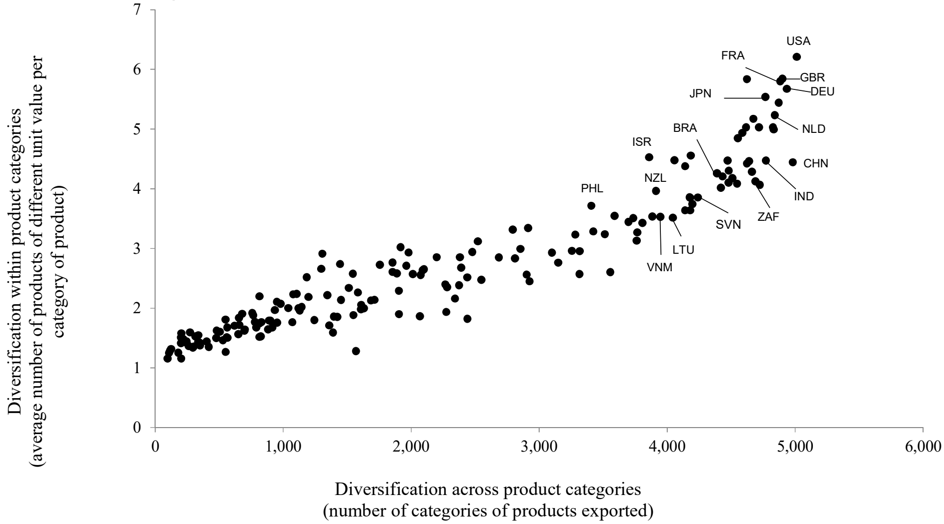
[3] I am using the term "categories of products" in this section to indicate that these are products that are not disaggregated by unit values.

Figure 4.1. Diversification within and across product categories

a) SITC rev.2 5-digit (2009)



b) HS 6-digt (2013)



Source: Author based on ESCAP (2011) and data from UN Comtrade.

Note: The three-letter codes used in the figure to represent country names are the alpha-3 country codes published in International Organization for Standardization (2006).

Figure 4.1 also suggests that for early stages of horizontal export diversification, the process of diversification across products is more intense than the process of diversification within-products. After an economy is able to produce goods from a large number of product categories (over around 1,200 in graph *a* and about 4,000 in graph *b*) the process of vertical diversification kicks in more strongly. In both graphs, that level of diversification is approximately equivalent to that of Viet Nam.

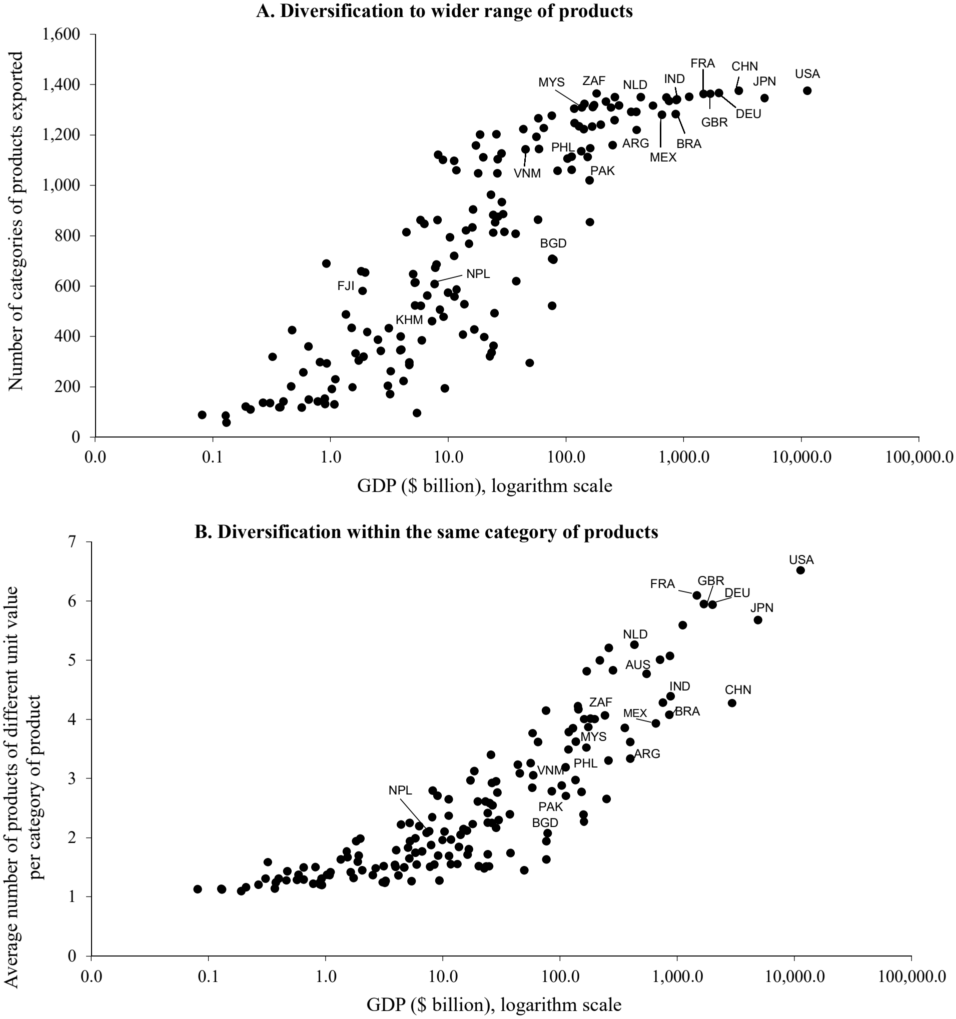
Other empirical studies have emphasized that developed countries diversify within product categories and that they tend to export higher unit value varieties. For example, Schott (2003) considers unit values of products to test Heckscher-Ohlin specialization patterns and finds evidence that suggests that rich countries have diversified within product categories (vertical product differentiation). The author interprets that pattern as a response by developed countries to competition from developing countries. Schott (2004) assesses trade specialization across and within products using data on U.S. imports of manufacturing products and finds a large variation of unit values even within very disaggregated product categories. He highlights the fact that low-wage countries export products to the U.S. that are also exported by high-wage countries, but the latter specialize in high-priced varieties while the former specialize in the low-priced ones. Hummels and Klenow (2005) assess the export of countries across the intensive margin (i.e. quantities exported of each type of product) and the extensive margin (number of different types of products exported). They find that the extensive margin accounts for 60% of higher levels of exports of larger economies. Richer countries also export higher quantities at higher prices within categories of products. Fontagné et al. (2008) reports that, when comparing the exports of the same products to the same market in 2000, the unit values of Japanese exports are 1.43 times higher than those from Brazil, 1.86 higher than those from India and 2.86 higher than those from China. They also compare different manufacturing and trade classifications at different levels of aggregation and show that the similarity of exports between countries decreases with increases in the granularity of the classification.

The results shown in Figure 4.1 are in line with those findings. However, they also suggest that not only developed but also developing countries diversify within product categories. Moreover, they also show that there is an association between the two forms of diversification, which to the best of my knowledge has not been discussed in the literature.

4.2 Diversification and total output

This section presents an empirical regularity related to the association between the level of diversification within and across products and the total GDP of an economy. This is illustrated in Figure 4.2 and Figure 4.3, using two different trade classifications. These figures show that the economies that have higher levels of GDP tend to export goods from a higher number of categories of products (graph *a*), and have more products in different classes of unit values (graph *b*). However, the patterns of diversification differ. For diversification toward a wider range of types of products, graphs form an S-shaped pattern (graph *a* in Figure 4.2 and Figure 4.3), while for diversification into different varieties of similar goods, the graphs form only the bottom half of the S-shaped pattern (graph *b* in Figure 4.2 and Figure 4.3).

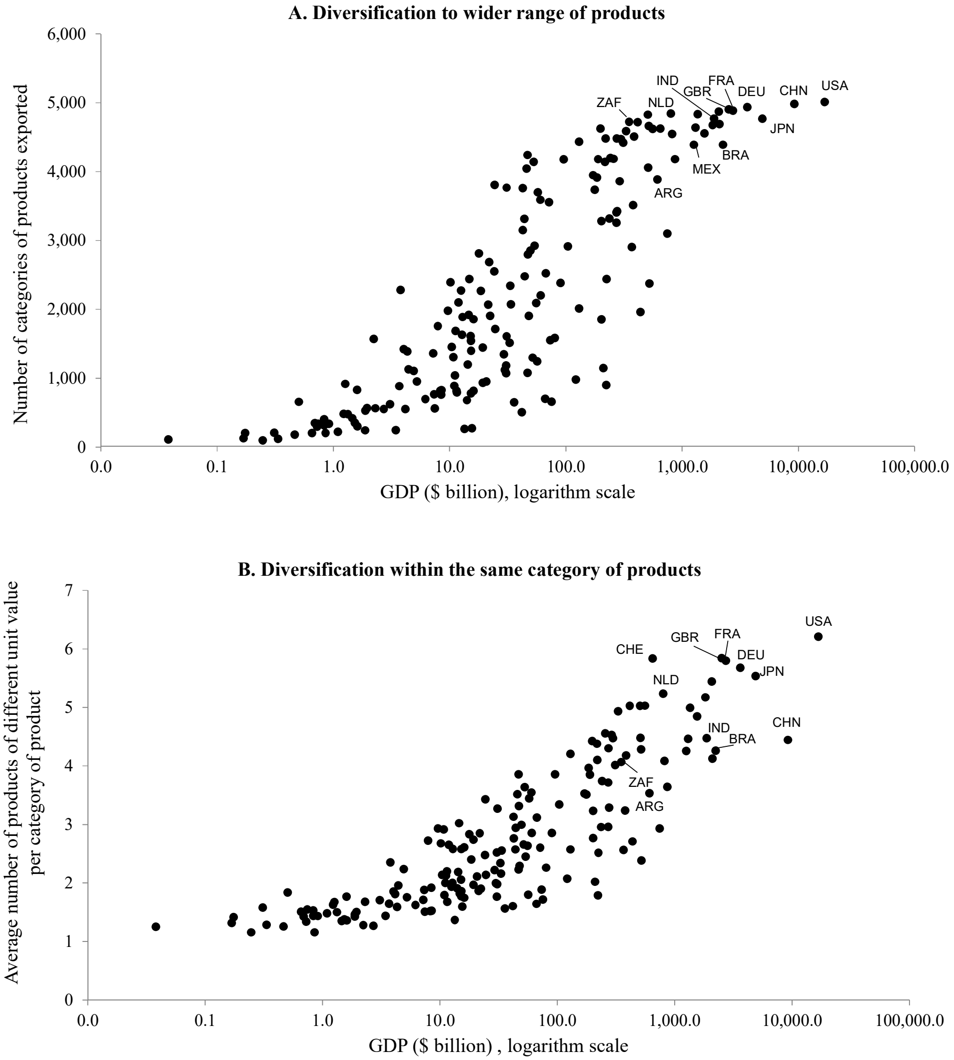
Figure 4.2. Diversification across products and GDP, SITC classification (2009)



Source: Author based on trade data from UN Comtrade and World Bank's WDI.

Notes: Products are originally classified using 5-digit SITC rev. 2 classification. The three-letter codes used in the figure to represent country names are the alpha-3 country codes published in International Organization for Standardization (2006).

Figure 4.3. Diversification across products and GDP, HS classification (2013)



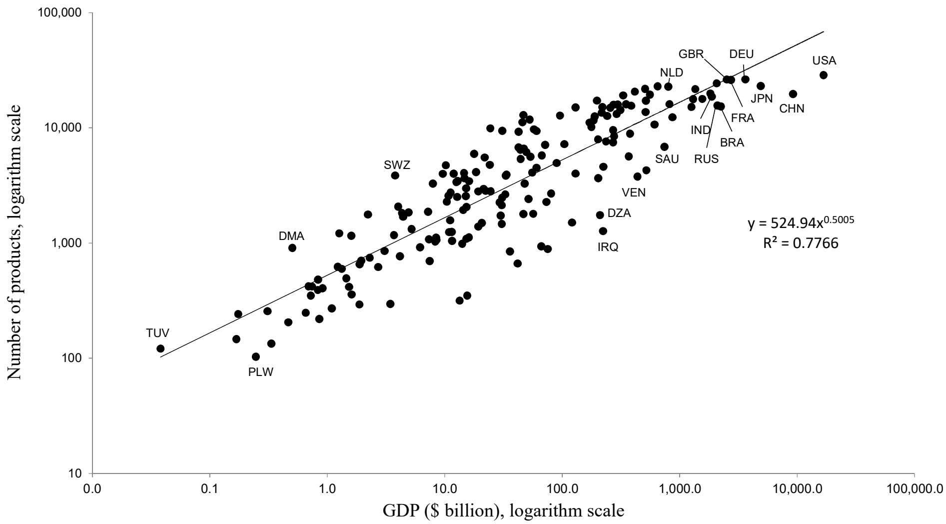
Source: Author based on trade data from UN Comtrade and World Bank's WDI.

Notes: Products are originally classified using 6-digit HS (2002) classification. The three-letter codes used in the figure to represent country names are the alpha-3 country codes published in International Organization for Standardization (2006).

The S-shaped curve shown in Figure 4.2 (graph *a*) and Figure 4.3 (graph *a*) is observed and discussed in Lei and Zhang (2014), which shows that the relationship between total GDP and diversification across products can be fitted by a logistic equation.

The figures suggest that richer economies do not stop to diversify. They rather diversify through differentiating their production by unit value, which is not captured by more aggregated production and trade classifications. In fact, the association is very strong between diversification considering both across and within products and total GDP, as illustrated in Figure 4.4. In the graph, the vertical axis shows the number of products classified by product category and further disaggregated by unit value using the method to classify products described in the previous chapter (for the rest of this dissertation, whenever the terms diversification or number of products are used, they refer to the number of products derived using that method).

Figure 4.4. Higher output is associated with diversification, 2013



Source: Author based on data from the UN Comtrade and from the World Bank's World Development Indicators (WDI).

Notes: Number of products exported is the number of category of products exported classified using HS 2002 trade data disaggregated at 6-digit level and further disaggregated by unit price; 2) Labels show countries using ISO 3-digit Alpha country code.

Except from Lei and Zhang (2014), the association shown above between diversification and total GDP is not highlighted in the empirical literature. That literature has focused on the association between diversification and income per capita as a proxy of economic development. An example is the much quoted 2003 American Economic Review article by Imbs and Wacziarg that shows that, as incomes increase, economies become more diversified. Such a pattern holds up to a fairly high level of income above which specialization seems to kick in. A puzzle exposed by that literature is that non-monotonic relationship between diversification and development. A possible cause for an inverted U-shape relationship is the level of disaggregation in product classification used in the analysis. [4] Robustness tests conducted using different product and trade classifications and different levels of disaggregation have confirmed the non-monotonic relationship (Imbs and Wacziarg, 2003; Cadot, Carrere and Strauss-Kahn 2012), but tests using classifications that account for product quality have found a positive relationship between diversification and income per capita (ESCAP, 2011; Papageorgiou and Spatafora, 2012).

4.3 Diversification and ubiquity

Another stylized fact found in the empirical literature on economic complexity is that as economies further diversify, they tend to move to the production of products that are slightly less ubiquitous than their existing production base, regardless of their initial level of diversification. This empirical regularity is presented and discussed by Hausmann and Hidalgo (2009 and 2011) using different trade classifications. This result remains robust to changes in trade classification and the methodology used to classify goods into different unit value classes (ESCAP, 2011 and 2015).

That empirical regularity is illustrated in Figure 4.5 using datasets based on SITC-based (graph *a*) and HS-based (graph *b*) bilateral trade data. In each graph, dots represent economies while the horizontal axis shows the diversification in terms of numbers of products, which is the same as the measure $k_{c,0}$ in the method of reflections discussed in the previous chapter. The vertical axis shows the measure $k_{c,1}$, which is the average ubiquity of the products exported by a given economy. That measure indicates how common the products exported by each economy are. For example, in graph *a*, Bangladesh (ISO code BDG) exported less than 2,000 types of products in 2009 and the average ubiquity of its product mix was over 90 countries, while China (ISO code CHN) had a diversification level slightly below 6,000 products and its export mix could be exported by less than 60 other countries, on average.

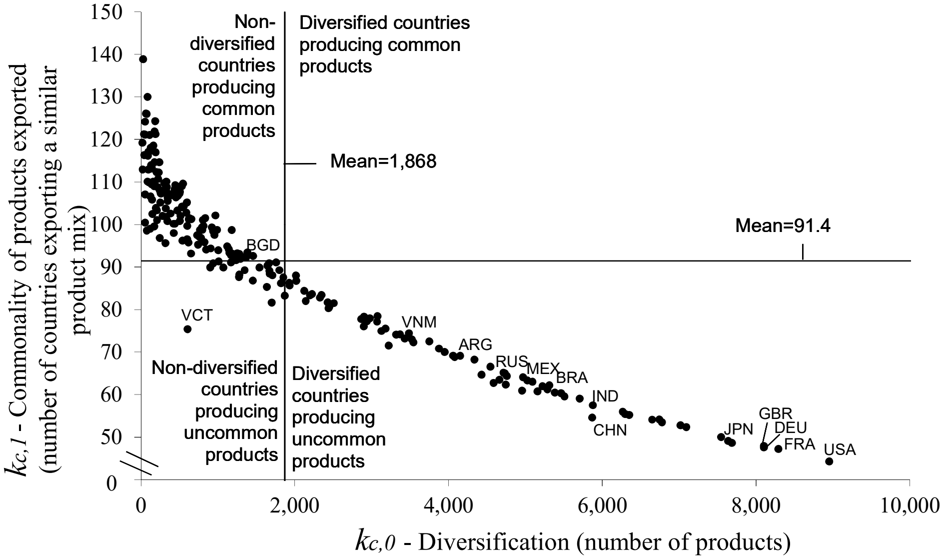
The graphs also show vertical and horizontal lines that indicate the global averages of each measure. In graph *a* for example, the vertical line shows that the average $k_{c,0}$ is 1,868 products and the vertical line indicates that the average $k_{c,1}$ is 91.4 countries. These lines divide the graph in four quadrants. The quadrant located in the left and top corner shows the economies that have diversification below the global average and average ubiquity of exports above the global

[4] Imbs and Wacziarg (2003) use measures of sectoral concentration to assess diversification, focusing on a Gini coefficient for the inequality of sector shares. The more equal the sector shares, the more diversified an economy.

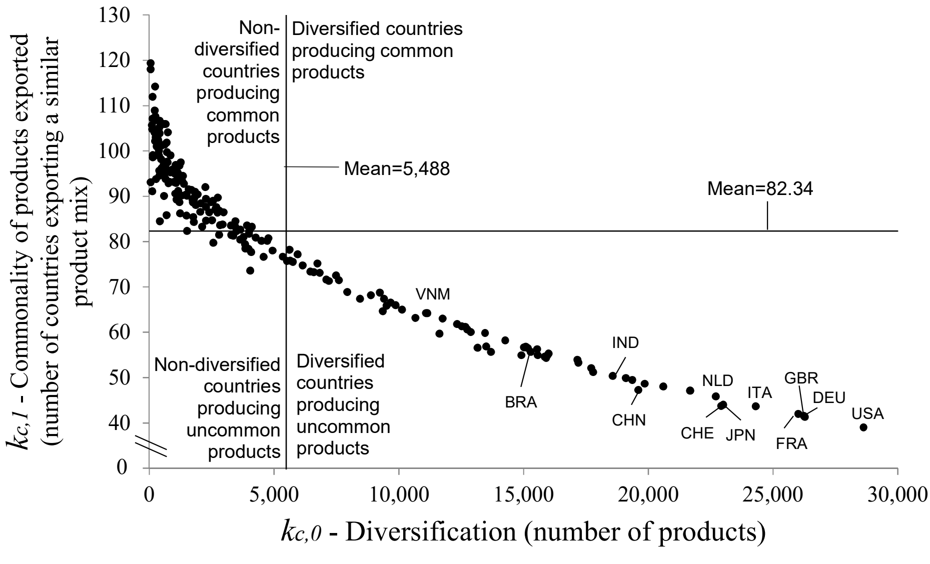
average. The majority of the economies considered in the analysis are located in that quadrant.

Figure 4.5. As economies diversify, they produce more exclusive products

a) Dataset based on SITC rev2. 5-digit, 2009



b) Dataset based on HS 6-digt, 2013



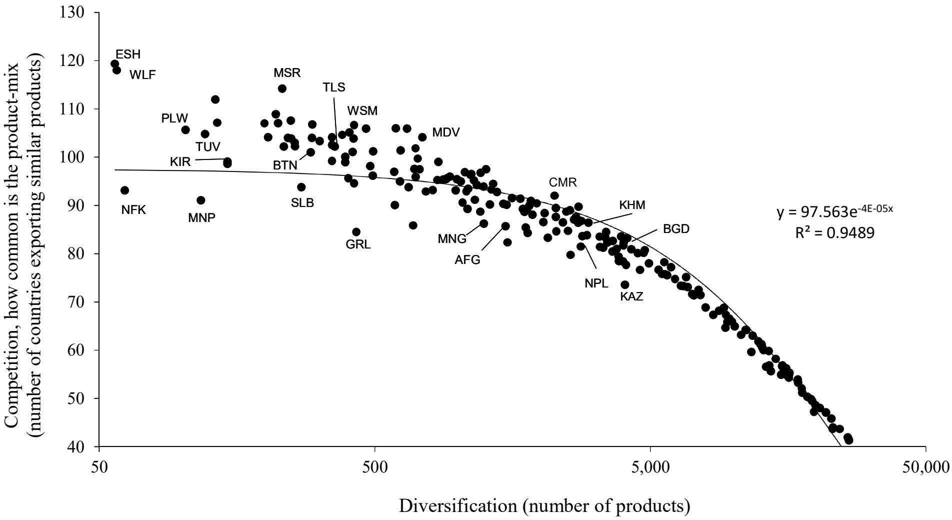
Source: Author based on ESCAP (2011) and data from UN Comtrade.

Note: The three-letter codes used in the figure to represent country names are the alpha-3 country codes published in International Organization for Standardization (2006).

The quadrant in the right bottom corner is the location of the economies that have above average diversification and below average ubiquity of exports. These are developed economies, large developing and emerging economies. Few economies are in the transition between the two quadrants – in the left bottom corner. They are less diversified than the global average but the average ubiquity of their exports is lower than the global average. It is noticeable that no economy is in the right top corner, which shows that no economy considered in the analysis has above average diversification but an export mix that has above average ubiquity.

Figure 4.6 presents the same information as in Figure 4.5 graph *b* but with the horizontal axis in logarithmic scale to focus on the smaller economies.

Figure 4.6. Diversification and commonality, focus on smaller economies

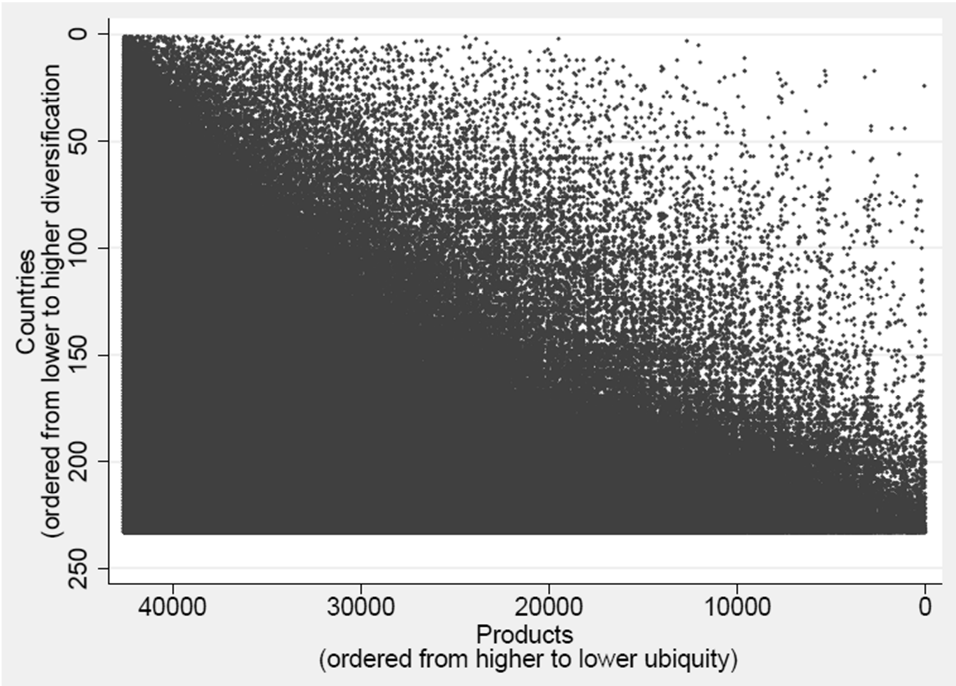


Source: Author based on ESCAP (2015) and data from UN Comtrade.

Notes: Products are originally classified using 6-digit HS (2002) classification. The three-letter codes used in the figure to represent country names are the alpha-3 country codes published in International Organization for Standardization (2006).

The relation between diversification and average ubiquity is also seen in the matrix of countries and products that they export, illustrated in Figure 4.7. One can imagine the figure divided by lines and columns, each line corresponding to one country and each column to one product. Dots in the figure correspond to pairs of countries and products, which are classified using trade data from UN Comtrade HS 2002 6-digit and further disaggregated by unit value. Countries in the figure are ordered from the least to the most diversified (from top to bottom) and products are ordered from the least to the most ubiquitous. The numbers on the horizontal axis mark the product number (the axis is presented in the reverse order, from the most to the least ubiquitous – left to right). The figure shows a triangular shape, with more diversified countries producing ever slightly less ubiquitous products.

Figure 4.7. Matrix of country and products, 2013



Source: Author based on data from UN Comtrade.

Haumann and Hidalgo (2011) provides an extensive discussion of the empirical regularity shown in the matrix of countries and products. They argue that such a regularity cannot be explained by trade theory. They note that Ricardo's classical trade theory or Heckscher-Ohlin types of theories make predictions regarding the export specialization of countries, but do not predict the number of types of products exported by a given country, or the average ubiquity of those exports, and the relation between these two measures. In fact, classical theory erroneously predicts export specialization and not diversification. New trade theory (e.g. Krugman, 1979; Helpman and Krugmann, 1985) was developed to explain why countries diversify and why there is intra-industry trade. That theory assumes the existence of different varieties of each product. These varieties are imperfect substitutes, which give firms some market power. The theory assumes that economies of scale reduce costs while competition drives profits down. Larger economies have bigger markets that can amortize development costs, as a consequence of which they are more diversified. This "New Trade theory," however, makes no prediction regarding which country will export which product; therefore, it does not address the measures of diversification and average ubiquity of exports and the relation between these measures. Hausmann and Hidalgo (2011) also discuss why other theories do not account for that empirical regularity, including growth theories that use the Dixit-Stiglitz model (Dixit and Stiglitz 1977), the grammar model of Kauffman (1993), Kremer's (1993) O-ring model, the recombinant growth model of Weitzman (1998) and trade models that follow Melitz (2003). Hausmann and Hidalgo (2011) then propose what they called a binomial model to account for this stylized fact. I will return to that model later in Chapter Seven.

4.4 Productive capacities

Based on the productive capacity index presented in the previous chapter, Table 4.1 shows the ranking of productive capacities for the year 2013. The first three columns of the table show the productive capacity of a given country measured as the distance to the global average productive capacity (which is indicated by zero) normalized by the standard deviation of the distribution of productive capacities. The table presents three columns to assess the effect of cut-offs to the value traded in the dataset used in the analysis. The idea is that if no cut-off is applied, products with small transaction values between countries (particularly exports from small economies such as many island countries) may indicate repatriation of goods instead of the existence of an economic sector in the country. The first column shows the result of the application of the method when considering all data in the trade dataset, meaning that no cut-off was applied to the values traded. The second and third columns show the result of the analysis applying cut-offs of US$ 10,000 and US$ 100,000 respectively. The ranking of countries considering the three cut-offs is shown in the next three columns while the last column shows the average ranking of each country. In general, the rankings do not change significantly when applying different cut-offs.

In this ranking, the United States has the highest productive capacity; one standard deviation higher than Germany, the country with the second highest level of productive capacity. When considering the average ranking, other countries that comprise the top ten in terms of productive capacities are France, United Kingdom, Italy, Japan, Switzerland, the Netherlands, Spain, Belgium and China. Most of these countries have productive capacities three standard deviations above the global average. If the productive capacity index were to follow a normal distribution, the probability of finding a country with such a high productive capacity would be rather negligible. At the bottom of the ranking are the Small Island economies. The analysis shows the lowest levels of productive capacity in the Federated States of Micronesia, Kiribati, Niue, Guinea-Bissau, Montserrat, Tuvalu, Wallis and Futuna Islands, Palau, Pitcairn and Western Sahara.

The countries for which above-average productive capacities are found are in general developed countries or emerging developing economies. Notable members of this group are Viet Nam, Lithuania, Estonia and Latvia, which used to be below the average until 2001. Most countries in the Asia-Pacific and Latin America regions, and all African economies with the exception of South Africa, have productive capacities that are below the global average.

Table 4.1. Productive capacity, 2013

	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
Country	None	10,000	100,000	None	10,000	100,000	mean
United States	5.236	5.513	6.052	1	1	1	1.0
Germany	4.326	4.750	5.514	2	2	2	2.0
France	4.057	4.567	4.848	4	3	3	3.3
United Kingdom	4.219	4.285	4.091	3	4	5	4.0
Italy	3.499	3.986	4.307	5	5	4	4.7
Japan	3.232	3.616	3.842	7	6	6	6.3
Switzerland	3.242	3.106	2.693	6	7	9	7.3
Netherlands	2.920	2.977	2.863	8	8	8	8.0
Spain	2.623	2.559	2.480	10	9	10	9.7
Belgium	2.634	2.525	2.417	9	10	11	10.0
China	2.348	2.447	2.896	12	11	7	10.0
Austria	2.371	2.234	2.009	11	12	12	11.7
Sweden	2.051	1.957	1.671	14	13	13	13.3
Canada	2.148	1.731	1.392	13	16	16	15.0
India	1.899	1.741	1.589	16	15	14	15.0
Denmark	1.973	1.769	1.378	15	14	17	15.3
Republic of Korea	1.653	1.645	1.578	17	17	15	16.3
Czech Republic	1.500	1.406	1.195	19	19	19	19.0
Poland	1.442	1.380	1.202	20	20	18	19.3
Australia	1.647	1.456	0.892	18	18	23	19.7
Singapore	1.240	1.241	0.957	22	21	21	21.3
Turkey	1.229	1.126	1.001	23	22	20	21.7
Hong Kong, China	1.255	1.058	0.740	21	24	25	23.3
Thailand	1.102	1.079	0.914	28	23	22	24.3

	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
Country	None	10,000	100,000	None	10,000	100,000	mean
Russian Federation	1.172	1.026	0.880	25	25	24	24.7
Finland	1.113	0.956	0.692	27	26	26	26.3
South Africa	1.207	0.906	0.597	24	27	31	27.3
Brazil	1.116	0.856	0.685	26	30	27	27.7
Hungary	1.040	0.860	0.642	30	29	30	29.7
Mexico	1.064	0.805	0.646	29	31	29	29.7
Portugal	1.029	0.862	0.569	31	28	32	30.3
Malaysia	0.882	0.796	0.665	33	32	28	31.0
Norway	0.922	0.715	0.450	32	33	34	33.0
Ireland	0.854	0.707	0.481	34	34	33	33.7
Israel	0.826	0.626	0.398	35	35	36	35.3
Slovakia	0.654	0.546	0.370	38	36	37	37.0
United Arab Emirates	0.720	0.509	0.276	36	38	39	37.7
Indonesia	0.559	0.485	0.413	41	39	35	38.3
Romania	0.599	0.517	0.326	40	37	38	38.3
Slovenia	0.692	0.481	0.250	37	40	40	39.0
Greece	0.610	0.381	0.115	39	42	43	41.3
Bulgaria	0.476	0.328	0.130	43	43	42	42.7
New Zealand	0.549	0.399	0.078	42	41	46	43.0
Viet Nam	0.377	0.293	0.220	46	44	41	43.7
Lithuania	0.397	0.250	0.073	44	45	47	45.3
Argentina	0.379	0.203	0.078	45	47	45	45.7
Ukraine	0.286	0.204	0.109	47	46	44	45.7
Estonia	0.247	0.119	-0.033	48	48	48	48.0
Luxembourg	0.228	0.076	-0.035	49	49	49	49.0
Philippines	0.205	0.064	-0.046	51	50	50	50.3
Latvia	0.182	0.064	-0.079	52	51	51	51.3
Croatia	0.216	0.023	-0.137	50	52	55	52.3
Serbia	0.147	0.005	-0.126	53	53	53	53.0
Chile	0.096	-0.047	-0.134	55	54	54	54.3
Colombia	0.122	-0.051	-0.147	54	55	56	55.0
Belarus	-0.051	-0.071	-0.107	59	56	52	55.7
Pakistan	-0.026	-0.108	-0.155	57	57	57	57.0
Peru	0.027	-0.119	-0.199	56	58	60	58.0
Egypt	-0.051	-0.120	-0.166	58	59	58	58.3

Country	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
	None	10,000	100,000	None	10,000	100,000	mean
Tunisia	-0.117	-0.144	-0.187	62	60	59	60.3
Morocco	-0.058	-0.148	-0.212	60	61	61	60.7
Saudi Arabia	-0.100	-0.195	-0.231	61	62	62	61.7
Sri Lanka	-0.194	-0.232	-0.264	67	64	63	64.7
Panama	-0.124	-0.199	-0.294	63	63	69	65.0
Costa Rica	-0.162	-0.245	-0.293	65	66	67	66.0
Cyprus	-0.210	-0.237	-0.280	69	65	65	66.3
Bosnia and Herzegovina	-0.188	-0.250	-0.293	66	67	68	67.0
Iran (Islamic Republic of)	-0.199	-0.264	-0.287	68	68	66	67.3
Kenya	-0.131	-0.272	-0.324	64	69	73	68.7
Kazakhstan	-0.273	-0.290	-0.279	73	70	64	69.0
Guatemala	-0.219	-0.296	-0.312	70	71	70	70.3
Lebanon	-0.231	-0.313	-0.333	71	72	74	72.3
Ecuador	-0.265	-0.325	-0.333	72	74	76	74.0
Uruguay	-0.306	-0.316	-0.318	78	73	72	74.3
TFYR of Macedonia	-0.281	-0.327	-0.337	74	75	77	75.3
El Salvador	-0.283	-0.331	-0.337	75	76	78	76.3
Bangladesh	-0.335	-0.332	-0.312	83	77	71	77.0
Malta	-0.317	-0.343	-0.333	79	78	75	77.3
Iceland	-0.290	-0.347	-0.340	76	80	79	78.3
Dominican Republic	-0.300	-0.346	-0.346	77	79	80	78.7
Honduras	-0.335	-0.362	-0.348	82	85	83	83.3
Mauritius	-0.336	-0.353	-0.353	84	81	85	83.3
Jordan	-0.347	-0.357	-0.346	88	83	81	84.0
Democratic People's Republic of Korea	-0.356	-0.357	-0.349	89	82	84	85.0
Swaziland	-0.322	-0.376	-0.369	81	87	90	86.0
Republic of Moldova	-0.371	-0.358	-0.347	93	84	82	86.3
Albania	-0.373	-0.374	-0.364	94	86	89	89.7
Cambodia	-0.403	-0.391	-0.356	99	90	86	91.7

	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
Country	**None**	**10,000**	**100,000**	**None**	**10,000**	**100,000**	**mean**
Georgia	-0.369	-0.386	-0.373	92	89	94	91.7
Venezuela	-0.344	-0.394	-0.372	87	95	93	91.7
United Republic of Tanzania	-0.336	-0.392	-0.375	85	92	99	92.0
Syrian Arab Republic	-0.414	-0.383	-0.359	102	88	87	92.3
Madagascar	-0.408	-0.393	-0.369	100	93	91	94.7
Namibia	-0.364	-0.392	-0.377	91	91	102	94.7
Ghana	-0.384	-0.395	-0.374	95	96	96	95.7
Nepal	-0.395	-0.393	-0.375	96	94	98	96.0
Nigeria	-0.321	-0.407	-0.382	80	102	108	96.7
Qatar	-0.357	-0.399	-0.379	90	97	105	97.3
Oman	-0.422	-0.405	-0.373	106	99	95	100.0
Uzbekistan	-0.456	-0.401	-0.362	119	98	88	101.7
Bahrain	-0.421	-0.413	-0.374	104	107	97	102.7
Botswana	-0.342	-0.413	-0.390	86	105	117	102.7
Zimbabwe	-0.421	-0.406	-0.378	105	100	103	102.7
Myanmar	-0.445	-0.410	-0.370	114	104	92	103.3
Trinidad and Tobago	-0.412	-0.409	-0.384	101	103	109	104.3
Macao, China	-0.430	-0.407	-0.381	108	101	107	105.3
Kuwait	-0.415	-0.416	-0.379	103	110	104	105.7
Bolivia	-0.439	-0.413	-0.376	112	106	101	106.3
Zambia	-0.402	-0.416	-0.388	98	111	114	107.7
Kyrgyzstan	-0.458	-0.415	-0.375	120	108	100	109.3
Armenia	-0.431	-0.416	-0.386	109	109	112	110.0
Nicaragua	-0.424	-0.420	-0.387	107	112	113	110.7
Azerbaijan	-0.440	-0.422	-0.384	113	113	110	112.0
Uganda	-0.399	-0.427	-0.393	97	118	121	112.0
Mozambique	-0.449	-0.423	-0.385	115	114	111	113.3
Cote d'Ivoire	-0.435	-0.424	-0.388	111	115	115	113.7
Paraguay	-0.467	-0.425	-0.381	127	116	106	116.3
Senegal	-0.432	-0.430	-0.392	110	121	120	117.0
Fiji	-0.450	-0.430	-0.394	116	120	122	119.3
Algeria	-0.466	-0.428	-0.389	125	119	116	120.0
San Marino	-0.462	-0.427	-0.395	122	117	124	121.0
Ethiopia	-0.467	-0.434	-0.391	126	122	119	122.3

	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
Country	**None**	**10,000**	**100,000**	**None**	**10,000**	**100,000**	**mean**
Lao People's Democratic Republic	-0.478	-0.438	-0.391	130	124	118	124.0
Cameroon	-0.451	-0.435	-0.399	117	123	133	124.3
Lesotho	-0.456	-0.441	-0.397	118	128	129	125.0
Togo	-0.465	-0.439	-0.397	124	125	128	125.7
Montenegro	-0.471	-0.440	-0.396	128	126	125	126.3
Jamaica	-0.460	-0.442	-0.398	121	129	132	127.3
Sierra Leone	-0.463	-0.440	-0.402	123	127	141	130.3
Mongolia	-0.485	-0.443	-0.398	133	130	130	131.0
Cuba	-0.490	-0.445	-0.396	138	133	126	132.3
Democratic Republic of the Congo	-0.481	-0.446	-0.399	132	134	134	133.3
Papua New Guinea	-0.496	-0.444	-0.396	143	131	127	133.7
Afghanistan	-0.473	-0.448	-0.401	129	137	138	134.7
Belize	-0.495	-0.447	-0.398	140	135	131	135.3
Angola	-0.478	-0.447	-0.404	131	136	145	137.3
British Virgin Islands	-0.498	-0.445	-0.401	145	132	137	138.0
Faeroe Islands	-0.509	-0.450	-0.395	160	138	123	140.3
Barbados	-0.489	-0.451	-0.404	136	139	151	142.0
Seychelles	-0.496	-0.451	-0.404	142	141	146	143.0
Malawi	-0.497	-0.453	-0.403	144	145	142	143.7
Tajikistan	-0.503	-0.451	-0.402	151	140	140	143.7
Gabon	-0.486	-0.452	-0.405	135	143	154	144.0
Iraq	-0.496	-0.453	-0.403	141	148	144	144.3
Andorra	-0.486	-0.452	-0.405	134	144	157	145.0
Suriname	-0.490	-0.453	-0.405	137	146	153	145.3
New Caledonia	-0.499	-0.453	-0.404	146	149	149	148.0
Yemen	-0.511	-0.454	-0.400	161	150	135	148.7
Libyan Arab Jamahiriya	-0.509	-0.454	-0.402	158	151	139	149.3
Sudan	-0.507	-0.455	-0.403	155	152	143	150.0
Turkmenistan	-0.516	-0.453	-0.401	167	147	136	150.0
Mali	-0.494	-0.456	-0.406	139	154	159	150.7

	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
Country	None	10,000	100,000	None	10,000	100,000	mean
Brunei Darussalam	-0.500	-0.452	-0.406	149	142	163	151.3
Haiti	-0.501	-0.457	-0.404	150	157	147	151.3
Congo	-0.504	-0.455	-0.404	153	153	150	152.0
Bahamas	-0.504	-0.457	-0.404	154	156	148	152.7
Niger	-0.499	-0.456	-0.407	147	155	165	155.7
Burkina Faso	-0.499	-0.458	-0.406	148	159	161	156.0
Guyana	-0.512	-0.457	-0.404	163	158	152	157.7
Mauritania	-0.512	-0.459	-0.405	162	165	155	160.7
Benin	-0.503	-0.460	-0.407	152	168	164	161.3
Dominica	-0.508	-0.459	-0.407	156	162	169	162.3
Aruba	-0.515	-0.458	-0.407	165	161	166	164.0
French Polynesia	-0.518	-0.459	-0.406	169	163	162	164.7
Gibraltar	-0.509	-0.459	-0.408	159	164	173	165.3
Guinea	-0.508	-0.461	-0.407	157	169	170	165.3
Liberia	-0.519	-0.460	-0.406	171	166	160	165.7
Greenland	-0.521	-0.460	-0.405	175	167	156	166.0
Occupied Palestinian Territory	-0.525	-0.458	-0.405	181	160	158	166.3
Rwanda	-0.516	-0.463	-0.408	168	175	171	171.3
Vanuatu	-0.525	-0.462	-0.407	180	171	167	172.7
Cayman Islands	-0.521	-0.462	-0.408	173	173	174	173.3
Antigua and Barbuda	-0.521	-0.462	-0.408	174	172	177	174.3
Tokelau	-0.516	-0.461	-0.409	166	170	189	175.0
American Samoa	-0.514	-0.464	-0.409	164	179	185	176.0
Turks and Caicos Islands	-0.525	-0.462	-0.408	179	174	175	176.0
Djibouti	-0.523	-0.463	-0.408	177	176	178	177.0
Maldives	-0.518	-0.464	-0.409	170	178	184	177.3
Burundi	-0.519	-0.464	-0.408	172	180	182	178.0
Cape Verde	-0.521	-0.464	-0.409	176	181	187	181.3
Somalia	-0.528	-0.465	-0.408	187	182	180	183.0
Solomon Islands	-0.532	-0.465	-0.407	197	185	168	183.3
Equatorial	-0.530	-0.465	-0.408	191	184	179	184.7

Country	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
	None	10,000	100,000	None	10,000	100,000	mean
Guinea							
Saint Kitts and Nevis	-0.528	-0.466	-0.408	186	186	183	185.0
Central African Republic	-0.527	-0.465	-0.409	183	183	190	185.3
Samoa	-0.529	-0.464	-0.409	188	177	192	185.7
Bermuda	-0.527	-0.466	-0.409	184	187	188	186.3
Bhutan	-0.532	-0.466	-0.408	196	188	176	186.7
Saint Lucia	-0.523	-0.466	-0.409	178	191	191	186.7
Grenada	-0.528	-0.466	-0.409	185	192	186	187.7
Marshall Islands	-0.534	-0.466	-0.408	204	189	172	188.3
Guam	-0.527	-0.466	-0.409	182	190	194	188.7
Cook Islands	-0.529	-0.466	-0.409	190	193	195	192.7
Gambia	-0.529	-0.466	-0.409	189	194	198	193.7
Falkland Islands (Malvinas)	-0.536	-0.466	-0.408	211	195	181	195.7
Anguilla	-0.533	-0.467	-0.409	200	196	193	196.3
Chad	-0.531	-0.467	-0.409	195	198	196	196.3
Saint Vincent and the Grenadines	-0.530	-0.467	-0.410	194	200	199	197.7
Nauru	-0.530	-0.467	-0.410	193	197	207	199.0
Saint Helena	-0.533	-0.467	-0.410	199	199	200	199.3
Timor-Leste	-0.530	-0.467	-0.410	192	201	205	199.3
Eritrea	-0.532	-0.468	-0.410	198	204	204	202.0
Tonga	-0.535	-0.467	-0.410	207	202	202	203.7
Saint Pierre and Miquelon	-0.535	-0.468	-0.410	206	203	203	204.0
Mayotte	-0.534	-0.468	-0.410	203	206	212	207.0
Norfolk Island	-0.539	-0.468	-0.409	218	207	197	207.3
Holy See	-0.536	-0.469	-0.410	210	212	201	207.7
Comoros	-0.534	-0.468	-0.410	205	208	213	208.7
Northern Mariana Islands	-0.537	-0.468	-0.410	213	205	208	208.7
Sao Tome and Principe	-0.533	-0.468	-0.411	201	210	216	209.0
Micronesia	-0.538	-0.468	-0.410	214	209	206	209.7

Country	Productive capacity index			Ranking			
	Cut-off ($)			Cut-off ($)			
	None	10,000	100,000	None	10,000	100,000	mean
(Federated States of)							
Kiribati	-0.537	-0.468	-0.410	212	211	209	210.7
Niue	-0.533	-0.469	-0.411	202	213	217	210.7
Guinea-Bissau	-0.535	-0.469	-0.410	208	216	211	211.7
Montserrat	-0.536	-0.469		209	215		212.0
Tuvalu	-0.538	-0.469	-0.410	215	214	214	214.3
Wallis and Futuna Islands	-0.540	-0.470	-0.410	219	219	210	216.0
Palau	-0.539	-0.469	-0.411	217	217	215	216.3
Pitcairn	-0.538	-0.469	-0.411	216	218	218	217.3
Western Sahara	-0.540	-0.470	-0.411	220	220	219	219.7

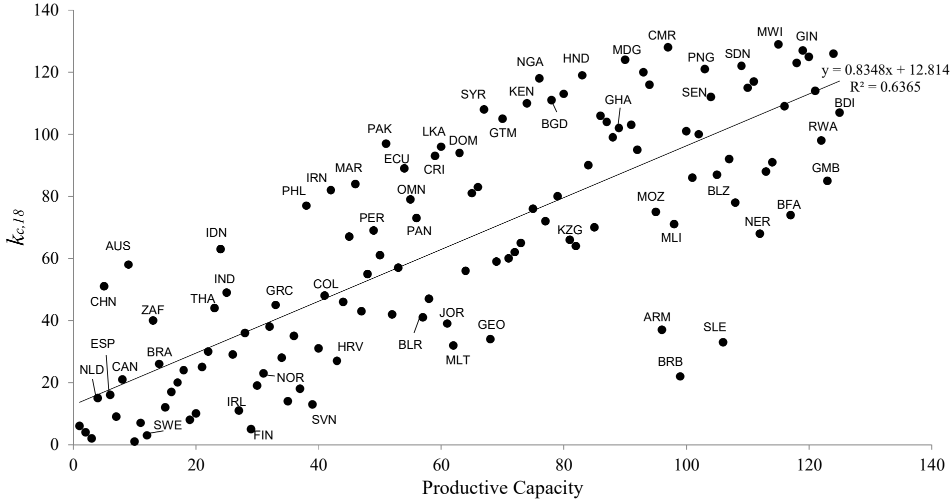
Source: Author's computations based on trade data from UN Comtrade.

The ranking presented in Table 4.1 is in general alignment with the ranking presented in Hidalgo and Hausmann (2009) in terms of having developed countries at the top of the ranking and least developed, landlocked developing and small island developing countries, particularly from Sub-Saharan Africa, in the bottom. However, there are big differences in the positions of many countries.

This is illustrated in Figure 4.8, which shows a comparison of the ranking produced using the method to estimate productive capacities presented in the previous chapter (horizontal axis) and the ranking of countries produced by Hidalgo and Hausmann (2009) (vertical axis), using the same initial dataset from Feenstra et al. (2005). The line in the graph indicates the regression line between the two rankings of countries. A notable difference between the two rankings is that emerging economies such as China (CHN), Brazil (BRA), India (IND), and South Africa (ZAF) are considered to have higher position in the ranking of productive capacities than in the ranking presented by Hidalgo and Hausmann. The ranking of productive capacities is somewhat closer the ranking produced by Tacchella et al. (2012), as illustrated in Figure 4.9.

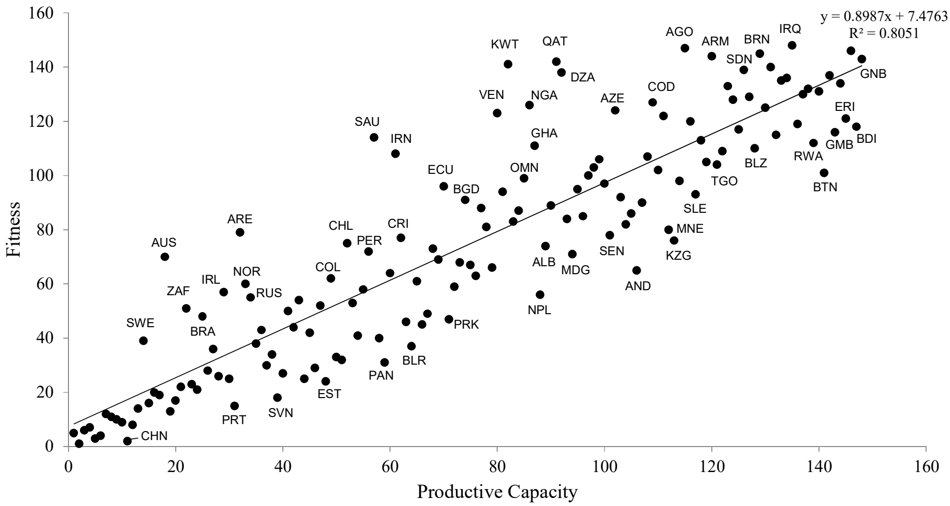
A fact that is not highlighted by Hidalgo and Hausmann (2009) or Tacchella et al. (2012), and that is obfuscated by the discussion of ranking positions between countries, is the fact that the distribution of the measure of productive capacity is fat-tailed. As mentioned previously, developed countries and some emerging economies are found to have levels of productive capacity that are many standard deviations above the mean, with the majority of the remaining economies with levels of productive capacity that are below the global average.

Figure 4.8. Comparison of productive capacity and Hidalgo and Hausmann index, 2000



Source: Productive capacity ranking: Author's computations based on trade data from UN Comtrade. $k_{c,18}$ ranking: Hidalgo and Hausmann (2009).

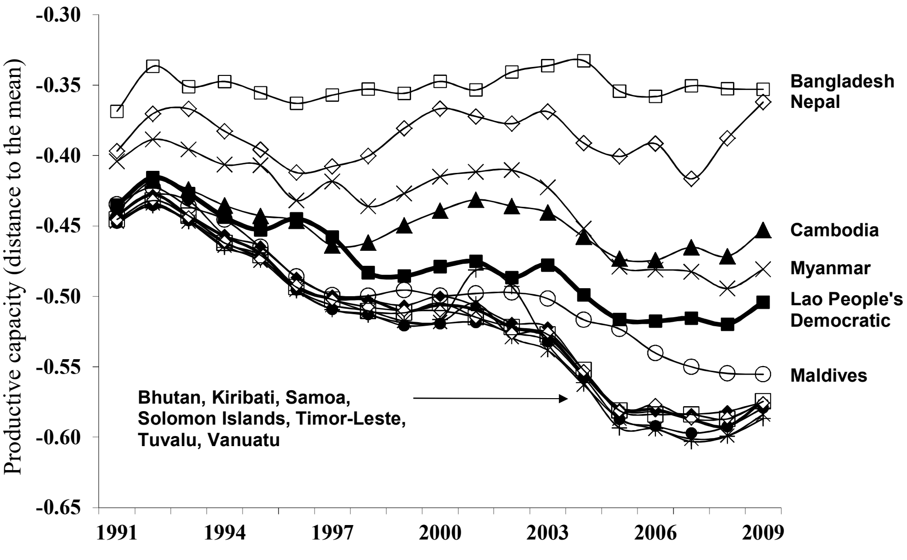
Figure 4.9. Comparison of productive capacity and fitness rankings, 2010



Source: Productive capacity ranking: Author's computations based on trade data from UN Comtrade. Fitness ranking: Tacchella et al. (2012).

Figure 4.10 illustrates how least developed countries got lagged further behind the global average during a period stretching over two decades. The figure focuses on the least developed countries of Asia and the Pacific region. Except for Bangladesh, all least developed countries in the region have ended the period further away from the global average in 2009 than in 1984. Six least developed countries (namely Bhutan, Samoa, Vanuatu, Solomon Islands, Timor-Leste, Kiribati and Tuvalu) have experienced a very similar evolution in their productive capacities in relation to the world's average, indicating that they possess very similar levels of productive capacity and such levels have not changed significantly during the last two decades. These countries are further away from the global average, not because they have lost their productive capacity but because they have not changed much in a world where others have increased their productive capacity. The Lao People's Democratic Republic and Maldives used to be the seventh and eighth members of this group in the first half of the 1990's but since then have improved their productive capacities, although not fast enough to catch up with the world average.[5]

Figure 4.10. Evolution of productive capacities of least developed countries in Asia-Pacific

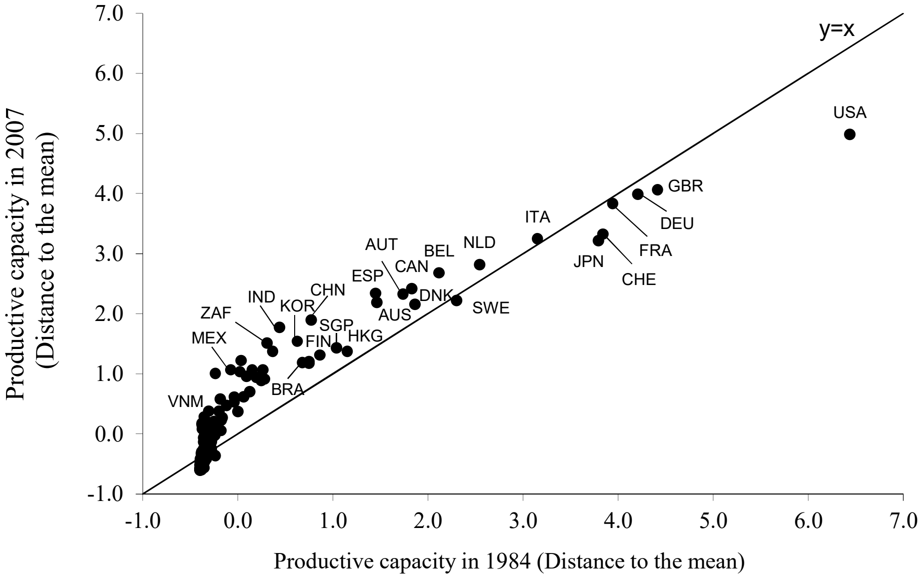


Source: Author's computations based on data from UN Comtrade.

[5] Maldives graduated from the least developed country category in 2011 and Samoa graduated in January 2014.

Valuable lessons can be learned from the experience of the countries that were able to increase their productive capacity. Figure 4.11 shows the productive capacity of countries in 1984 (horizontal axis) and in 2007 (vertical axis), measured as the distance from the respective average productive capacities in these two years. The diagonal line indicates levels of productive capacity that are equally distant to the average in 1984 and 2007. Countries that are located below the diagonal line have experienced losses in their productive capacity relative to the world's average during that period, while countries that are located above the diagonal line have increased their productive capacity.

Figure 4.11. Change in productive capacity (1984-2007)



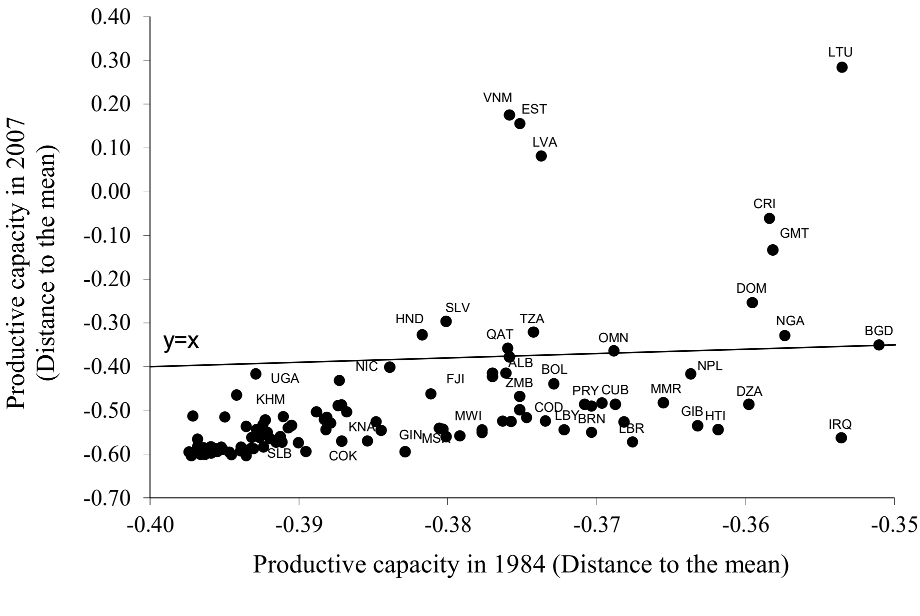
Source: Author's computations based on trade data from UN Comtrade.

Notes: 1992 is the initial year for Estonia, Georgia, Croatia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Slovenia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan. 1993 is the initial year for Czech Republic, Eritrea, Macedonia, FYR and Slovak Republic.

As Figure 4.11 indicates, many countries were able to increase their productive capacity relative to the world's average. Emerging economies such as Brazil, China, India, Mexico, South Africa, Viet Nam, Asian Tigers such as Republic of Korea, Singapore, and Hong-Kong, as well as some European countries including Austria, Belgium, Finland, the Netherlands and Spain have increased their productive capacity faster than the global average and are represented in the graph by dots above the diagonal line. An interesting fact is that countries that were much above the average in 1984 have come closer to the average in 2007, while countries that in 1984 were above the average, but closer to it, were able to distance themselves further. This suggests convergence in productive capacity during that period among the countries that were above the average. On the other hand, the majority of the countries that in 1984 had a productive capacity at a similar level to the least developed countries – roughly more than 0.35 standard deviations below the world's average - have become yet more distant from the world average, which suggests increasing divergence of productive capacities at the global level (Figure 4.12).

The stylized fact highlighted in Figure 4.11 and Figure 4.12 is that countries that are less diversified have tended to lag further behind over the years. Catch up happened mainly in the intermediate group of countries, for which the diversification gap to the more diversified countries was narrower. Countries that were less diversified tended to fall further behind. One can see the parallel between this stylized fact and the stylized fact presented and discussed in Verspagen (1993, p.107): "In the world as a whole, falling behind is more relevant for the poorest countries than catching up. In general, the high- and middle-income countries grow fastest, while most low-income countries grow only at a slow rate."

Figure 4.12. Change in productive capacity (1984-2007), countries with low productive capacity in 1984



Source: Author's computations based on trade data from UN Comtrade.

Notes: 1992 is the initial year for Estonia (EST), Latvia (LVA) and Lithuania (LTU).

The countries that have changed most in the period from 1984 to 2007 were India, United Arab Emirates, South Africa, China, Poland, Turkey, Mexico, Thailand, the Republic of Korea and Spain (Table 4.2). Seventy economies have experienced positive changes, but not a single least developed country has increased its productive capacity relative to the global average in that period.

Table 4.2. Countries that have increased their productive capacities, 1984-2007

	Productive Capacity (mean=0, standard deviation=1)		
Country	**1984-1986**	**2005-2007**	**Difference**
India	0.46	1.74	1.28
United Arab Emirates	-0.23	1.03	1.26
South Africa	0.36	1.55	1.19
China	0.76	1.91	1.15
Poland	0.02	1.13	1.11
Turkey	-0.06	1.01	1.07
Mexico	0.06	1.03	0.96
Thailand	0.18	1.07	0.90
Korea, Rep.	0.66	1.54	0.88
Spain	1.49	2.30	0.81
Hungary	0.09	0.89	0.80
Australia	1.33	2.12	0.79
Indonesia	-0.17	0.61	0.78
Canada	1.71	2.47	0.76
Israel	0.28	1.04	0.75
Malaysia	0.19	0.95	0.75
New Zealand	0.23	0.94	0.71
Portugal	0.28	0.87	0.59
Greece	0.13	0.71	0.58
Romania	-0.14	0.41	0.56
Bulgaria	-0.20	0.35	0.55
Argentina	0.06	0.61	0.55
Brazil	0.66	1.19	0.53
Austria	1.79	2.31	0.51
Belgium	2.18	2.69	0.51
Viet Nam	-0.38	0.12	0.50
Egypt, Arab Rep.	-0.30	0.18	0.49
Singapore	1.03	1.49	0.45
Norway	0.77	1.21	0.44
Colombia	-0.23	0.20	0.43

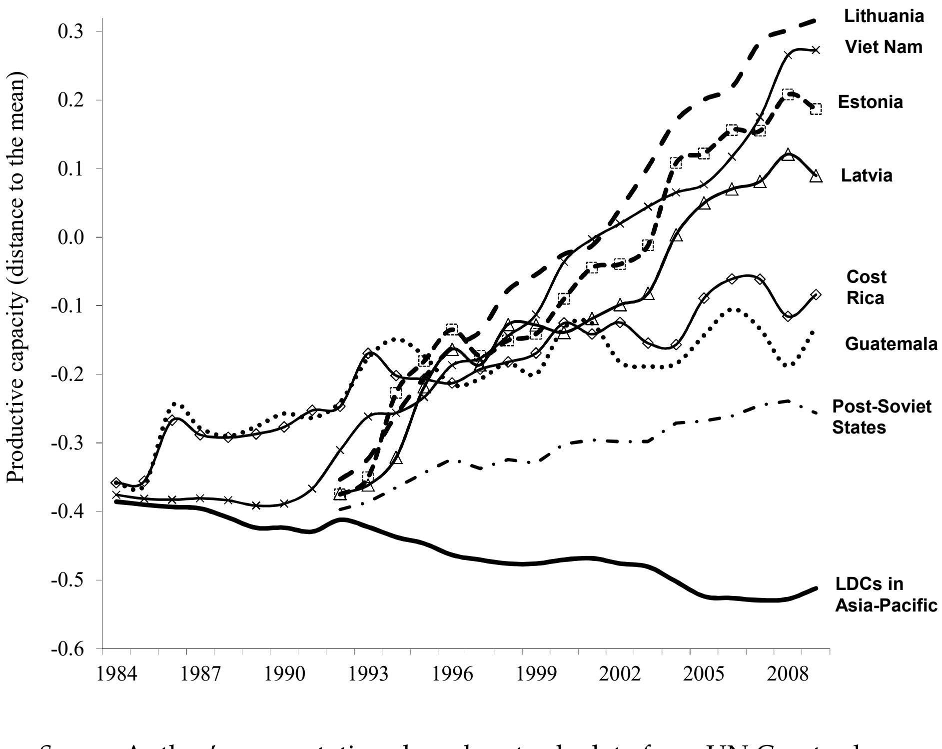
Country	Productive Capacity (mean=0, standard deviation=1) 1984-1986	2005-2007	Difference
Saudi Arabia	-0.17	0.26	0.43
Finland	0.88	1.31	0.43
Ireland	0.76	1.17	0.41
Philippines	-0.01	0.38	0.39
Chile	-0.23	0.15	0.37
Denmark	1.84	2.19	0.35
Iran, Islamic Rep.	-0.34	0.00	0.33
Pakistan	-0.22	0.06	0.29
Kenya	-0.32	-0.05	0.27
Lebanon	-0.29	-0.02	0.27
Peru	-0.21	0.05	0.26
Netherlands	2.59	2.85	0.26
Costa Rica	-0.33	-0.07	0.26
Hong Kong, China	1.12	1.36	0.24
Morocco	-0.23	-0.02	0.21
Guatemala	-0.32	-0.13	0.19
Sri Lanka	-0.28	-0.09	0.19
Panama	-0.15	0.04	0.19
Tunisia	-0.26	-0.08	0.18
Syrian Arab Republic	-0.35	-0.17	0.18
Venezuela, RB	-0.29	-0.12	0.17
Ecuador	-0.34	-0.18	0.17
Cyprus	-0.29	-0.12	0.16
Jordan	-0.34	-0.20	0.14
Italy	3.14	3.26	0.13
Mauritius	-0.33	-0.21	0.12
Trinidad and Tobago	-0.32	-0.21	0.11
Dominican Republic	-0.36	-0.25	0.11
Korea, Dem. Rep.	-0.31	-0.21	0.10
Iceland	-0.28	-0.21	0.07
El Salvador	-0.36	-0.29	0.07
Nigeria	-0.36	-0.30	0.06
Uruguay	-0.28	-0.23	0.06
Netherlands Antilles	-0.33	-0.28	0.05
Honduras	-0.37	-0.33	0.04
Tanzania	-0.38	-0.35	0.03
Bahrain	-0.35	-0.33	0.02
Oman	-0.37	-0.35	0.02

	Productive Capacity (mean=0, standard deviation=1)		
Country	**1984-1986**	**2005-2007**	**Difference**
Qatar	-0.38	-0.37	0.01
Zimbabwe	-0.34	-0.34	0.00
Bangladesh	-0.35	-0.35	0.00

Source: Author's computations based on trade data from UN Comtrade.

Notable is the change in productive capacities experienced by Viet Nam (VNM), Lithuania (LTU), Estonia (EST) and Latvia (LVA), as illustrated in Figure 4.13. They all started at levels of productive capacities similar to the least developed countries and were able to raise their productive capacities to a level above the world's average. Estonia, Latvia and Lithuania also have performed better than the average Post-Soviet state in that period.

Figure 4.13. Great transformers that started from levels similar to the LDCs (1984-2009)



Source: Author's computations based on trade data from UN Comtrade.

Notes: The values for the groups of LDCs in the Asia-Pacific and Post-Soviet states are calculated as unweighted averages of normalized values of productive capacities of the countries that compose these groups. In this graph the group of Post-Soviet states does not include the Russian Federation. The group is comprised of: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

4.5 Product complexity

In the previous chapter, a product complexity index was presented aiming at providing a measure of the productive capacities required to produce a given good. The use of that measure in the analysis of patterns of exports shows another empirical regularity, that a rich country does not specialize in more complex products but rather exports products within a wide range of complexity. In addition to more complex products, rich countries also produce low complexity products just as the smaller economies. As for those smaller economies, their exports are limited to low complexity products.

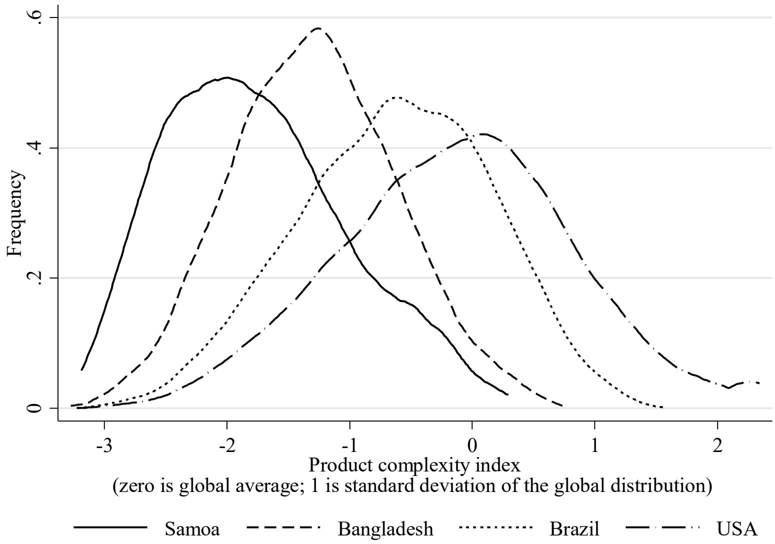
To illustrate that fact, Figure 4.14 presents two graphs comparing the distribution of the measure of product complexity of selected countries. Graph (*a*) shows the proportion of products of different complexity that are produced by Samoa, Bangladesh, Brazil and the United States, and graph (*b*) shows the same comparison between Cambodia, Kenya, Mexico and the Netherlands. The graphs were normalized to have the products with average complexity in the middle (measured as zero complexity) and standard deviations from the average measured as one. Products exported were classified originally using HS (2002) trade data for the year 2013, disaggregated at 6-digit level and further disaggregated by unit value by applying the methodology described in the previous chapter.

It is clear from the figure that developed economies such as the United States and the Netherlands export products of a rather large range of complexity. These economies produce low complexity products just as the poorer countries, but also produce more complex products. As for smaller economies, such as Cambodia and Bangladesh, which are among the least developed countries, their exports are concentrated in products with lower complexity. In particular, small island countries that produce fewer products, such as Samoa, have a high proportion of their product-mix concentrated in a set of products of low complexity. Larger developing economies such as Brazil and Mexico export products that cover a range of product complexities in between the more advanced and the smaller economies.

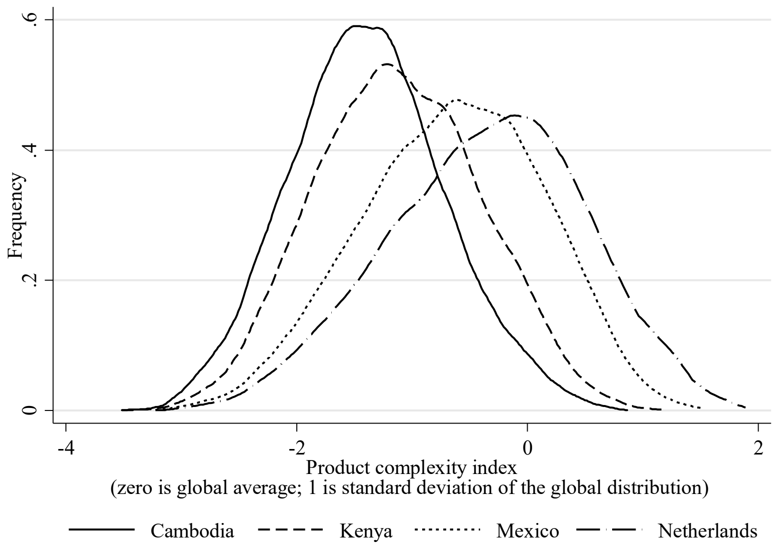
I have reported that empirical regularity in Freire (2012a) and in the Chapter 3 of ESCAP (2012). Felipe et al. (2012) provides a comprehensive analysis of product complexity and economic development. They find that the major exporters of more complex products are the high-income countries and the major exporters of less complex products are the low-income countries. In addition, export shares of the more complex products increase with income, while export shares of the less complex products decrease with income.

Figure 4.14. The complexity of the product-mix of selected countries (2013)

a)



b)



Source: Author's computations based on data from UN Comtrade.

With the information about the distribution of product complexity of the various economies, it is possible to test a hypothesis that the total output of an economy is a function of its set of productive capacities and the intensity of its use by the workforce. The results are presented in Table 4.3. The average complexity of production of 174 economies for which 2010 data is available explains 77% of the variation of their GDP. When controlling for the size of the population and the age dependency ratio as percentage of the working-age population, 91% of the variation of GDP is explained. These associations are statistically significant and have the expected signs – increases in the average complexity of the product-mix or in the population size are associated with increases in GDP, while increases in the age dependency are associated with decreases in GDP, everything else constant. Increases in the average complexity of production represent not only a shift in the share of more complex activities but also an actual expansion of the complexity of production. The association between GDP and the maximum complexity of country's production is as strong as between GDP and the average complexity, as presented in columns 4 to 6 in the table.

Figure 4.15 shows the association between the actual GDP of selected economies and the predicted GDP when considering the average product complexity of their export mix, as per the regression model number 3 in Table 4.3. The figure shows graphs related to data for the year 2010 (graph *a*) and 2013 (graph *b*), to allow for a comparison of the relative positions of countries in two different points in time. Both graphs show that countries that export commodities (oil and gas in particular) tend to have a GDP higher than predicted by the average product complexity of their exports and the size of their labour force. This is expected given the high price of commodities in the period covered. The graphs highlight some of the countries in that situation, namely Equatorial Guinea (GNQ), Brunei Darussalam (BRN), Angola (AGO), Iraq (IRQ), Kuwait (KWT), Qatar (QAT), Venezuela (VEN), Norway (NOR) and Saudi Arabia (SAU). Other countries have a GDP much lower than that expected given the average product complexity of their exports. Some notable examples are China (CHN), India (IND), Thailand (THA), Viet Nam (VNM) and Moldova (MDA). This may reflect the fact that these countries still have a large share of the population engaged in low productive agriculture. Therefore, the size of their working age population does not correctly reflect the size of the labour force engaged in the activities with product complexity near the average complexity of their exports.

The change in relative positions of some countries when comparing both graphs is notable. For example, China and India have increased the average product complexity of their exports relative to that of the USA. Brazil (BRA) and Russia (RUS) also progressed relative to Western European countries such as Italy (ITA), France (FRA) and the United Kingdom (GBR).

Table 4.3. Association between output and the complexity of production, 2010

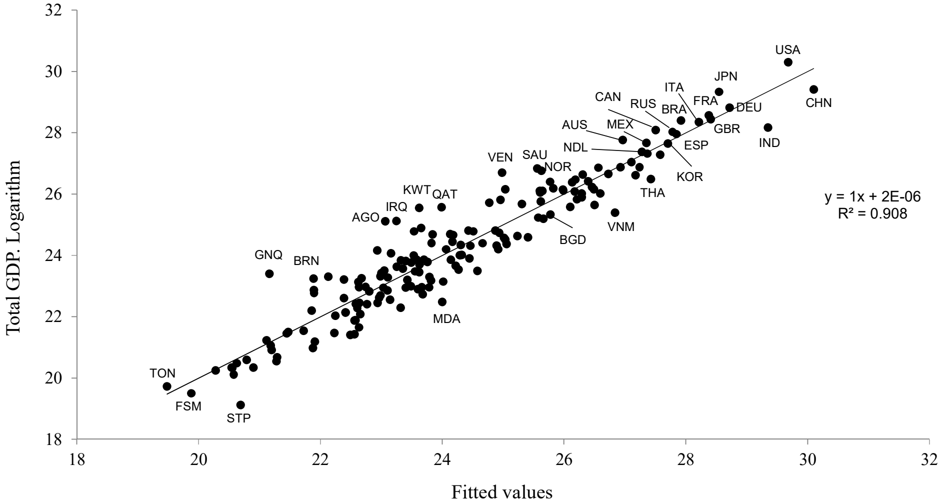
	Dependent variable: GDP (current US$) (Logarithm)					
	- 1 -	- 2 -	- 3 -	- 4 -	- 5 -	- 6 -
Average complexity of product-mix	4.712	3.639	2.831			
	(24.22)**	(22.65)**	(14.63)**			
Population (logarithm)		0.478	0.591		0.465	0.588
		(13.06)**	(15.72)**		(12.27)**	(15.37)**
Age dependency ratio (% of working-age population)			-0.024			-0.026
			(6.31)**			(6.80)**
Maximum complexity of product-mix				3.977	3.072	2.35
				(24.37)**	(21.89)**	(14.35)**
Constant	29.874	21.038	19.731	20.341	13.873	14.191
	(121.11)**	(30.10)**	(29.71)**	(113.44)**	(25.54)**	(29.24)**
Observations	174	174	174	174	174	174
R-squared	0.77	0.89	0.91	0.78	0.88	0.91

Absolute value of t-statistics in parentheses * significant at 5%; ** significant at 1%

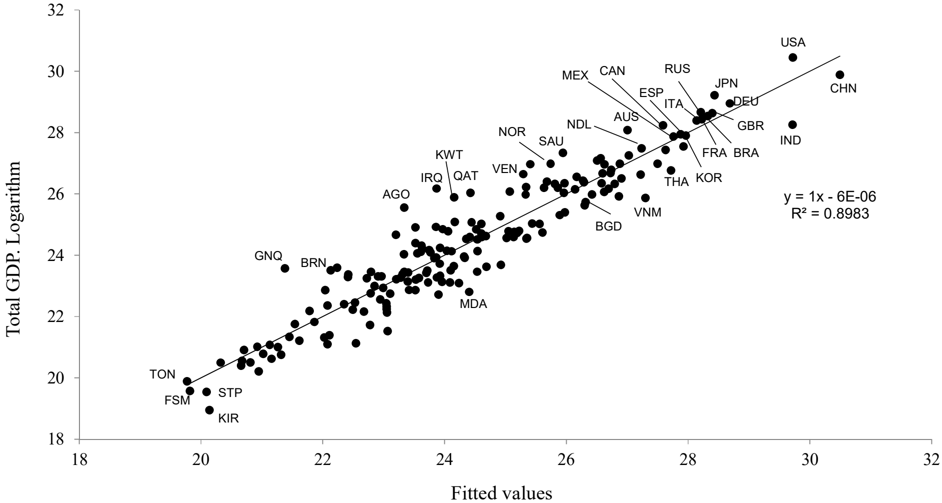
Source: Author's computations based on data from UN Comtrade and the World Bank World Development Indicators.

Figure 4.15. Association between GDP and average complexity of export mix

a) 2010



b) 2013

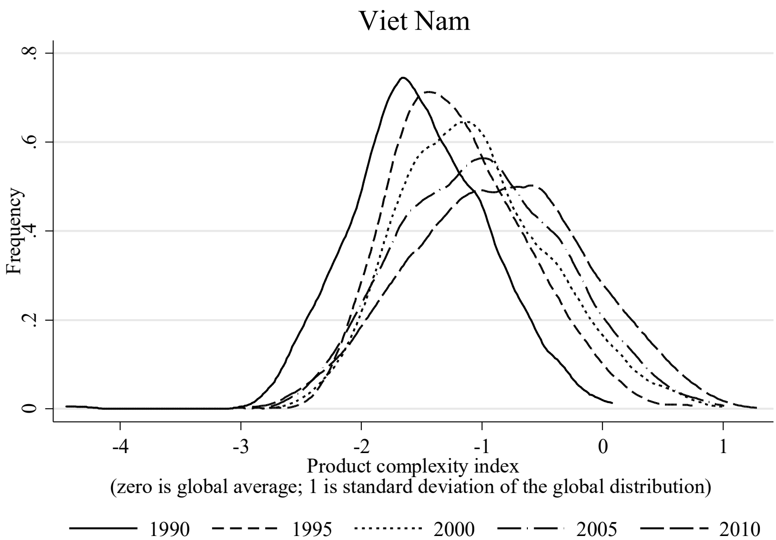


Source: Author's computations based on data from UN Comtrade.
Note: The specification relates to the regression (3) presented in Table 4.3.

It is important to note that such strong associations between the average complexity of the export mix and the total GDP exist despite the fact that the measure of product complexity is based only on the binary information of a country exporting a product or not, as a proxy of information regarding the production of the country. That measure does not include any information related to services value added, which in fact constitute a larger share of GDP in most countries. A possible explanation, which has to be further tested, is that services are intertwined to other economic activities in agriculture and industry, and the average complexity of the latter already has embedded the information regarding the complexity of services.

The analysis of the evolution of the distribution of the complexity of the export mix of selected economies shows that development is associated with the expansion of exports towards products of higher complexity. This empirical regularity is illustrated in Figure 4.16, which shows the changes in the distribution of product complexity of Viet Nam's exports, which as mentioned is one of the few countries that were able to transform their productive capacities in the past 25 years, starting from very low levels. The graph is normalized to have the products with global average complexity in the middle (measured as zero complexity) and standard deviations from the average measure as one. The figure shows that, from 1990 to 2010, the average complexity of the product-mix shifted to the right and expanded towards more complex products. The shift was larger in the period from 1990 to 1995. In the subsequent periods, the distribution expanded towards more complex products, increasing the spread of the product complexity in the export mix.

Figure 4.16. Increasing complexity of Viet Nam's products



Source: Author's computations based on data from UN Comtrade.

The same pattern of a relatively rapid shift of the average of the distribution to the right, and an increase in the spread, is shown in Figure 4.17. It depicts the evolution of the distribution of product complexity of selected developing countries in the period from 1990 to 2010. In China and India that shift started in a somewhat similar way in the period from 1990 to 1995. From 1995 to 2000, China's distribution moved more rapidly to the right than India's one, creating a distribution shaped with two humps, which may reflect the existence of a production base driven by market-oriented foreign investment and demand in parallel to a traditional state-owned industry. From 2000 to 2010 that move continued with further expansion towards more complex production. In India, the shift was also evident, although more gradual. Rapid change in the shape of the distribution of product complexity is also observed for Brazil from 2000 to 2005, for Mexico from 1995 to 2000, for the Russian Federation from 1995 to 2000, for South Africa from 1990 to 1995, and for Malaysia from 1995 to 2000. Similarly to China and India, the main change in the distribution of product complexity in those countries in the subsequent years was the expansion towards more complex products.

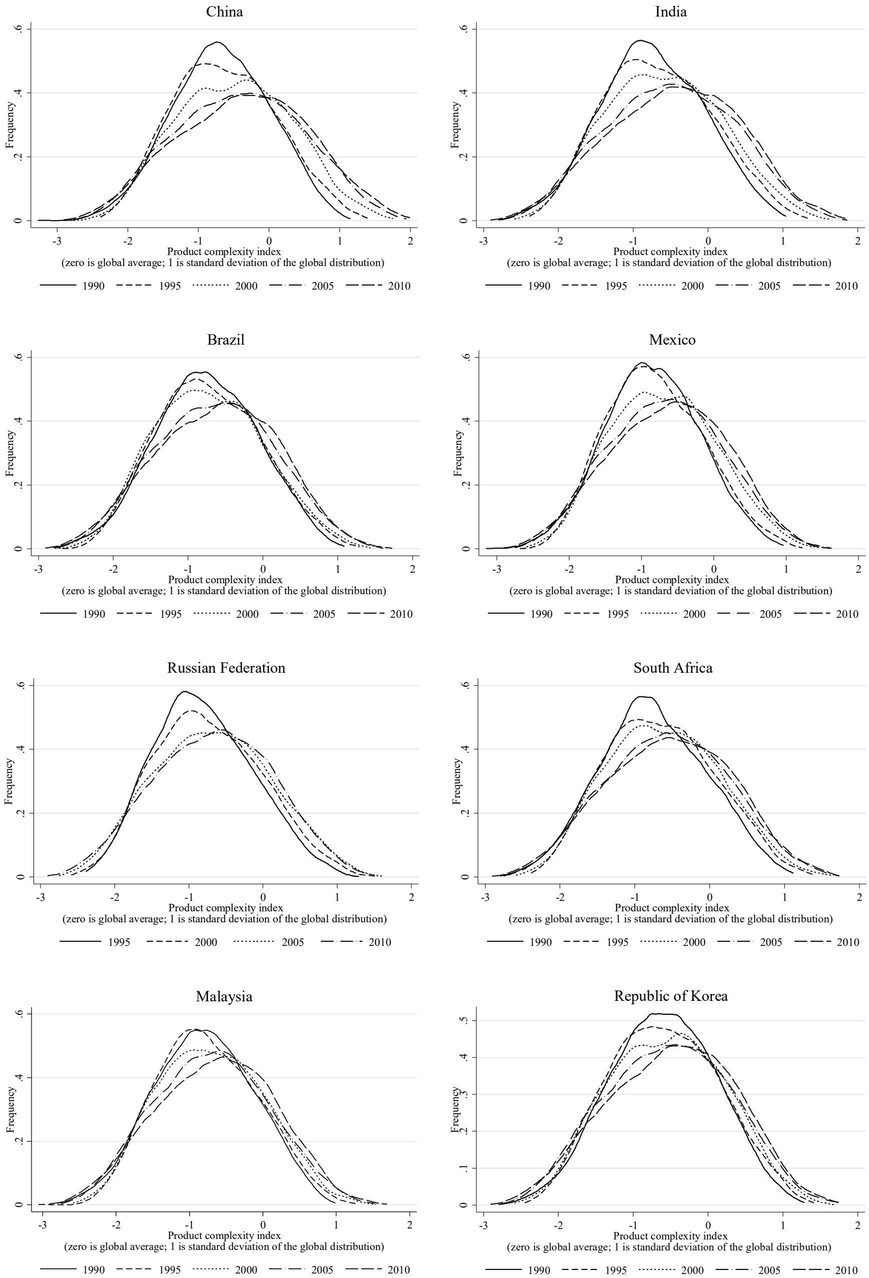
Hidalgo et al. (2007) and Hidalgo and Hausmann (2009, 2011) have discussed that the production of countries become more complex as they develop. The evidence presented here shows that that happens usually by expanding the exports towards more complex products. Countries do not abandon the less complex production, it only becomes less important in the export basket.

Figure 4.18 presents similar graphics for selected developed economies. It is noticeable that the distributions of product complexity of their exports do not shift in the same way as those of the emerging economies discussed above. The upper bound of their distributions moved marginally during the period. That reflects the fact that these countries have been at the frontier of technological development. A feature that is particular to the distribution of these economies (with the exception of the Netherlands) is the hump on the right side, which suggests a stronger focus on production and exports of more complex products. These humps have shrunk and moved to the right over time, resulting in a more "normal" distribution. Interestingly, the dynamic in those countries in the period from 1990 to 1995 was the opposite of that in emerging developing economies.

The distributions expanded to the left, increasing the range of production towards less complex products. That change is more evident in the distributions of the United States, Germany, Japan, the United Kingdom, France and Switzerland. Throughout the 1990 to 2010 period, most changes in the distributions of the developed countries highlighted in Figure 4.18 were related to less complex products.

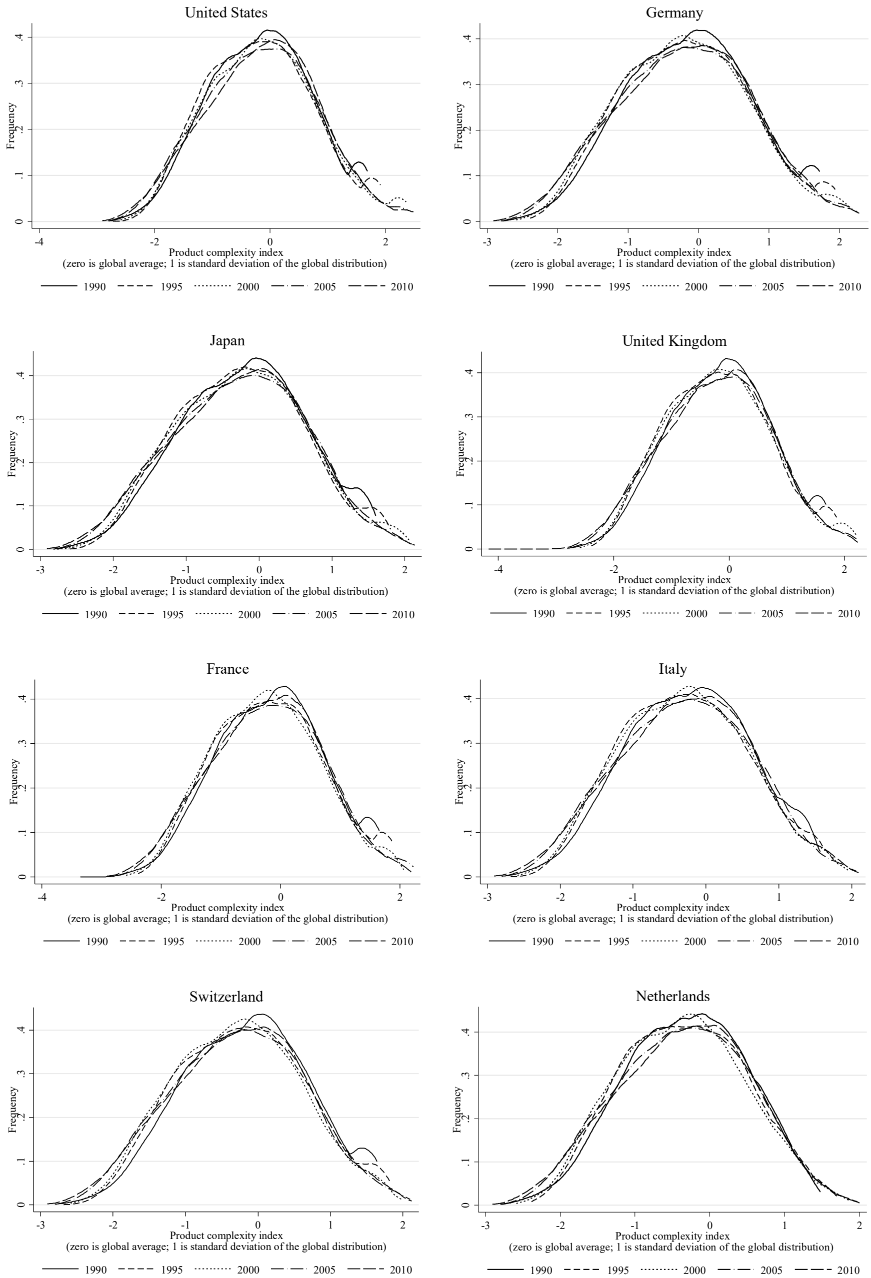
The set of graphs presented in Figure 4.19 illustrates the very different dynamics of the change in product complexity in least developed countries. They show that instead of the rapid continuous move towards more complex products seen in the group of emerging developing economies, these countries have either experienced slow increase or periods of progress alternated with others of regress. Many times, the distribution became more skewed towards less complex products.

Figure 4.17. Evolution of product complexity, selected developing countries



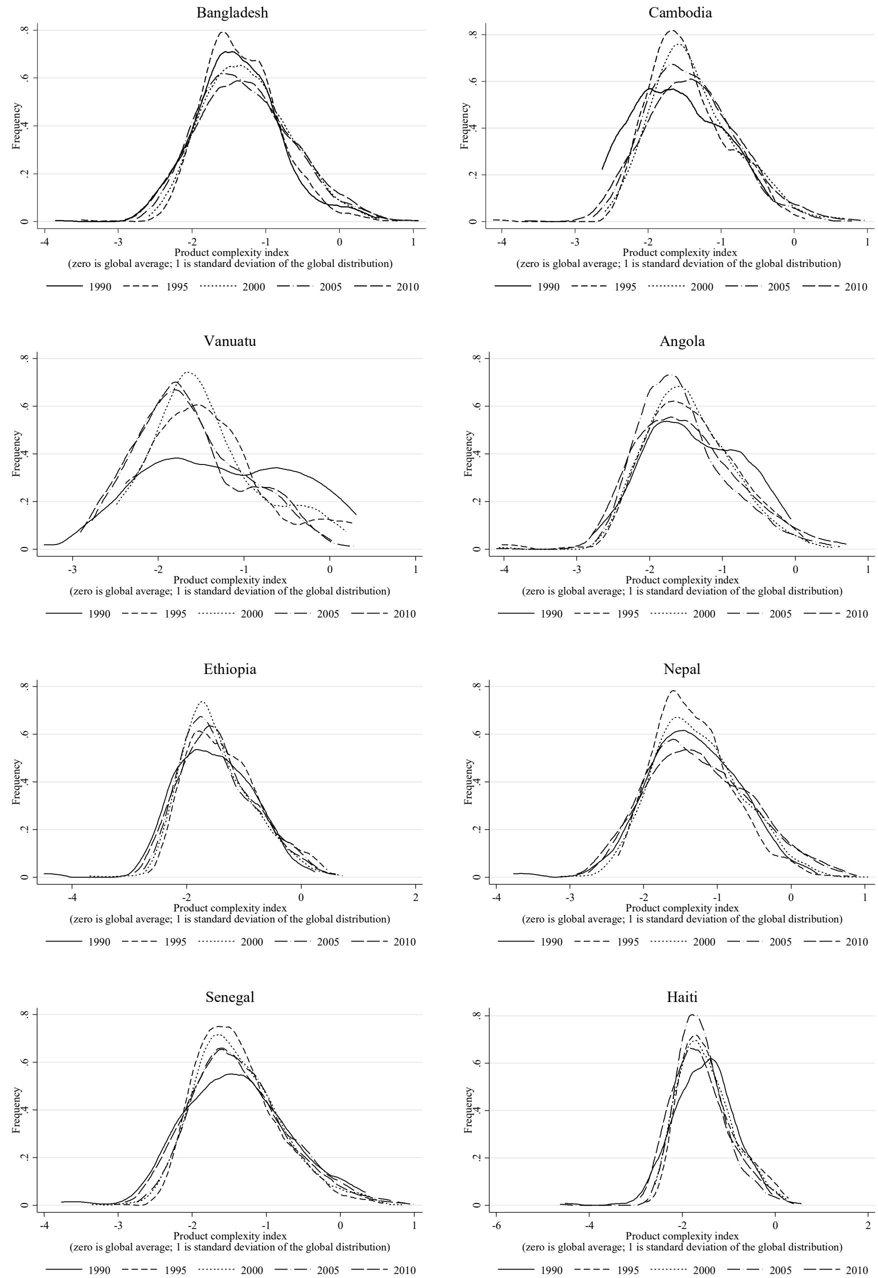
Source: Author’s computations based on data from UN Comtrade.

Figure 4.18. Evolution of product complexity, selected developed countries



Source: Author's computations based on data from UN Comtrade.

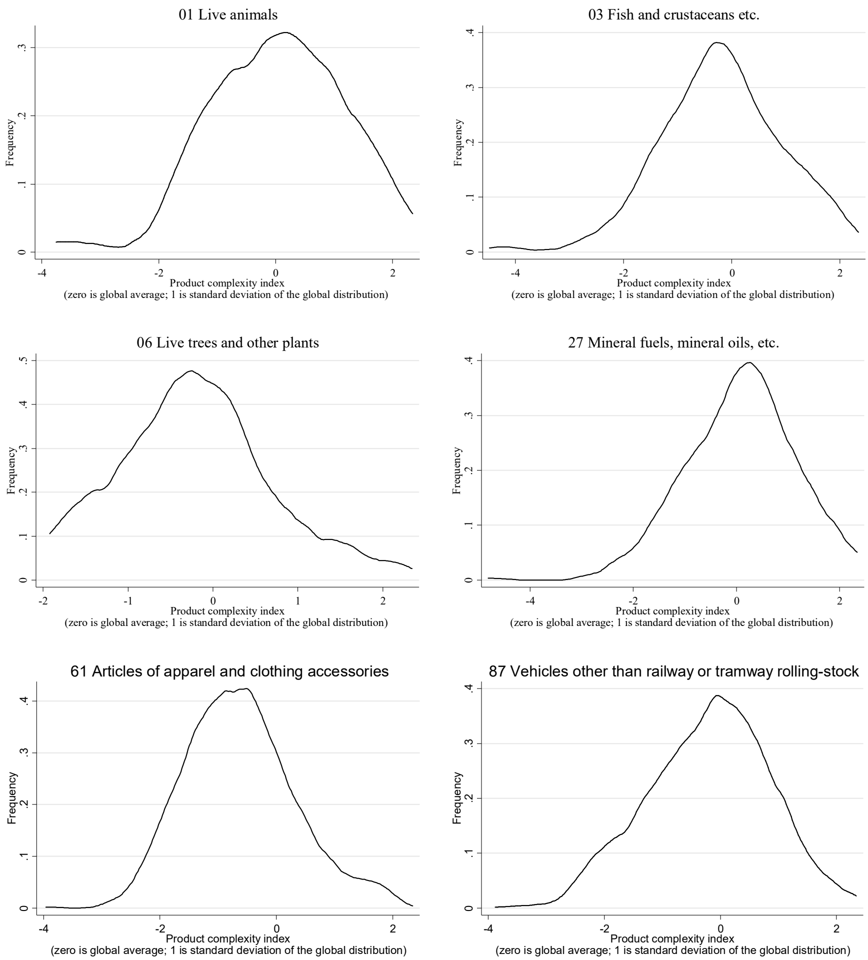
Figure 4.19. Evolution of product complexity, selected LDCs



Source: Author's computations based on data from UN Comtrade.

Another empirical regularity is that there is no clustering of complexity levels within particular types of products. That fact is illustrated in Figure 4.20, which shows the distribution of the complexity of products of different types as classified by HS 2002 (2-digit). In each industry, there are low, medium and high complexity products, suggesting that what matters in terms of product complexity is not the broad industry classification but the individual products within the industry. For example, there are manufactured products of very low complexity and agricultural products of high complexity.

Figure 4.20. Examples of the distribution of complexity of products by industry (2013)



Source: Author’s computations based on data from UN Comtrade.

There are, however, differences in the average product complexity between broader economic sectors. Industries of food and live animals, beverages and tobacco and miscellaneous manufactured articles, which include apparel and clothing accessories, have on average products of lower complexity (Table 4.4). Many product categories with high average complexity have the same maximum complexity (2.34). This is because the highest product complexity within each product category is usually of products that are only exported by the most diversified country. Therefore, they all have the same product complexity.

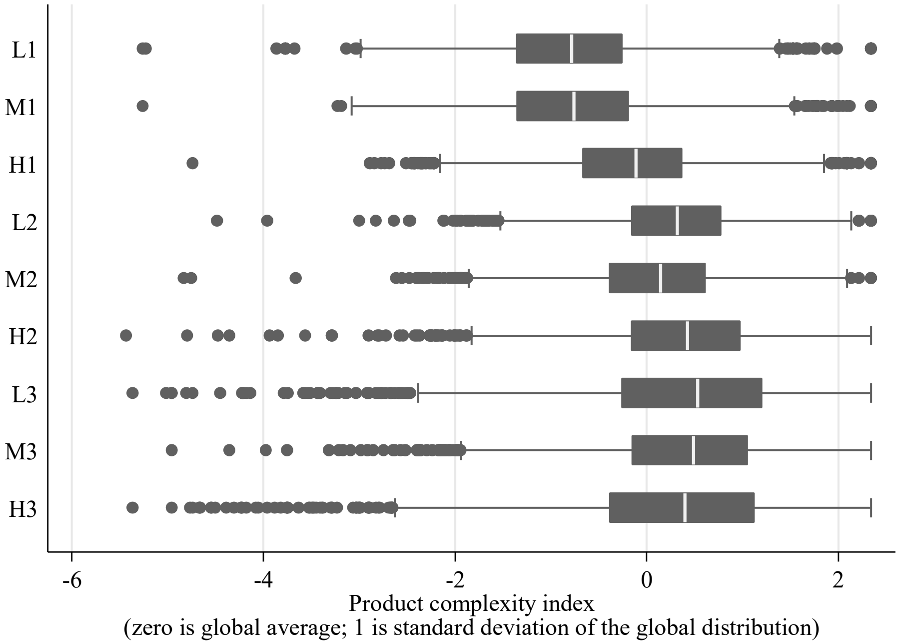
Table 4.4. Summary statistics of complexity of selected HS product categories

HS	description	mean	min	median	max	skew
Top 10 product categories with higher average complexity						
81	Other base metals; cermets; etc.	0.80	-3.67	0.78	2.34	-0.57
29	Organic chemicals.	0.71	-3.41	0.72	2.34	-0.26
37	Photographic or cinematographic goods.	0.69	-2.47	0.72	2.34	-0.42
28	Inorganic chemicals; etc.	0.66	-4.18	0.66	2.34	-0.38
75	Nickel and articles thereof.	0.61	-1.25	0.50	2.34	0.24
47	Pulp of wood, etc.	0.55	-2.90	0.55	2.34	-0.51
55	Man-made staple fibres.	0.51	-4.77	0.54	2.34	-0.77
93	Arms and ammunition; parts etc.	0.46	-4.18	0.48	2.34	-1.14
45	Cork and articles of cork.	0.45	-0.85	0.56	1.86	0.01
53	Other vegetable textile fibres; etc.	0.43	-2.99	0.48	2.34	-0.66
Bottom 10 product categories with lower average complexity						
24	Tobacco and manufactured substitutes.	-0.65	-4.13	-0.84	1.93	0.20
33	Essential oils and resinoids, etc.	-0.65	-2.82	-0.71	2.34	0.53
94	Furniture; bedding, mattresses, etc.	-0.69	-2.67	-0.72	2.34	0.11
62	Articles of apparel and clothing, etc.	-0.71	-5.23	-0.75	2.05	0.29
18	Cocoa and cocoa preparations.	-0.72	-2.38	-0.80	1.93	0.97
22	Beverages, spirits and vinegar.	-0.73	-3.63	-0.79	2.34	0.38
64	Footwear, gaiters and the like; parts, etc.	-0.75	-3.51	-0.80	2.34	0.38
49	Printed books, newspapers, pictures, etc.	-0.80	-3.19	-0.74	1.84	0.01
42	Articles of leather; saddlery, etc.	-0.98	-3.53	-1.08	1.87	0.53
97	Works of art, collectors' pieces, etc.	-1.00	-4.54	-0.85	1.09	-0.46

Source: Author's computations based on data from UN Comtrade.

Figure 4.21 shows the distribution of product complexities across unit value classes. Although lower-unit value products could be as complex as higher-unit value products, they have on average lower complexities than middle- and high-unit value products. This highlights the fact that another way for increasing product complexity is through differentiating production into higher-unit value products.

Figure 4.21. The complexity of products by unit value range (2013)



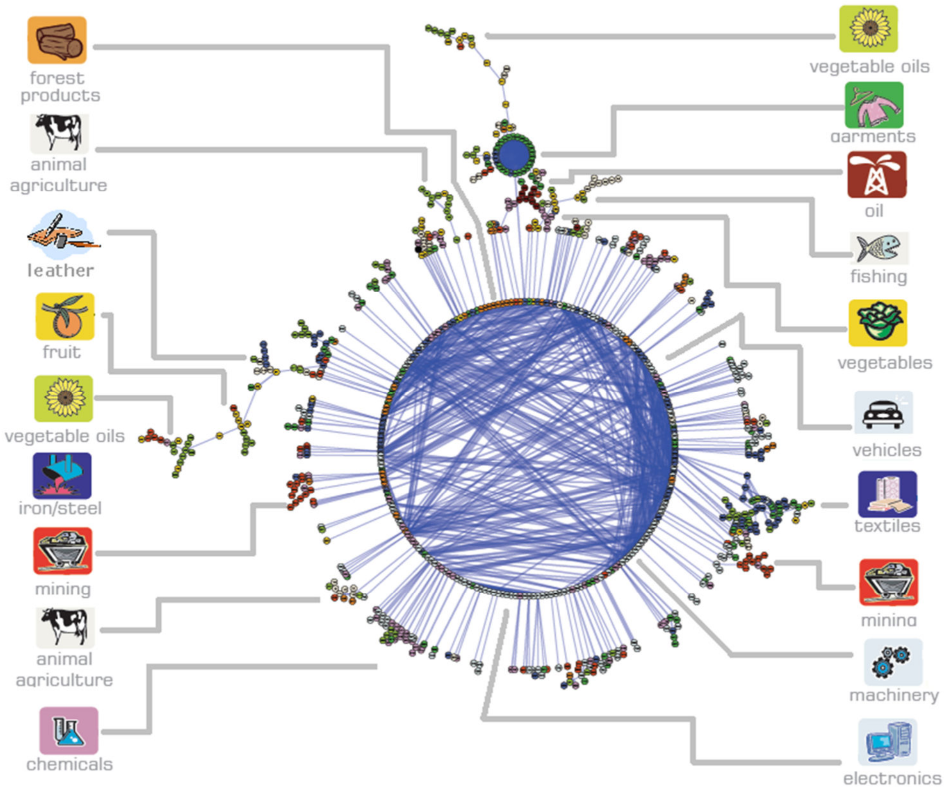
Source: Author's computations based on data from UN Comtrade.

4.6 Product space

Another pattern related to diversification discussed in the previous chapter is that the existing product-mix of a country affects the potential new products that could emerge in the economy. Diversification, therefore, seems to be path dependent. That empirical regularity is illustrated by product space maps, the graphical representation of the likelihood that pairs of products are jointly exported (Hidalgo et al., 2007). Figure 4.22 illustrates this stylized fact. In the figure, each small circle represents a single product. These products are then clustered according to the likelihood that they are part of the same export mix. The lines linking the products indicate associations, based on the probability that the export of one is accompanied by the export of the other.

The large circle in the centre of the map represents the core of the space where many products – largely manufactured goods, machinery and transport equipment – are linked by a dense network of lines. Further out, around the periphery, are clusters of less-connected products. These include some traditional industries of developing countries such as garments, fish, fruit, vegetable oils and textiles. Of these more peripheral clusters, the largest is the one composed by garment products, arranged in a circle in the top-middle of the product space.

Figure 4.22. The global product space map



Source: Author's computations based on Hidalgo et al. (2007) and ESCAP (2011).

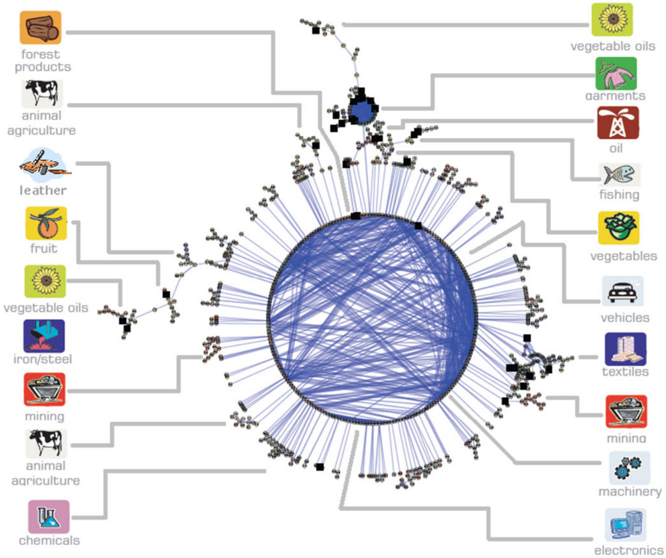
Note: The maps were produced using the open-source software platform Cytoscape, which is available from www.cytoscape.org.

A characteristic of the product space map is that goods produced by the same industry can be far apart. For example, the map has two clusters of products of the vegetable oils industry. The one at the top is linked with garment production, while the one in middle-right is associated with the production of fruit.

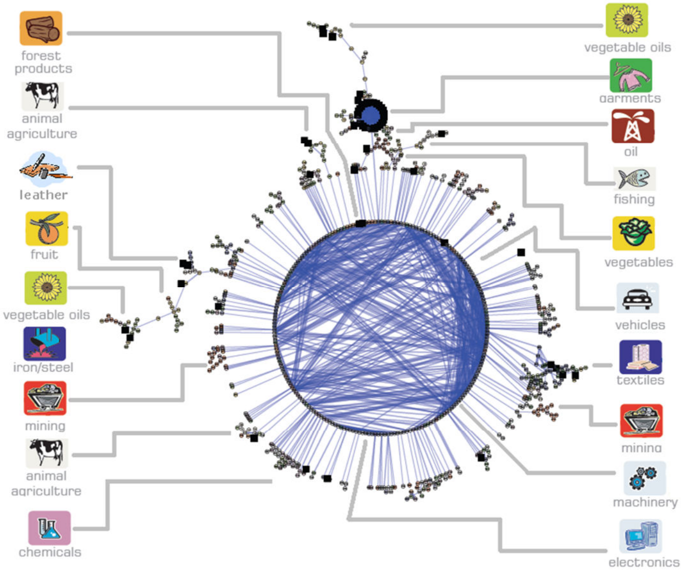
The product space map can be used to track a diversification history of countries. This is illustrated in Figure 4.23 for Cambodia, the products of which exported in 1991 and 2009 are highlighted on the map with bigger squares.

Figure 4.23. Cambodia's presence in the product space map

(a) 1991



(b) 2009



Source: Author based on Hidalgo et al. (2007) and ESCAP (2011).

Notes: The maps were produced using the open-source software platform Cytoscape, which is available from www.cytoscape.org.

In 1991, almost all Cambodia's exports were in the periphery: one in the vegetable oils cluster at the top of the map; a few others in the garment, fishing, textiles, and mining clusters at the right; and still others in the animal agriculture, fruit and vegetable oils cluster on the left. The only ones in the core were forest products. By 2009, however, Cambodia was exporting almost all the products in the garment cluster.

The figures above were created considering a trade dataset using the SITC 4-digit classification. Figure 4.24 illustrates a product space constructed using the same algorithm but using more disaggregated data, the HS 6-digit trade classification further disaggregated by unit value categories. Each small circle in the figure represents a product and the links between products represent the likelihood that the pair of products is jointly produced. The figure shows only the pairs that are produced with a higher than 85% probability. An empirical regularity illustrated by the product space in Figure 4.24 is that some products are connected to many others, thus their production increases the likelihood of further diversification. On the other hand, the production of a product that belongs to a pair that is isolated in the product space map gives fewer opportunities for diversification towards new products.

A result of the path dependency of the diversification process is that it seems difficult for countries to "leapfrog", moving directly from the production of one product to another that is far away in the product space. For example, if a country has its production base mainly in primary products and they are far from say, mobile phones, then the probability of a country diversifying in the short term towards the latter is smaller.

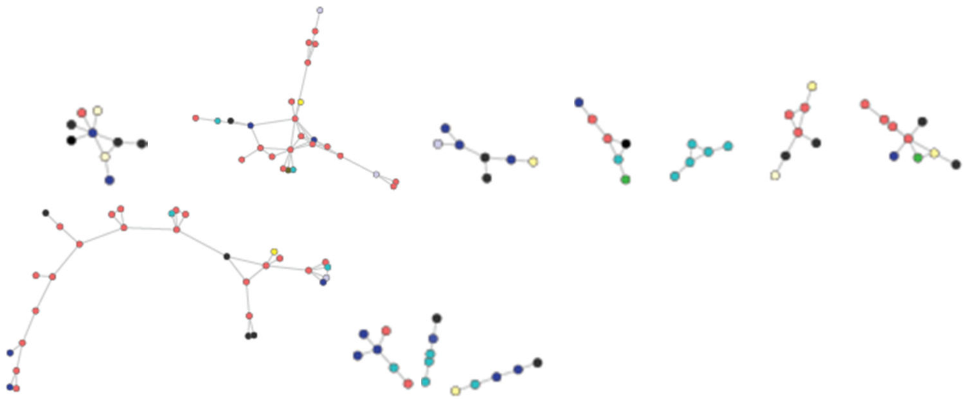
Another way to illustrate that empirical regularity is to consider how products of a certain complexity are connected to other products, as illustrated in Figure 4.25. The figure depicts the complexity of all products produced in 2013 classified at 6-digit level HS 2002 and further disaggregated by unit value along the horizontal axis. The scale is normalized in such a way that the average global complexity is zero and the standard deviation of the distribution of product complexity is one. The graph shows the complexity of potential new products (i.e. a product that is not exported by the country) along the vertical axis. Therefore, each dot in the graph represents a pair composed by an existing and a potential new product. The shades of the dots indicate the proximity of the existing and new products in the product space.

The graph shows that up to the level of global average complexity, the complexity of potential new products is close to the complexity of existing products (i.e. half a standard deviation above and below), while for products with above average complexity the distribution is more diffused with opportunities one standard deviation above and below. That result suggests that for most of the products produced in developing countries, the potential new products that could emerge with high probability are those very close in terms of productive capacities required to be produced.

Figure 4.24. The global "product space" map of 2013 and the path-dependent process of diversification: some paths lead to many potential new products, others yield fewer options

Dense network of diversification paths

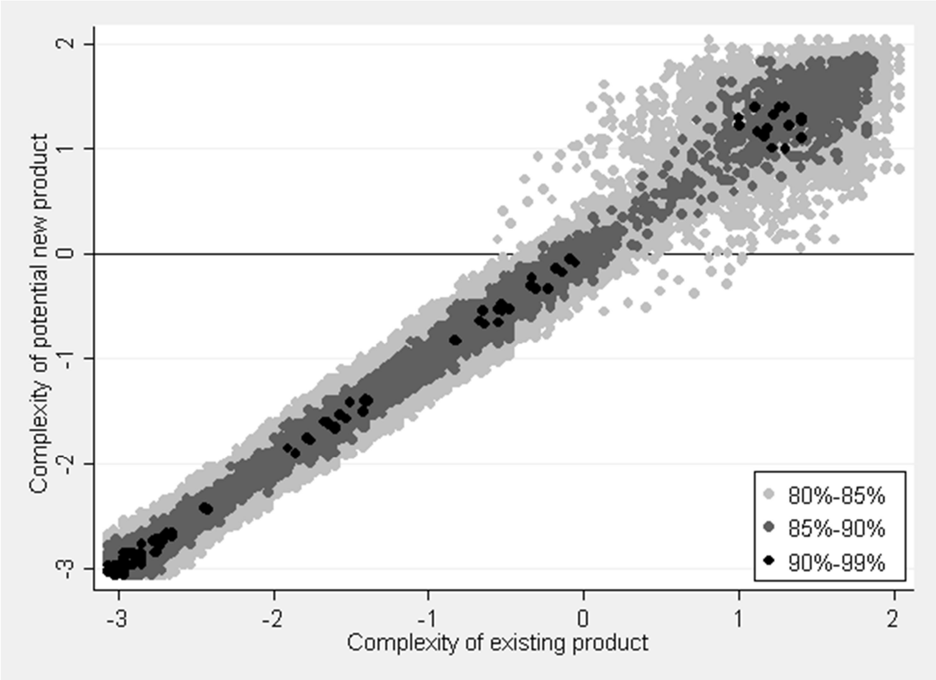
Example of diversification paths with limited opportunities for further diversification



Source: ESCAP (2014), based on Hidalgo et al. (2007) and on trade data from UN Comtrade.

Notes: This map indicates products and the links between products. The overall shapes they form are arbitrary. The map was produced using the open-source software platform Cytoscape, which is available from www.cytoscape.org.

Figure 4.25 Map of potential new products for diversification by proximity to existing product mix



Source: Author’s computations based on data from UN Comtrade.

4.7 Summary

This chapter uses the methods and datasets presented in Chapter Three to highlight empirical regularities related to export diversification. It shows that diversification within and across categories of products occurs simultaneously. Countries that export a broader range of product categories also export goods within a broader range of unit values. In addition, the level of diversification within and across products is associated with the total GDP of an economy. Such an association has not been highlighted in the empirical literature, which has focused on the association between diversification and income per capita as a proxy of economic development. Another empirical regularity is that as economies diversify, they tend to export products that are less ubiquitous than their existing production base. That relation between diversification and ubiquity is observable in the matrix of countries and products that they export.

The analysis of the distribution of productive capacities suggests that this distribution is fat-tailed. The United States, Germany, France, United Kingdom, Italy, Japan and Switzerland have levels of productive capacities that are three standard deviations above the global average. Other countries with above global average productive capacity are developed countries or emerging developing economies, while the majority of economies from Latin America, Asia-Pacific and African regions have productive capacity below global average. Some of the countries that have increased their productive capacity the most in the period from 1984 to 2007 were India, United Arab Emirates, South Africa, China, Poland, Turkey, Mexico, Thailand, the Republic of Korea and Spain. Notable is the change in productive capacities experienced by Viet Nam, Lithuania, Estonia and Latvia, which have started from levels comparable to those of the least developed countries and have reached above global average productive capacity. Countries that are less diversified have tended to lag further behind over the years. Countries that were able to catch up with the frontier economies were the ones in which the initial diversification gap was relatively narrow.

The analysis of the complexity of products exported shows that larger economies do not specialize in exporting more complex products; they export products within a wide range of complexity. Smaller economies export products within a narrower range that overlaps with the complexity of products exported by larger economies. The average complexity of exports is a good predictor of GDP of countries, particularly when considering the size of the population and the age dependency ratio. The analysis of the evolution of the distribution of the complexity of the export mix of selected economies shows that development is associated with the expansion of exports towards products of higher complexity. These more complex products are found in all industries, although some economic sectors have higher average product complexity. Another pattern highlighted in the chapter is the product space, and that potential new products that could emerge with high probability are those close in terms of productive capacities required to be produced.

The next chapter will discuss the role of governments in facilitating economic diversification towards more complex products, based on these empirical regularities.

5

The need for industrial policy: strategic diversification vs. a laissez-faire approach[1]

This chapter discusses whether an active role of the government through industrial policy is required to foster structural transformation and economic diversification or whether market incentives would be sufficient to drive this process of catching up. This discussion is relevant given the renewed interest in industrial policies for promoting growth and employment. The debate on industrial policies has a long history of polarized arguments between the neoliberal position (which is critical to any kind of selective policies) and the neo-structuralism position (which calls for the resurgence of policies that dynamically target, foster and protect infant industries).

[1] This chapter is based on Freire (2013b). Strategies for Structural Transformation in South Asian Countries, *Seoul Journal of Economics* 26, No. 3 2013: 311-336.

5.1 Debate on industrial policy

The incentives for creation and combination of productive capacities are shaped by economic institutions and the expected demand for the new products (Lall, 1992; Acemoglu and Robinson, 2012; Bresser-Perreira, 2012). Therefore, the question for policymakers in developing countries is how to foster the emergence of more complex economic activities given the technological level of the current production base and the incentives created by domestic and global demand.

An optimum path of diversification of economic activities may exist, consisting of the continuous move to selected activities that are more complex and that are closely related to the existing productive capacities of the country. The literature on the Developmental state suggests that such an approach of selecting economic activities is a prime role for the state (Johnson, 1982; Amsden, 1989; Wade, 2003). The main instrument for that is industrial policy, which has usually been associated with targeted government interventions that foster specific manufacturing sectors aimed at accelerating structural transformation by promoting industrialization (Lall, 2005; Shapiro, 2007; Chang, 2009). On the other hand, the rent-seeking view of the selection process argues that governments cannot and should not pick winners, because the process of economic activity identification and promotion is full of self-fulfilling incompetence and corruption (Pack, 2000; Noland and Pack, 2003; Krueger, 2011).

Kosacoff and Ramos (1999) provides a comprehensive list of traditional arguments for and against industrial policy. The arguments in favour are usually related to the need of selective government intervention to correct market failures associated to economies of scale, externalities, and imperfections on the capital and goods markets. The arguments against industrial policies are usually based on the premises that government can always design taxes and subsidies to correct such "distortions", which anyway are rare. Therefore, government intervention should be limited; and in case governments implement industrial policies, the costs would be higher than the potential gains because the whole process is prone to rent-seeking and corruption (Wade, 2007).

Lall (2005) lists two approaches to stimulate industrialization to characterize the two sides of the debate: the neoliberal and the structuralist approaches. The neoliberal approach advocates integration in the global economy and resource allocation by free markets, while the structuralist approach advocates government interventions with selective policies that support particular activities, firms or technologies. Reinert (2007) argues that the mainstream neoliberal approach would not accept the argument that countries need to diversify into more productive economic activities because they lack the tools to distinguish between different economics activities. A similar argument is made by Pasinetti (1993) when comparing the focus of neoliberal framework on exchange and the focus of structuralist approach on production.

The differences between the neoliberal and the structuralist approaches are also reflected in the debate about the effects of specialization and diversification on growth. The neoliberal approach sees no connection between diversification and growth, on the contrary, sequential specialization would generate growth - by specializing in the sectors in which a country has comparative advantage the resulting factor accumulation and the free market allocation of resources would drive the process of dynamic change of comparative advantage and structural transformation. On the other hand, the structuralist approach considers the increasing diversification of goods and services in the economy as one of the most quintessential characteristics of the process of structural transformation (Saviotti and Pyka, 2004a, 2004b, 2004c). Therefore, to accelerate such a process, the objective of industrial policy is to "diversify the economy and generate new areas of comparative advantage…'New' refers to both products that are new to the local economy and to new technologies for producing an existing product" (Rodrik, 2004).

Another set of arguments in favour of industrial policies are related to transaction costs and failures of coordination (Kosacoff and Ramos, 1999). Hausmann and Rodrik (2006) suggest that, in general, market failures that affect structural transformation are related to coordination failures and information spillovers. Coordination failures arise when the decision for investment depend on whether another investment by another actor is made, and vice versa. Information spillovers reduce the incentives of first entrants to take risks because they would bear all the cost of failures but would provide valuable information to others if they succeed. These are also the justifications listed by Lin (2012) on the case for a state role in leading development. Glăvan (2007) provides a critique to the information spillover argument by noting that the level of entrepreneurship does not depend on institutions, because it is an inherent function of human behaviour and all entrepreneurial decisions are taken under uncertainty.

In terms of implementation, industrial policies are usually seen as microeconomic policies with macroeconomic effects, which are targeted to specific sectors to benefit the whole economy. Wade (2010) suggests that, by the experience of East-Asia, there are two types of industrial policies: "leading the market" and "following the market". The first refers to governments making investment decisions that cannot be expected to be made by the private sector. These are the "picking the winner" type of industrial policies. Wade (2010) argues that the majority of the experiences in East-Asia were of the "following the market" type, which are characterized by government supporting some of the investment decisions of the private sector, nudging their incentives towards given products. Both in "leading the market" and "following the market" there is a need for the state to identify the areas to support.

A recurrent justification for the need of industrial policy is the problem of coordinating investment decisions and the role that the government has in publicly providing inputs to enable entrepreneurs to discover new economic activities. For example, Hausmann, Hwang and Rodrik (2007) suggest that the cost of discovery of how to produce a new product is a binding constraint, because firms may not innovate to the socially desirable level given that they are not able to fully internalize the costs of discovering how to adapt the production of goods that already exist in other countries. They also note the body of literature that emphasize other binding constraints such as limited access to credit for investment (Banerjee and Munshi, 2004), weak institutions that are challenged by corruption and do not enforce contracts and property rights (Fisman, 2001; Svensson, 2003), and barriers to competition and entry of firms in new sectors (Djankov, La Porta, Lopez-de-Silanes and Shleifer, 2002; Aghion, Burgess, Redding and Zilibotti 2005).

However, the discussion of markets incentives in terms of how entrepreneurs would respond to potential demand has been less explored in the literature. It is possible that even when the government provides the required inputs to solve coordination problems and facilitate the move to activities that are better positioned in the product space, market incentives would push entrepreneurs towards other activities (those not as well positioned but with perceived higher demand).

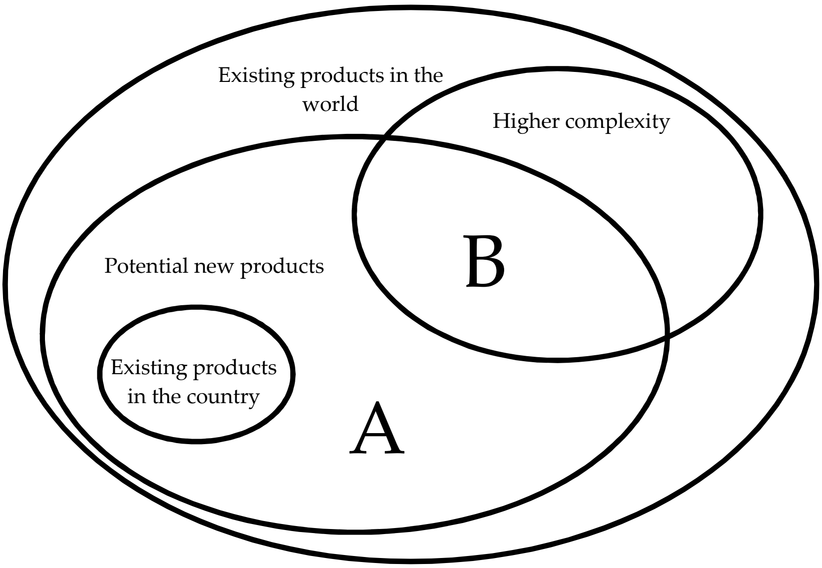
This chapter explores the hypothesis that industrial policy may also be justified in cases when demand factors are very likely to prevent an economy to build productive capacities. The hypothesis proposed here suggests a binding constraint on catching up, additional to those usually considered in the literature on economic development. In the framework described here, the elimination of the binding constraints listed in the paragraphs above would not contribute to moving the production of a country towards more complex products; it would only facilitate the discovery of new products. If the majority of those new products have below average complexity, the country would remain producing low complexity products.

5.2 Analytical approach

This chapter examines the probability of socially desirable economic activities emerging under economic institutions that create incentives for entrepreneurship but do not target any sector in particular.

Figure 5.1 describes an approach to assess such a probability. It illustrates that the possible economic activities for diversification that would result in the socially desirable outcome of higher complexity (B) is a sub-set of the possible new economic activities in the country (A). For economic agents to move to the sub-set B of potential new products, there should be incentives for the creation or adoption and combination of the required technologies. These incentives are shaped by economic institutions and the expected demand for the new products. Economic institutions define and enforce the "rules of the game", the set of incentives and constraints that economic agents face for acquisition and combination of technologies. Expected demand for new products, both domestic and foreign, also shape incentives that economic agents face while choosing between possible economic activities to invest in.

Figure 5.1. The sub-set of desirable economic activities for diversification.



Therefore, the question is how to foster the emergence of economic activities with higher complexity through changes in economic institutions, given the existing productive capacities and the domestic and global demand for potential new products. A required set of economic institutions would foster new economic activities in general, usually by creating an enabling environment conducive to business while encouraging investment in new technologies and skills, and creating economic opportunities for a broad cross-section of society. However, despite necessary, these institutions may not be sufficient if the new economic activities that emerge have low complexity. The question is when to apply a "laissez-faire" approach in which the market guides the identification of opportunities for new economic activities, or a strategic diversification approach in which the government create incentives to actively steer the private sector towards targeted economic activities.

The optimum strategy would be based on the assessment of the probability (P) that more complex economic activities would emerge given the existing technologies and market incentives, assuming that economic institutions that create an environment that fosters the emergence of new economic activities are in place. Considering $d(x)$ as the sum of the expected demand levels for the products in the set x, the share of the expected demand for the potential new products that result in socially desirable outcomes in the total demand for all potentially new products is given by $P = d(B)/d(A)$.

If such a probability is known, choosing between laissez-faire and strategic diversification becomes somewhat straightforward. If P is higher than 0.5, higher than average complexity sectors are more likely to emerge and the laissez-faire approach is sufficient. On the other hand, if P is lower than 0.5, a strategic approach is required to create incentives for the private sector to discover and invest in the socially desirable sub-set of potentially new economic activities.

5.3 Methodology and data

The methodology used to assess the probability that more complex economic activities would emerge given the existing technologies and market incentives is the following:

1) Identify the economic activities that are more likely to emerge given the existing set of technologies that comprise the economy

To identify those sectors, we use the product space (Hidalgo et al., 2007) and the measure of proximity between products A and B (Φ_{AB}) in the product space. As described in Chapter Three, the proximity is calculated as the minimum value between the conditional probability $P(A|B)$ of a country exporting A given that it exports B and the conditional probability $P(B|A)$ of a country exporting B given that it exports A:

$$\Phi_{AB} = \Phi_{BA} = min(P(A|B), P(B|A))$$

The proximity between two products, therefore, ranges from 0%, in the case in which no country exports both products, to 100% in the case in which all countries that export one good also exports the other.

To identify the products that are located nearby in the product space of each country, a value has to be chosen for the threshold of proximity between products that correspond to a "usual" distance covered during the diversification process. I estimate such threshold by analysing the proximity between *existing* and *new* products, where existing products are those products that were part of the exports of countries in 2009 and new products are those that were not part of the exports of countries in 2009 but were part in 2010.[2] That analysis has focused on the less diversified countries to provide information on the distribution of proximity between existing and new products of most developing countries.

Figure 5.2 presents the result of that analysis. It shows the diversification of countries in 2009 along the horizontal axis, while the vertical axis indicates the proximity in percentages. The three sets of markers represent the 25, 50 (median) and 75 percentiles of the distribution of proximity levels higher than 70%. For most countries, the median of the distribution of proximities is above 80%, the 25 percentile is around 76% and the 75 percentile is around 83%. This chapter adopts the median value (80%) as the threshold to identify products that are nearby in the product space.

2) Identify the products with higher complexity

To identify those products, we apply the method of reflections proposed by Hidalgo and Hausmann (2009) as described in Chapter Three.

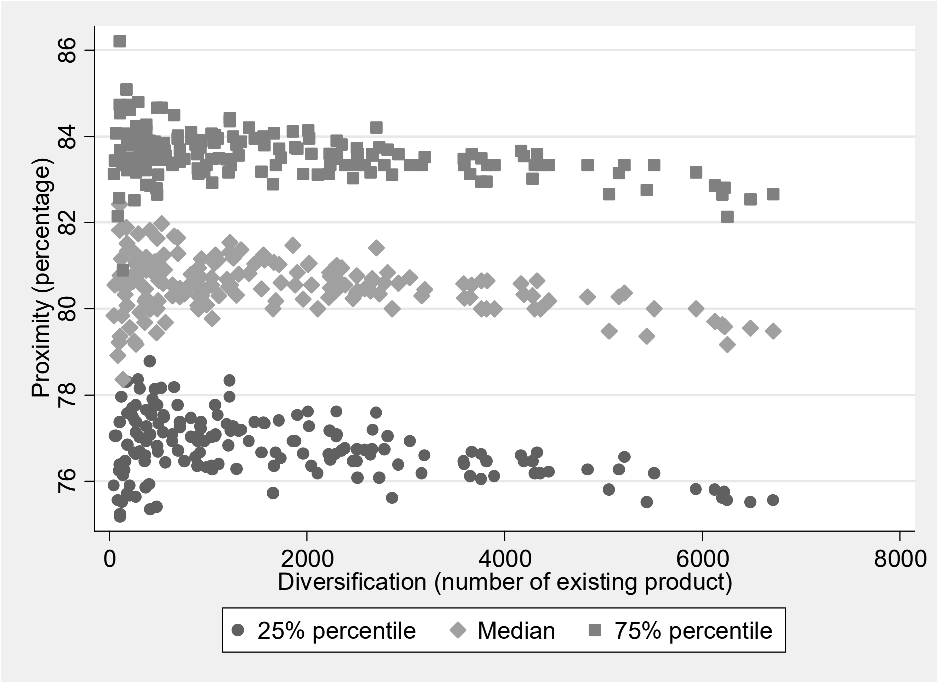
3) What is the probability of those activities that are more complex to emerge, given market incentives?

Here we assume that entrepreneurs face demand incentives when choosing between different potential new economic activities. New products with higher demand potential are more likely to be selected, other things being equal.

To estimate the export potential of a product, this thesis uses an export opportunity measure for potential new products proposed in Freire (2013b). This measure is a monetized type of overlap index designed to measure the degree to which the potential new exports of one country match the expanding import markets of another. A higher degree of export opportunity for potential new products indicates more favourable prospects for trade expansion towards the new products given the past rate of growth of their import markets. This does not mean that the firms in the exporting country would necessarily be able to take full advantage of this market growth, because they would compete with existing exporters and other potential newcomers. Nevertheless, a higher degree of export opportunity for potential new products indicates more favourable prospects for trade expansion.

[2] The timeframe of two years for the analysis was chosen because this is the minimum interval based on the trade data (there is no data with a higher frequency). Future research could replicate the analysis with different timeframes to verify how they affect the results.

Figure 5.2. Proximity between existing and new products.



Source: Author based on data from UN Comtrade.

The index of export opportunity of product *i* for country *c* (XOP_{ci}) is here defined as:

$$XOP_{ci} = \sum_d \sum_i \left(\frac{m_{id}^{t1}}{M^{t1}} - \frac{m_{id}^{t0}}{M^{t0}}\right) \times M^{t1} \quad \text{(V.1)}$$

Where *M* is the total imports by all countries in all products, m_{id} represents imports of product *i* in country *d*, *t0* is year 2009 and *t1* is 2010. Therefore, the index represents the change in the import market of a product *i* between two periods.

Only the sectors *i* that meet the following criteria are included: 1) the share of the sectoral imports in total world imports has increased between the two periods ($\frac{m_{id}^{t1}}{M^{t1}} > \frac{m_{id}^{t0}}{M^{t0}}$), and 2) the sector represents a potential new product for the country *c* in consideration (Φ_{ij} > 80% for at least one product *j* in the existing product mix of country *c*).

The selection of new products for diversification may also be affected by their potential for import replacement. The import replacement opportunity (*MOP*) for country c of a potential new product i is defined in this chapter as the value of total imports of that product by country in 2010 (M_{ci}^{2010}).

$$MOP_{ci} = M_{ci}^{2010} \tag{V.2}$$

This chapter uses the disaggregated trade data from UN Comtrade using the Harmonized System code (HS 2002) at 6-digit level, which covers 221 economies from 2007 to 2010. It is used to apply the method of reflections, to calculate the proximity between products in the product space, and to calculate the export and import replacement opportunities. The data is further disaggregated by quantity unit code and by unit value range using the methodology described in Chapter Three.

5.4 Example of application of the methodology

In this section, we use the results of the analysis of the product space of Cambodia to exemplify the application of the method. Figure 5.3 illustrates the map of potential new exports in the case of Cambodia. The average complexity of Cambodia's product-mix is -1.44, therefore, new products with complexity above that level would contribute in pushing the distribution of complexity of the country's product-mix towards more complex products. The figure shows that the majority of the potential new products is concentrated above the country's average product complexity, increasing the probability of the emergence of more complex economic activities.

Every year, many new products are produced and the production of many others is discontinued. The increase of productive capacity of a country entails a higher rate of success in the diversification towards new products that are more complex than the average. These more complex new products face lower competition, thus have higher chances to succeed, and given that they are also more numerous in the total set of potential new products, this increases the chance that these are actually discovered by entrepreneurs.

As discussed, another factor that influences the rate of discovery of new products is its expected demand. Products that are in high demand are more likely to attract entrepreneurs and are also more likely to succeed. To estimate the product's export potential, we use the export opportunity measure described in the previous section.

Figure 5.4 maps the export opportunities of the potential new products in the case of Cambodia. It shows that the potential new products with higher export opportunities (over $100 million) are concentrated at the less-complex part of the set. These results indicate that new products with below average complexity are more likely to attract entrepreneurs.

Figure 5.3. Map of potential new products for diversification, Cambodia

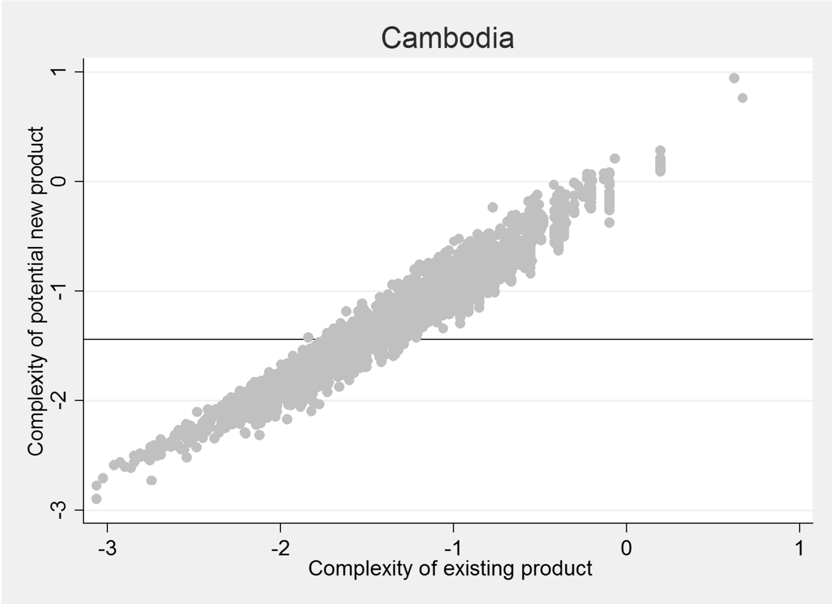
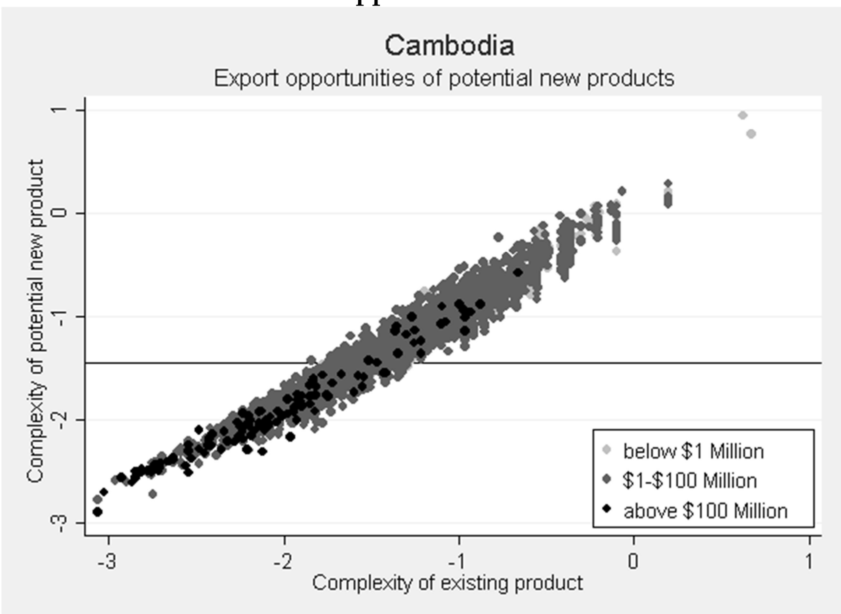


Figure 5.4. Map of potential new products for diversification and export opportunities

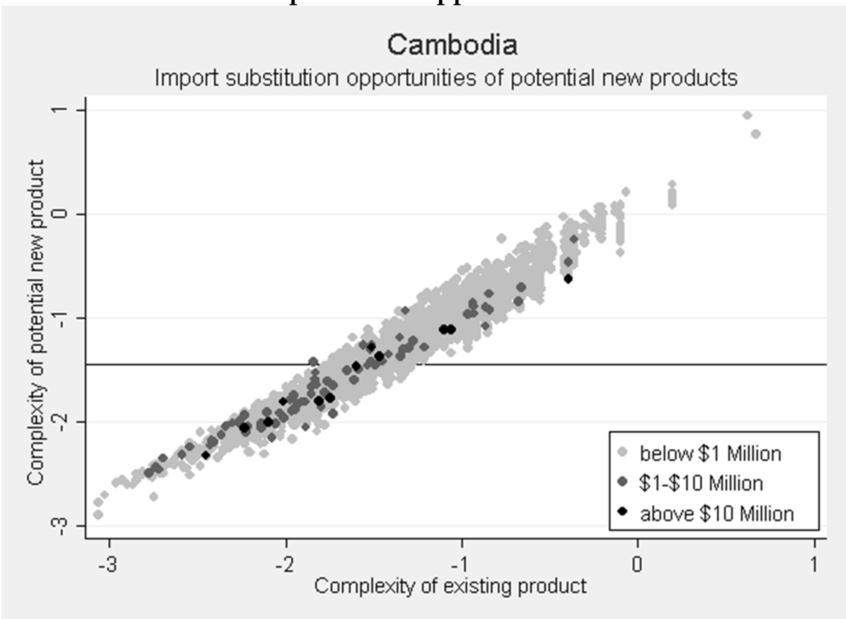


Source: Author's computations based on 2010 data from UN Comtrade.

Note: Zero marks the world average product complexity and one indicates a standard deviation from the mean.

The selection of new products for diversification may also be affected by their potential to replace imports. As described in the previous section, the import replacement opportunity for country *c* of a potential new product *i* is considered as the value of total imports of that product by country *c* in 2010. Figure 5.5 maps such import replacement opportunities. It shows that the potential new products with higher import replacement opportunities also have complexity levels below the country's average. Therefore, it is likely that the change in the distribution of product complexity, and consequently in the country's productive capacity, would be driven by the higher demand for lower-complexity new products, both in export and domestic markets.

Figure 5.5. Map of potential new products for diversification and import replacement opportunities



Source: Author based on 2010 data from UN Comtrade.

Note: Zero marks the world average product complexity and one indicates a standard deviation from the mean.

Table 5.1 shows the key numbers to consider: the share of potential new products with complexity above the country's average (65%), the share of export opportunities with complexity above the country's average (26%), and the share of import replacement opportunities with complexity above the country's average (41%). These numbers show that 6 in every 10 dollars of import replacement opportunities and over 2 in every 3 dollars of export opportunities are in potential new economic activities with complexity below the country's average. New products with below average complexity are, therefore, more likely to attract entrepreneurs, perpetuating the low complexity of the country's product mix.

Table 5.1 Potential new products related to those already produced in Cambodia

Number of existing products	2 124
Number of potential new products for emulation	2 670
Percentage of potential new products with above country's average complexity	65%
Percentage of export opportunities with above country's average complexity	26%
Percentage of import replacement opportunities with above country's average complexity	41%

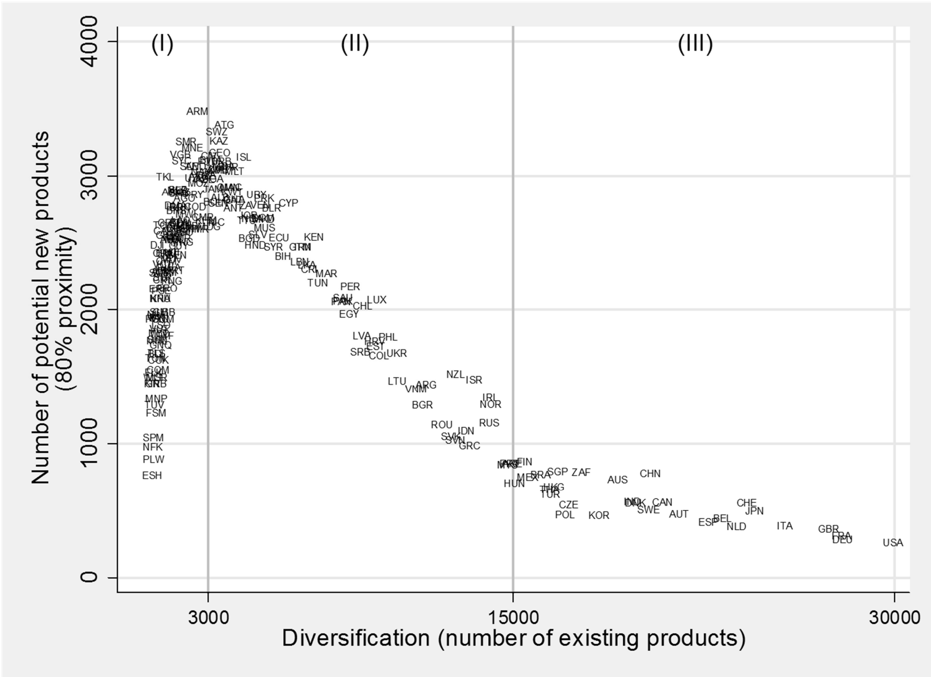
Source: Author's calculations based on 2010 data from UN Comtrade.

5.5 Results and discussion

We use the same method as described above to assess the probability that more complex new products emerge in 221 economies, using trade data for 2010. Based on the analysis of these maps, Figure 5.6 shows the relation between the existing level of diversification of the economy and the number of potential new products for emulation (the proximity to the existing products in the product space of which is at least 80%). The figure shows that the number of potential new products increases sharply with the number of existing products in the country's product-mix, but up to a point of about 3,000 products. About 57% of the 221 economies are within this range of diversification. Beyond this point, the number of potential new products decreases with the increase of products in the product-mix. For the most diversified countries – those with numbers of existing products around 15,000 products – the number of potential new products diminishes more gradually with the increase in the level of diversification.

We can use the product space to better understand the pattern shown in Figure 5.6. Countries that are less diversified have few "existing" products and, therefore, a relatively low number of potential new products that are nearby in the product space. As a result, they have very few opportunities for diversification. However, those products that they can "discover" also open up new products, and that process happens very quickly (which results in the steep curve in the left side of the graph). That pattern quickly reaches a maximum, after which the newly discovered products no longer open up too many new possibilities. That happens because the product space is finite in the short run (although it expands in the long run); after a certain number of products in the export base of a country is reached, the potential new products to be discovered starts to decrease. As a result, the number of potential new products declines.

Figure 5.6. Relationship between the level of diversification and the number of potential new products



Source: Author's computations based on UN Comtrade data.

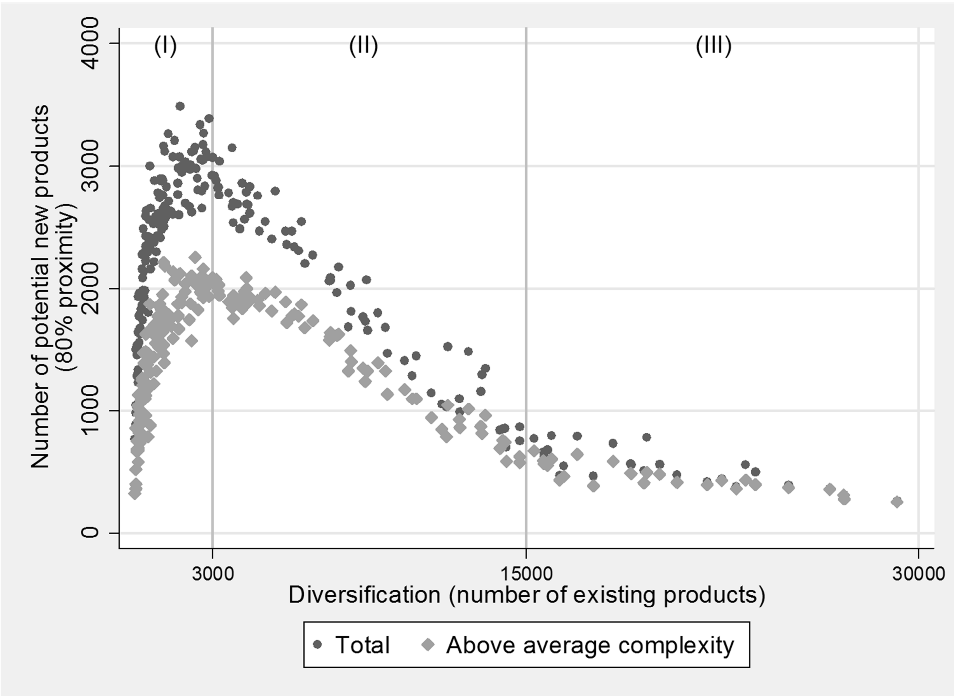
Note: Opportunities for emulation: I – increasing (promote emulation); II – decreasing (shift from emulation to product innovations); III - decreasing and marginal (promote product innovations).

There are basically two stages in this process: the initial stage of low diversification and increasing opportunities for diversification, and the stage of relatively higher diversification and decreasing opportunities. However, in terms of policy, this result suggests the possibility of three well defined strategies for innovation dependent on the level of diversification, which are represented by the Roman letters in Figure 5.6. Countries with less diversified product mix have many opportunities to diversify by emulating developed countries (I). As countries diversify, such strategy results in gradually fewer potential new products and, to continue to diversify, the country should start to combine emulation with product innovation (II). For the more diversified countries, product innovation seems to be the main strategy, given the relatively low number of potential new products for diversification through emulation (III).

Of course, less diversified countries could also engage in product innovation and find new products that are relevant to their own context. However, there may be few possibilities for product innovation that are new to the world in less diversified countries because the ones that existed were already produced by more diversified countries. As argued by Reinert (2007, p.39) "*Poor countries tend to specialize in the economic activities which rich countries can no longer mechanize or innovate further, and are then typically criticized for not innovating enough.*" [3]

As discussed in previous sections, not all potential new products would push the complexity of the economy's product mix to a higher level. The opportunities for countries to diversify and promote structural transformation are in products that are more complex. This is illustrated in Figure 5.7.

Figure 5.7. Potential new products with above average complexity



Source: Author's computations based on UN Comtrade data.

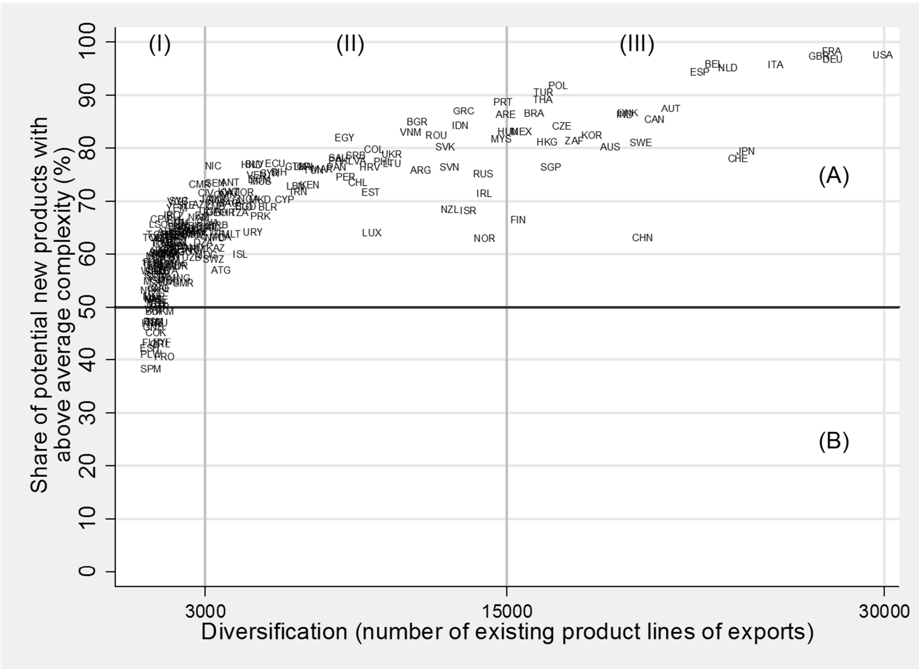
Note: Opportunities for emulation: I – increasing (promote emulation); II – decreasing (shift from emulation to new innovations); III - decreasing & marginal (promote new innovations).

[3] This view is also similar to that in Vernon's (1966) product cycle in which it is assumed a gradual move of production from the original place of product innovation to other countries.

The black dots in Figure 5.7 represent the total number of potential new products in each economy and the grey diamonds represent the number of potential new products with above average complexity. The figure shows a sizeable difference in the number of potential new products represented by dots and diamonds for economies that have lower levels of diversification, while the difference is much smaller for higher levels of diversification.

Figure 5.8 shows the association between the level of diversification of each economy and the share of the potential new products that are also more complex. The figure is divided in two sections by the line that represents a 50% share of potential new products with above average complexity. In section (A) are the economies for which more than half of the potential new products are products with above average complexity, while economies with less than half of such share are in section (B).

Figure 5.8. Share of the potential new products that are also more complex



Source: Author's computations based on data from UN Comtrade.

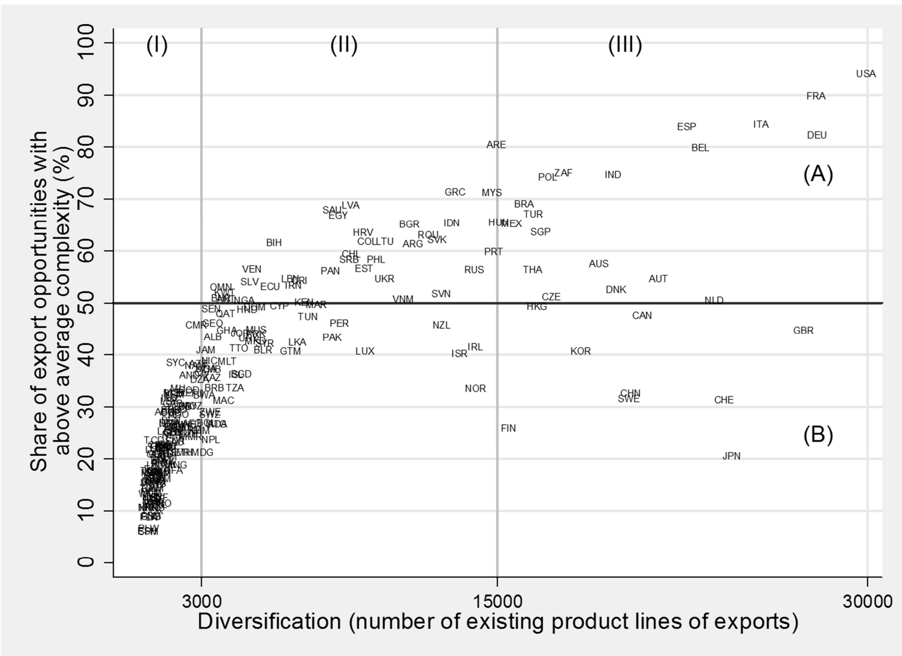
Note: Opportunities for emulation: I – increasing (promote emulation); II – decreasing (shift from emulation to product innovations); III - decreasing & marginal (promote product innovations); Selective policies for emulation: A – Not Required; B – Required.

The figure shows that the proportion of potential new products with above country's average complexity increases with the level of diversification of the country (A). However, for some less diversified economies, such share represents less than 50% of potential new products (B). This suggests that the countries that have lower share of potential new products with above country's average complexity, and therefore with lower opportunity to move up in the complexity ladder, are exactly the less diversified economies that in principle could benefit more from an emulation strategy. These countries would require industrial policies, following the structuralist approach discussed in Section 5.1, in which the government actively promote the discovery process of the private sector towards the potential new products with above average complexity.

As discussed in the previous section, we assume that entrepreneurs take into consideration the potential demand of new products when deciding between potential new economic activities. We also assume that new exports with high export opportunity have higher chances of success. Therefore, the assessment of the share of export and import substitution opportunities with above country's average complexity adds another layer to the analysis.

Figure 5.9 shows the number of existing products in the country's product mix along the horizontal axis and the share in percentage of the export opportunities of potential new products with above complexity along the vertical axis.

Figure 5.9. Effect of export opportunities on the incentives for innovation



Source: Author's computations based on data from UN Comtrade.

Note: Opportunities for emulation: I – increasing (promote emulation); II – decreasing (shift from emulation to product innovations); III - decreasing &

marginal (promote product innovations); Selective policies for emulation: A – Not Required; B – Required.

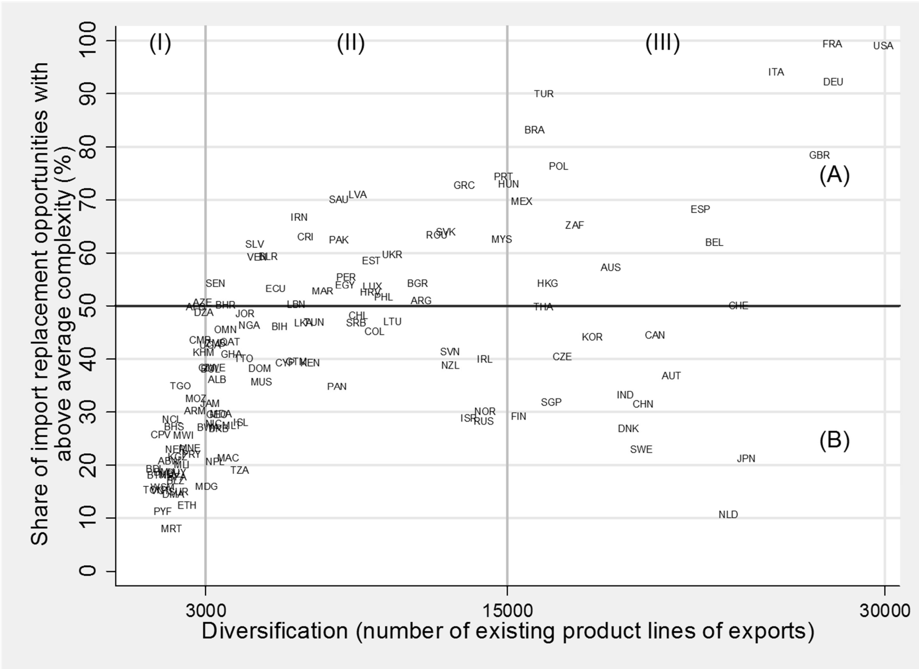
Comparing Figure 5.8 and Figure 5.9 reveals that the effect of demand incentives in terms of exports is to push the number of potential new products with above average complexity down. For the economies whose shares are lower than 50% (groups I-B, II-B and III-B) it is reasonable to suppose that a higher proportion of new economic activities that emulate more diversified country's production would have below average complexity. Although this outcome makes perfect sense in the short-term as the one that maximizes the efficient use of the limited resources, it poses a severe impediment for the catching up strategy of the group of less diversified economies (I-B). In the long run, it perpetuates the relative lower level of productive capacities and opportunities of productive employment in these economies.

Similarly, opportunities for import replacement also create the incentives either for increasing or for reducing the average complexity of a country's product mix. Figure 5.10 illustrates this effect by showing the level of diversification along the horizontal axis, and along the vertical axis the share of the import replacement opportunities of potential new products with above average product complexity. The figure shows that a minority of economies are likely to benefit from a non-selective approach to import replacement. The governments of other economies have to strategically create targeted incentives to push entrepreneurs in import replacement economic activities towards the potential new products with above average complexity.

The joint analysis of export and import replacement incentives is illustrated in Figure 5.11, which shows the share of the import replacement opportunities of potential new products with above average complexity along the vertical axis and the similar share of exports along the horizontal axis. The graph is divided into four quadrants. The quadrants with just a few economies are (1) and (4). In quadrant (1) are the economies that could adopt a laissez-faire approach to import replacement but should adopt a strategic diversification approach towards new export opportunities.

In quadrant (4) are the economies the new exports of which are likely to have above average complexity. These economies could adopt a non-selective approach towards export diversification and let the market guide the identification of new export opportunities. On the other hand, import replacement is likely to result in new products that have below average complexity. Therefore, the state has a role to play in actively promoting the emulation of economic activities that result in higher long-term gains.

Figure 5.10. Effect of import replacement opportunities



Source: Author's computations based on data from the UN Comtrade.

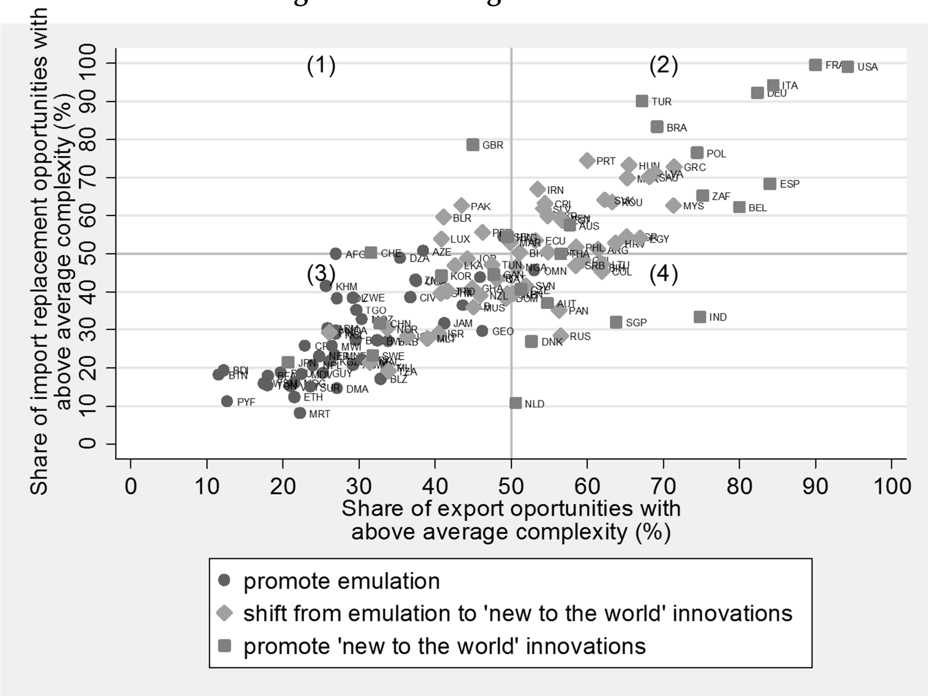
Note: Opportunities for emulation: I – increasing (promote emulation); II – decreasing (shift from emulation to product innovations); III - decreasing & marginal (promote product innovations); Selective policies for emulation: A – Not Required; B – Required.

In quadrant (2) are the countries that do not require selective policies, neither for export nor for import replacement. Many of the developed countries are in this quadrant, but none of the countries with lower levels of diversification are there. Brazil, Mexico, South Africa and Turkey are examples of large emerging economies in this quadrant. These countries could benefit from general macroeconomic policies that promote exports and import replacement, for example through exchange rate policies (Rodrik, 2007; Bresser-Pereira, 2012).

The remaining countries and the majority of the economies with lower levels of diversification are located in quadrant (3). They are in the difficult position of not being able to rely on the market incentives to drive the economy towards increasing productive capacities. If left to the market alone, the new exports or import replacements that emulate the production of richer countries are more likely to have below average complexity. These economies have to adopt an approach based on strategic diversification to create incentives towards economic activities with higher complexity. The implementation of such strategic diversification requires the selective promotion of new economic activities using targeted industrial, infrastructure, trade, investment and private sector development policies.

The results in Figure 5.11 support the arguments of Reinert (2007) that the poorer the nation the less the laissez-faire approach would help the country to catch up. The majority of the less diversified countries, which is the main indication of lower development in Reinert's reading of history, would not be able to rely on the market for driving the decision of entrepreneurs towards more productive activities.

Figure 5.11. Strategies for emulation

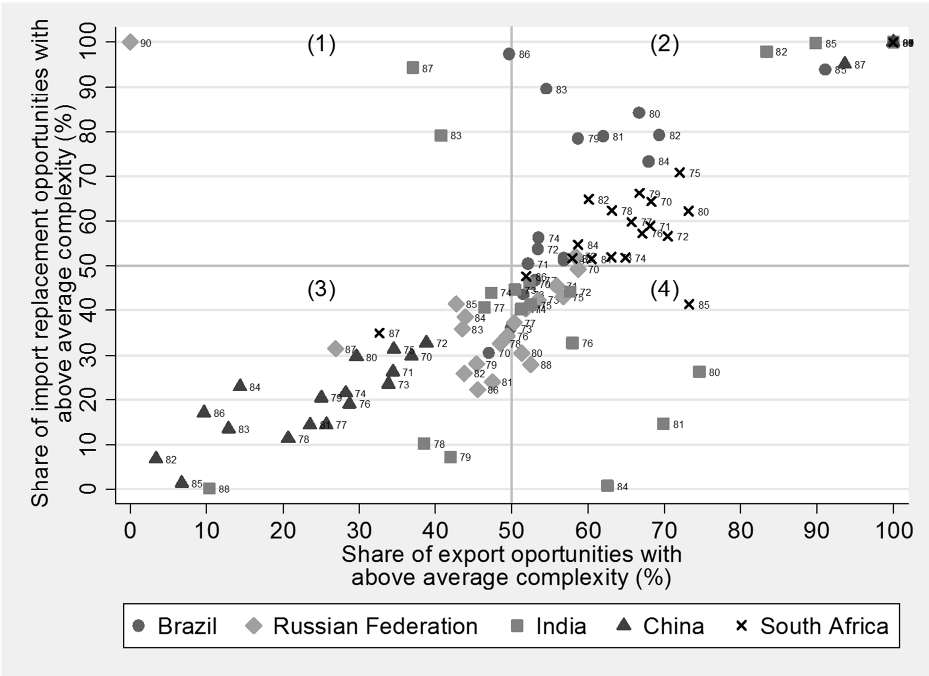


Source: Author's computations based on data from UN Comtrade.

Note: Strategies for emulation: (1) import replacement – non-selective, export – selective; (2) import replacement – non-selective, export – non-selective; (3) import replacement – selective, export –selective; and (4) import replacement – selective, export – non-selective.

The analysis presented uses the threshold of 80% of proximity, but the effect of demand may change for different levels of proximity. To assess such relationships, Figure 5.12 and Figure 5.13 show the same analysis presented in Figure 5.11 but for different levels of proximity for selected group of countries. For each country and level of proximity, the figure shows the share in percentage of the import replacement opportunities of potential new products with above average complexity along the vertical axis and the corresponding share of exports along the horizontal axis. The labels of the markers are the proximity levels considered in the analysis. For example, a marker with label 83 would represent the result of the analysis considering only the potential new products that are within an 83% distance from the product-mix of the country.

Figure 5.12. Strategies for emulation at different levels of proximity, BRICS



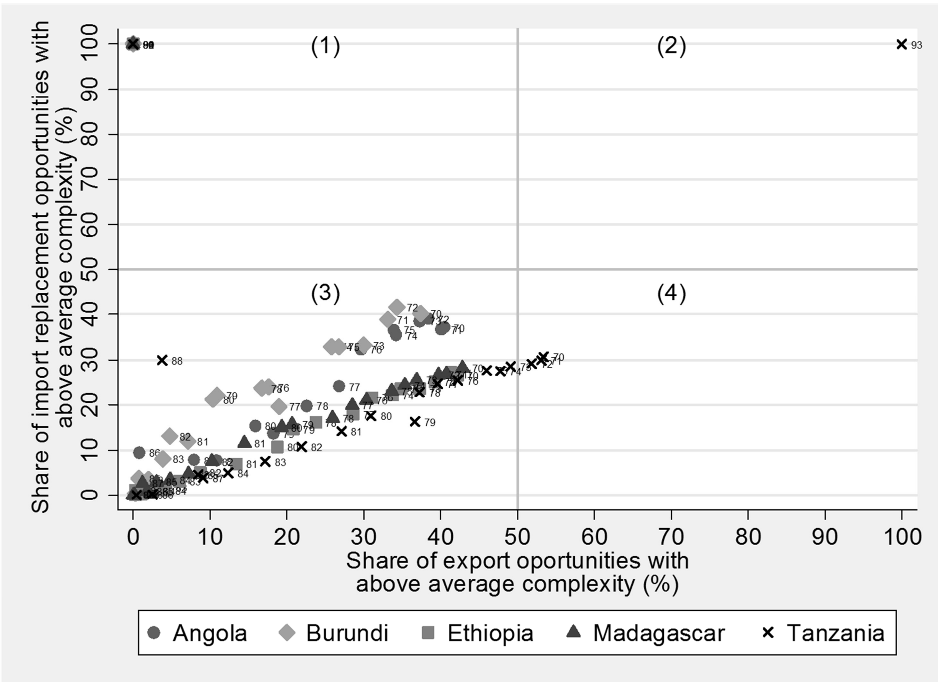
Source: Author's computations based on data from UN Comtrade.

Note: Strategies for emulation: (1) import replacement – non-selective, export – selective; (2) import replacement – non-selective, export – non-selective; (3) import replacement – selective, export –selective; and (4) import replacement – selective, export – non-selective.

Figure 5.12 shows the result for the group of the so-called BRICS. The result suggests that the opportunities for emulation in these countries are affected differently by demand. Brazil and South Africa are in quadrant (2) for almost all levels of proximity, which suggests that these countries do not require selective policies. On the other hand, China and the Russian Federation are located mainly in quadrant (3), which indicates the need for selective policies. India shows a very diverse pattern with opportunities for emulation at different levels of proximity scattered in all quadrants. That suggests the need for a careful identification of potential new products with above average complexity and the product-based analysis of targeted strategies for diversification to avoid the pitfalls of a "one size fits all" approach.

Figure 5.13 shows the result of the analysis for selected five African least developed countries. In all cases, the countries would be better off if they adopt a selective policy for the strategic diversification of their economies.

Figure 5.13. Strategies for emulation at different levels of proximity, selected African LDCs



Source: Author's computations based on UN Comtrade data.

Note: Strategies for emulation: (1) import replacement – non-selective, export – selective; (2) import replacement – non-selective, export – non-selective; (3) import replacement – selective, export –selective; and (4) import replacement – selective, export – non-selective.

5.6 Summary

This chapter examines whether an active role of the government is required to foster structural transformation and economic diversification or whether markets incentives would be sufficient to drive this process of catching up. It uses empirical methods to identify the potential new products for diversification given the current production base of a country and the demand incentives created by export and import replacement opportunities.

The results show that less diversified countries have many opportunities to diversify by emulating developed countries. As countries diversify, countries should start to combine emulation with product innovation because there are gradually fewer potential new products for emulation. Opportunities for emulation reach the lowest point for the most diversified countries, which would be better off by focusing on product innovation.

But the effect of demand in terms of exports and import replacement is to push the number of potential new products for diversification with above average complexity down. Given that fact, the majority of the economies with lower levels of diversification would not be able to rely on the market incentives to drive the economy towards increasing productive capacities. If left to the market alone, the new exports or import replacements that emulate the production of more diversified countries are more likely to have below the average complexity. These countries have to strategically diversify by creating incentives towards economic activities with higher complexity. The implementation of such strategic diversification requires industrial policies - the selective promotion of new economic activities through the use of targeted sectoral, infrastructure, trade, investment and private sector development policies.

In addition to its relevance to the formulation of development policies, this research contributes to industrial policy literature by exploring the use of empirical data and the role of demand to verify the need for selective policies. The analysis of empirical evidence, as presented in this chapter, could be used in the process of identification of strategic direction of diversification. A list of potential products could serve as a public good that could be made available to governments and the private sector. It reduces the cost of discovery of potential successful new economic activities by informing entrepreneurs of the new products that require productive capacities similar to those already available in the country. It also allows governments to play a more active role in promoting that discovery process by the private sector through the use of industrial and investment policies.

6

Identification of potential new sectors: the case of countries with special needs in the Asia-Pacific region[1]

This chapter discusses how to use the methodology described in the previous chapter to identify products to target in industrial policies. The objective is to identify the sectors that would maximize the opportunities for countries to build their productive capacities and promote structural transformation through the

[1] This chapter is based on ESCAP (2015), "Asia-Pacific Countries with Special Needs Development Report 2015: Building Productive Capacities to Overcome Structural Challenges", which I authored, and on Freire (2014a), "The role of agriculture in closing development gaps of LDCs", ESCAP Policy Papers on Countries with Special Needs CSN/14/01.

emulation of the productive structure of more developed countries. This chapter illustrates the use of the methodology by applying it to the group of countries with special needs in the Asia-Pacific region.

6.1 Introduction

As discussed in the previous chapter, governments in less diversified countries have a role in nudging the discovery process towards new products that have higher complexity. Successful diversification towards these new products will generate the new technologies that will increase the productive capacity of the country. These new products will also facilitate the process of diversification towards other products with higher complexity. This process of increasing product complexity, and consequently increasing productive capacity, has a social benefit that cannot be captured by the private entrepreneur. The society will benefit if a larger proportion of entrepreneurs take their chances on those products of higher complexity, but that benefit is not internalized by the entrepreneurs themselves. Therefore, the diversification towards these products is likely to be below the optimum social level. In these cases, the government should, through selective industrial policies, support and facilitate the diversification towards those new products of above average complexity and that are in high demand.

Building productive capacities is critical for economies and countries with special needs (CSN), namely the least developed countries (LDCs), landlocked developing countries (LLDCs) and Small Island developing States (SIDS) in Asia-Pacific to overcome their structural challenges and "to benefit from greater integration into the global economy, increase resilience to shocks, sustain inclusive and sustainable growth and eradicate poverty, achieve structural transformation and generate full and productive employment and decent work for all" (United Nations, 2011).[2]

The importance of the transformation of productive capacities has received growing attention by the international community and it was given priority among the goals and actions agreed in major United Nations Conferences related to the

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[2] This chapter focuses on the group of economies and countries with special needs in the Asia-Pacific region comprised of: LDCs - Afghanistan, Bangladesh, Bhutan, Cambodia, Kiribati, Lao People's Democratic Republic, Myanmar, Nepal, Solomon Islands, Timor-Leste, Tuvalu, Vanuatu; LLDCs - Armenia, Azerbaijan, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan; SIDS - Cook Islands, Fiji, Maldives, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Tonga; Other small Island economies: French Polynesia, Guam, and New Caledonia.

CSN (Table 6.1). The focus of national and international policy on developing productive capacities and the related expansion of productive employment is also seen as critical for achieving sustained development.

Table 6.1. Building productive capacities as part of the internationally agreed development goals for CSN

	Productive Capacity Goals
Transforming our world: the 2030 Agenda for Sustainable Development	We will strengthen the productive capacities of least developed countries in all sectors, including through structural transformation. We will adopt policies which increase productive capacities, productivity and productive employment; financial inclusion; sustainable agriculture, pastoralist and fisheries development; sustainable industrial development; universal access to affordable, reliable, sustainable and modern energy services; sustainable transport systems; and quality and resilient infrastructure.
Programme of Action for the Least Developed Countries for the Decade 2011-2020	Achieve sustained, equitable and inclusive economic growth in least developed countries, to at least the level of 7 per cent per annum, by strengthening their productive capacity in all sectors through structural transformation and overcoming their marginalization through their effective integration into the global economy, including through regional integration.
Vienna Programme of Action for Landlocked Developing Countries for the Decade 2014-2024	To promote growth and increased participation in global trade, through structural transformation related to enhanced productive capacity development, value addition, diversification and reduction of dependency on commodities.
Small Island Developing States Accelerated Modalities of Action (Samoa Pathway)	To develop and strengthen partnerships to enhance the participation of small island developing States in the international trade in goods and services, build their productive capacities and address their supply-side constraints.

Source: Author, based on ESCAP (2015).

Specific challenges are faced by these countries in building productive capacities through economic diversification, which includes CSN that are exporters of primary commodities, particularly oil and minerals, face demand incentives to further specialize in extractive sectors; these economies also have the tendency to face exchange rate appreciations, which hinder the expansion of tradable sectors; LLDCs and SIDS face high costs of trade; and more populous Asia-Pacific CSN with surplus labour often face low effective demand for new products, because wage rates tend to increase slower than productivity levels.

The next section briefly presents the status of productive capacities of Asia-Pacific CSN. It is followed by the discussion of the role of economic diversification in increasing productive capacities in terms of achieving higher output and reducing competition faced in international markets. The path dependence that characterizes the diversification process is also discussed. Here we use the methodology described in the previous chapter to identify opportunities for economic diversification in Asia-Pacific CSN. The result of that analysis is a tailored list of sectors/markets that present higher opportunities for successful diversification of these countries.

6.2 Productive capacities in countries with special needs in the Asia-Pacific region

Productive capacities are usually defined as a combination of productive resources, entrepreneurial capabilities and production linkages which together determine the capacity of a country to produce and effectively compete in global markets, and enable it to grow and develop. Some examples of definitions of productive capacities within the United Nations System are the following:

"*Productive resources, entrepreneurial capabilities and production linkages which together determine the capacity of a country to produce goods and services and enable it to grow and develop*" (UNCTAD, 2006).

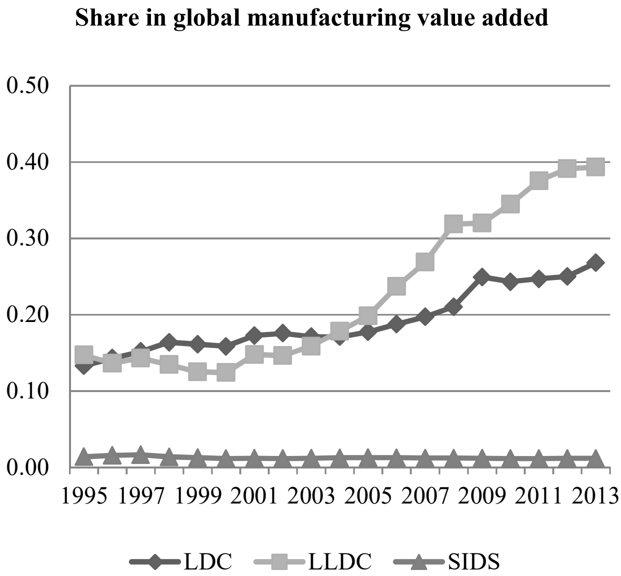
"*[P]roductive capabilities are personal and collective skills, productive knowledge and experiences embedded in physical agents and organizations needed for firms to perform different productive tasks as well as to adapt and undertake in-house improvements across different technological and organizational functions*" (UNIDO, 2011).

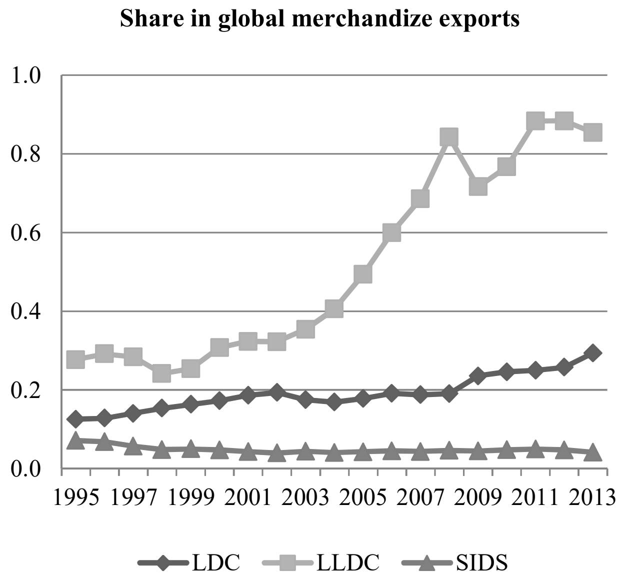
"*[A]bility to produce efficiently and to compete globally*" (OHRLLS, 2013).

Analysis of common measures of production and trade shows that the Asia-Pacific CSN have in general low productive capacities. The Asia-Pacific CSN represent 5.2% of the global population[3] but contribute with less than 0.4% of global manufacturing production, 1.1% of merchandise exports, 0.5% of manufactured exports, and 0.25% of high-technology exports (Figure 6.1 and Figure 6.2).

[3] Source: Author's computations, based on data from the ESCAP Online Database and the World Bank WDI.

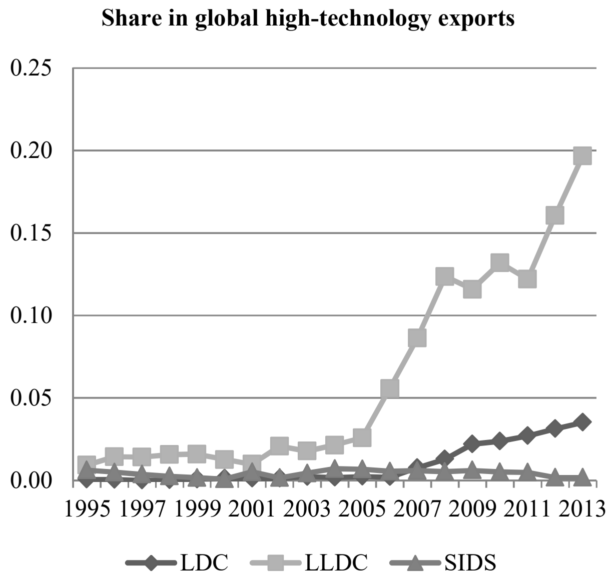
Figure 6.1. Shares in international production and trade, Asia-Pacific CSN (in percentages)





Source: Author's computations, based on trade data from the ESCAP Online Database and the World Bank WDI.

Figure 6.2. Shares in international trade in manufacturing and high-technology products, Asia-Pacific CSN (in percentages)



Source: Author's computations based on trade data from the ESCAP Online Database and the World Bank WDI.

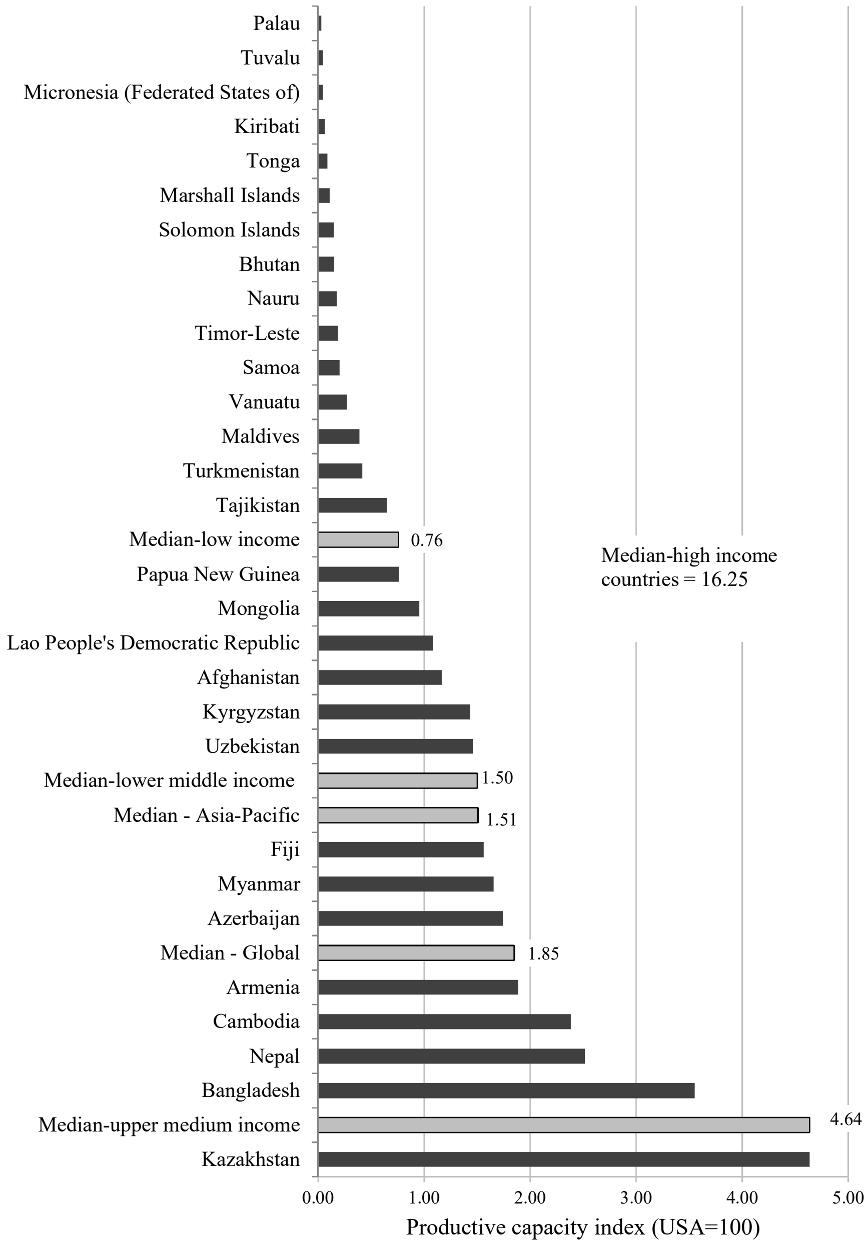
Among the Asia-Pacific CSN, the LLDCs have higher productive capacities, followed by the LDCs. These groups have also shown some progress in the past 10 years in increasing their participation in production and trade. The higher and more recent increase was in the share of high-technology exports of LLDCs, which went from 0.03% to 0.20% from 2005 to 2013, although that increase can be traced back to one single country, Kazakhstan. Also noticeable is the increase of the share of Asia-Pacific LDCs since 2006, which is mainly due to the emergence of the pharmaceutical industry in Bangladesh. On the other hand, the group of 14 small islands developing countries in Asia-Pacific have contributed only marginally with less than 0.01% in those measures. More worryingly, their participation has been declining steadily over the past two decades.

Using the productive capacity index presented in Chapter Three, Figure 6.3 shows that the productive capacity in Asia-Pacific CSN in 2013 represents only a few percentage points of the productive capacity of the USA, which is the country with the highest productive capacity. The Asia-Pacific CSN with the highest levels of productive capacity are Kazakhstan (4.64), Bangladesh (3.55), Nepal (2.52), Cambodia (2.38) and Armenia (1.89), which is slightly above the global median productive capacity. Azerbaijan (1.74), Fiji (1.56) and Myanmar (1.66) have productive capacities below the global median but above the median of the Asia-Pacific region, which is slightly above the median productive capacity of lower-middle income countries. The other 21 CSN in Asia-Pacific have productive capacity below that line and 15 of them below the median of the group of low income countries (0.76). The Asia-Pacific CSN with the lowest productive capacities are the Federated States of Micronesia (0.05), Tuvalu (0.05), and Palau (0.03).

Analysis of the evolution of productive capacities in Asia-Pacific CSN suggests that these countries have made slow progress when compared with the global and regional averages (Figure 6.4). When comparing with the CSN of other regions, the Asia-Pacific LDCs have shown higher productive capacities than their counterparts, while Asia-Pacific LLDCs and SIDS trailed behind. The biggest difference is between SIDS in the Asia-Pacific and in other regions, the former having on average only a quarter of the productive capacity of the latter.

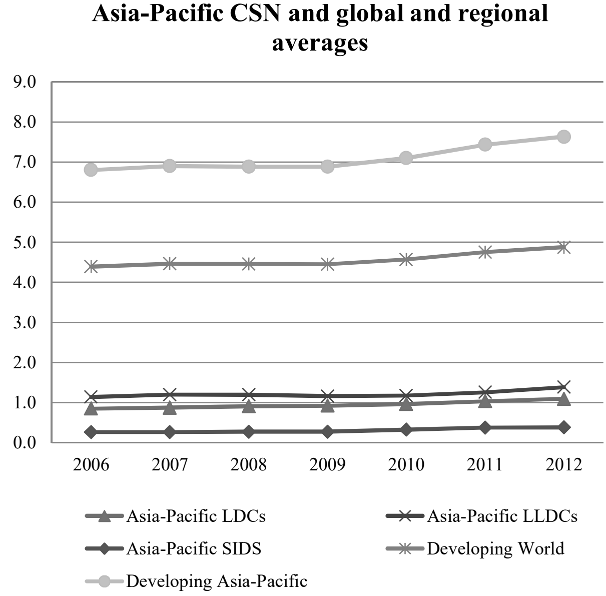
The analysis of the evolution of the three-year average productive capacities of the Asia-Pacific CSN in the period 2006 to 2012 shows that, while the majority of these countries have not moved out of a narrow band of low levels of productive capacities, some countries have shown noticeable progress. Among the Asia-Pacific LDCs, productive capacity has increased markedly since 2009 in Cambodia from 1.5 to 2.1 in 2012, in Myanmar from 1.2 to 1.7, and in Bangladesh from 3.0 to 3.6. Nepal has experienced slower but steady progress since 2006, while Afghanistan has since 2009 lost the gains made in the 2006-2008 period (Figure 6.5). Among the Asian LLDCs, Kazakhstan has made remarkable progress since 2010, increasing its productive capacity from 2.2 to 3.4. Also noticeable is the increase in productive capacity in Fiji, from 2007 (1.2) to 2011 (2.2) (Figure 6.6).

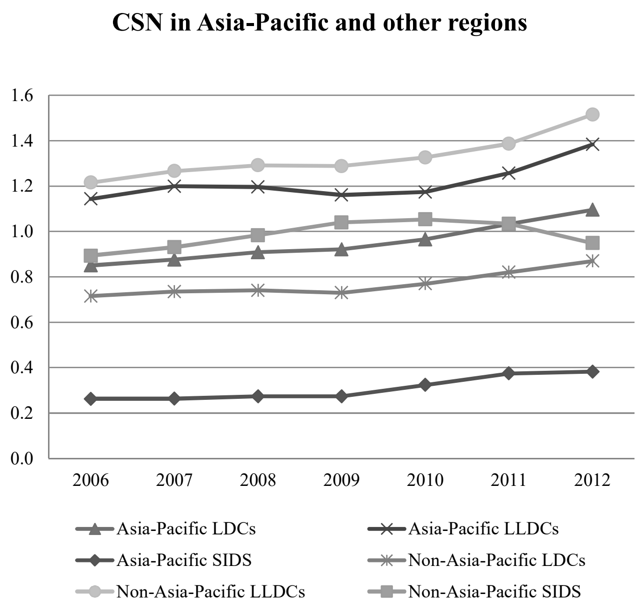
Figure 6.3. Productive capacity, Asia-Pacific CSN, 2013



Source: Author's computations based on trade data from UN COMTRADE.

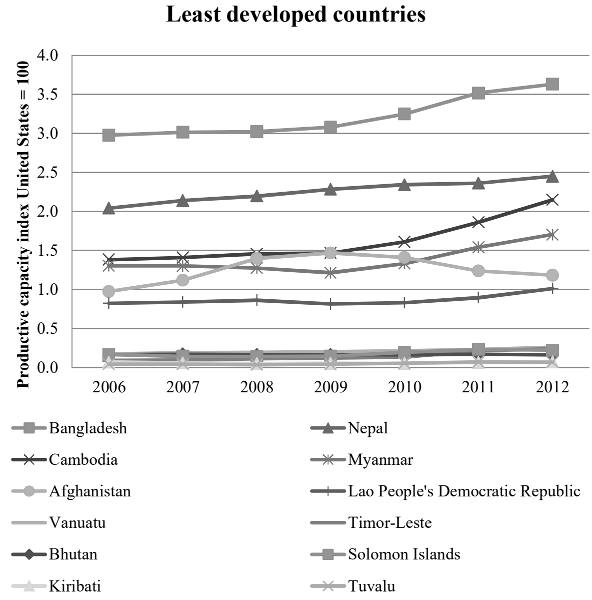
Figure 6.4. Evolution of average productive capacity, 2006-2012, Country groupings (productive capacity index, USA=100)

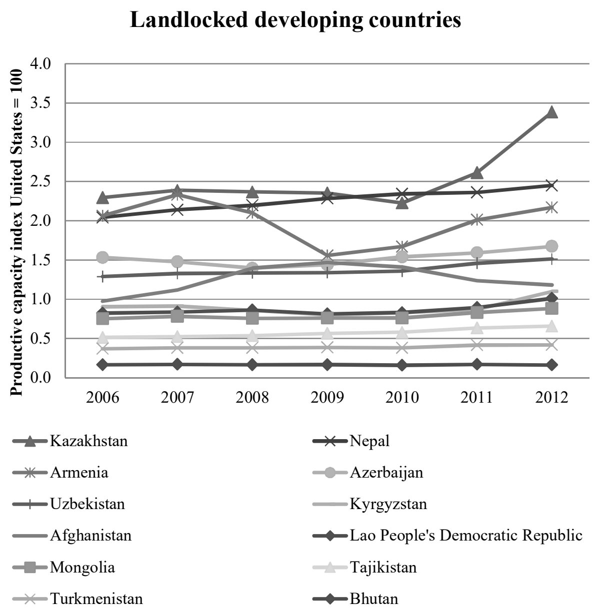




Source: Author based on trade data from UN Comtrade.
Note: The values presented are three-year moving averages.

Figure 6.5. Evolution of average productive capacity, 2005-2013, Asia-Pacific LDCs and LLDCs (productive capacity index, USA=100)

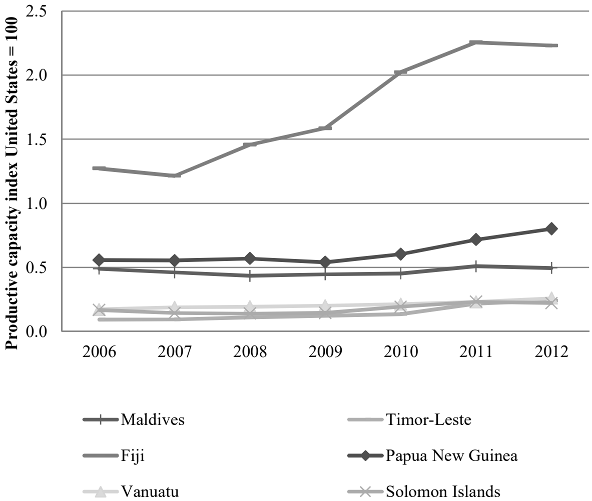




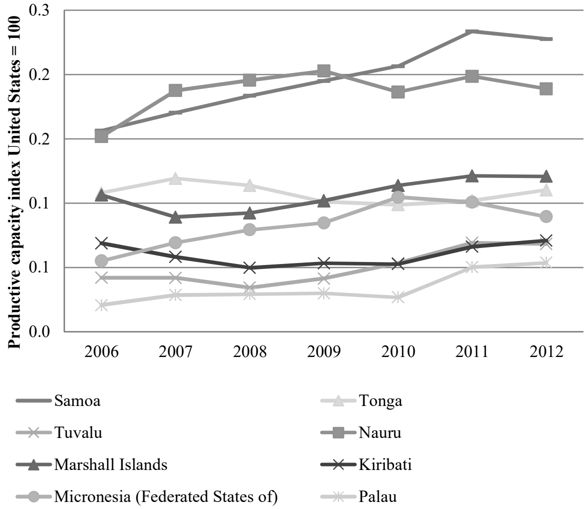
Source: Author's computations based on trade data from UN Comtrade.
Note: The values presented are three-year moving averages.

Figure 6.6. Evolution of average productive capacity, 2005-2013, Asia-Pacific SIDS (productive capacity index, USA=100)

Melanesian and other selected small developing island States



Polynesian and Micronesian small island developing states



Source: Author's computations based on trade data from UN Comtrade.
Note: The values presented are three-year moving averages.

In countries endowed with natural resources, low productive capacities, and high trade costs (due remoteness and/or poor trade infrastructure) create incentives for specialization in primary commodities with relative inelastic demand to the trade costs. In fact, the production and trade structure of most of Asia-Pacific CSN is characterized by product baskets that are highly dominated by primary commodities. Many of these countries have become more exposed to commodity-related risks compared with a decade ago, making their economies more vulnerable to declines in commodity prices in the world market (ESCAP, 2012). This suggests the need for creating a more diversified production base in these countries.

6.3 The problem of identification of industries to target

Lin and Monga (2010) argue that a major factor that contributed to the failure of some of the industrial policies of the past is the inability of governments to identify the appropriate industries to target based on country's endowment structure and level of development. These authors made an important contribution to the debate on the methods to identify potential new sectors by proposing a six-step procedure to identify and facilitate growth. The very first step of this procedure is for latecomers to "… identify the list of tradable goods and services that have been produced for about 20 years in dynamically growing countries with similar endowment structures and a per capita income that is about 100% higher than their own" (Lin and Monga, 2010, p.17). The other steps of the procedure are related to removing the constraints to the emergence of those industries that have such an advantage and to creating the conditions to allow them to become the country's actual comparative advantage.

Lin and Monga (2010) do not elaborate much on this very first identification step. The choice for parameters such as 20 years of production of tradable goods and services or 100% higher income per capita seems to be the result of the reading of the fast growth of some emerging economies in the past decade. Its advantage is that it is easy to apply. It is straightforward to identify those fast-growing economies. Most of them are in Asia, such as China, Malaysia, the Republic of Korea, Singapore, Thailand, and Viet Nam, and tradable goods and services have been fuelling their growth.

Some doubts regarding Lin and Monga's procedure have been raised. Both the technologies used in the production and consumption patterns may have changed fundamentally in the past 20 years, in a way that information about the production of countries in the past is not relevant for countries today (Velde, 2011). One can argue, for example, that the innovations in information and communication technologies have changed production processes in a broad range of sectors and the capabilities required to enter today in a specific industry are very different from those required two decades ago. Similarly, the rise of a middle class in populous emerging economies such China, Brazil and India may have changed consumption patterns in a way that the products that are in higher demand now are very different from those in demand in the past.

Commenting on the method proposed by Lin and Monga (2010), Ricardo Hausmann argues that better methods to identify the potential industries for diversification should use the product space and measures of product complexity.[4]

As discussed in Chapter Two (section 2.2) several studies have used the product space methodology to analyse the possibilities for export diversification of countries (e.g. Hausmann and Klinger, 2008; Vitola and Davidsons, 2008; De La Cruz and Riker, 2012; Neves, 2012; Hausmann and Hidalgo, 2013; Freitas et al., 2013; Felipe and Hidalgo, 2015).

For example, Hausmann and Klinger (2008) use a similar methodology to identify the potential new products for diversification for Colombia. They identify the potential new products that are close in the product space to existing exports of that country and further identify those that are more sophisticated by using the measure *EXPY* proposed by Hausmann, Hwang and Rodrik (2006). Freitas and Salvado (2008) and Freitas et al. (2013) use the same approach of identifying products with above average sophistication to identify the opportunities for diversification for Portugal. Similarly, Neves (2012) uses that approach to identify the opportunities for diversification in China and India. Anand et al. (2012) found that moving to more sophisticated products can be an important contributor to economic growth. Felipe et al. (2012) argue that the significance of the complexity of the productive structure of a country for its development suggests the need for policies that foster economic diversification through the development of new and more complex products.

However, in the studies mentioned above the use of product space only covers the supply side of the opportunities for diversification. The demand for products is not considered in the analysis. An exception is Hausmann and Hidalgo (2013), who indicate the proportion of global trade for each category of potential new products identified in their analysis. Potential new products for diversification identified only by using the product space may not offer demand incentives for entrepreneurs to take required risks. In the framework proposed in this chapter, in addition to using a measure of product capacity that is not related to income, we add the analysis of the potential demand to account for the incentives faced by entrepreneurs.

The next section revisits the methodology presented in the previous chapter.

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[4] Source: "A comment on: The New Structural Economic, A Rethinking of Development Economics and Policy". Available from http://siteresources.worldbank.org/DEC/Resources/84797-1104785060319/598886-1104852366603/599473-1223731755312/Hausmann_comment_on_Justin_Lin.pdf.

6.4 Methodology for strategic diversification

How could countries identify potential new sectors in their diversification strategies? The answer to this question is the methodology presented in the previous chapter. The questions that we should answer are:

1) If economic institutions that create an environment that foster the emergence of new economic activities are in place, which economic activities are more likely to emerge given the existing set of technologies that comprises the economy?

2) Which of those are associated with more complex sectors?

3) Which of them offer higher export or import replacement opportunities?

As presented in the previous chapter, to address the first question, we use the product space of countries (Hidalgo et al., 2007) and the revised measure of proximity with 80% probability. To address the second question, we apply the method of reflections proposed by Hidalgo and Hausmann (2009) to quantify the set of technologies required to produce each potential new product. To address the third question in terms of exports, we use the index of export opportunity presented in the previous chapter. In terms of imports, we consider the total import of the product as the potential for import replacement.

Once the list of potential new products is identified through that method, the next step is to aggregate the products into industries and classify them by higher export or import replacement opportunities. The assumption is that many of the government related interventions (in terms of regulation, infrastructure, or human capacity building) required to facilitate the emergence of products of a given industry would be similar.

The next section shows the result of the application of that method for the case of the CSN in the Asia-Pacific region.

6.5 Potential sectors for diversification

The opportunities for CSN in Asia-Pacific for diversifying their economies with higher probability are in products that are more complex and that are nearby in the product space to the existing product mix. Based on the analysis of the data to construct these maps, Table 6.2 displays the top five industries of each Asia-Pacific CSN with highest shares in percentages of potential new products. For Afghanistan, the top five industries defined as such are base metals and articles of base metals (18%); textiles and textile articles (18%); plastic and rubber and articles thereof (16%); machinery and electrical equipment (14%);[5] and chemicals (11%).

[5] This includes machinery and mechanical appliances, electrical equipment and parts, sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles.

Table 6.2. Top five industries with highest percentages of potential new products, Asia-Pacific LDCs, 2013 (Percentage of diversification opportunities)

	Base metals	Chemicals	Mach. & elect. Equip.	Plast.& rubber	Textiles	Others
Asia-Pacific least developed countries						
Afghanistan	18	11	14	16	18	24
Bangladesh	22	15	15	17		31
Bhutan	13	16	5		47	19
Cambodia	20	17	12	12	11	28
Kiribati		23	10	20	30	16
Lao PDR	12		12	12	38	26
Myanmar	18	9	12	12	22	27
Nepal	16	12	17	16	15	24
Solomon Islands	13	15	18		35	21
Timor-Leste	13	11	9	17	24	26
Tuvalu	11	11	16	16	32	14
Vanuatu	15	16	12	22	9	25
Selected Asia-Pacific landlocked developing countries						
Armenia	17	15	15	16	15	21
Azerbaijan	16	15	15	16	17	21
Kazakhstan	22	17	14	14	10	23
Kyrgyzstan	22	13	12	12	16	26
Mongolia	19	13	10	12	30	17
Tajikistan	18	6	5	14	39	19
Turkmenistan	17	8		10	40	25
Uzbekistan	19	10	14	15	14	28
Selected Asia-Pacific small island developing States						
American Samoa	19	13	12	16	13	28
Cook Islands	25	9	9	17	17	25
Fiji	16	16	13	13	19	22
French Polynesia	21	13	13	11	31	11
Guam	13		12	12	36	27
Maldives	14	6	8	10	37	25
Marshall Islands	13		22	17	22	26
Micronesia	12	15	8	8	46	12
Nauru		11	11	5	58	16
New Caledonia	14	14	13	13	24	22
Niue	19	16	8	15	20	22
Northern Mariana Islands	27	18	9			45
Palau	20			40	20	20
Papua New Guinea	20	16	14	13	13	24
Samoa	19	10	10	6	39	15

	Base metals	Chemicals	Mach. & elect. Equip.	Plast.& rubber	Textiles	Others
Tonga	22	11	11	33	17	6

Source: Author's computations based on data from UN Comtrade.

Notes: In some countries, other industries show up in the top five. These are: Bangladesh (paper, 7%), Bhutan (paper, 8%), Kiribati (stone, ceramic and glass, 3%), Lao People's Democratic Republic (paper, 7%), Solomon Island (paper , 8%), Turkmenistan (paper, 8%), French Polynesia (paper, 8%), Marshall Islands (optical photo, watches, musical instruments, 9%), Nauru (stone, ceramic and glass, 5%), Northern Mariana Islands (paper, 9% and food and beverages, 9%), Palau (paper, 20%).

Those same five industries compose the top five in almost all Asia-Pacific CSN. The concentration of opportunities within few industries is a common result among these countries, with five industries accounting for 72% or more of the potential new products with a complexity above the country's average. In particular, textiles and textile articles such as apparel accounts for a large share of potential new opportunities in the Federated States of Micronesia (46%), French Polynesia (31%), Bhutan (47%), Lao People's Democratic Republic (38%), Guam (36%), Maldives (37%), Mongolia (30%), Nauru (58%), Samoa (39%), Solomon Islands (35%), Tajikistan (39%), Turkmenistan (40%), and Tuvalu (32%).

The analysis of opportunities for diversification by industry as presented in Table 6.2 sheds some light on the potential target areas for diversification. However, in addition to the identification of promising areas, it is important to identify the factors that could facilitate or prevent the process of discovery of these new economic activities by the business sector.

6.5.1 Export opportunities

We assume that products that are in high demand are more likely to attract entrepreneurs, and that entrepreneurs who take risks in these high-demand sectors are also more likely to succeed. This section presents results of the analysis of potential new sectors for diversification that have both higher product complexity and export opportunity. The analysis considers the increase in global imports of each sector in the period 2012-2013 to calculate the index of export opportunity as presented in section 5.3.

Table 6.3 shows the potential new sectors for diversification with high export opportunities for each LDC in the Asia-Pacific region. For example, in Afghanistan, with over 60% of export opportunities, the top new sectors are plastic and articles of plastic; machinery and mechanical appliances; organic chemicals; paper and paperboard, and articles of pulp, paper and board; and iron and steel. The first two account for over 35% of the new opportunities. In Bhutan, articles of apparel and accessories account for a quarter of the export opportunities. Other sectors with higher potential are iron and steel; organic chemicals; and stone, plaster, cement, asbestos, mica, and similar articles. Machinery and mechanical appliances, plastic and paper sectors also show among the top export opportunities of potential new sectors in Lao People's Democratic Republic. Two new sectors also join the top five: stone and ceramic products and articles of apparel. In Nepal, electrical and electronic equipment makes it into the top five of potential new sectors, with 5%. Other sectors are plastic, machinery, articles or iron and steel and paper. The table shows that the same sectors often appear on top for this group of countries, but the actual products within each product category vary across countries.

Table 6.3. Potential new sectors with large shares of export opportunities, Asia-Pacific LDCs, 2013 (Percentage of total)

Sector	percentage
Afghanistan	
Plastics and articles thereof	21
Machinery & mech. appliance etc.	16
Organic chemicals	8
Iron and steel	8
Paper & paperboard, articles of pulp, paper and board	8
Sum of others with smaller share	39
Bangladesh	
Plastics and articles thereof	17
Machinery & mech. appliance etc.	10
Paper & paperboard, articles of pulp, paper and board	10
Iron and steel	8
Articles of iron or steel	5
Sum of others with smaller share	49
Bhutan	
Articles of apparel, accessories, knit or crochet	14
Iron and steel	14
Articles of apparel, accessories, not knit or crochet	11
Organic chemicals	11
Stone, plaster, cement, asbestos, mica, etc., articles	7
Sum of others with smaller share	44
Cambodia	
Plastics and articles thereof	12
Paper & paperboard, articles of pulp, paper and board	9
Aluminium and articles thereof	7
Machinery & mech. appliance etc.	7
Articles of iron or steel	6
Sum of others with smaller share	59

Sector	percentage
Kiribati	
Plastics and articles thereof	41
Tanning, dyeing extracts, tannins, derivs., pigments etc.	8
Miscellaneous chemical products	7
Optical, photo, technical, medical, etc. apparatus	6
Carpets and other textile floor coverings	6
Sum of others with smaller share	32
Lao People's Democratic Republic	
Machinery & mech. appliance etc.	14
Plastics and articles thereof	13
Paper & paperboard, articles of pulp, paper and board	8
Ceramic products	8
Articles of apparel, accessories, knit or crochet	6
Sum of others with smaller share	52
Myanmar	
Paper & paperboard, articles of pulp, paper and board	14
Plastics and articles thereof	11
Machinery & mech. appliance etc.	9
Iron and steel	6
Aluminium and articles thereof	6
Sum of others with smaller share	54
Nepal	
Plastics and articles thereof	23
Machinery & mech. appliance etc.	10
Electrical, electronic equipment	5
Articles of iron or steel	5
Paper & paperboard, articles of pulp, paper and board	4
Sum of others with smaller share	52
Solomon Islands	
Electrical, electronic equipment	32
Articles of apparel, accessories, knit or crochet	9
Articles of iron or steel	8
Optical, photo, technical, medical, etc. apparatus	8
Paper & paperboard, articles of pulp, paper and board	8
Sum of others with smaller share	35
Timor-Leste	
Machinery & mechanical appliance etc.	22
Mineral fuels, oils, distillation products, etc.	18
Articles of apparel, accessories	15
Electrical, electronic equipment	14
Parts & accessories for motor vehicles	9

Sector	percentage
Sum of others with smaller share	22
Tuvalu	
Plastics and articles thereof	37
Machinery & mech. appliance etc.	15
Articles of apparel, accessories, not knit or crochet	6
Optical, photo, technical, medical, etc apparatus	6
Articles of apparel, accessories, knit or crochet	5
Sum of others with smaller share	30
Vanuatu	
Plastics and articles thereof	33
Paper & paperboard, articles of pulp, paper and board	14
Iron and steel	7
Machinery & mech. appliance etc.	5
Articles of iron or steel	5
Sum of others with smaller share	37

Source: Author's computations, based on data from UN Comtrade.

Table 6.4 lists the potential new sectors for diversification with large shares of export opportunities in selected LLDCs in Asia-Pacific. For example, it shows that the sectors of plastic and articles of plastic, and of machinery and mechanical appliances also offer the highest export opportunities for potential new products in Armenia, the other top sectors are iron and steel; paper and paperboard, and articles of pulp, paper and board; and copper and articles of copper. Similarly, in Azerbaijan, plastic and articles of plastic, and of machinery and mechanical appliances are the top 2 potential new sectors in terms of export opportunities. However, the set of potential sectors is less concentrated and the top five sectors, which include miscellaneous chemical products; impregnated, coated or laminated textile fabric; and rubber and articles of rubber, account for just over 40% of total export opportunities.

Table 6.4. Potential new sectors with large shares of export opportunities, selected Asia-Pacific LLDCs, 2013 (Percentage of total)

Sector	percentage
Armenia	
Plastics and articles thereof	18
Machinery & mech. appliance etc.	16
Iron and steel	7
Copper and articles thereof	5
Paper & paperboard, articles of pulp, paper and board	5
Sum of others with smaller share	49

Sector	percentage
Azerbaijan	
Plastics and articles thereof	17
Machinery & mech. appliance etc.	9
Miscellaneous chemical products	6
Impregnated, coated or laminated textile fabric	5
Rubber and articles thereof	4
Sum of others with smaller share	60
Kazakhstan	
Plastics and articles thereof	16
Machinery & mech. appliance etc.	16
Organic chemicals	10
Iron and steel	10
Paper & paperboard, articles of pulp, paper and board	8
Sum of others with smaller share	41
Kyrgyzstan	
Plastics and articles thereof	16
Iron and steel	11
Machinery & mech. appliance etc.	7
Articles of iron or steel	5
Paper & paperboard, articles of pulp, paper and board	5
Sum of others with smaller share	56
Mongolia	
Organic chemicals	13
Machinery & mech. appliance etc.	9
Cocoa and cocoa preparations	8
Ceramic products	8
Plastics and articles thereof	7
Sum of others with smaller share	55
Tajikistan	
Plastics and articles thereof	32
Articles of apparel, accessories, knit or crochet	10
Articles of iron or steel	9
Iron and steel	7
Articles of apparel, accessories, not knit or crochet	5
Sum of others with smaller share	38
Turkmenistan	
Plastics and articles thereof	18
Iron and steel	10
Articles of apparel, accessories, knit or crochet	8
Ceramic products	8
Paper & paperboard, articles of pulp, paper and board	7

Sector	percentage
Sum of others with smaller share	48
Uzbekistan	
Plastics and articles thereof	20
Organic chemicals	9
Machinery & mech. appliance etc.	6
Rubber and articles thereof	6
Paper & paperboard, articles of pulp, paper and board	6
Sum of others with smaller share	52

Source: Author based on data from UN Comtrade.

The diversification of many of the Asia-Pacific SIDS is hampered by the small population of these countries and, in many cases, they could improve their productive capacities and create jobs by supporting sustainable tourism, fisheries and aquaculture. However, if diversification strategies are considered, the results presented in Table 6.5 could support the identification of potential new products. The table shows that plastics sectors also present large shares of export opportunities for potential new products in Asia-Pacific SIDS: examples are Kiribati (41%), Tonga (60%), Tuvalu (37%), and Vanuatu (33%). Articles of apparel and accessories offer opportunities for diversification with high potential for exports gains in the Maldives (15%), Marshall Islands (28%), Micronesia (Federated States of) (43%), Nauru (35%), and Samoa (27%). As an example, the list of the top 10 export opportunities in Asia-Pacific SIDS is presented in Annex VI.1.

Table 6.5. Potential new sectors with large shares of export opportunities, selected Asia-Pacific SIDS, 2013 (Percentage of total)

Sector	percentage
American Samoa	
Plastics and articles thereof	18
Electrical, electronic equipment	11
Optical, photo, technical, medical, etc apparatus	9
Ceramic products	7
Paper & paperboard, articles of pulp, paper and board	4
Sum of others with smaller share	51
Cook Islands	
Plastics and articles thereof	26
Dairy products, eggs, honey, edible animal product nes	9
Miscellaneous chemical products	8
Articles of apparel, accessories, knit or crochet	6
Optical, photo, technical, medical, etc apparatus	6
Sum of others with smaller share	45

Sector	percentage
Fiji	
Plastics and articles thereof	17
Machinery & mech. appliance etc.	8
Paper & paperboard, articles of pulp, paper and board	6
Aluminium and articles thereof	5
Miscellaneous chemical products	4
Sum of others with smaller share	59
French Polynesia	
Machinery & mech. appliance etc.	17
Plastics and articles thereof	16
Impregnated, coated or laminated textile fabric	8
Miscellaneous chemical products	6
Articles of iron or steel	6
Sum of others with smaller share	46
Guam	
Electrical, electronic equipment	20
Ceramic products	14
Plastics and articles thereof	14
Articles of apparel, accessories, knit or crochet	10
Cereal, flour, starch, milk preparations and products	10
Sum of others with smaller share	32
Maldives	
Plastics and articles thereof	15
Machinery & mech. appliance etc.	14
Articles of apparel, accessories, knit or crochet	9
Articles of apparel, accessories, not knit or crochet	6
Paper & paperboard, articles of pulp, paper and board	5
Sum of others with smaller share	51
Marshall Islands	
Electrical, electronic equipment	35
Machinery & mech. appliance etc.	24
Articles of apparel, accessories, not knit or crochet	22
Articles of apparel, accessories, knit or crochet	6
Plastics and articles thereof	6
Sum of others with smaller share	7
Micronesia (Federated States of)	
Iron and steel	28
Articles of apparel, accessories, not knit or crochet	27
Articles of apparel, accessories, knit or crochet	16
Essential oils, perfumes, cosmetics, toileteries	8
Machinery & mech. appliance etc.	5

Sector	percentage
Sum of others with smaller share	16
Nauru	
Footwear, gaiters and the like, parts thereof	25
Articles of apparel, accessories, knit or crochet	23
Articles of apparel, accessories, not knit or crochet	12
Plastics and articles thereof	9
Optical, photo, technical, medical, etc. apparatus	7
Sum of others with smaller share	24
New Caledonia	
Electrical, electronic equipment	19
Plastics and articles thereof	17
Machinery & mech. appliance etc.	12
Paper & paperboard, articles of pulp, paper and board	5
Articles of iron or steel	5
Sum of others with smaller share	42
Niue	
Plastics and articles thereof	23
Machinery & mech. appliance etc.	12
Paper & paperboard, articles of pulp, paper and board	8
Inorganic chemicals, precious metal compound, isotopes	7
Glass and glassware	6
Sum of others with smaller share	43
Northern Mariana Islands	
Tanning, dyeing extracts, tannins, derivs., pigments etc.	30
Machinery & mech. appliance etc.	18
Miscellaneous edible preparations	18
Tin and articles thereof	7
Iron and steel	5
Sum of others with smaller share	22
Palau	
Iron and steel	56
Paper & paperboard, articles of pulp, paper and board	23
Plastics and articles thereof	17
Impregnated, coated or laminated textile fabric	4
Papua New Guinea	
Machinery & mech. appliance etc.	13
Plastics and articles thereof	12
Miscellaneous chemical products	11
Paper & paperboard, articles of pulp, paper and board	9
Iron and steel	5
Sum of others with smaller share	50

Sector	percentage
Samoa	
Articles of apparel, accessories, not knit or crochet	19
Electrical, electronic equipment	15
Plastics and articles thereof	13
Footwear, gaiters and the like, parts thereof	9
Articles of apparel, accessories, knit or crochet	8
Sum of others with smaller share	36
Tonga	
Plastics and articles thereof	60
Cereal, flour, starch, milk preparations and products	6
Iron and steel	6
Machinery & mech. appliance etc.	6
Electrical, electronic equipment	4
Sum of others with smaller share	18

Source: Author's computations based on data from UN Comtrade.

The top export markets for the potential new products of the Asia-Pacific CSN are presented in Table 6.6. The result suggests that trade links with the markets in Europe and North America remains very important. However, the Asia-Pacific region itself also offers about a quarter of the export opportunities for these potential new sectors. Therefore, intraregional integration and cooperation in Asia-Pacific is critical for fostering diversification in the Asia-Pacific CSN.

Table 6.6. Top global export markets for potential new products of Asia-Pacific CSN, 2013 (percentage)

	Export market					
Exporter	**Europe**	**Asia-Pacific**	**North America**	**West Asia**	**Latin America**	**Others**
Asia-Pacific least developed countries						
Afghanistan	50	25	11	6	5	1
Bangladesh	48	24	14	6	4	1
Bhutan	34	23	24	8	4	5
Cambodia	48	23	16	4	4	1
Kiribati	54	27	7	3	4	1
Lao PDR	45	26	19	3	2	0
Myanmar	48	25	15	4	4	1
Nepal	45	26	15	5	3	1
Solomon Islands	39	21	28	6	5	0
Timor-Leste	59	13	18	2	4	2
Tuvalu	41	30	14	3	6	2
Vanuatu	43	28	14	5	7	1
Selected Asia-Pacific landlocked developing countries						
Armenia	45	28	13	5	3	1

Exporter	Export market Europe	Asia-Pacific	North America	West Asia	Latin America	Others
Azerbaijan	46	24	17	3	3	1
Kazakhstan	46	28	13	4	5	1
Kyrgyzstan	43	24	18	5	3	1
Mongolia	51	22	16	3	3	1
Tajikistan	45	27	11	7	4	1
Turkmenistan	43	27	12	7	6	2
Uzbekistan	49	22	20	2	4	1
Selected Asia-Pacific small island developing States						
American Samoa	44	21	21	3	6	1
Cook Islands	42	28	17	3	5	2
Fiji	43	29	15	3	4	1
French Polynesia	44	27	20	1	3	0
Guam	50	31	11	2	1	1
Maldives	45	29	16	2	2	1
Marshall Islands	57	36	2	3	1	1
Micronesia	40	42	4	5	1	4
Nauru	54	29	11	1	1	1
New Caledonia	45	29	15	6	3	0
Niue	45	29	13	3	2	2
Northern Mariana Islands	38	33	17	8	2	1
Palau	50	29	1	3	0	8
Papua New Guinea	48	27	11	4	4	1
Samoa	42	28	16	6	4	1
Tonga	52	25	8	5	4	2

Source: Author's computations based on data from UN Comtrade.

6.5.2 Import replacement opportunities

In addition to export opportunities, the potential for import replacement of new products may also drive the investment decision of entrepreneurs and firms. This effect is more important in more populous countries, such as Bangladesh and Kazakhstan, but would not be an option for the majority of Asia-Pacific SIDS given the small size of their population and economy.

Table 6.7 presents the top five potential new sectors with higher than $500 thousand import replacement opportunities. The list by country is very heterogeneous. Some sectors have remarkable large shares such as manmade filaments in Afghanistan (86%); furniture, lighting, signs, prefabricated buildings in Bhutan (100%); aluminium and articles thereof in Cambodia (77%), cocoa and cocoa preparations in Mongolia (63%); miscellaneous edible preparations in Northern Mariana Islands (96%), articles of iron or steel in Solomon Islands (46%), and articles of apparel, accessories, knit or crochet in Tajikistan (90%). Other sectors that are part of the top five import replacement opportunities in many countries are plastic, paper, iron and steel and machinery and mechanical appliances.[6]

Table 6.7. Potential new sectors for diversification with large shares of import replacement opportunities, Asia-Pacific CSN, 2013

Sector	percentage
Selected Asia-Pacific LDCs	
Afghanistan	
Manmade filaments	86
Plastics and articles thereof	4
Paper & paperboard, articles of pulp, paper and board	2
Photographic or cinematographic goods	2
Soaps, lubricants, waxes, candles, modelling pastes	2
Sum of others with smaller share	4
Bangladesh	
Plastics and articles thereof	16
Miscellaneous chemical products	16
Machinery & mech. appliance etc.	8
Tanning, dyeing extracts, tannins, derivs., pigments etc.	7
Iron and steel	7
Sum of others with smaller share	46
Cambodia	
Aluminium and articles thereof	77
Iron and steel	7
Machinery & mech. appliance etc.	4
Articles of iron or steel	3
Paper & paperboard, articles of pulp, paper and board	3
Sum of others with smaller share	6
Lao People's Democratic Republic	
Iron and steel	31
Rubber and articles thereof	29
Aluminium and articles thereof	6
Articles of apparel, accessories, knit or crochet	5
Special woven or tufted fabric, lace, tapestry etc.	4

[6] The list of potential new sectors for diversification with large shares of import replacement opportunities is more concentrated than the list related to export opportunities. The reason is because the set of possible new products is smaller than in the case of exports, given that it considers only the products that the country imports but does not export. The list of possible new products is further reduced by the cut-off applied ($500 thousand).

Sector	percentage
Sum of others with smaller share	24
Myanmar	
Aluminium and articles thereof	12
Plastics and articles thereof	12
Electrical, electronic equipment	9
Miscellaneous manufactured articles	9
Impregnated, coated or laminated textile fabric	6
Sum of others with smaller share	52
Nepal	
Paper & paperboard, articles of pulp, paper and board	32
Inorganic chemicals, precious metal compound, isotopes	17
Photographic or cinematographic goods	5
Machinery & mech. appliance etc.	4
Optical, photo, technical, medical, etc. apparatus	4
Sum of others with smaller share	37
Solomon Islands	
Articles of iron or steel	46
Soaps, lubricants, waxes, candles, modelling pastes	36
Tanning, dyeing extracts, tannins, derivs., pigments etc.	7
Electrical, electronic equipment	6
Articles of apparel, accessories, not knit or crochet	2
Sum of others with smaller share	3
Selected Asia-Pacific LLDCs	
Armenia	
Cocoa and cocoa preparations	22
Iron and steel	14
Plastics and articles thereof	12
Paper & paperboard, articles of pulp, paper and board	8
Machinery & mech. appliance etc.	6
Sum of others with smaller share	39
Azerbaijan	
Articles of iron or steel	32
Machinery & mech. appliance etc.	25
Iron and steel	13
Paper & paperboard, articles of pulp, paper and board	7
Plastics and articles thereof	7
Sum of others with smaller share	16
Kazakhstan	
Machinery & mech. appliance etc.	21
Plastics and articles thereof	17
Iron and steel	10

Sector	percentage
Paper & paperboard, articles of pulp, paper and board	8
Articles of iron or steel	6
Sum of others with smaller share	39
Kyrgyzstan	
Cocoa and cocoa preparations	23
Iron and steel	14
Articles of iron or steel	14
Paper & paperboard, articles of pulp, paper and board	10
Plastics and articles thereof	9
Sum of others with smaller share	30
Mongolia	
Cocoa and cocoa preparations	63
Wood and articles of wood, wood charcoal	8
Articles of apparel, accessories, knit or crochet	5
Plastics and articles thereof	5
Rubber and articles thereof	4
Sum of others with smaller share	15
Tajikistan	
Articles of apparel, accessories, knit or crochet	90
Other made textile articles, sets, worn clothing etc.	3
Iron and steel	2
Plastics and articles thereof	2
Glass and glassware	1
Sum of others with smaller share	4
Turkmenistan	
Machinery & mech. appliance etc.	38
Articles of iron or steel	27
Plastics and articles thereof	8
Iron and steel	4
Electrical, electronic equipment	4
Sum of others with smaller share	19
Uzbekistan	
Plastics and articles thereof	19
Paper & paperboard, articles of pulp, paper and board	18
Iron and steel	17
Rubber and articles thereof	12
Machinery & mech. appliance etc.	7
Sum of others with smaller share	27
Selected Asia-Pacific SIDS	
French Polynesia	
Articles of iron or steel	26

Sector	percentage
Cereal, flour, starch, milk preparations and products	11
Paper & paperboard, articles of pulp, paper and board	9
Miscellaneous chemical products	8
Tools, implements, cutlery, etc. of base metal	6
Sum of others with smaller share	40
Maldives	
Cereal, flour, starch, milk preparations and products	23
Plastics and articles thereof	16
Articles of apparel, accessories, knit or crochet	11
Other made textile articles, sets, worn clothing etc.	8
Vegetable, fruit, nut, etc. food preparations	5
Sum of others with smaller share	37
New Caledonia	
Miscellaneous edible preparations	98
Aluminium and articles thereof	2
Papua New Guinea	
Cereal, flour, starch, milk preparations and products	27
Machinery & mech. appliance etc.	24
Aluminium and articles thereof	8
Plastics and articles thereof	6
Tools, implements, cutlery, etc. of base metal	6
Sum of others with smaller share	29
Samoa	
Electrical, electronic equipment	29
Iron and steel	26
Articles of apparel, accessories, not knit or crochet	15
Paper & paperboard, articles of pulp, paper and board	7
Tanning, dyeing extracts, tannins, derivs., pigments etc.	6
Sum of others with smaller share	17

Source: Author's computations based on data from COMTRADE.

Note: Potential new sectors with higher than $500 thousand of import replacement opportunity.

6.6 Identification of new export opportunities in agro-industries with links to existing agricultural produce

This section presents the application of the methodology to identify opportunities for diversification in the case of the group of least developed countries in Asia-Pacific focusing on agriculture and agro-industries. These countries face severe structural impediments to growth and sustainable development. Given that the majorities of their populations make a living from agriculture, the development of that sector is a key priority of action for their inclusive and sustainable development.

This section identifies possibilities for diversification in agro-industries that have links with existing agricultural production. For example, diversification towards the sector of meat food preparations may benefit from a domestic production of meat; similarly the agro-industry of cereal, flour, starch and milk products could use cereal and milk from the domestic agricultural production.[7] Such an approach echoes the unbalanced growth strategies of economic development with the promotion of backward linkages of the 1950s: investment in agro-industries creates demand and encourages investment in the production of the required agricultural inputs.[8] The strategy focuses on developing the manufacturing and services sectors without neglecting agriculture, which will be the beneficiary of the investment through backward linkages.[9]

The application of this methodology suggests clusters that have the highest export opportunity potential for new products in the South Asian LDCs (Table 6.8). In the case of Afghanistan, the potential new agro-industries that are particularly promising are meat food preparations and cereal, flour, starch, milk preparations, given the composition of existing agricultural production with large shares in meat, cereals and milk. In Bangladesh, the agro-industries of meat, fish and vegetable preparations present the large shares in total export opportunities and linkages with existing agricultural production. Cereals, and paddy rice in particular, account for the largest share of agricultural production in value but the associate agro-industry offers less export opportunity than those mentioned above.

In the case of Bhutan, the agro-industries related to cereal, flour, starch, milk preparations and meat food preparations present the higher export opportunities and backward linkages with existing agricultural production, particularly if they exploit the niche markets for chilli seasoned food. In Nepal, the potential new agro-industries with higher share in the total export opportunities are related to animal

[7] In this analysis, the identification of linkages between agro-industries and agricultural production is carried out at such a general level. Further research could consider using input-output data to identify all possible backward linkages.

[8] The unbalanced growth doctrine argues that economic development requires unbalanced sectoral growth. Albert O. Hirschman (1958) formulated the theory behind that economic development approach and introduced the concepts of backward and forward linkages.

[9] For example, ESCAP (1969) noted the supporting role played by agro-industries in several countries that had increased their efforts in agriculture. These agro-industries used the agricultural commodities as inputs or provided inputs for farm production.

feeding preparations, meat and vegetable food, and cereal, flour, starch, milk preparations.

Table 6.8. Potential new agro-industries with higher export opportunities and linkages with existing agricultural production, South Asian LDCs

Existing agricultural production	Percentage of production	Potential new agro-industry	Percentage of total export opportunities
Afghanistan			
Meat (cattle, sheep, goat)	37	Meat food preparations nes.	23
Cereals (wheat, rice, barley)	19	Cereal, flour, starch, milk products	15
Milk (cattle, sheep, goat)	14	Prep. used in animal feeding	13
Fruits and nuts	21	Vegetable food preparations	8
Vegetables	3	Flour, meal etc., not for human	7
Others	4	Others	34
Bangladesh			
Cereals (rice, maize, wheat)	78	Meat food preparations nes.	32
Aquaculture	7	Fish and seafood food preparations	13
Vegetables	4	Vegetable food preparations	13
Fruits and nuts	3	Sugars and sugar confectionery	9
Milk (goat, cattle, chicken)	3	Cereal, flour, starch, milk products	8
Meat (cattle, goat)	2	Others	24
Others	2		
Bhutan			
Fruits & Nuts	32	Cereal, flour, starch, milk products	50
Cereals (rice, maize, millet)	22	Meat food preparations nes.	24
Chillies and spices	13	Fruit, nut food preparations	7
Meat (cattle, pig)	10	Vegetable food preparations	7
Vegetables	8	Extracts etc of coffee, tea or mate	6
Milk (cow)	8	Others	6
Others	6		
Nepal			
Cereals (rice, maize, wheat)	37	Prep. used in animal feeding	22
Vegetables	20	Meat food preparations nes.	21
Meat (cattle, goat, chicken)	14	Vegetable food preparations	17
Milk (buffalo, cow)	12	Cereal, flour, starch, milk products	10
Fruits and nuts	10	Fish food preparations nes.	10
Aquaculture	1	Others	20
Others	6		

Source: Author's computations, based on Freire (2013b, 2014) and data from UN Comtrade, FAO STATs Food and Agricultural commodities production and FAO Fishery and Aquaculture Global Statistics (accessed 19 February 2014).

Notes: Agricultural products show the percentage of production in value among the 20 most important food and agricultural commodities for each country in 2012. Data on fisheries and aquaculture refer to 2011.

Table 6.9 shows the result of the analysis for the LDCs in South-East Asia. It suggests that the potential new agro-industries in Cambodia with higher potential export opportunities are preparations of cereal, flour, starch and milk, preparations used in animal feeding, meat and vegetable food preparations. In Lao People's Democratic Republic, the top three potential new agro-industries that link with the existing production are related to beverages, meat food preparations and cereal, flour, starch, milk preparations. The top two potential new agro-industries with over half of the export opportunities for Myanmar are cereal, flour, starch, milk preparations, and meat food preparations. Timor-Leste differs from the other South East Asian LDCs because it shares many of the structural challenges of LDCs of the Pacific in terms of remoteness. The country is also going through a process of nation building, including infrastructure and institutions, and it has very little productive capacities, even when compared with the levels of other LDCs (see Annex VI.2 for in depth discussion of the opportunities for diversification in Timor-Leste, as an example of the analysis of this chapter applied to a single country). The analysis for that country suggests that the top two potential new agro-industries with higher shares of export possibilities are beverages and cereal, flour, starch, milk preparations.

The case for an integrated strategy for agricultural development is perhaps even stronger in the LDCs of the Pacific. The main employment opportunities offering higher wages are in services, particularly tourism, which is not able to absorb the surplus labour of agricultural subsistence workers. The alternative for many is to work abroad and to send back remittances. The promotion of viable agro-based processing activities providing local food to tourism sector could create productive jobs out of subsistence agriculture and increase demand for existing agricultural products, including fisheries, and may have a great impact in reducing rural-urban disparities in these island states.

The result of the analysis of potential new agro-industries applied to the Pacific LDCs is shown in Table 6.10. In Kiribati, subsistence farming grows food crops like bananas, breadfruit, and papaya, and agro-industries in vegetable, fruits and nuts food preparations could facilitate the transition from subsistence to market-oriented agricultural production. The Solomon Islands have a larger population (over 500 million) that can support a more diversified economy. The top five potential new agro-industries with higher share of total export opportunities are cocoa preparations, flour and starch products, fish food preparations, fruit juices and vegetable food preparations.

Table 6.9. Potential new agro-industries with higher export opportunities and linkages with existing agricultural production, South-East Asian LDCs

Existing agricultural production	Percentage of production	Potential new agro-industry	Percentage of total export opportunities
Cambodia			
Rice, maize and soybeans	61	Cereal, flour, starch, milk products	17
Cassava	18	preparations used in animal feeding	17
Meat (cattle, pig, chicken, duck)	9	Meat food preparations nes.	15
Vegetables	4	Vegetable food preparations	14
Aquaculture	3	Fish and seafood food preparations	11
Fruits and nuts	3	Others	26
Others	3		
Lao People's Democratic Republic			
Cereals (rice, maize)	48	Beverages, spirits and vinegar	18
Meat (pig, cattle, buffalo, chicken)	12	Meat food preparations nes.	17
Fruits & Nuts	9	Cereal, flour, starch, milk products	15
Vegetables	9	Vegetable food preparations	13
Aquaculture	6	Fish and seafood food preparations nes.	7
Cassava	5	Others	30
Coffee	5		
Sugar cane	1		
Others	5		
Myanmar			
Cereals (rice)	40	Cereal, flour, starch, milk products	29
Meat (chicken, pig, cattle, duck)	19	Meat food preparations nes.	23
Vegetables	16	Vegetable food preparations	9
Fruits and nuts	7	fruit juices and veg. juice, no spirit	9
Aquaculture	6	Beverages, spirits and vinegar	7
Milk	2	Others	23
Sugar cane	2		
Others	7		
Timor-Leste			
Meat (pig, cattle, chicken, goat)	37	Beverages, spirits and vinegar	22
Cereals (rice, maize)	31	Cereal, flour, starch, milk products	16
Vegetables	9	Miscellaneous edible preparations	12
Coffee	7	Wastes of food industry, animal fodder	10
Fruits and nuts	7	Cocoa and cocoa preparations	8

Existing agricultural production	Percentage of production	Potential new agro-industry	Percentage of total export opportunities
Cassava	2	Others	32
Others	6		

Source: ESCAP, based on Freire (2013b, 2014) and data from UN Comtrade, FAO STATs Food and Agricultural commodities production and FAO Fishery and Aquaculture Global Statistics (accessed 19 February 2014).

Notes: Agricultural products show the percentage of production value in the 20 most important food and agricultural commodities for each country in 2012. Data on fisheries and aquaculture refer to 2011.

Table 6.10. Potential new agro-industries with higher export opportunities and linkages with existing agricultural production, Pacific LDCs

Existing agricultural production	Percentage of production	Potential new agro-industry	Percentage of total export opportunities
Kiribati			
Coconuts	67	Cereal, flour, starch, milk products	38
Fruits & Nuts	10	Vegetable food preparations	26
Meat (pig, chicken)	9	Fruit juices and veg. juice, no spirit	11
Roots and tubers	5	Meat food preparations nes.	8
Vegetables	4	Sauces, mixed condiments, etc.	6
Aquaculture	2	Others	11
Others	2		
Solomon Islands			
Coconuts	33	Cocoa and cocoa preparations	26
Roots and tubers	20	Flour, starch preparations and products	23
Palm oil	14	Fish and seafood food preparations nes.	10
Fruits & Nuts	13	Fruit juices and veg. juice, no spirit	8
Vegetables	5	Vegetable food preparations	6
Meat (pig, cattle, chicken)	4	Others	27
Others	6		
Tuvalu			
Coconuts	26	Flour, starch preparations and products	32
Fruits & Nuts	28	Sugars and sugar confectionery	25
Meat (pig, chicken)	28	preparations used in animal feeding	18
Vegetables	12	Fruit juices and veg. juice, no spirit	6
Roots and tubers	3	Fruit, nut food preparations	4

Existing agricultural production	Percentage of production	Potential new agro-industry	Percentage of total export opportunities
Others	4	Others	15
Vanuatu			
Coconuts	54	Flour, starch, milk products	37
Meat (cattle, pig, chicken)	18	Meat food preparations nes.	25
Roots & tubers	10	Beverages, spirits and vinegar	10
Fruits & Nuts	9	Vegetable food preparations	7
Vegetables	3	Sauces, mixed condiments, etc.	4
Cocoa beans	2	Others	16
Aquaculture	1		
Others	3		

Source: ESCAP based on Freire (2013b, 2014) and data from UN Comtrade, FAO STATs Food and Agricultural commodities production and FAO Fishery and Aquaculture Global Statistics (accessed 19 February 2014).

Notes: Agricultural products show the percentage of production value in the 20 most important food and agricultural commodities for each country in 2012. Data on fisheries and aquaculture refer to 2011.

Tuvalu, on the other hand, faces a particular challenge in terms of its small population (11,000 people). With such a small number, it becomes very difficult to build productive capacities. Its main sources of foreign exchange come from fishing license fees paid by foreign fishing fleets, the lease of the ".tv" internet domain name, remittances, ODA and income received from the Tuvalu Trust Fund (TTF), which was established in 1987 (DESA, 2012). The result of the analysis shows that new agro-industries in flour, starch preparations and products, and sugars and sugar confectionery present higher opportunities and backward linkages with the few existing production. Vanuatu has a more diversified economy, including meat production and exports. The top potential new agro-industries resulting from the analysis reflect that fact: meat food preparations and flour, starch, milk products.

6.7 Summary

This chapter focuses on the countries with special needs in Asia-Pacific and uses the methodology presented in the previous chapter to identify the appropriate sectors and products to target based on country's endowment structure and level of development. The chapter follows several studies that have used the product space to analyse the possibilities for export diversification of countries. The chapter also presents a list of potential new sectors for diversification in agro-industries that have links with existing agricultural production in Asia-Pacific LDCs. A novelty presented is the consideration of the demand for products to estimate the export opportunities of potential new products. The analysis presented in this chapter can be used in the process of identification of strategic direction of diversification. Information similar to the list of potential new sectors presented could serve as a public good that could be made available to the private sector. It reduces the cost of discovery of potential successful new economic activities by informing entrepreneurs of the new products that require productive capacities similar to those already available in the country. Annex VI.2 illustrates use of the methodology to identify possible new sectors for diversification considering the case of Timor-Leste.

The next chapter will shift the discussion to the theoretical consideration of the explanation of the stylized facts related to diversification that have guided the analysis in this and in the previous chapters.

Annex

VI.1. Examples of potential products for diversification of SIDS in Asia-Pacific

Table 6.11. List of top 10 export opportunities of SIDS in Asia-Pacific

(HS classification) Description, price range
American Samoa
(390110) Polyethylene having a sp.gr. of <0.94, in primary forms, $0-1
(853931) Electric discharge lamps (excl. ultra-violet lamps), fluorescent..., $0-1
(691010) Ceramic sinks, wash basins, wash basin pedestals, baths, clos ..., $43-43
(390319) Polystyrene other than expansible, in primary forms, $1-2
(901910) Mechano-therapy appls.; massage app.; psychological app., $12-47
(903120) Test benches, $869-17449
(180632) Chocolate & oth. food preps. cont. cocoa, in blocks, $0-4
(950440) Playing cards, $1-1
(481151) Paper & paperboard, coated/impregnated/covered..., $1-9
(441119) Fibreboard of wood/oth. ligneous mats., whether or not ..., $0-1
Cook Islands
(390110) Polyethylene having a sp.gr. of <0.94, in primary forms, $0-1
(040690) Cheese (excl. of 0406.10-0406.40), $0-3
(381121) Additives for lubricating oils cont. petroleum oils/oils ..., $3-6
(390720) Polyethers other than polyacetals, in primary forms, $2-4
(390799) Polyesters (excl. of 3907.10-3907.91), in primary forms, $2-6
(380830) Herbicides, anti-sprouting prods. & plant-growth regulators..., $4-17
(281512) Sodium hydroxide (caustic soda), in aqueous solution ..., $0-4
(903120) Test benches, $869-17449
(700319) Cast glass & rolled glass, in non-wired sheets, whether or not..., $7-15
(392010) Plates, sheets, film, foil & strip, of polymers of ethylene,..., $5-11
Fiji
(760612) Plates, sheets & strip, rect. (incl. square), of a thkns. >0.2mm..., $0-3

(390319) Polystyrene other than expansible, in primary forms, $1-2

(700600) Glass of 70.03/70.04/70.05, bent/edge-wkd./engraved/..., $1-22

(390390) Polymers of styrene, in primary forms (excl. of 3903.11-3903.30), $1-3

(590320) Textile fabrics impregnated/coated/covered/laminated with..., $10-28

(390799) Polyesters (excl. of 3907.10-3907.91), in primary forms, $2-6

(180632) Chocolate & oth. food preps. cont. cocoa, in blocks/slabs/bars..., $4-10

(390690) Acrylic polymers other than poly(methyl methacrylate), in $0-2

(380830) Herbicides, anti-sprouting prods. & plant-growth regulators,..., $4-17

(281512) Sodium hydroxide (caustic soda), in aqueous solution..., $0-4

French Polynesia

(848071) Moulds for rubber/plastics, injection/compression types, $15-70

(390720) Polyethers other than polyacetals, in primary forms, $2-4

(590320) Textile fabrics impregnated/coated/covered/laminated with $10-28

(380830) Herbicides, anti-sprouting prods. & plant-growth regulators, $4-17

(821192) Knives having fixed blades (excl. table knives & knives ..., $3-3

(730630) Tubes, pipes & hollow profiles (excl. of 7306.10 & 7306.20..., $1-4

(390950) Polyurethanes, in primary forms, $3-6

(760720) Aluminium foil, whether or not printed, backed with..., $4-11

(900290) Lenses, prisms, mirrors & oth.optical elements, of any mat..., $474-1069

(320417) Pigments & preps. based thereon, $6-17

Guam

(850980) Electro-mech. dom. appls., with self-contained elec. 1 ..., $21-212

(691010) Ceramic sinks, wash basins, wash basin pedestals, baths..., $43-43

(190110) Preparations for infant use, put up for RS, $4-9

(390390) Polymers of styrene, in primary forms (excl. of 3903.11-3903.30), $1-3

(901910) Mechano-therapy appls.; massage app.; psychological., $12-47

(392020) Plates, sheets, film, foil & strip, of polymers of propylene..., $0-2

(611012) Jerseys, pullovers, cardigans, waist-coats & sim. arts..., $42-113

(690919) Ceramic wares for laboratory/chemical/oth. technical…, $6-90

(481159) Paper & paperboard, coated/impregnated/covered with plastics

..., $0-2

(190410) Prepared foods obt. by the swelling/roasting of cereals/., $2-4

Maldives

(848071) Moulds for rubber/plastics, injection/compression types, $0-15

(848071) Moulds for rubber/plastics, injection/compression types, $15-70

(390319) Polystyrene other than expansible, in primary forms, $1-2

(721070) Flat-rolled prods. of iron/non-alloy steel, of a width of 600mm..., $1-1

(330420) Eye make-up preps., $16-71

(180632) Chocolate & oth. food preps. cont. cocoa, in blocks/slabs/bars $4-10

(392020) Plates, sheets, film, foil & strip, of polymers of propylene…$0-2

(640520) Footwear with uppers of textile mats., n.e.s., $4-12

(730660) Tubes, pipes & hollow profiles (excl. of 7306.10-7306.50)..., $0-2

(392062) Plates, sheets, film, foil & strip, of poly(ethylene..., $2-9

Marshall Islands

(850980) Electro-mech. dom. appls., with self-contained elec. motor..., $21-212

(847950) Industrial robots, n.e.s. in Ch.84, $20109-35428

(620213) Women's/girls' overcoats, raincoats, car-coats, capes..., $34-82

(610230) Women's/girls' overcoats, car-coats, capes, cloaks, anoraks..., $15-33

(853932) Electric discharge lamps (excl. ultra-violet lamps)..., $11-25

(390791) Polyesters (excl. of 3907.10-3907.60), unsaturated…$2-5

(390791) Polyesters (excl. of 3907.10-3907.60), unsaturated…. $0-2

(630140) Blankets (excl. elec.) & travelling rugs, of synth. fibres, $5-14

(701959) Woven fabrics of glass fibres (excl. of 7019.40), n.e.s. in 70.19, $4-21

(730441) Tubes, pipes & hollow profiles (excl. of 7304.10-7304.39)..., $25-51

Micronesia (Federated States of)

(721391) Bars & rods, hot-rolled, in irregularly wound coils, of..., $0-0

(610712) Men's/boys' underpants & briefs, knitted or crocheted… $4-10

(620192) Men's/boys', anoraks (incl. ski-jackets), wind-cheaters..., $25-56

(330510) Shampoos, $0-2

(620312) Men's/boys' suits (excl. knitted or crocheted), of synth. fibres, $31-74

(610433) Women's/girls' jackets & blazers, knitted or crocheted …. $14-40

(840490) Parts of the auxiliary plant of 8404.10 & 8404.20, $9-78

(620113) Men's/boys overcoats, raincoats, car coats, capes..., $0-30

(391710) Artificial guts (sausage casings) of hardened protein/… $9-24

(821000) Hand-operated mech. appls., weighing 10kg/less, used in the..., $0-5

Nauru

(640291) Footwear (excl. waterproof) with outer soles & uppers of ..., $15-29

(392020) Plates, sheets, film, foil & strip, of polymers of propylene..., $0-2

(902710) Gas/smoke analysis app., $0-83

(610220) Women's/girls' overcoats, car-coats, capes, cloaks, anoraks..., $12-27

(340600) Candles, tapers and the like, $0-2

(611593) Hosiery, knitted or crocheted, of synth. …$14-42

(846610) Tool holders & self-opening dieheads suit. for use solely ..., $23-117

(611511) Panty hose & tights, knitted or crocheted, of synth...., $17-49

(851210) Lighting/visual signalling equip. of a kind used on bicycles, $4-4

(620431) Women's/girls' jackets & blazers (excl. knitted or crocheted) ..., $52-128

New Caledonia

(850980) Electro-mech. dom. appls., with self-contained elec. motor..., $21-212

(847950) Industrial robots, n.e.s. in Ch.84, $20109-35428

(853931) Electric discharge lamps (excl. ultra-violet lamps), fluorescent..., $0-1

(390720) Polyethers other than polyacetals, in primary forms, $2-4

(390390) Polymers of styrene, in primary forms (excl. of 3903.11-3903.30), $1-3

(390799) Polyesters (excl. of 3907.10-3907.91), in primary forms, $2-6

(730439) Tubes, pipes & hollow profiles (excl. of 7304.10-7304.31)..., $1-5

(901910) Mechano-therapy appls.; massage app.; psychological., $12-47

(721933) Flat-rolled prods. of stainless steel, of a width of 600mm/more..., $0-2

(611012) Jerseys, pullovers, cardigans, waist-coats & sim. arts..., $42-113

Niue

(390319) Polystyrene other than expansible, in primary forms, $1-2

(845811) Horizontal lathes (incl. turning centres) for removing metal

$23181-97436

(390390) Polymers of styrene, in primary forms (excl. of 3903.11-3903.30), $1-3

(280920) Phosphoric acid & polyphosphoric acids, whether or not… $0-4

(480255) Paper & paperboard, not cont. fibres obt. by a mech...., $0-2

(701939) Webs, mattresses, boards & sim. nonwoven prods. of glass fibres, $2-11

(292429) Cyclic amides (incl. cyclic carbamates) & their derivs. $9-73

(340213) Non-ionic surface-active agents, whether or not PURS, $0-2

(190410) Prepared foods obt. by the swelling/roasting of …$2-4

(848071) Moulds for rubber/plastics, injection/compression types, $70-152

Northern Mariana Islands

(320619) Pigments & preps. based on titanium dioxide other than..., $0-2

(210112) Preparations with a basis of extracts/essences/concs...., $3-12

(841620) Furnace burners other than those for liquid fuel, incl...., $13-52

(800700) Articles of tin n.e.s. in Ch.80, $6-31

(721699) Angles, shapes & sections of iron/non-alloy steel, n.e.s. in 72.16, $1-4

(340530) Polishes & sim. preps. for coachwork (excl. metal polishes), $3-9

(252020) Plasters (consisting of calcined gypsum/calcium sulphate)..., $0-1

(482290) Bobbins, spools, cops & sim. supports of paper pulp/paper/ ..., $1-5

(621040) Men's/boys' garments made up of fabrics of ….$68-141

(910521) Wall clocks, electrically operated, $0-5

Palau

(721070) Flat-rolled prods. of iron/non-alloy steel, of a width of..., $1-1

(481151) Paper & paperboard, coated/impregnated/covered with plastics..., $1-9

(392111) Plates, sheets, film, foil & strip, cellular, of polymers of styrene, $2-9

(392340) Spools, cops, bobbins & sim. supports, of plastics, $3-11

(591110) Textile fabrics, felt & felt-lined woven fabrics,..., $10-50

Papua New Guinea

(381512) Supported catalysts, with precious metal/precious metal..., $33-166

(390319) Polystyrene other than expansible, in primary forms, $1-2

(903120) Test benches, $869-17449

(481159) Paper & paperboard, coated/impregnated/covered with..., $2-5

(843311) Mowers for lawns/parks/sports-grounds, powered, with the..., $121-822

(730640) Tubes, pipes & hollow profiles (excl. of 7306.10-7306.30..., $3-13

(481151) Paper & paperboard, coated/impregnated/covered with..., $1-9

(441119) Fibreboard of wood/oth. ligneous mats., whether or not …$0-1

(840410) Auxiliary plant for use with boilers of 84.02/84.03 (e.g.,..., $8-39

(821210) Razors (excl. plastic razors presented without their blades..., $0-2

Samoa

(620293) Women's/girls' anoraks (incl. ski-jackets), wind-cheaters..., $24-56

(390110) Polyethylene having a sp.gr. of <0.94, in primary forms, $0-1

(853931) Electric discharge lamps (excl. ultra-violet lamps), fluorescent..., $0-1

(640291) Footwear (excl. waterproof) with outer soles ..., $15-29

(730439) Tubes, pipes & hollow profiles (excl. of 7304.10-7304.31)..., $1-5

(901910) Mechano-therapy appls.; massage app.; psychological aptitude…$12-47

(853530) Isolating switches & make-&-break switches, for a …$14-59

(900319) Frames & mountings for spectacles/goggles or the like, of..., $15-33

(300450) Medicaments cont. vitamins/oth. prods. of 29.36 (excl. of..., $16-96

(721012) Flat-rolled prods. of iron/non-alloy steel, of a width of 600mm..., $1-1

Tonga

(390720) Polyethers other than polyacetals, in primary forms, $2-4

(392020) Plates, sheets, film, foil & strip, of polymers of propylene..., $0-2

(390950) Polyurethanes, in primary forms, $3-6

(390422) Poly(vinyl chloride), plasticised, in primary forms … $1-3

(841821) Refrigerators, h-hold. type, compression-type, elec./oth., $0-222

(190120) Mixes & doughs for the preparation of bakers' wares of 19.05, $1-3

(392111) Plates, sheets, film, foil & strip, cellular, of polymers of styrene, $2-9

(850140) AC motors (excl. of 8501.10 & 8501.20), single-phase, $31-274

(730449) Tubes, pipes & hollow profiles (excl. of 7304.10-7304.39… $0-5

(590699) Rubberised textile fabrics (excl. of 59.02, 5906.10 & 5906.91), $5-23

VI.2. Opportunities for economic diversification in Timor-Leste[10]

This section illustrates the application of the methodology described in Chapter Five to identify possible new sectors for diversification considering the case of Timor-Leste.

Timor-Leste's economy is heavily dependent on the revenues of the petroleum sector, which has limited capacity for job creation and is vulnerable to the volatilities in oil prices. There has been strong economic growth in non-oil GDP in recent years but this growth has been dependent on increased government expenditures financed by petroleum revenues leading to strong growth in the construction sector and corporate profits (rather than labour income).

Timor-Leste's Strategic Development Plan (SDP) recognises that achieving strong rates of economic growth over the medium and long term will require a diversification of the economy away from petroleum production and government spending. In that connection, the SDP sets out a long-term policy framework to build a diversified economy. This includes an approach of 'front loading' fiscal policy to build the core productive infrastructure necessary to support a strong economy and develop a sustainable private sector. It also proposes developing three key strategic industries, petroleum, tourism and agriculture, to underpin Timor-Leste's economic base. A program of economic reforms, including establishing Special Economic Zones, telecommunications liberalization, a development bank and simplification of business regulation will also provide an impetus for further progress and, most importantly, create investment opportunities and employment.

Agriculture, tourism and downstream petroleum sectors are highlighted as keys sectors in the SDP and are seen as driving economic diversification and growth, but they would not be able to create enough jobs for the growing labour force. An internal report commissioned by the Ministry of Finance of Timor-Leste on the potential of the country's endowments to reach the SDP targets suggests that jobs that can be created in those sectors are likely to be outpaced by labour force growth, thus reducing the relative employment opportunities in the coming decade. Increases in output in agriculture that could be achieved through higher labour productivity, may keep constant the number of people working in agriculture in an optimistic scenario. Tourism and petrochemical sectors could create medium to higher skilled jobs, but not sufficient numbers to accommodate the estimated labour force by 2030.

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[10] This section is based on a study that I conducted in 2014 while working at ESCAP, at request of the Ministry of Finance of Timor-Leste, to identify practical policies that its government could implement to increase economic diversification of the country.

Therefore, efforts should be made to foster economic diversification within and beyond those key sectors to generate increased employment and job opportunities, so that more people can engage in jobs and productively contribute to the achievements of the country. This means generating employment and jobs that can utilize and capitalize on the creative energy of the young Timorese population, thereby unlocking the potential of the country.

Export opportunities

In Timor-Leste, the top potential new sectors with high export opportunities in global markets are machinery and mechanical appliances (22%); mineral fuels, oils, distillation products (18%); and articles of apparel (15%) (Table 6.3). Of those three, the latter two (mineral fuels and articles of apparel) are the sectors that have the higher likelihood of success based on the close linkages with the current endowments of the country, namely surplus labour and petroleum resources. The apparel sector has the additional advantage of being a cluster that allows for fast diversification of products within that sector. Footwear is also a sector with good export prospects, in terms of increasing market, and that has good potential considering the country's endowments. The list of potential new products in these three sectors classified by HS 6-digit are shown in Table 6.12.

When considering the share of export opportunities to ASEAN countries, the top opportunities for Timor-Leste are in the sectors of mineral fuels, oils, distillation products (50%); machinery and mechanical appliances (20%); and electrical and electronic equipment (11%) (Table 6.13). Again, the sector of mineral fuels presents close linkages with the country's endowments. Potential new products in the sector of machinery appliances includes products such as parts of the sewing machines, oil/petrol-filters for internal combustion engines, and parts of the filtering/purifying machines and appliances (Table 6.14). In the electrical and electronic sector, the potential new products for diversification include products such as discs for laser reading systems, switches, electric discharge lamps, and electric conductors. Some of these sectors require larger capital investment but not necessarily highly skilled workers, which could still be at reach of Timor-Leste's labour force.

The top opportunities for potential new products of Timor-Leste in China are in the sectors of mineral fuels (32%) (Table 6.15). The sector of rubber and articles thereof is also listed among the top sectors with export opportunities, but Timor-Leste is not a producer of rubber which eliminates the potential for backward-forward linkages. Other sectors with higher share of export opportunities to China are machinery and mechanical appliances (17%) and electrical and electronic equipment (11%).

The top opportunities for potential new products of Timor-Leste in Japan are in the articles of apparel (79%) (Table 6.16). Other sectors with top export opportunities to that market are textile articles (9%), footwear (8%) and articles of leather (3%).

Table 6.12. Potential new products for diversification with large shares of export opportunities to global markets, selected sectors, Timor-Leste, 2013

(HS classification) Description, price range
Mineral fuels, oils, distillation products, etc
(271019) Petroleum oils & oils obt. from bituminous mins. (excl. crude) & preps. $0-3
Articles of apparel, accessories
(610130) Men's/boys' overcoats, car-coats, capes, cloaks, anoraks $18-39
(610333) Men's/boys' jackets & blazers, knitted or crocheted, of synth. fibres, $15-38
(610442) Women's/girls' dresses, knitted or crocheted, of cotton, $9-22
(610444) Women's/girls' dresses, knitted or crocheted, of art. fibres, $14-37
(610462) Women's/girls' trousers, bib & brace overalls, breeches & shorts , $5-12
(610610) Women's/girls' blouses, shirts & shirt-blouses, knitted or crocheted, $0-13
(610690) Women's/girls' blouses, shirts & shirt-blouses, knitted or crocheted, $9-25
(610910) T-shirts, singlets & oth. vests, knitted or crocheted, of cotton, $0-8
(610990) T-shirts, singlets & oth. vests, knitted or crocheted, other than of cotton $0-6
(611090) Jerseys, pullovers, cardigans, knitted or crochet $13-30
(611120) Babies' garments & clothing accessories, knitted or crocheted, $20-47
(611490) Garments, n.e.s., knitted or crocheted, of textile mats. $16-79
(611511) Panty hose & tights, knitted or crocheted, of synth. fibres, meas. $17-49
(611592) Hosiery, knitted or crocheted, of cotton, $13-83
(611710) Shawls, scarves, mufflers, mantillas, veils and the like, $0-2
(620291) Women's/girls' anoraks (incl. ski-jackets), wind-cheaters, $43-110
(620339) Men's/boys' jackets & blazers (excl. knitted or crocheted $23-122
(620342) Men's/boys' trousers, bib & brace overalls, breeches & shorts $0-27
(620343) Men's/boys' trousers, bib & brace overalls, breeches & shorts, $12-25
(620349) Men's/boys' trousers, bib & brace overalls, breeches & shorts , $14-28
(620432) Women's/girls' jackets & blazers (excl. knitted or crocheted), of cotton, $21-53
(620443) Women's/girls' dresses (excl. knitted or crocheted), of synth. fibres, $0-36
(620452) Women's/girls' skirts & divided skirts (excl. knitted or crocheted), $10-23
(620459) Women's/girls' skirts & divided skirts (excl. knitted or crocheted), $14-

(HS classification) Description, price range
36
(620462) Women's/girls', trousers, bib & brace overalls, breeches & shorts $12-25
(620463) Women's/girls', trousers, bib & brace overalls, breeches & shorts $11-23
(620469) Women's/girls', trousers, bib & brace overalls, breeches & shorts $0-31
(620520) Men's/boys' shirts (excl. knitted or crocheted), of cotton, $0-22
(620630) Women's/girls' blouses, shirts & shirt-blouses $10-19
(620791) Men's/boys' singlets & oth. vests, bathrobes, dressing gowns & sim. $12-37
(620920) Babies' garments & clothing accessories (excl. knitted or crocheted), $0-17
(621132) Track suits (excl. knitted or crocheted), men's/boys'; oth. garments $47-93
(621133) Track suits (excl. knitted or crocheted), men's/boys'; oth. garments, $52-102
(621490) Shawls, scarves, mufflers, mantillas, veils and the like $3-9
(621520) Ties, bow ties & cravats (excl. knitted or crocheted), $16-57
(621710) Made up clothing accessories (excl. knitted or crocheted), n.e.s., $49-103
Footwear
(640299) Footwear (excl. waterproof) with outer soles & uppers of rubber, $0-8
(640399) Footwear (excl. waterproof) with outer soles of rubber/plastics, $21-34
(640419) Footwear (excl. waterproof) with outer soles of rubber/plastics, $0-10
(640590) Footwear other than with uppers of leather/composition leather, $5-35

Table 6.13. Potential new sectors for diversification with large shares of export opportunities to ASEAN, Timor-Leste, 2013

Sector	Percentage
Mineral fuels, oils, distillation products, etc	50
Machinery & mechanical appliance etc	20
Electrical, electronic equipment	11
Parts & accessories for motor vehicles	7
Articles of leather, animal gut, harness, travel goods	2
Plastics and articles thereof	2
Articles of apparel, accessories	2
Furniture, lighting, signs, prefabricated buildings	1
Paper & paperboard, articles of pulp, paper and board	1
Sum of others with smaller share	3

Table 6.14. Potential new products for diversification with large shares of export opportunities to ASEAN countries, selected sectors, Timor-Leste, 2013

HS classification) Description, price range
Machinery & mechanical appliance etc
(840999) Parts suit. for use solely/princ. with the engines of 84.07/84.08 $0-54
(842123) Oil/petrol-filters for int. comb. engines, $0-7
(842199) Parts of the filtering/purifying mach. & app. of 84.21 $14-46
(842290) Parts of the mach. of 8422.11-8422.40, $26-184
(845121) Drying machines other than of 84.50, each of a dry linen cap., $317-332
(845290) Parts of the sewing machines of 84.52 (excl. of 8452.30 & 8452.40), $19-163
(847130) Portable digital auto. data processing machines, weighing not >10kg, $0-781
(847330) Parts & accessories (excl. covers, carrying cases and the like) suit. $0-43
(848180) Taps, cocks, valves & sim. appls. for pipes/boiler shells/tanks/vats $13-47
(848390) Toothed wheels, chain sprockets & oth., $0-12
Electrical, electronic equipment
(851790) Parts of the app. & equip. of 85.17, $0-65
(852390) Prepared unrecorded media for sound recording/sim. recording of oth., $7-22
(852439) Discs for laser reading systems (excl. those for repr. $0-2
(852439) Discs for laser reading systems (excl. those for repr. $2-62
(852520) Transmission app. for radio-telephony/radio-telegraphy, $0-127
(852812) Reception app. for television, whether or not incorp. $184-410
(853650) Switches other than isolating switches & make-&-break switches, $24-93
(853690) Electrical app. for switching/protecting electrical circuits, $20-72
(853710) Boards, panels, consoles, desks, cabinets & oth. bases, $0-34
(853890) Parts suit. for use solely/princ. with the app. of 85.35/85.36/85.37, $0-19
(853931) Electric discharge lamps (excl. ultra-violet lamps), fluorescent, $0-1
(854441) Electric conductors (excl. of 8544.11-8544.30), for a voltage not >80V, $0-14
(854441) Electric conductors (excl. of 8544.11-8544.30), for a voltage not >80V, $14-67

Table 6.15. Potential new sectors for diversification with large shares of export opportunities to China, Timor-Leste, 2013

Sector	Percentage
Mineral fuels, oils, distillation products, etc	32
Rubber and articles thereof	25
Machinery & mechanical appliance etc	17
Electrical, electronic equipment	11
Articles of apparel, accessories	5
Articles of iron or steel	3
Plastics and articles thereof	3
Wadding, felt, nonwovens, yarns, twine, cordage, etc	2
Articles of leather, animal gut, harness, travel goods	1

Table 6.16. Potential new sectors for diversification with large shares of export opportunities to Japan, Timor-Leste, 2013

Sector	Percentage
Articles of apparel, accessories, not knit or crochet	79
Other made textile articles, sets, worn clothing etc	9
Footwear, gaiters and the like, parts thereof	8
Articles of leather, animal gut, harness, travel goods	3

Agriculture and agro-industries

This section discusses specific sub-sectors of agriculture and agro-industries that could be promoted to encourage economic diversification. As discussed when considering the export opportunities in the global markets, the top sectors in agriculture and agro-industries with large shares in export opportunities are in beverages, spirits and vinegar (22%); cereal, flour, starch, milk preparations and products (16%); and miscellaneous edible preparations (12%) (Table 6.9). Sectors that could have a link with livestock production in Timor-Leste account for 17% of global export opportunities of potential new products: residues, wastes of food industry, animal fodder (10%); and animal, vegetable fats and oils, cleavage products, etc (7%). Export opportunities for products of coffee, tea malt and spices, for which Timor-Leste has a clear link with its current endowments, account for 2% of global export opportunities of potential new products. Two sectors with high export opportunities but for which Timor-Leste do not produce the agricultural inputs are: cocoa and cocoa preparations (8%) and tobacco and manufactured tobacco substitutes (5%).

Table 6.17 presents the potential new products in the sectors with top export opportunities in global markets. In the sector of beverages, spirits and vinegar, the list includes products such as mineral waters, beer made from malt and wine. The experience of Fiji with exports of mineral water that target a specific niche may be informative for any strategy to capitalize on that sector. In the sector of cereal, flour, starch, milk preparations and products, potential new products include pasta, malt extract and other food preparations of flour /meal/starch/malt, and foods prepared by the swelling/roasting of cereals/cereal products. Products of other edible preparations include preparations with a basis of extracts, essences or concentrates of coffee, tea and malt, and protein concentrates.

Table 6.17. Potential new products in agriculture and agro-industries with large shares of global export opportunities, selected sectors, Timor-Leste, 2013

HS classification) Description, price range
Beverages, spirits and vinegar
(220110) Mineral waters (nat./art.) & aerated waters, not cont. added sugar/oth. $0-1
(220210) Waters, incl. min. waters & aerated waters, cont. added sugar/oth., $0-1
(220290) Non-alcoholic beverages other than waters of 2202.10, $0-2
(220300) Beer made from malt, $0-2
(220429) Wine other than sparkling wine of fresh grapes, incl. fortified; $1-6
(220110) Mineral waters (nat./art.) & aerated waters, not cont. added sugar, $0-1
(220210) Waters, incl. min. waters & aerated waters, cont. added sugar/oth. , $0-0
Cereal, flour, starch, milk preparations and products
(190120) Mixes & doughs for the preparation of bakers' wares of 19.05, $1-3
(190190) Malt extract; oth. food preps. of flour/groats/meal/starch/malt extact ,$1-4
(190219) Uncooked pasta, not stuffed/othw. prepd., not cont. eggs, $1-2
(190230) Pasta (excl. of 1902.11-1902.20), $1-3
(190410) Prepared foods obt. by the swelling/roasting of cereals/cereal prods., $2-8
(190420) Prepared foods obt. from unroasted cereal flakes/mixts., $2-5
(190490) Cereals other than maize (corn) in grain form/in the form of flakes/oth. $1-4
(190531) Sweet biscuits, $0-5
(190532) Waffles & wafers, $2-11
(190540) Rusks, toasted bread & sim. toasted prods., $1-4
(190590) Bread, pastry, cakes, biscuits & oth. bakers' wares n.e.s. in Ch.19, $0-9
Miscellaneous edible preparations
(210112) Preparations with a basis of extracts/essences/concs. of coffee, $3-12

(210120) Extracts, essences & concs. of tea/matÎ˜, & preps., $3-17
(210220) Inactive yeasts; oth. single-cell micro-organisms, $2-15
(210320) Tomato ketchup & oth. tomato sauces, $1-2
(210390) Sauces & preps., n.e.s.; mixed condiments., $0-10
(210410) Soups & broths & preps. therefor, $2-6
(210500) Ice cream & oth. edible ice, whether or not cont. cocoa, $5-9
(210610) Protein concs. & textured protein subs., $2-10
(210690) Food preps., n.e.s., $2-30

This analysis suggests that expanding markets for the potential new products of Timor-Leste in agriculture and agro-industries are in Germany (which represents 14% of the share of the expanding markets), Canada (8%), Japan (7%), United States (7%), Mexico (6%), China (4%), France (4%), Malaysia (4%), and Singapore (4%).

When considering the share of export opportunities to ASEAN countries, the top opportunities for Timor-Leste's diversification in agriculture and agro-industries are in the sectors of residues, wastes of food industry, animal fodder (18%); Cereal, flour, starch, milk preparations and products (15%); and Beverages, spirits and vinegar (12%) (Table 6.18). The sector of residues, wastes of food industry, animal fodder was also among the top four when considering the global export opportunities, and it moves to the top position when considering the expanding markets in ASEAN. The specific potential new products under that sector are dog and cat food and other preparations used in animal feeding (Table 6.19). Another sector has strengthened its position when considering export opportunities to ASEAN as opposed to the global markets is the sector of milling products, malt, starches, inulin, wheat gluten with 9% of export opportunities in ASEAN. The potential new products in that sector are wheat flour, maize starch and potato starch.

Table 6.18. Potential new agriculture and agro-industries sectors for diversification with large shares of export opportunities to ASEAN, Timor-Leste, 2013

Sector	Percentage
Residues, wastes of food industry, animal fodder	18
Cereal, flour, starch, milk preparations and products	15
Beverages, spirits and vinegar	12
Miscellaneous edible preparations	11
Milling products, malt, starches, inulin, wheat gluten	9
Vegetable, fruit, nut, etc food preparations	7
Coffee, tea, mate and spices	6
Edible fruit, nuts, peel of citrus fruit, melons	4

Sugars and sugar confectionery	4
Tobacco and manufactured tobacco substitutes	4
Sum of others with smaller share	10

Table 6.19. Potential new products for diversification in agriculture and agro-industries sectors with large shares of export opportunities to ASEAN countries, selected sectors, Timor-Leste, 2013

HS classification) Description, price range
Residues, wastes of food industry, animal fodder
(230910) Dog/cat food, put up for RS, $1-3
(230990) Preparations of a kind used in animal feeding other than dog/cat food, $0-0
(230990) Preparations of a kind used in animal feeding other than dog/cat food , $0-4
Milling products, malt, starches, inulin, wheat gluten
(110100) Wheat/meslin flour, $0-1
(110812) Maize (corn) starch, $0-1
(110813) Potato starch, $0-1

When considering export opportunities in other Asia-Pacific countries, the sectors with higher opportunities in China are of miscellaneous edible preparations (53%), vegetable, fruit, and nut food preparations (13%), and cereal, flour, starch, milk preparations and products (12%); in Japan the sector with higher export opportunity in the sector of tobacco and manufactured tobacco substitutes (78%), miscellaneous edible preparations (7%) and animal, vegetable fats and oils, and cleavage products (4%).

Regarding fisheries, Timor-Leste production includes marine crabs, tropical spiny lobsters, tuna-like fishes and Yellow tuna,[11] but the analysis of potential products for diversification was not able to identify new opportunities in that sector. A possible strategy would be to increase the production of existing fisheries products as a first step.

Import replacement opportunities

Given the small domestic market, import replacement opportunities are not expected to drive the investment decision of entrepreneurs and firms when considering investing in new production. Thus, the prospects of import replacement for economic diversification in Timor-Leste are low. Nevertheless,

[11] FAO Fishery and Aquaculture Global Statistics (accessed March 2015)

given the high import dependency of the country, this chapter identifies the sectors with the high import replacement opportunities.

If import replacement is considered, the sectors with the highest import replacement opportunities are beverages, spirits and vinegar (19%) and cereal, flour, starch, milk preparations and products (12%) (Table 6.20). These sectors with top import replacement opportunities are also among the sectors with top export opportunities in global and ASEAN markets. Therefore, export-led diversification in these sectors could also meet the domestic demand.

Table 6.20. Potential new agriculture and agro-industries sectors for diversification with large shares of export opportunities to ASEAN, Timor-Leste, 2013

Sector	Percentage
Beverages, spirits and vinegar	19
Cereal, flour, starch, milk preparations and products	12
Tobacco and manufactured tobacco substitutes	9
Articles of iron or steel	7
Milling products, malt, starches, inulin, wheat gluten	6
Electrical, electronic equipment	5
Vehicles other than railway, tramway	5
Furniture, lighting, signs, prefabricated buildings	4
Soaps, lubricants, waxes, candles, modelling pastes	4
Plastics and articles thereof	3
Sum of others with smaller share	27

7

Modelling approach

This is the first chapter in the third part of this book, which focuses on the study of possible explanations for the stylized facts related to diversification. This chapter shows examples of models that have been proposed to explain some of the empirical regularities presented in Chapter Four. It also presents original analysis of diversification conducted using some of the modelling techniques that are inspired by those models. The chapter concludes by discussing the modelling strategy adopted in the following chapters to link empirical results with the formalism of economic dynamics of the literature on structural and technological change.

7.1 Introduction

As discussed in Chapter One, in addition to the importance of economic diversification for developing economies, a key motivation of this dissertation is the value of linking the empirical literature on economic complexity to the economic theory of structural change. Making this connection is relevant because the study of the dynamics of the structure of an economy in a framework that is able to replicate stylized facts could shed some light on the mechanisms underlining the diversification process. Economic theory could provide possible explanations for the patterns of economic diversification observed across countries. It could also provide new tools to inform policymakers in developing countries in designing and implementing policies and strategies for promoting diversification, structural transformation, and catch up with developed economies.

Considering the evolution of economic ideas since the classics, it is fair to say that economic theories have not particularly focused on economic diversification, although many times recognizing its link with development.[1]

An example of early economic theory addressing diversification is noted in Reinert (2007) who points out that the Italian philosopher Antonio Serra in the seventeenth-century considered diversification as a key issue in his theory of development and underdevelopment.[2] Classical economists have also noted the importance of diversification. For example, Adam Smith's (1776) division of labour implies an increasing variety of work (economic diversification), to provide all the material and equipment used in each specific activity. Thus, division of labour results in specialization at the individual level and economic diversification at the national level; they are two sides of the same coin. Smith also highlighted the interlinkages among a diversity of specialized activities,[3] which was also emphasized by others such as Friedrich List (1841)[4] and Jean-Baptiste Say (1803).[5]

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[1] In fact, more compelling narratives of the importance of diversification for development can be found outside the realm of economic theory. The following quote by the journalist and urban activist Jane Jacobs is an example: "Our remote ancestors did not expand their economies much by simply doing more of what they had already been doing; piling up more wild seeds and nuts, slaughtering more wild cattle and geese, making more spearheads, necklaces, burins and fires. They expanded their economies by adding new kind of work. So do we. Innovating economies expand and develop. Economies that do not add new kinds of goods and services, but continue only to repeat old work, do not expand much nor do they, by definition, develop." (Jacobs, 1969, p.49).

[2] "In Serra's view the key to economic development was to have a large number of different economic activities, all subject to the falling costs of increasing returns" (Reinert, 2007, p. 7).

[3] "The miner, the builder of the furnace for smelting the ore, the feller of the timber, the burner of the charcoal to be made use of in the smelting-house, the brick-maker, the brick-layer, the workmen who attend the furnace, the mill-wright, the forger, the smith, must all of them join their different arts in order to produce them." (Smith, 1776, I.1.11).

[4] "As the pin manufactory only prospers by the confederation of the productive force of the individuals, so does every kind of manufacture prosper only by the

Diversification was also seen as a form of increasing economic resilience by fostering a variety of jobs (Hume, 1752),[6] of allowing an increase in the individual opportunities (Hamilton, 1789),[7] and of balancing the economy (List, 1841).[8] Others have also noted the importance of diversification to foster trade (e.g. Whately, 1831),[9] as well as the importance of trade to foster diversification through emulation (e.g. Hume, 1752).[10] However, arguably, David Ricardo's (1817)

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confederation of its productive forces with those of all other kinds of manufacture." (List, 1841, II.XIII.9)

[5] "A pair of boots undergoes a variety of processes, whereof all are not executed by the bootmaker alone; the grazier, the tanner, the currier, all others, who immediately or remotely furnish any substance or tool used in the making of boots, contribute to the raising of the product". (Say, 1803, I.VIII.22).

[6] "The emulation among rival nations serves rather to keep industry alive in all of them: And any people is happier who possess a variety of manufactures, than if they enjoyed one single great manufacture, in which they are all employed. Their situation is less precarious; and they will feel less sensibly those revolutions and uncertainties, to which every particular branch of commerce will always be exposed." (Hume, 1752, II.VI.5).

[7] "[Diversification enables] furnishing greater scope for the diversity of talents and dispositions, which discriminate men from each other" and "affording a more ample and various field for enterprise." (Hamilton, 1789, pp.10-11).

[8] "As in the pin manufactory, so also in the nation does the productiveness of every individual—of every separate branch of production—and finally of the whole nation depend on the exertions of all individuals standing in proper relation to one another. We call this relation the balance or the harmony of the productive powers." (List, 1841, II.XIII.9).

[9] "In proportion then as the division of labour was extended, exchanges would become more and more frequent. For, diversity of production is evidently the foundation of exchange; since, as long as each individual provides for all his own wants, and only for them, he will have nothing to part with, and nothing to receive." (Whately, 1831, VI.13).

[10] "If we consult history, we shall find, that, in most nations, foreign trade has preceded any refinement in home manufactures, and given birth to domestic luxury. The temptation is stronger to make use of foreign commodities, which are ready for use, and which are entirely new to us, than to make improvements on any domestic commodity, which always advance by slow degrees, and never affect us by their novelty...[but] Imitation soon diffuses all those arts; while domestic manufactures emulate the foreign in their improvements, and work up every home commodity to the utmost perfection of which it is susceptible." (Hume, 1752, II.I.15).

principle of comparative advantage moved the attention of economic theory towards gains from specialization.[11]

Pasinetti (1993) argues that, in terms of theory of value, all economic theories since the classics belong to either the 'exchange' paradigm, which focuses on optimum allocation of scarce goods, or the 'production' paradigm, which focuses on the improvement of application of labour on the production of goods and services. That division could also be applicable to the way that theory relates to diversification. The 'exchange' paradigm assumes a given number of types of goods and therefore has no place for economic diversification. The 'production' paradigm, on the other hand, deals with technological progress, through process and product innovation, and therefore is able to study the process of diversification.

For example, in general, the trade literature is an example of the exchange paradigm. It puts forward two main hypotheses to explain the patterns of specialization of countries, given a set of types of products that they are able to produce. The first is based on the principle of comparative advantage of the Ricardian or the Heckscher-Ohlin (1991) type. The second is the new trade theory (e.g. Krugman, 1979), which was developed to address the fact that countries do not specialize as predicted by the traditional trade theory. The new trade theory assumes that products come in different varieties that are imperfect substitutes, which gives firms competing in the same category of product some market power. Competition drives prices down by reducing profits while economies of scale reduce costs. The theory, however, does not predict which country will specialize in which product because it uses the Dixit-Stiglitz model (Dixit and Stiglitz, 1977) that assumes a continuum of symmetric products (Hausmann and Hidalgo, 2011).

The literature on growth theory, on the other hand, has emphasized the key role of technological change and could be characterized within the production paradigm. Within that strand of literature, aggregated models (e.g. Solow, 1956, 1957) by design in general do not deal with diversification. Some endogenous growth models have considered expanding growth variety as the driver of growth.

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[11] "Under a system of perfectly free commerce, each country naturally devotes its capital and labour to such employments as are most beneficial to each. This pursuit of individual advantage is admirably connected with the universal good of the whole. By stimulating industry, by regarding ingenuity, and by using most efficaciously the peculiar powers bestowed by nature, it distributes labour most effectively and most economically: while, by increasing the general mass of productions, it diffuses general benefit, and binds together by one common tie of interest and intercourse, the universal society of nations throughout the civilized world. It is this principle which determines that wine shall be made in France and Portugal, that corn shall be grown in America and Poland, and that hardware and other goods shall be manufactured in England." (Ricardo, 1817, Ch.7).

For example, Romer (1990) and Grossman and Helpman (1991) develop models of increasing product diversity through research and development which drives economic growth. However, they formulate a continuum of goods that have no intrinsic difference from each other, and therefore do not address the characteristic path dependence in the diversification process, which is highlighted in other strands of the literature (e.g. Gerschenkron, 1962; Dosi, 1982, 1988) and illustrated in Chapter Four.

Structuralist growth models, on the other hand, disaggregate the analysis into sectors, which provides a framework to study diversification. However, for many structuralist growth models the concept of diversification is not a central element. Gibson (2010), for example, considers the dual role of investment as component of aggregate demand and as a flow that augments the stock of capital as the central concept of structuralists growth models. Similarly, the comprehensive compilation of structuralist growth theories in Setterfield (2010) does not mention the importance of diversification to economic growth among the common or emerging themes of that literature.

In some cases the importance of diversification is emphasized, but no formal treatment for it is given in the model. For example, Pasinetti's (1993) elegant model of a pure labour economy shows that the introduction of new goods and services in the economy is one of the elements that could prevent the tendency towards technological unemployment that would result from the asymmetry between the unlimited growth of labour productivity and the growth of demand, which is limited by the consumption saturation illustrated by Engel's (1857) law. Despite the importance of economic diversification to the formulation of Pasinetti's model, there is no formal treatment of diversification in his modelling of structural economic dynamics.[12]

A notable exception is Saviotti and Pyka (2004a, 2004b, 2004c, 2013, 2017), who provide a foundation for a structuralist model of economic development that is driven by endogenous diversification and based on the demand for new products. The model's dynamics show the emergence of new firms as a function of the difference between the maximum and actual demand, availability of finance, intra- and inter-sector competition and search activities. However, the analysis concentrates on countries in autarky and there is no path dependence in the process of diversification adopted in the model.

More recently, empirical results related to economic diversification highlighted in the literature of economic complexity have attracted some attention to the need

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[12] According to Pasinetti: "(t)he introduction of new goods and services generates no analytical difficulty. It only implies that the list of production processes and produced goods lengthens (the size of the production mix becomes larger) over time. We may simply consider the number m (of sectors and goods) as itself a function of time by writing m(t)" (Pasinetti, 1993, p.54).

to put forward new hypotheses to explain and understand how those regularities are generated. The next section discusses examples of models that have been proposed to specifically explain some of the patterns of diversification of countries. That discussion is followed by an analysis of diversification applying some of the modelling techniques discussed. The final section discusses the modelling strategy adopted in the following chapters to link the empirical results to structural economic dynamics.

7.2 Explaining the stylized facts

This section discusses models that have been proposed to explain selected empirical regularities uncovered by the literature on economic complexity. The following four stylized facts presented in Chapter Four are highlighted in the discussion: 1) diversification is associated with higher GDP; 2) diversification is associated with slightly lower ubiquity of production; 3) opportunities for catching up in terms of diversification are not equally distributed; less diversified countries tend to fall behind and countries with intermediate levels of diversification tend to catch up; 4) diversification is path dependent. The discussion does not intend to be exhaustive in the coverage of models but rather to illustrate modelling strategies adopted in the literature.

The first example is the model presented in Hausmann and Hidalgo (2011), called the binomial model, which explains the stylized fact related to the negative association between diversification of countries and average ubiquity of their exports. The authors also focus on another three empirical regularities of the network of countries connected to the products that they export: the non-lognormal distributions of country diversification, product ubiquity, and proximity in the product space.

The binomial model is based on two assumptions: (i) products require the combination of a potentially large number of capabilities to be produced, and (ii) countries only produce the goods for which they have the capabilities to produce (and they produce all the products for which they have the required capabilities). These are basically the same assumptions behind the method of reflections as proposed in Hidalgo and Hausmann (2009).

The model uses three matrices to represents the world economy. The first is a country-capability matrix (C_{ca}) in which each row represents a country and each column a capability. Cells in that matrix have the value of 1 when a particular capability (a) is available in the country (c), and zero otherwise:

$$C_{ca} = \begin{cases} 1, & \text{if country has capability} \\ 0, & \text{otherwise} \end{cases} \quad \text{(VII.1)}$$

The second matrix (P_{pa}) represents products and the capabilities required to produce them. Each row in the matrix represents a given product and each column a capability. The binomial model uses a production function à la Leontief, in which the production of each good requires the existence of a specific set of capabilities. Cell in the matrix receive the value of 1 to indicate that a given product (p) require a particular capability (a) to be produced, and zero otherwise:

$$P_{pa} = \begin{cases} 1, & \text{if product requires capability} \\ 0, & \text{otherwise} \end{cases} \tag{VII.2}$$

A third matrix (M_{cp}) is the matrix of countries and the products that they export. This matrix can be derived from the first two as follows:

$$M_{cp} = \begin{cases} 1, \text{if } \sum_a^{N_a} C_{ca} P_{pa} = \sum_a^{N_a} P_{pa} \\ 0, \quad \text{otherwise} \end{cases} \tag{VII.3}$$

Where N_a is the number of capabilities.

The first two matrices (C_{ca} and P_{pa}) are considered as empirically unobservable, while M_{cp} is observable through trade data. This framework is the formalization of the illustrative description of the tripartite network connecting countries, productive capacities and products shown in Figure 3.1 in Chapter Three.

The model assumes that a country c has a given capability a available (C_{ca}= 1) with probability r. Similarly, it assumes that a product p requires a given capability a (P_{pa}= 1) with probability q.

Based on this model, the authors then verify analytically the association between diversification and average ubiquity and the distribution of diversification, ubiquity and proximity in the product space. They also calibrate the values of r and q based on the empirical matrix M_{cp} derived from trade data using various trade classifications.

The authors suggest that the implication of the binomial model, based on the analysis of its calibration to empirical data, is that a trap in the process of economic diversification can emerge. If a country has few capabilities, and it is therefore less diversified, the probability that the development or acquisition of a new capability would unlock the production of a new product is low. The authors argue that, as a result, the demand for new capabilities will be low in these countries, which will trap them in a lower level of diversification. The analysis suggests, on the other hand, that more diversified countries would be able to produce many more new products. The model results in increasing returns for diversification in terms of the accumulation of capabilities.

The diversification trap described above is based on the assumption that innovators and government in less diversified countries would not demand new capabilities because they know that the likelihood is low that any new capability will be able to synergize with existing capabilities to produce a new product. This assumption attributes considerable knowledge to those actors, which (in my view surprisingly) is not used to plan a strategy for capability accumulation that could overcome that problem.

The binomial model provides an explanation for stylized fact 2; it replicates the negative association between diversification of countries and the average ubiquity of their exports. The model also results in less diversified countries being trapped in low levels of diversification, which is one of the elements of the stylized fact 3, but it does not indicate that countries with intermediate levels of diversification would tend to catch up. Therefore, the binomial model does not fully replicate stylized fact 3. The model was not designed to address stylized fact 1 and it is also not suitable to address stylized fact 4 because it is static in nature: it does not deal with the dynamic accumulation of capabilities and the process of innovation. Moreover, the binomial model does not provide any information about economic indicators, such as output, growth, employment, and balance of trade, and is not suitable to explore policy-related questions that link diversification with the structural economic dynamics of countries.

Recently, Lei and Zhang (2014) proposed a revision of Hausmann and Hidalgo's (2011) model to replicate an empirical regularity related to stylized fact 1 and shown in Chapter Four as the S-shaped curve in the relationship between total GDP and diversification across products (see Figure 4.2 graph *a* and Figure 4.3 graph *a*). The authors show that the binomial model is not able to replicate this empirical regularity and propose the inclusion of a "substitutability" parameter in the framework of the tripartite network of countries, capabilities and products. This parameter represents the proportion of capabilities required to produce a good that could be replaced by other capabilities and still result in the production of that good. The inclusion of this parameter assumes, for example, that a smaller economy does not need to have the complete set of capabilities required for the production of a good in a larger economy, because some of those capabilities could be replaced by other capabilities available in the smaller economy. Lei and Zhang (2014) derives an analytical relation between total GDP and diversification, and solve that function for a set of values of the substitutability and of the probability that a product requires a given capability. They found that substitutability is an important parameter to replicate the ceiling effect of the S-shaped curve found in the empirical results.

While the model proposed in Lei and Zhang (2014) follows the modelling strategy presented in Hausmann and Hidalgo (2011) to investigate an empirical regularity related to diversification in a given period of time, Klimek et al. (2012) adopts the tripartite network framework and explores the dynamics of the diversification process.

The dynamic framework presented by Klimek et al. (2012) is based on a revised version of the Schumpeterian evolutionary model proposed by Thurner et al. (2010). While in the latter new products emerge as the result of the combination of existing products, in the former products requires capabilities to be produced and new products emerge through the combination of existing capabilities in a given economy. These models also account for the fact that new products may replace existing products, which implies a model of Schumpeterian creative-destruction.

The model proposed in Klimek et al. (2012) is composed of binary vectors, matrices and rule tables. At any time t and for each country c, a binary product vector $\pi_{c,p}(t)$ indicates if a product p is produced (1) or not (0) in the country. The set of capabilities available in each country is indicated by a binary capability vector $\sigma_c(t)$, in which the i'th position of the vector assumes value 1 to indicate that capability i is available in the country and 0 otherwise. The model indicates whether a new capability i is acquired by the combination of existing capabilities j and k according to the following production process:

$$\sigma_{c,i}(t+1) = \alpha^{+}_{ijk}\sigma_{c,j}(t)\sigma_{c,k}(t) \quad \text{(VII.4)}$$

where α^{+}_{ijk} is an entry in a production rule table and has the value 1 if i can be acquired by the combination of j and k and is 0 otherwise.

The model assumes that an existing product p may disappear if its production requires a sub-set of the capabilities required by a new product q. The rationale is that the new product q may be an improved version of p. The destruction process is modelled as follows:

$$\sigma_{c,i}(t+1) = 1 - \alpha^{-}_{ij}\sigma_{c,j}(t) \quad \text{(VII.5)}$$

where α^{-}_{ij} is an entry in a destruction rule table and takes the value of 1 if capacity i replaces capability j and has a value of 0 otherwise.

The model links products to the capabilities that they require to be produced through a matrix M_{ip}. Each cell in the matrix receives the value of 1 to indicate that a given product (p) requires a particular capability (i) to be produced, and 0 otherwise:

$$M_{ip} = \begin{cases} 1, & \text{if product requires capability} \\ 0, & \text{otherwise} \end{cases} \quad \text{(VII.6)}$$

Based on matrix M_{ip}, for each country c, the binary product vector $\pi_{c,p}(t)$ is derived.

The model assumes that at each time t and in each country c, an existing (new) capability i can also be lost (acquired) exogenously with probability γ.

The model is implemented through the execution of the following algorithm:

1. In each time t, randomly select a country c and a country c';

2. For each capability i available in country c ($\sigma_{c,i}$(t)=1), set $\sigma_{c,i}$(t)=0 and $\sigma_{c',i}$(t)=1 with probability γ. This step accounts for the exogenous change in the set of capabilities;
3. Select a capability i at random;
4. Calculate all the productive and destructive effects on i by the other capabilities as follows:

$$\Delta_i(t) = \sum_{j,k} \alpha^{+}_{ijk}\sigma_{c,j}(t)\sigma_{c,k}(t) - \sum_j \alpha^{-}_{ij}\sigma_{c,j}(t) \quad \text{(VII.7)}$$

$$\sigma_{c,i}(t+1) = \begin{cases} 1, \text{if } \Delta_i(t) > 0 \\ 0, \text{if } \Delta_i(t) < 0 \\ \sigma_{c,i}(t), \text{otherwise} \end{cases} \quad \text{(VII.8)}$$

5. Repeat steps 3 and 4 until the effects on all capabilities are calculated; then start again from step 1 to select another country at random;
6. After all countries have been selected and the effects of all capabilities are calculated, update the product vector $\pi_{c,p}$(t) and go to the next time period.

The model results in a general tendency for increasing diversification over time, which is stronger in countries that initially have intermediate levels of diversification. Therefore, the model is able to replicate stylized fact 3, in which opportunities for diversification are not equally distributed.

The model could also be used to replicate stylized fact 4 related to path dependency. The emergence of new capabilities is ruled by the combination of existing capabilities, which results in path dependency. The model also assumes exogenous emergence (disappearance) of capabilities, which would reduce the path dependency effect, but that can be adjusted by setting a low value for probability γ.

The Klimek et al. (2012) model is somewhat related to the recombinant growth model proposed by Weitzman (1998) and the grammar model as presented by Kauffman (2008). In these models, new products emerge as the combination of previous products. In the recombinant growth model, possibilities for diversification increase with the level of diversification and the limits of growth are related to the capacity to process the huge amount of possible new combinations rather than to the ability to generate new combinations. In Kauffman's grammar model, central to growth is whether new products are a building block for on average less than one, exactly one or more than one new products.

Kauffman (2008) also provided inspiration to Saracco et al. (2015), who propose a dynamic model to explain stylized fact 2, related to the negative association between diversification of countries and the average ubiquity of their export mix. The model assumes that countries compete to obtain the ability to produce and export new products and that the potential new products that a country can produce are part of the "adjacent possible" as per Kauffman (2008).[13]

The model is implemented as an algorithm composed of three main steps:

1. At each time $\underline{t}$, the first step is the selection of one country in which the innovation will occur. The model assumes that country c has a probability to be selected given by:

$$P_1(c) \sim k_c^{\alpha}, \quad \alpha > 0 \tag{VII.9}$$

   where k_c is the diversification of country c and α is a parameter of the model. The result is that more diversified countries are more likely to be selected.

2. The second step is the selection of one product in the basket of exports of the country selected. The product selected will be the basis for either new product innovation or product emulation in the third step. The model assumes that a product p is selected with probability given by:

$$P_2(p|c) \sim k_p^{\beta}, \quad \beta > 0 \tag{VII.10}$$

   where k_p is the ubiquity of product p and β is a second parameter of the model. Eq. (VII.10) indicates that products that are exported by more countries are more likely to be selected.

3. The third step is the emergence of a new product that could be either new to the world (product innovation) or an emulation of a product already exported by other countries (product emulation). Possible candidates for emulation are products in the set p' of products that already exist in the world and are directly connected to product p in the product space, but are

[13] An adjacent possible can be understood as a set of all possible new products that could be created in a single step based on the combination of technologies that already exist in the economy. Using an example to illustrate, suppose country *A* produces three products, in which the first is characterized by technology *a*, the second by technology *b* and the third by technology *ab*. The adjacent possible of country *A* is a set of six products, each one characterized by one of the following technologies: *aa*, *aab*, *bb*, *ba*, *bab*, and *abab*. That is the set of new products that can be reached by combining any two technologies in a single step using the initial set of technologies. That is what is here called adjacent possible. We could imagine many other products that are not part of that adjacent possible. For example, a product that is characterized by technology *aaa* could not be created from this initial set in a single step.

not produced by country c. If the product is new to the world, the model assumes that it is part of the set of products (p^*) that are part of the adjacent possible of country c. The model assumes that $\tilde{p}$ is a generic element of the set resulting from the union of $p'$and p^*. A single element of the set $\tilde{p}$ is selected with a probability given by:

$$P_3(\tilde{p}|c,p) \sim (k_{\tilde{p}} + k^0)^\gamma, \quad k^0, \gamma > 0 \tag{VII.11}$$

Where k^0, γ are parameters of the model. Given that the ubiquity of a product that is new to the world is zero ($k_{p*} = 0$), Eq. (VII.11) indicates that the emulation of existing products is more likely than product innovation.

The algorithm described above is iterated until the number of products produced in the world is the same as the number of products in the empirical data used for the calibration of the model. When that number is reached, the parameter k^0 is set to zero, which prevents the creation of any product that is new to the world given that by Eq. (VII.11) the probability $P_3$of these products being selected would become zero. From that moment, only emulation occurs. The algorithm is then iterated until the density of the network of countries connected to products resembles the empirical data.

The authors found that the model replicates many empirical regularities related to the matrix representing the network of countries connected to the products that they export, including the negative association between diversification and ubiquity of production (stylized fact 2). The model also yields the path dependency observed in the data (stylized fact 4).

Ferrarini and Scaramozzino (2016) adopt another modelling approach to investigate the association between production complexity and the level and growth of a country's output. The model assumes that the level of complexity of a production sector in an economy is a technological characteristic of that sector. It also assumes that increases in production complexity could have a potential positive effect on output by enhancing human capital, which is modelled following Lucas (1988). It could also have a negative effect, however, by increasing the risk of failure of production by increasing the number of tasks that have to be completed in the production process, which is modelled following the O-ring theory proposed in Kremer (1993).

The model assumes that the level of output of a sector i is an increasing function of the time allocated to production (λ_c) and the human capital employed in the sector (h_c), and is also affected by the level of complexity of that industry (z^i). The model formalizes this function as follows:

$$Q_c^i = \lambda_c h_c e^{\alpha_c z^i} \tag{VII.12}$$

$$\alpha_c = \theta_c - \delta_c \tag{VII.13}$$

in which α_c is a parameter that captures the balance between the potential positive (θ_c) and the negative (δ_c) effects of production complexity on output.

Total output of country c is given by:

$$Q_c = L_c \int_0^\infty Q_c^i \, \varphi_c(z^i) dz^i \tag{VII.14}$$

where L_c is the size of the labour force and $\varphi_c(z^i)$ is the density function of complexity in country c.

The model assumes that z^i in country c has a general gamma distribution characterized by a shape parameter k, which is considered to be associated with the existing level of technology and to be constant across all countries, and the scaling parameter β_c, which is considered to be country-specific:

$$z^i \sim \text{Gamma}(k, \beta_c) \tag{VII.15}$$

Substituting Eq. (VII.15) in Eq. (VII.14) results in the following expression for the level of output:

$$Q_c = L_c \lambda_c h_c \times \frac{1}{(1-\alpha_c \beta_c)^k} \tag{VII.16}$$

Eq. (VII.16) indicates that the effect of the scaling parameter β_c is determined by the sign of the parameter α_c. If the positive effect of complexity in terms of increasing human capital dominates, then higher complexity is associated with higher output. On the other hand, if the negative effect of increasing risk of failure in the production process dominates, then higher complexity would result in lower output. The authors also derive an analytical expression for growth of output and the result suggests that increasing complexity is generally associated with higher growth.

Ferrarini and Scaramozzino (2016) propose a new measure of country adaptability in product space as a proxy of production complexity and test the predictions of their model through panel regressions. In those regressions, the dependent variable is the logarithm of the level of GDP per capita in each country, and the independent variables are the average density for the country in the product space (representing complexity), the total active labour force, the labour force participation, and the years of schooling, all in logarithms. The results of their analysis support the prediction of the model.

Table 7.1 summarizes the discussion in this and the previous section by listing models of different strands of literature and indicating the stylized facts that they are able to replicate. The table shows that none of the models considered addresses the four empirical regularities simultaneously.

Two strategies can be identified in the models discussed in this section. The first is the proposition of a new theoretical framework based on the tripartite network connecting countries, capabilities and products, and the study of the structure and possible evolution of that network following rules that are, to a large extent, dissociated of economic fundamentals (Hausmann and Hidalgo, 2011; Lei and Zhang, 2014; Klimek et al., 2012, and Saracco et al., 2015). The second strategy is seen in Ferrarini and Scaramozzino (2016) and relates to adopting the assumptions of capabilities and complexity within a more traditional economic theoretical framework, and, based on that combination, use the empirical data to test predictions of the model. The next section puts those two strategies into practice to explore their application.

Table 7.1. Models and their explanation of the stylized facts.

	Stylized fact			
Model	**1**	**2**	**3**	**4**
Trade				
Krugman, 1979				
Heckscher and Ohlin, 1991				
Structural change				
Saviotti and Pyka, 2004a, 2004b, 2004c	X		X	
Pasinetti, 1981, 1993	X			
Endogenous growth				
Romer, 1990	X			
Grossman and Helpman, 1991	X			
Economic complexity				
Hausmann and Hidalgo, 2011		X		
Lei and Zhang, 2014	X	X		
Klimek et al., 2012			X	X
Saracco et al., 2015		X		X
Ferrarini and Scaramozzino, 2016				
Kauffman, 2008	X			X
Weitzman, 1998	X			X

Notes: Stylized facts: 1 – Diversification is associated with higher total GDP; 2 – Diversification is associated with slightly lower ubiquity of production; 3 – Opportunities for caching up in terms of diversification are not equally distributed and less diversified countries tend to fall behind; and 4 – Diversification is path dependent.

7.3 Exploring modelling approaches

This section presents two examples of the application of the strategies discussed above to explain some of the empirical regularities related to diversification. The first model aims at explaining analytically the stylized fact 2 (negative association between diversification and average ubiquity) by studying a way that the matrix of countries and products can be replicated. The model assumes that at each period the possible new products for diversification are part of the adjacent possible à la Kauffman (2008) and that the combination of capabilities to create new products is constrained by the capacity of countries to search the possible solutions as proposed by Weitzman (1998). The analysis of that model indicates that the creation of new products through the combination of capabilities could generate the relationship between diversification and average ubiquity observed in the empirical data.

The second model adopts the assumptions of capabilities and complexity in a traditional structuralist model, in this case the Pasinetti (1993) model, to explore explanations for the stylized fact 1 related to the positive association between total output and diversification. The resulting model predicts that total output is positively associated with the level of productive capacities of the country, the exchange rate between the national currency and US dollar, and the size of the population. This prediction is then tested using the measure of productive capacities presented in Chapter Three.

7.3.1 Analysis of the matrix of countries and products

The following model presents an analysis of the relation between diversification of countries and the average ubiquity of their products. It aims at explaining the apparent break in the curve of the logarithm of those measures as seen in Figure 4.6, in which average ubiquity does not change much with the level of diversification for less diversified countries, but for more diversified countries there is a negative relationship between the logarithm of the two measures.

The model follows the evolution of diversification of one single country A. Let us suppose that there are n_c time periods considered and that in each period there is the emergence of a set of products that are elements of the same adjacent possible of the country in the previous period. N_i is the number of products that are part of the adjacent possible number i, with N_1 as the set of original products. We assume that at each period j the country produces the same types of goods produced in time j-1 and all products in the adjacent possible. That scheme is illustrated in Table 7.2, in which row j represents time j and each column i represents the N_i products that are part of the adjacent possible of the country in time j-1. In the table, $k_{c,0}$ indicates diversification of the country in each period and

$k_{p,0}$ the ubiquity of products if we were considering the country at each time period as a different country.

Table 7.2. Model with adjacent possible of country *A*

Time (j)	Sets of products					$k_{c,0}$
1	N_1					N_1
2	N_1	N_2				$N_1 + N_2$
3	N_1	N_2	N_3			$N_1 + N_2 + N_3$
…	…	…	…			…
n_c	N_1	N_2	N_3	…	N_{n_c}	$\sum_{i=1}^{n_c} N_i$
$k_{p,0}$	$\boldsymbol{n_c}$	$\boldsymbol{n_c - 1}$	$\boldsymbol{n_c - 2}$	…	**1**	

The diversification of the country in time j is given by:

$$k_{c,0} = \sum_{i=1}^{j} N_i \tag{VII.17}$$

For each product that is part of a block of products i, its ubiquity is given by:

$$k_{p,0} = n_c - i + 1 \tag{VII.18}$$

And for each period j the average ubiquity is given by:

$$k_{c,1} = \frac{\sum_{i=1}^{j} (n_c - i + 1) N_i}{\sum_{i=1}^{j} N_i} \tag{VII.19}$$

The equation (VII.19) can be simplified as follows:

$$k_{c,1} = \frac{\sum_{i=1}^{j} (n_c - i + 1) N_i}{\sum_{i=1}^{j} N_i} = \frac{(n_c + 1) \sum_{i=1}^{j} N_i - \sum_{i=1}^{j} i N_i}{\sum_{i=1}^{j} N_i} = (n_c + 1) - \frac{\sum_{i=1}^{j} i N_i}{\sum_{i=1}^{j} N_i} =>$$

$$=> k_{c,1} = (n_c + 1) - \frac{\sum_{i=1}^{j} i N_i}{k_{c,0}} \tag{VII.20}$$

Suppose that products require specific capacities to be produced (Hausmann and Hidalgo, 2009) and that, following the same constraint proposed in Weitzman (1998), there is a limit of the number of combinations of capacities that can be discovered, indicated by L. That limit is given by the physical constrains of the amount of labour and time available to search and test the usefulness of the combination of existing capabilities. Therefore, there is a threshold time period t such as that, after that time, the maximum number of products is given by L:

$$N_i = L, \quad j > t \tag{VII.21}$$

For higher values of the time period j, the diversification can be approximated by:

$$k_{c,0} = \sum_{i=1}^{j} N_i \approx N_j \tag{VII.22}$$

and for values of j close to, but lower than the threshold, the approximation is:

$$\sum_{i=1}^{j} iN_i \approx jN_j \tag{VII.23}$$

Therefore, for values of $j \leq t$ close to the threshold t:

$$k_{c,1} = (n_c + 1) - \frac{\sum_{i=1}^{j} iN_i}{k_{c,0}} \approx (n_c + 1) - j \tag{VII.24}$$

and the slope of the curve $lnk_{c,1}\ x\ lnk_{c,0}$ is given by:

$$\frac{\partial lnk_{c,1}}{\partial lnk_{c,0}} \approx \frac{\partial\ ln\left((n_c+1)-j\right)}{\partial lnk_{c,0}} = 0 \tag{VII.25}$$

Hence, for early time periods in which the country was less diversified, there is no association between the level of diversification of the country and the average ubiquity of its production.

On the other hand, for periods after the threshold (i.e. values of $j > t$):

$$\sum_{i=1}^{j}(n_c - i + 1)N_i \approx \sum_{i=t}^{j}(n_c - i + 1)L = L\sum_{i=t}^{j}(n_c - i + 1) = L\,\alpha \tag{VII.26}$$

in which α is a term to represent $\sum_{i=t}^{j}(n_c - i + 1)$.

Substituting Eq. (VII.26) in Eq. (VII.19) yields the average ubiquity at time j being given by:

$$k_{c,1} = \frac{\sum_{i=1}^{j}(n_c - i + 1)N_i}{k_{c,0}} = \frac{L\,\alpha}{k_{c,0}} \tag{VII.27}$$

Thus, the relation between the logarithms of $k_{c,1}$ and $k_{c,0}$ is:

$$\ln\left(k_{c,1}\right) = \ln(L\,\alpha) - \ln(k_{c,0}) \tag{VII.28}$$

and the slope of the curve $lnk_{c,1}\ x\ lnk_{c,0}$ is given by:

$$\frac{\partial lnk_{c,1}}{\partial lnk_{c,0}} = -1 \tag{VII.29}$$

Therefore, for periods of time in which the country is more diversified, there is a negative association between diversification and average ubiquity.

Now suppose that other countries follow the path of diversification of country *A* described above, with different levels of success. If we were to create a matrix of countries connected to products, that matrix would resemble Table 7.2. Moreover, the results described above would represent the relationship between diversification and average ubiquity of that matrix of countries and products. Therefore, the model described above indicates that the empirical regularity discussed could be replicated by a mechanism of innovation in which new products are created by a country at the frontier of technology by the combination of existing capabilities (Kauffman, 2008) but with limits on the number of capabilities that can be combined (Weitzman, 1998), and in which other countries emulate the production of the frontier country, with different levels of success.

7.3.2 Analysis of the relationship between output and productive capacities

In this sub-section I explore the combination of Pasinetti's (1993) model with the assumptions related to countries, capabilities and products that are common in the economic complexity literature. The objective is to test the prediction of the resulting model in relation to the association between total GDP and productive capacities.

I adopt the same approach of Pasinetti (1993) in formulating a minimal theoretical scheme to represent basic characteristics of structural dynamics of a pure labour economy. The economy is described by an ensemble of m sectors each producing a specific and highly differentiated consumption good that is produced by labour only. Each individual produces or contributes to the production of a single good, and obtains the other goods that she or he consumes through exchange.

A new element to Pasinetti's formulation of the structural economic dynamics is the representation of a sector by means of two set of characteristics as in Saviotti and Pyka (2004a, 2004b, 2004c). In Saviotti and Pyka's definition of a sector, the two sets are the set of the technical characteristics representing the internal structure of the products and the set of services supplied to the users. The authors define a sector by the provision of common services in the set of services characteristics. In the model proposed here, however, the two set of characteristics are the set of technologies required for the production of the good and the set of services characteristics of the product. We distinguish a sector by the set of technologies required for production. This definition is similar to that adopted by Metcalfe et al. (2005), in which each sector is distinguished by the unique knowledge base embodied in the production methods.

Formally:

$$\{\tau_i\} \Leftrightarrow \{S_i\} \qquad \text{(VII.30)}$$

Where τ_i is the set of technologies required for the production of i and S_i is the set of services characteristics.

As in Pasinetti's model, in a given period, each sector i is described by a labour coefficient l_i and a per-capita consumption coefficient c_i. Suppose that the labour coefficient of sector i is a function of the set of productive knowledge associated with the production of i. This assumption is similar to that proposed by Hidalgo and Hausmann (2009) that products require a specific set of capabilities to be produced; some of these capabilities are available in a country, but not all of them; and only the products for which the required sets of capabilities are available in a country are produced there.

Such set of productive knowledge can be interpreted as labour-embodied technology, based on Arthur's (2009) definition of technology as a "means to fulfil a human purpose" that can be a device, a method or a process. In the case of a *pure labour economy*, the set of labour-embodied technologies can be defined as the set of all methods and processes to produce the good.

Formally, the labour coefficient is a function of the set of labour-embodied technologies:

$$l_i = f(\tau_i) \qquad i=1,2,\ldots,m, \qquad \text{(VII.31)}$$

Other elements of the Pasinetti's model are also adopted by the model described in this sub-section. Total population $N(t)$ and working population $L(t)$ coincide:

$$L(t) \equiv N(t) \qquad \text{(VII.32)}$$

Physical quantities are defined in per-capita terms as:

$$q_i(t) = \frac{Q_i(t)}{N(t)} \qquad i=1,2,\ldots,m, \qquad \text{(VII.33)}$$

And the price of sector i's product is represented by p_i.

Also as in Pasinetti's model, the relation between labour and consumption coefficients, and prices and quantities is given by a production scheme according to Leontief's closed model, consisting of two systems. The physical quantity system is given by:

$$\begin{bmatrix} 1 & 0 & \cdots & 0 & -c_1 \\ 0 & 1 & \cdots & 0 & -c_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & -c_m \\ -l_1 & -l_2 & \cdots & -l_m & 1 \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_m \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix} \qquad \text{(VII.34)}$$

While the price system is given by Eq.(VII.35) below, setting the wage $w = 1$, which means that prices are represented in terms of wage rates:

$$\begin{bmatrix} 1 & 0 & \cdots & 0 & -l_1 \\ 0 & 1 & \cdots & 0 & -l_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & -l_m \\ -c_1 & -c_2 & \cdots & -c_m & 1 \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_m \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix} \qquad \text{(VII.35)}$$

All magnitudes that appear in Eq.(VII.34) and Eq.(VII.35) are functions of time, but the time indices were suppressed for simplification.

The necessary condition that has to be satisfied to ensure non-trivial solutions for Eq.(VII.34) and Eq.(VII.35) exist is that the determinant of the coefficient matrices in both equations are zero. That condition is the same for both systems and is equivalent to:

$$\sum_{i=1}^{m} c_i \, l_i = 1 \qquad \text{(VII.36)}$$

When this condition is fulfilled, the solution for the physical quantities is:

$$q_i = c_i \qquad i=1,2,\ldots,m, \qquad \text{(VII.37)}$$
$$Q_i = c_i N \qquad i=1,2,\ldots,m, \qquad \text{(VII.38)}$$

The solution for the price systems is:

$$p_i = l_i \qquad i=1,2,\ldots,m, \qquad \text{(VII.39)}$$

Total output by sector i ($Y_i(t)$) (in value terms) is given by the price multiplied by the quantity produced:

$$Y_i = p_i Q_i \qquad i=1,2,\ldots,m, \qquad \text{(VII.40)}$$

Substituting Eq.(VII.38) and Eq.(VII.39) in Eq.(VII.40) yields:

$$Y_i = l_i \, c_i N \qquad i=1,2,\ldots,m, \qquad \text{(VII.41)}$$

Total output of the economy is the sum of the output of the individual sectors:

$$Y = \sum_{i=1}^{m} Y_i = N \sum_{i=1}^{m} l_i c_i \qquad i=1,2,\ldots,m, \qquad \text{(VII.42)}$$

Substituting Eq.(VII.31) in Eq.(VII.42) (to express the labour coefficients as a function of the set of technologies) yields total output:

$$Y = \sum_{i=1}^{m} Y_i = N \sum_{i=1}^{m} f(\tau_i) c_i \qquad i=1,2,\ldots,m, \qquad \text{(VII.43)}$$

We can now use Eq.(VII.43) to analyse the association between productive capacities and total output across countries.

A simple regression model can be formulated as follows (logarithms are taken of both sides of Eq.(VII.43)):

$$\ln(Y) = \ln(N) + ln(\textstyle\sum_{i=1}^{m} f(\tau_i) c_i) \qquad i=1,2,\ldots,m, \qquad \text{(VII.44)}$$

As country comparisons can only meaningfully be made using a common currency, total output and the right side of Eq.(VII.44) are divided by a term representing the exchange rate (λ).

$$l\,n\left(\frac{Y}{\lambda}\right) = -\ln\lambda + \ln(N) + ln(\textstyle\sum_{i=1}^{m} f(\tau_i) c_i) \qquad i=1,2,\ldots,m, \qquad \text{(VII.45)}$$

Equation (VII.45) suggests that a cross country analysis of the association between a country's total GDP in dollar terms and its diversification could be analysed by a regression model that includes: (a) the exchange rate between the national currency and US dollar, (b) the size of the population and (c) the sum of the set of technologies required to produce each product in the economy, weighted by the consumption coefficients. The terms (a) and (b) are easily obtained from the databases of international organizations such as the United Nations. The term (c) is obviously not available. Given our assumptions related to a specific set of technologies required for production of a given good, let us suppose that we can use the measure of productive capacities of an economy obtained through the method of reflections as presented in Chapter Three as a proxy of (c).

Therefore, using *PCAP* as a proxy for the ensemble of labour-embodied technologies in the economy, Eq.(VII.45) can be rewritten as:

$$ln(Y/\lambda) = -\ln(\lambda) + \ln(N) + lnPCAP \qquad i=1,2,\ldots,m, \qquad \text{(VII.46)}$$

And the regression model is written as:

$$l\,n\left(\frac{Y}{\lambda}\right) = \alpha\ln(\lambda) + \beta\ln(N) + \gamma lnPCAP + \delta_{2005} + \textstyle\sum_{j=2006}^{2010} \delta_j\, DY_j + \varepsilon \qquad i=1,2,\ldots,m, \qquad \text{(VII.47)}$$

Year dummies (DY_j) were included to allow for pooling data over the period from 2005 to 2010 in the analysis. A regression analysis was conducted using GDP, population and exchange rate data from the World Bank Development Indicators database, and *PCAP* derived from disaggregated UN Comtrade trade data at HS 2002 6-digit level and further disaggregated by unit value range using the methodology presented in Chapter Three. The results are presented in Table 7.3.

Table 7.3. Regression analysis: GDP and productive capacities

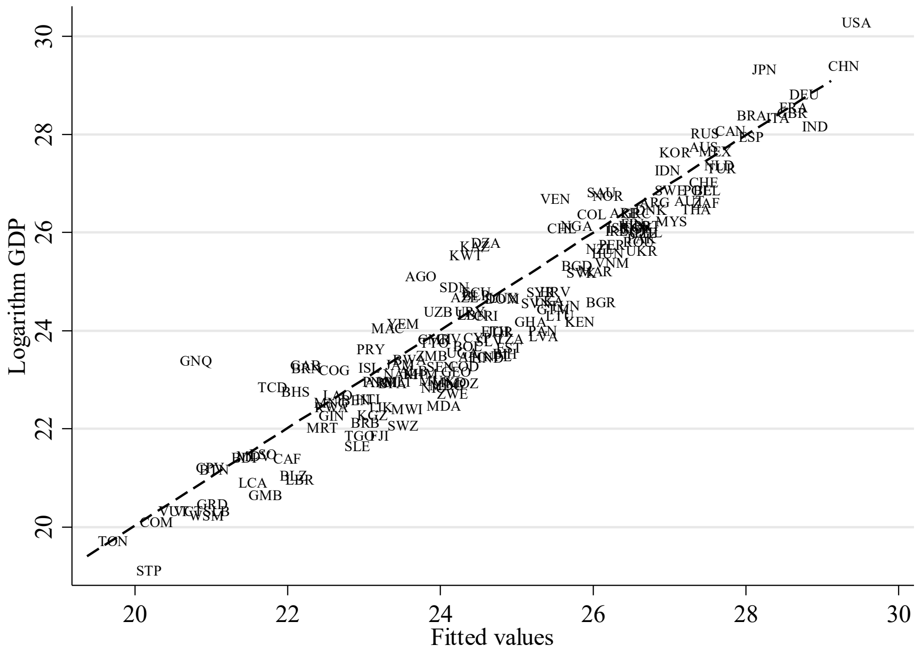
	Logarithm GDP (current US$)		
	(1)	(2)	(3)
PCAP (logarithm)	1.157	0.94	0.853
	(65.38)**	(61.98)**	(49.10)**
Population, total (logarithm)		0.378	0.444
		(24.86)**	(27.58)**
Official exchange rate, LCU per USD,			-0.097
period average (logarithm)			(9.95)**
Year 2005	-37.923	-32.311	-28.395
	(39.92)**	(43.71)**	(34.35)**
Year 2006	0.259	0.228	0.216
	(2.53)*	(2.68)**	(2.67)**
Year 2007	0.862	0.743	0.697
	(8.41)**	(8.77)**	(8.64)**
Year 2008	1.314	1.135	1.059
	(12.63)**	(13.30)**	(12.95)**
Year 2009	1.341	1.138	1.061
	(12.86)**	(13.61)**	(13.19)**
Year 2010	1.38	1.174	1.109
	(13.02)**	(14.05)**	(13.71)**
Observations	1003	1003	995
R-squared	0.82	0.88	0.9

Robust t-statistics in parentheses * significant at 5%; ** significant at 1%

Source: Author's computations based on data from the World Bank Development Indicators database and trade data from UN Comtrade.

The coefficients of the three independent variables are statistically significant and the associations are in the direction expected considering Eq.(VII.47). Higher total GDP is associated with higher value for the ensemble of the set of technologies, larger populations and lower exchange rates, other things equal. The set of independent variables explains 90% of the variation of GDP values in the sample. Figure 7.1 presents the result of the regression analysis (3).

Figure 7.1. Result of regression analysis (3), GDP and productive capacities, year=2010



Source: Author's computations based on data from the World Bank Development Indicators database and trade data from UN Comtrade.

Note: Along the horizontal axis are values of GDP fitted using variables *PCAP*, population, exchange rate, and year dummies.

An alternative proxy for the term (c) in Eq.(VII.47) is the diversification of the economy. This can be justified in at least two ways. First, *PCAP* is calculated as the measures of diversification divided by measures of average ubiquity of exports. In a simplified form, we could consider the following:

$$PCAP \approx \frac{k_{c,0}}{k_{c,1}} \tag{VII.48}$$

Therefore, Eq.(VII.47) can be rewritten as:

$$ln(Y/\lambda) = \alpha \ln(\lambda) + \beta \ln(N) + \gamma ln k_{c,0} + \vartheta \ln k_{c,1} + \ \delta_{2005} + \sum_{j=2006}^{2010} \delta_j \, DY_j + \ \varepsilon \tag{VII.49}$$

Another possible justification is that, based on the model, the ensemble of labour-embodied technologies of an economy increases at each passage of time, after new products have been created. Therefore, as a direct consequence of the basic hypotheses of the model, the ensemble is a function of the number of products in the economy.

The regression analysis based on (VII.49) was conducted using the same datasets as in the analysis of (VII.47). The result of the analysis is presented in Table 7.4.

Table 7.4. Regression analysis: GDP and diversification

	Logarithm GDP (current US$)		
	(1)	(2)	(3)
Diversification, number of products (logarithm)	0.883	0.559	0.548
	(14.16)**	(11.55)**	(11.58)**
Average ubiquity of exports (logarithm)	-3.767	-3.876	-3.364
	(12.17)**	(17.73)**	(14.26)**
Population, total (logarithm)		0.386	0.444
		(25.51)**	(27.65)**
Official exchange rate, LCU per USD,			-0.087
period average (logarithm)			(8.34)**
Year 2005	32.775	29.777	27.031
	(18.12)**	(23.00)**	(19.63)**
Year 2006	0.174	0.178	0.168
	-1.73	(2.19)*	(2.15)*
Year 2007	0.375	0.376	0.359
	(3.73)**	(4.64)**	(4.60)**
Year 2008	0.574	0.575	0.543
	(5.62)**	(7.05)**	(6.90)**
Year 2009	0.46	0.45	0.431
	(4.52)**	(5.67)**	(5.64)**
Year 2010	0.536	0.507	0.5
	(5.20)**	(6.43)**	(6.53)**
Observations	1003	1003	995
R-squared	0.82	0.89	0.9

Robust t-statistics in parentheses * significant at 5%; ** significant at 1%

Source: Author's computations based on data from the World Bank Development Indicators database and trade data from UN Comtrade.

Again, all coefficients are statistically significant and the associations are in the direction expected by considering (VII.49). Higher total GDP is associated with higher diversification, larger populations and lower exchange rate, respectively and other things being equal. The set of independent variables explain 90% of the variation of GDP values in the sample.

It should be noted that diversification and productive capacities are associated with total GDP and not the GDP per capita of an economy. That result can be verified by subtracting $\ln(N)$ from both sides of Eq.(VII.46):

$$ln(Y/\lambda) - \ln(N) = \alpha \ln(\lambda) + \beta \ln(N_i) + \gamma lnPCAP - \ln(N)$$

Which results in:

$$ln(Y/\lambda N) = \alpha \ln(\lambda) + (\beta - 1) \ln(N) + \gamma lnPCAP \qquad \text{(VII.50)}$$

A regression model based on Eq.(VII.50) shows that the analysis of the association between GDP per capita and productive capacities should include the total population as an independent variable. This is an important result because, as mentioned in Chapter Four, the literature has focused on analysing the association between diversification and output per capita (Cadot et al., 2012; Klinger and Lederman, 2004).

7.4 Modelling strategy

The discussion of the models presented in the previous sections suggests that current approaches to explain the stylized facts found in the empirical literature are either dissociated from economic theory or have to make assumptions that relate existing concepts (e.g. technology) to measures of unobservable concepts such as productive capacities, complexity and adaptability in product space. Although these approaches can arguably result in possible explanations for the stylized facts, as shown for example with the two models presented in the previous section, some gaps remain in our understanding of the relation between diversification and structural economic dynamics.

The rest of the thesis will explore ways to narrow this gap. To understand the stylized facts listed in the previous sections better, it is necessary to have a model that considers: a) the existence of multiple sectors in an economy, and analyses how that structure changes and affects key macro-economic indicators (e.g. employment, gross national product, total consumption and balance of trade); and b) the existence of multiple countries, as part of a global economy in which these countries trade with each other.

Explicit analytical accounts of the economic structure can be traced back to the Classical period of economics with the *Tableau Économique* of Quesnay and the work of Marx. Taylor (2004), for example, lists Schumpeter, Sraffa, Young, Kalecki, Keynes and Leontief among the economists that considered economic structure in the modern period from 1900 to 1940. This brief account illustrates the fact that structural change has an important tradition in economic theory.

Among the models of structural dynamics, Pasinetti (1981) is, according to Silva and Teixeira (2008), the most cited study in the literature. That study presents a comprehensive investigation of structural change and economic dynamics in which the primary source of change is technological progress resulting from human learning. It also explicitly considers the effects of different rates of technological progress and change in consumption patterns in the various sectors of an economy, which is usually not considered in contemporary models of economic growth (e.g. Grossman and Helpman 1991, 2016; Romer 1990). Based on that, I have decided to take Pasinetti's (1993) model, which could be considered the pure labour economy version of Pasinetti (1981), as the basis for an investigation of economic structural dynamics and diversification.

The discussion in the next chapters will follow two different tracks that have emerged naturally during my investigation. First, I will add assumptions related to countries, capabilities and products, which are common to the literature on economic complexity, to Pasinetti's (1993) model and will study the implications for structural economic dynamics. The second track is to extend Pasinetti's model, which describes an economy in autarky, to consider international trade to enable the study of the effects of trade on diversification and vice-versa.

The second track requires two key modifications to Pasinetti's framework. I need to first propose a model of trading economies following Pasinetti's investigation of the structural economic dynamics of open economies, which he presented without the benefit of a formal model. Some models have proposed such formalizations (e.g. Araujo and Teixeira, 2004; Araujo, 2013; Araujo and Trigg, 2015). However, these formalizations are not used here because they result in full specialization of exports based on price, which is not consistent with the empirical pattern of diversification in which, for many products, multiple countries are producers and exporters.

In this book, I adopt two mechanisms to account for non-full specialization of production and trade. First, the model considers the existence of markup and assumes that the same type of product produced in different countries could have the same international price by adjusting those markups if production costs are different. The second mechanism is a linear programming approach inspired by the World Trade Model proposed by Duchin (2005). Duchin's model determines output in each sector and each country by minimizing the factors of production, including labour, under certain constraints such as the limited amount of labour available. Therefore, it does not assume *ex-ante* full specialization and allows for situations in which similar products with different production costs coexist in the global market. This mechanism is implemented in the static (short-term) formulation of the model.

Second, Pasinetti's (1993) model is developed in terms of a 'natural system', which leads to a normative theory of full employment and effective demand to be used as a benchmark to assess the actual workings of a given economic system (Scazzieri, 2012). However, the study of the effect of the structural economic dynamics and diversification on employment at the sectoral and economy-wide levels is an important component of my research. Therefore, it is important that the model that I use to investigate the effects of diversification is capable to take account of employment levels. As result, I do not assume full employment and effective demand in the model. The same approach is followed by Araujo (2013) and Araujo and Trigg (2015).

This decision has direct implications in terms of modelling strategy related to the assumption regarding how output of each sector is determined. Taylor (2004) provides a comprehensive discussion on that topic. In that regard, he divides models of structural dynamics into two groups: a) models that assume that output is determined by full employment of labour and capital (Say's law/ Walras's law), and b) models that adopt the Keynes-Kalecki principle of effective demand.

Examples listed by Taylor (2004) of models that postulate full employment are the neoclassical growth models such as by Romer (1990), Lucas (1988), and Grossman and Helpman (1991), which consider full employment of labour and assume that prices adjust to make the economy reach such state, as well as models by Kaldor, Passineti, Goodwin, Lewis, Marglin, and Latin American Structuralists such as Celso Furtado. Examples of models that follow Keynes-Kalecki principle of effective demand include those by Leontief, Harrod-Domar, Rosenstein-Rodan, Nurkse, Scitovsky, Robinson, Myrdal, Hirschman, Kuznet, Chenery, and Arrow.

In this book, I assume the Keynesian view of consumer demand and adopt Clower's (1965) "dual-decision hypothesis" in which households decide on the expenditure in the next period based on the income of the current period. This mechanism is implemented in the dynamic formulation of the model.

7.5 Summary

This chapter opens the discussion of possible explanations for the stylized facts that were presented in the first part of the thesis and that guided the analysis in the second part. The chapter briefly discusses how different strands of literature have considered diversification and presents selected models that have been proposed in the literature to explain related empirical regularities.

The chapter identifies two modelling strategies in the literature. The first relates to the proposition of theoretical frameworks based on the tripartite network connecting countries, capabilities and products, but somewhat dissociated of economic theory (Hausmann and Hidalgo, 2011; Lei and Zhang, 2014; Klimek et al., 2012, and Saracco et al., 2015). The second strategy uses a more traditional economic framework, adds to it the assumptions related to capabilities and complexity, and use the empirical data to test predictions of the model (e.g. Ferrarini and Scaramozzino, 2016).

Two models using those strategies have been presented in the chapter. The first has the objective to explain the negative association between diversification and average ubiquity analytically, and the second tests model predictions related to the association between total output and diversification. These discussions and the models presented show that these approaches could produce possible explanations for the stylized facts. However, they also show that the models proposed are not particularly grounded in economic theory and therefore there is scope for investigations on the relation between diversification and structural economic dynamics.

The chapter discusses the two tracks in modelling strategy adopted in the thesis. The first relates to the adoption of assumptions related to countries, capabilities and products to Pasinetti's (1993) model to study the implications for structural economic dynamics. The second track extends Pasinetti's model to consider international trade. The first track will be presented in the next chapter (Eight) and the second track in the four chapters that follow it.

8

Diversification in a Pasinettian model

This chapter explores the implications of the explicit formalization of diversification within the theoretical framework of structural economic dynamics proposed by Pasinetti (1993). The model proposed in this chapter adopts the usual assumptions of the empirical literature on economic complexity (e.g. Hausmann and Hidalgo, 2009) to account for the stylized facts discussed in the previous chapters. The discussion focuses on the predictions related to technological unemployment. The results presented in this chapter suggest that innovation without diversification has the effect of increasing purchasing power in the short term but it results in technological unemployment and a consequent decrease in per capita income in the long term. On the other hand, the emergence of novelty with diversification results in inflation in the short term, but helps fighting technological unemployment on the other hand.

8.1 Introduction

As discussed in the previous chapter, Pasinetti's (1993) framework of structural economic dynamics is one of the most cited models in the literature of structural change (Silva and Teixeira, 2008). Pasinetti (1993) presents a multi-sectoral model of structural change and economic dynamics of a "pure labour" economy in which the primary source of change is technological progress resulting from human learning. This model is used for the study of economic dynamics and its relationship with economic characteristics such as the structure and levels of prices, consumption, savings, rates of interest, and inter-temporal distribution of income.

One of the focuses of Pasinetti's investigation is the problem of technological unemployment.[1] This phenomenon is described in Pasinetti's framework as follows. Technological progress (i.e. innovations based on new devices, methods and processes) is continuously used to augment the productivity of labour in the production of commodities. Different sectors experience technical progress at different and time-varying rates, but there is no natural upper limit for progress. On the other hand, per capita consumption patterns follow S-shaped paths that ultimately result in stable levels of consumption per capita for higher level of incomes. If there were no new products (i.e. no diversification of production), the fate of the economic system would be to generate technological unemployment. Less and less people would be required to produce commodities in the quantity that would satisfy the needs of the entire population.

Pasinetti (1993) discusses two ways to avoid technological unemployment. The first relates to changes in the proportion of the working population relative to total population and the proportion of time devoted to work; people could enjoy more leisure time. Note that this was the same logical conclusion that Keynes reached in his 1930's essay entitled "Economic Possibilities for our Grandchildren". In that essay, Keynes noted the enormous and continuous technological progress and capital accumulation since the sixteenth century, and argued that the future economic problem of the human race would not be the production of goods to fulfil our *absolute* needs,[2] but what we as a society would do with all the leisure time that we would ultimately have available.

Clearly such an image of the future is far from the reality of economic life. Therefore, another mechanism has to be in place to prevent technological unemployment. Pasinetti (1993) noted that economic diversification is such a mechanism. New economic sectors create new jobs that could absorb the workers who are not needed in traditional sectors (Gualerzi, 2012). They also create new goods and services that meet human needs, which were not satisfied by existing products.

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[1] A comprehensive discussion of Pasinetti's results in terms of the employment consequences of new technologies is found in Hagemann (2012).

[2] Keynes (1930) makes the distinction between absolute needs, those that are not relative to the position of other people, and those that are relative in the sense that we enjoy them because they make us feel superior to others.

However, despite the importance given to diversification in addressing technological unemployment, Pasinetti's (1993) model only formalizes technical progress in terms of improvements of productivity in producing existing products, not in terms of new products. Pasinetti (1993) lists diversification as one of the main characteristics of technical progress, and noted that the emergence of new products can be included in the model by considering that the list of economic sectors increases over time. Nevertheless, he has not addressed the path of such change and how diversification comes about. In addition, such a solution does not allow for more elaborated analysis of the role of diversification in the economic system.

This chapter explores the role of diversification by explicitly adding it to Pasinetti's (1993) model and adopting the assumptions related to the countries, capabilities and products that are common to the literature on economic complexity (e.g. Hausmann and Hidalgo, 2009). The next section provides the description of the model, which is followed by an analysis of structural economic dynamics. The chapter discusses the implications of economic diversification in terms of total output and employment vis-à-vis the predictions in Pasinetti (1993).

8.2 The model

The model follows the framework presented in Pasinetti (1993): an economy is composed by an ensemble of m production sectors each making a specific and highly differentiated consumption good that is produced by means of labour alone. One household sector provides labour to the production sectors and consumes the commodities that these sectors produce. These commodities could be either goods or services. Each individual in the population is engaged in the production of a single commodity, and obtains the commodities that she or he consumes through exchange. A unit of labour is remunerated by the wage rate.

In the dynamic formulation of the model, the economy changes with: 1) changes in the size of the population, which affect the total quantities that are demanded of each commodity produced and the total labour available for production, 2) the exogenous change of consumption patterns, which changes the quantities of the commodities demanded, and 3) exogenous technical progress.

The description of the model in the short run is the same as in Eq. (VII.30) to Eq. (VII.42) in the previous chapter. As in Pasinetti's (1993) model, in a given unit of time, each sector i has a labour coefficient l_i and a per-capita consumption coefficient c_i.

Here I adopt an approach similar to that described in the previous chapter in section 7.3.2, in which a production sector is characterized by the set of labour-embodied technologies required for production. In this chapter, we further characterize these technologies as a network represented by a direct graph.

Formally, each sector i can be represented by a network τ_i that consist of a set of n technologies($T_i = \{t_1, t_2, t_3, \dots, t_n\}$), which are the nodes of the network, and an n x n adjacency matrix g, of which each element g_{xy} can take a value of either 0 or 1 representing the relation between technologies x and y:

$$\tau_i = (T_i , g) \qquad i=1,2,\dots,m, \qquad \text{(VIII.1)}$$

Any two sectors i and j are differentiated by the network of technologies used in the production:

$$\tau_i \neq \tau_j \qquad i,j=1,2,\dots,m,\ i\neq j \qquad \text{(VIII.2)}$$

We assume that each technology in the network ($t_j \in T_i$) is composed by a set of operations that are performed sequentially. Operations are here defined as the activity in which labour is employed. For example, the act of moving an object from location A to location B is assumed to be composed of a set of operations such as "move to location A", "grab the object", "lift the object", "turn to the direction of location B"¸ and so on and so forth.

8.2.1 *Basic hypotheses*

In Pasinetti's (1993) model, the path of change of variables over time is modelled using exponential functions. For example, if the population is assumed to grow over time at a growth rate of g, this is initially modelled as:

$$N(t) = N(0)e^{gt} \qquad \text{(VIII.3)}$$

However, the model also assumes that the rate of change of variables varies over time. To implement this, time is divided into finite stretches of length z, which are called phases. It is assumed that the rates of change of the variables of the model remain constant within each phase. Formally, a new variable θ is defined as follows:

$$\theta = t - \eta z \qquad \text{(VIII.4)}$$

Where η is the largest integer that leaves a positive remainder θ when multiplied by z and subtracted from t. The variable θ represents the time elapsed within a phase.

Using variable θ, Eq.(VIII.3) is rewritten as follows:

$$N(t) = N(t - \theta)e^{g\theta} \qquad \text{(VIII.5)}$$

Similar to the other variables of the model, we assume that the number of products changes over time, remaining constant within a time phase. However, we do not use an exponential function to model its path of change. For simplification, we assume that the economy starts without products in *t=0* and $k \geq 0$ new products are created at every passage from one time phase to another:

$$m(t) = m(t-\theta) + k; \qquad m(0) = 0, \qquad k \geq 0 \qquad \text{(VIII.6)}$$

8.2.2 Labour coefficients

As discussed, we assume that each sector is characterized by a network of technologies. A change in such a network results in the emergence of another sector. The network of existing technologies associated with each sector does not change. For each sector, the labour coefficient remains unchanged from the time of its emergence, which we represent by the symbol (t_i^*):

$$l_i(t) = \begin{cases} l_i(t_i^*), & t = t_i^* \\ l_i(t-\theta), & t > t_i^* \end{cases} \qquad i=1,2,\ldots,m \qquad \text{(VIII.7)}$$

This is a departure from Pasinetti's (1993) model. Pasinetti assumes that there is technical progress over time with increases in labour productivity given by a rate of growth of productivity, which is different across sectors. In the model presented in this chapter, there is no technical progress as such. Productivity in each sector is assumed to remain constant given that any changes in productivity has to be the result of a change in the combination of technologies required to make the specific product associated to that sector, and different combinations of technologies result in different products, and, therefore, the emergence of a new sector in the economy.

8.2.3 Consumption coefficients

We assume that changes in consumption coefficients are the result of exogenous consumer decisions, which are affected by the appearance of a new sector in the economy. Let us first consider a situation in which no new sector has emerged in the economy during the latest passage of time. Note that there is still the assumption that consumer's decisions are exogenously affected by changes in tastes, social norms, etc. Therefore, we assume that, for each commodity *i*, the growth rate of consumption coefficient driven by those exogenous decisions is (r_i), which we assume constant within each time phase.

Formally:

$$c_i(t) = c_i(t-\theta)e^{r_i\theta} \qquad i=1,2,\ldots,m-1 \quad \text{(VIII.8)}$$

The rates of change vary from one commodity to the other. Hence, for any commodity *i* and for any commodity *j*:

$$r_i \neq r_j \qquad\qquad i,j=1,2,\ldots,m-1,(\ i \neq j) \quad \text{(VIII.9)}$$

Now, let us assume that a new commodity m appeared during the latest passage of time. The consumption coefficient of m during the time phase that follows that transition is given by $c_m(t)$. The appearance of a new commodity has an impact on the demand of other products because of the potential for substitution or complementarities (Gualerzi, 2012). Such an effect will be reflected in changes in consumption patterns and we assume they are factored into the consumption coefficients (r).

Note that the formalization of the changes in consumption patterns presented above has followed the scheme presented in Pasinetti's (1993) model. However, we will now introduce some changes to deal with the special case of the new product m providing the same services provided by an existing product i.

If m provides exactly the same services as provided by i (they are perfect substitutes) and the price of m is lower than the price of i, then the demand for i will drop to zero because we assume that in this situation consumers will always prefer the product with lower price. On the other hand, if m provides exactly the same services as provided by i but the price of m is higher than the price of i then the demand for m will be zero and the sector would not have emerged in the first place.

Formally:

$$c_i(t) = \begin{cases} c_i(t-\theta)e^{r_i\theta}, & \text{if } S_i \neq S_m \\ 0 & \text{, otherwise} \end{cases} \qquad i=1,2,\ldots,m-1 \qquad \text{(VIII.10)}$$

Assume that for each sector i, in which the services provided by product i are different from those provided by the new sector m ($S_i \neq S_m$), the consumption coefficients (r_i) can be divided into two components: 1) a rate of change in consumption that is exclusively the result of complementarity or substitution effects of the appearance of the new product (r_{im}) on the demand for product i; and 2) a rate of change in consumption (r_{i*}) that is the result of exogenous decisions triggered by any factor other than the appearance of m. As discussed, this would include consumer decisions driven by changes in tastes, social norms, income, etc. Formally:

$$r_i = r_{i*} - r_{im} \qquad\qquad if\ \ S_i \neq S_m \qquad \text{(VIII.11)}$$

The equation (VIII.10) is then revised as follows:

$$c_i(t) = \begin{cases} c_i(t-\theta)e^{(r_{i*}-r_{im})\theta}, & \text{if } S_i \neq S_m \\ 0 & \text{, otherwise} \end{cases} \qquad i=1,\ldots,m-1 \ \text{(VIII.12)}$$

If there are no substitution or complementarity effects, r_{im} would not result in any changes in the consumption coefficient of i. Note that this is the same as if there were no new products in the economy. If the introduction of the new product creates new needs that can be fulfilled by product i and, therefore, increase demand for i due to complementarity of services, which otherwise would not exist without the introduction of m, then r_{im} would increase the consumption coefficient of sector i. Similarly, if the new product m results in substitution effects on the demand of product i, this demand would decrease.

Therefore, the effect of m on the demand for i (r_{im}), in case that the services provided by product i are different from those provided by the new sector m ($S_i \neq S_m$), are given by one the three conditions:

$0 < r_{im}$	reduction of demand for i
$r_{im} = 0$	no changes in demand for i
$r_{im} < 0$	increase of demand for i

8.2.4 Structural dynamics of prices

In each economic sector i the price of a product does not change over time in relation to the wage rate (w=1):

$$p_i(t) = l_i(t) = l_i(t_i^*) = p_i(t_i^*) \qquad i=1,2,\ldots,m \qquad \text{(VIII.13)}$$

This is the expected result of the assumption of a constant network of technologies characterizing a particular sector. Without change of economic sectors in the economy there is no change in the amount of labour required for the production of a commodity. In the case considered of a pure labour economy, no changes in labour coefficient results in no changes in the price of the commodity.

8.2.5 Structural dynamics of production

Combining the assumptions for change in population (VIII.6) and changes in consumption patterns (VIII.12), the solution for the physical quantities system is then written as:

$$Q_i(t) = \begin{cases} c_i(t-\theta)N(t-\theta)e^{(g+r_{i*}-r_{im})\theta}, & \text{if } S_i \neq S_m \\ 0, & \text{otherwise} \end{cases} \qquad i=1,2,\ldots,m-1 \qquad \text{(VIII.13)}$$

$$Q_m(t) = c_m(t)N(t-\theta)e^{g\theta} \qquad \text{(VIII.14)}$$

The dynamics of the quantities produced of each product i ($S_i \neq S_m$) are governed by three components: 1) a scalar component of the rate of population growth (g), which affects all economic sectors exactly in the same way, 2) a structural component that is specific to each sector given by the a rate of change in consumption that is exclusively the result of complementarities or substitution effects of the appearance of the new product (r_{im}), and 3) another structural component given by the rate of change in consumption (r_{i*}) that is the result of exogenous decisions triggered by any other factor but the appearance of m.

8.3 Analysis of structural economic dynamics

8.3.1 Quantitative change – autarky

Quantitative change would occur when there is no change in the composition and number of products of which the economy is comprised:

$$m(t) = m(t-\theta) \qquad \text{(VIII.15)}$$

As discussed, labour coefficients do not change, as well as prices in terms of wage rates (VIII.13):

$$p_i(t) = l_i(t) = l_i(t_i^*) = p_i(t_i^*) \qquad i=1,2,\dots,m,$$

For each sector i, the growth rate of consumption coefficient is the result of exogenous consumer decisions, but not influenced by substitution or complementarities of new products, given that those are assumed inexistent. Thus (VIII.11) becomes:

$$r_i = r_{i*} \qquad \text{(VIII.16)}$$

Quantities produced in each sector are given by:

$$Q_i(t) = c_i(t-\theta)N(t-\theta)e^{(g+r_{i*})\theta} \qquad i=1,2,\dots,m, \qquad \text{(VIII.17)}$$

Therefore, change in quantities of product i is a function of population growth g (scale factor) and a structural component that is specific to each sector given by the rate of change in consumption (r_{i*}).

In that case, employment by sector and in the aggregate of the economy would change by the combination of these two rates:

$$E_i(t) = l_i(t)Q_i(t) = l_i(t_i^*)c_i(t-\theta)N(t-\theta)e^{(g+r_{i*})\theta} \Rightarrow$$
$$\Rightarrow E_i(t) = E_i(t-\theta)e^{(g+r_{i*})\theta} \qquad i=1,2,\dots,m, \qquad \text{(VIII.18)}$$

This equation shows that changes in employment in each sector i would depend on the combination of population growth and change in consumption patterns. The effect of these rates of change on employment would be, therefore, given by one the three conditions:

$g + r_{i*} < 0$	Sector i lays off workers
$g + r_{i*} > 0$	Sector i absorbs new workers
$g + r_{i*} = 0$	Sector i has no change in the number of workers

At the macroeconomic level, employment in the overall economy $E(t)$ is given by the sum of employment in each economic sector:

$$E(t) = N(t-\theta)e^{g\theta}\sum_{i=1}^{m}(l_i(t_i^*)c_i(t-\theta)e^{(r_{i*})\theta}) \qquad i=1,2,\ldots,m, \qquad \text{(VIII.19)}$$

Full employment in the economy ($E(t) = N(t-\theta)e^{g\theta}$) can only be achieved when all changes at sectoral level compensate each other. People that lost jobs in sectors that had laid off workers found employment in sectors that were absorbing workers. Clearly, it is not an easy task to attain such a balance in the economy. It would require labour mobility and transferability of skills and know-how to allow for a swift transition of workers from one sector to another.

Similar results are obtained by the analysis of output by sector and total output, given that output is given by the price of the commodity multiplied by the quantity produced:

$$Y_i(t) = p_i(t)Q_i(t) = l_i(t)w(t)c_i(t)N(t) =>$$
$$=> Y_i(t) = l_i(t_i^*)w(t)c_i(t-\theta)N(t-\theta)e^{(g+r_{i*})\theta} \qquad i=1,2,\ldots,m, \qquad \text{(VIII.20)}$$

The output of a sector reduces when ($g + r_{i*} < 0$) and increases when ($g + r_{i*} > 0$).

Total output of the economy is the sum of these outputs of the individual sectors:

$$Y(t) = \sum_{i=1}^{m} Y_i(t) =>$$
$$=> Y_i(t) = l_i(t_i^*)w(t)c_i(t-\theta)N(t-\theta)e^{(g+r_{i*})\theta} \qquad i=1,2,\ldots,m, \qquad \text{(VIII.21)}$$

Total expenditure of the income received by the households in the economy ($Y(t) = w(t)N(t-\theta)e^{g\theta}$) would only occur when all changes at sectoral level compensate each other. When the reduction in income generated in some sectors is compensated by the additional income created in other sectors.

Stagnant economies

As discussed above, in the absence of novelty in the economy, the rates of change in consumption patterns will be determined exogenously by changes in tastes, social norms, etc. Suppose that such changes are not frequent and that, for long periods of time, the rate of change of consumption coefficient in each sector is close to zero:

$$r_{i*} = r_{j*} \approx 0 \qquad i,j=1,2,\ldots,m,\ i \neq j \qquad \text{(VIII.22)}$$

The shares of output and employments by sector are then given by:

$$\frac{Y_i(t)}{Y(t)} = \frac{l_i(t_i^*)w(t)c_i(t-\theta)N(t-\theta)e^{g\theta}}{w(t)N(t-\theta)e^{g\theta}\sum_{i=1}^{m} l_i(t_i^*)c_i(t-\theta)} = \frac{l_i(t_i^*)c_i(t-\theta)}{\sum_{i=1}^{m} l_i(t_i^*)c_i(t-\theta)} \qquad \text{(VIII.23)}$$

$$\frac{E_i(t)}{E(t)} = \frac{l_i(t_i^*)c_i(t-\theta)N(t-\theta)e^{g\theta}}{N(t-\theta)e^{g\theta}\sum_{i=1}^{m} l_i(t_i^*)c_i(t-\theta)} = \frac{l_i(t_i^*)c_i(t-\theta)}{\sum_{i=1}^{m} l_i(t_i^*)c_i(t-\theta)} \qquad \text{(VIII.24)}$$

These equations show that there is no structural change. The shares of employment and output by sector in the total economy would remain constant over time. The economy grows at the rate of population growth but the structure of the economy remains the same.

8.3.2 Qualitative change – autarky

The opposite of quantitative change is "real" development, which comes about through qualitative change of the economy. Qualitative change would occur if there are changes in the composition of products with the emergence of $k > 0$ new products:

$$m(t) = m(t-\theta) + k \qquad \text{(VIII.25)}$$

We assume that there are three ways in which a new product could emerge: (1) through division of labour, (2) through variations of technology, or (3) through combination of previous technologies to create a new product. To describe these processes, we introduce the terms "parent sector" and "child sector". A parent sector is the network of technologies from which a new network of technologies derives, which we will call a child sector. Both in division of labour and in variation of technologies, one parent sector undergoes a specific change from which a new child sector emerges. In the case of combination of technologies, parts of parent sectors are combined to create a new child sector.

The differences between the three processes are presented in Table 8.1, based on the comparison between parent and child sectors in terms of their sets of operations and structures of the network of technologies.

Table 8.1. Typology of novelty processes: comparison between child and parent sectors

Operations		*Structure of the network*: Change	*Structure of the network*: No change
	Change	Combination of technologies	Variation of technologies
	No change	Division of labour	No novelty

Division of labour

The first process (division of labour) is the change in the parent sector by dividing one labour-embodied technology into two. In this process, there is a change in the structure and the set of technologies of the network, but the set of operations of the parent sector is carried out by the child sector.

Formally, suppose that in a given sector *i*, characterized by the network of technologies: $\tau_i = (T_i\ , \mathrm{g})$, a given labour-embodied technology of the network ($t_j \in T_i = \{t_1, t_2, t_3, \dots, t_n\}$) can be divided into two labour-embodied technologies (t_{ja} and t_{jb}) that together have exactly the same set of operations of the labour-embodied technology t_j.

Now suppose a new sector *m* emerges as the result of division of labour by dividing t_j into t_{ja} and t_{jb}. The sector *m* is then characterized by a network $\tau_m = (\{t_k\}\ , g)$ that consist of a set of *n+1* technologies $T_m = T_i - \{t_j\} \cup \{t_{ja}, t_{jb}\}$, which are the nodes of the network, and a *n+1* x *n+1* adjacency matrix *g.*

If the technologies t_{ja} and t_{jb} are be performed in parallel the elements of the adjacency matrix associated with them are given by:

$$\begin{cases} g_{ja,y} = g_{jb,y} = g_{j,y} \\ g_{x,ja} = g_{x,jb} = g_{x,j} \\ g_{ja,ja} = g_{jb,jb} = 0 \end{cases} \qquad \text{(VIII.26)}$$

In the case that they are performed in sequence, and if we assume that t_{ja} is performed before t_{jb}, the elements of the adjacency matrix associated with them are given by:

$$\begin{cases} g_{jb,y} = g_{j,y} \\ g_{x,ja} = g_{x,j} \\ g_{x,jb} = g_{ja,y} = 0 \\ g_{ja,jb} = 1 \\ g_{ja,ja} = g_{jb,jb} = 0 \end{cases} \tag{VIII.27}$$

Note that the only difference between sectors m and i is the application of t_{ja} and t_{jb} in sector m in contrast to the application of technology t_j in sector i. That difference has no effect on the set of operations on which labour act upon. Therefore, m and j have the same set of characteristics in the space of services (S_m=S_j), which implies that they meet the same human need. Sector m, however, is more efficient than sector j, and this has implications in terms of prices of products, competition between sectors m and j, and the resulting structure of the economy. These implications will be discussed later in this section.

Variation of technologies

The second process that creates new sectors is the variation of technologies, in which workers explore variations in the set and sequence of operations that comprise the labour-embodied technology that they use in their work. In this case, the structure of the network of technologies remains the same but there is a change in the operations within a particular labour-embodied technology.

Formally, given a network of labour-embodied technologies $\tau_i = (T_i, g)$, suppose that each labour-embodied technology of the network ($t_j \in T_i = \{t_1, t_2, t_3, \dots, t_n\}$) has one variation t_j' that has a different set of operations but that performs exactly the same activity more efficiently (i.e. the outputs of the operations of t_j and t_j' are the same, but the latter requires less labour).

Combination of technologies

The third process is the combination of existing technologies to create a new network of technologies. In this case the result is a new child sector in which the network of technologies is new to the economy and the set of operations is a subset of the larger set of operations in the economy, but is different from the set of operations of the parent sectors.

Formally, a new sector m can be represented by a network τ_m that consist of a set of n existing technologies ($T_m = \{t_1, t_2, t_3, \dots, t_n\}$), which are the nodes of the network, and an n x n adjacency matrix g:

$$\tau_m = (\{t_k\}, g) \qquad k=1,2,\dots,n \tag{VIII.28}$$

Drivers of novelty and the effect on economic diversification

In the model, we assume that both division of labour and variations of technologies are driven by learning and the human tendency to save efforts. Their objective is to produce a commodity that provides the same services that are already provided by a product that already exist in the economy, but with less work (Table 8.2).

Similarly, we assume that the process of combination of technologies can be driven by learning and the human tendency to save efforts, in which case it is called process innovation. However, we also assume that combination of technologies can be driven by learning and the desire to fulfil an otherwise unfulfilled human need. In this case, combination of technologies results in product innovation. It produces a commodity that provides a set of services that is not provided by any other product in the economy.

Therefore, in the cases of the emergence of a new sector m through either division of labour, variations of technologies or process innovation, the set of services of the new sector is assumed to be the same as the set of services of a sector j in the economy. On the other hand, if the new sector m emerges through product innovation, the set of services that it provides is not provided by any other sector in the economy.

As discussed in a previous section, when a new sector m provides the same services provided by an existing sector j, the price of m is assumed to be lower than the price of j, otherwise the new sector would not have had emerged in the first place. Moreover, there would be no demand for the product produced by sector j, thus the sector would disappear from the economy. Note that given that the new product m replaces an existing product j, the number of products in the economy would not change – there is no economic diversification.

Table 8.2. Typology of novelty processes by driver

Process	Driver	Set of Services	Price	Diversification
Division of labour	Learning and save efforts	$S_m = S_j$	$p_m < p_j$	No
Variation of technologies	Learning and save efforts	$S_m = S_j$	$p_m < p_j$	
Process innovation	Learning and save efforts	$S_m = S_j$	$p_m < p_j$	
Product innovation	Learning and fulfil an unfulfilled human need	$S_m \neq S_j$	$p_m \gtreqless p_j$	Yes

On the other hand, in the case of product innovation, there is no constrain in the price of the new product m. As long as it fulfils a human need and that the levels of income in the economy are sufficient for people to purchase it, as assumed, the product m will emerge in the economy. That new product will be added to the set of commodities being produced. Therefore, product innovation results in the diversification of the economy.

The following sections discuss the dynamics of the model in the case of the emergence of new products with and without diversification.

Novelty without diversification

Suppose that a new product m emerges in the economy providing the same set of services already provided by an existing sector j. We assume that the driver of that process was learning and the tendency to save efforts, thus the labour coefficient associated with the production of m is lower than the labour coefficient of product j:

$$l_m(t) < l_j(t) \tag{VIII.29}$$

and the price of the new product is lower than the price of product j:

$$p_m(t) = l_m(t)w < l_j(t)w = p_j(t) \tag{VIII.30}$$

The analysis presented in next sub-sections shows that novelty without diversification results in increasing purchasing power of the population in the short term, but it also drives the economy towards technological unemployment and a decrease in per capita income in the long term.

Increasing purchasing power in the short term

Note that since m and j have the same set of characteristics in the space of services (S_m=S_j) and meet the same human need, the effect of the appearance of the new sector in the economy is similar to the effect of technical change as described in Pasinetti's (1993) model. Technical progress affects demand because it "*compels the members of the community to make new decisions; they must decide on which commodities they are going to spend the increments of their incomes.*" (Pasinetti, 1981, p.68).

To verify this mechanism in operation, note that, when the macroeconomic condition (VII.36) is fulfilled, income is fully utilized to purchase the goods produced in the economy. In other words, the sum of the per-capita demand of all products at current prices is the same as the wage rate (w). Applying this relation for the hypothetical case of no novelty (in a particular unit of time) will result in the following:

$$c_1^* p_1^* + c_2^* p_2^* + \cdots + c_j^* p_j^* + c_{m-1}^* p_{m-1}^* = w \tag{VIII.31}$$

We use the superscript * to indicate that this composition of demand relates to the hypothetical case of no novelty in the economy.

Now, applying the same relation for the case in discussion of the appearance of a new product m results in:

$$c_1 p_1 + c_2 p_2 + \ldots + c_m p_m + c_{m-1} p_{m-1} = w \qquad \text{(VIII.32)}$$

Given that the price of the new product m is lower than the price of the commodity j ($p_m < p_j^*$) the members of the community would not spend their full income and would have savings in the amount of $(c_j^* p_j^* - c_m p_m)$ if there were no changes in the consumption coefficients of the products in the economy. The result of the appearance of the new product is similar to an increase in income available to each member of the economy. As highlighted by Pasinetti in the quotation above, technical progress triggers new demand decisions and, in consequence, changes in the consumption coefficient in every sector.

Note that such a result also applies to the new sector m. Despite providing exactly the same services as the product of the parent sector j, the consumption coefficient of the new product m is not necessarily the same as the consumption coefficient of product j in the hypothetical scenario of no novelty ($c_j^*(t)$). It may be higher, given the increase in income available to spend:

$$c_m(t) \geq c_j^*(t) \qquad \text{(VIII.33)}$$

Given that the price of m is lower than the price of j, the effect of m on the demand for j is to drive the consumption per-capita coefficient of commodity j to zero, and all demand will be supplied by m:

$$Q_j(t) = 0 \qquad \text{(VIII.34)}$$

$$Q_m(t) = c_m(t) N(t-\theta) e^{g\theta} \qquad \text{(VIII.35)}$$

Given that m and j have the same set of characteristics in services space (S_m=S_j), the new product m has no effect on the quantity of any other product in terms of product substitution or complementarity, except for the quantity of product j.

$$r_{im} = 0, \ \forall\, i \neq j, i \neq m$$

$$c_i(t) = c_i(t-\theta) e^{(r_{i*} - r_{im})\theta} = c_i(t-\theta) e^{r_{i*}\theta}, \quad \forall\, i \neq j, i \neq m \qquad \text{(VIII.36)}$$

$$Q_i(t) = c_i(t-\theta) N(t-\theta) e^{(g + r_{i*})\theta}, \qquad \forall\, i \neq j, i \neq m \qquad \text{(VIII.37)}$$

Tendency to technological unemployment

Total employment, after the required substitutions, is given by:

$$E(t) = N(t-\theta)e^{g\theta}\left(\sum_{i=1}^{m-1} l_i(t_i^*)c_i(t-\theta)e^{r_{i*}\theta} + l_m(t)c_m(t)\right) \quad \text{(VIII.38)}$$

Full employment in the economy ($E(t) = N(t-\theta)e^{g\theta}$) could only be achieved when the number of jobs created by the new sector m is the same as the net number of jobs lost in the other sectors, including sector j, due to change in demand. The capacity of sector m to absorb the number of workers that were laid down by sector j is given by the following relations:

$\frac{c_m}{c_j^*} = \frac{l_j}{l_m}$ Sector m absorbs the same number of workers laid off by sector j

$\frac{c_m}{c_j^*} > \frac{l_j}{l_m}$ Sector m absorb more workers than those laid off by sector j

$\frac{c_m}{c_j^*} < \frac{l_j}{l_m}$ Sector m absorb less workers than those laid off by sector j

If the increase in demand ($\frac{c_m}{c_j^*}$) for the product that provides the services ($S_m = S_j$) is higher than the reduction in labour required to produce the product ($\frac{l_j}{l_m}$), the new sector would absorb more workers than the number of workers that were laid off by sector j. For products that are in an upward part of the S-shaped curve of consumption (Engel's law), that form of generating novelty would result in net creation of jobs. On the other hand, for a product that is close to or in the saturation part of that curve, the emergence of the new sector m would not have much effect in creating jobs.

In fact, in the long term, if the only form of emergence of novelty in the economy was through the mechanism described above – resulting in a new product with exactly the same set of services as the parent sector –changes in the structure of the economy would be characterized by two facts. First, the number of products would not change - every time that a new product appears it would drive the demand of the product produced by the parent sector to zero and the number of sectors would remain the same. Second, the economy would be driven to technological unemployment. With the reduction of prices of products, the income available to each member of the economy would increase, driving up the consumption coefficients of each sector. However, consumption coefficients could not increase indefinitely and eventually there would be no possible increase in consumption coefficients to compensate for the decreases in prices ($r_{i*} \to 0$). The economy would tend to technological unemployment.

<u>*Decreasing per capita output in the long term*</u>

Moreover, in real per capita terms, the economy would tend to shrink. That result is verified by considering first the total output of the economy (in value terms), which is the sum of the product of price and quantity of commodities produced in each sector:

$$Y = \sum_{i=1}^{m} p_i Q_i = \sum_{i=1}^{m} l_i \, w \, c_i \; N = w \, N \sum_{i=1}^{m} l_i \; c_i \tag{VIII.39}$$

Considering prices in labour equivalents (*w=1*) and dividing by the total population, the per capita output is given by:

$$y = \sum_{i=1}^{m} l_i \; c_i \tag{VIII.40}$$

Now consider the output per capita in periods t and $t - \theta$, making sectors m and j explicit in each period:

$$y(t) = (\sum_{i=1}^{m-1} l_i(t_i^*) c_i(t-\theta) e^{r_{i*}\theta} + l_m(t) c_m(t)) \tag{VIII.41}$$

$$y(t-\theta) = (\sum_{i=1}^{m-1} l_i(t_i^*) c_i(t-\theta) + l_j\left(t_j^*\right) c_j(t-\theta)) \tag{VIII.42}$$

Considering this in the long term, if novelty in the economy only results from processes that create products that provide services already provided in economy but with higher productivity, consumption per capita of all commodities would tend to saturation ($r_{i*} \rightarrow 0$). Therefore, the change in per capita output would be given by:

$$y(t) - \; y(t-\theta) = (l_m(t) c_m(t) - l_j\left(t_j^*\right) c_j(t-\theta)) \tag{VIII.43}$$

Given that product *m* would replace product *j*, which is already considered in saturation, then:

$$c_m(t) = c_j(t-\theta) \tag{VIII.44}$$

And the change in per capita output would be given by:

$$y(t) - \; y(t-\theta) = c_j(t-\theta)(l_m(t) - l_j\left(t_j^*\right)) \tag{VIII.45}$$

Since the labour coefficient of sector *m* is lower than that of sector *j*:

$$l_m(t) < l_j\left(t_j^*\right)$$

The per capita output will decrease over time:

$$y(t) - \; y(t-\theta) < 0 \tag{VIII.46}$$

Therefore, income per capita of the population would decrease if novelty was only generated thought processes that create products that provide services already provided in economy, but with higher productivity.

Novelty with diversification

Now, suppose that a new product m emerges in the economy through product innovation. We assume that the driver of that process is learning and the desire to fulfil an unfulfilled human need. The labour coefficient of product m is l_m, the consumption per capita coefficient is c_m and the price and quantity are given by:

$$p_m(t) = l_m(t)\ w(t)$$

$$Q_m(t) = c_m(t)N(t-\theta)e^{g\theta}$$

The analysis presented in the next sub-sections shows that novelty with diversification results in an inflationary tendency in the short term, but that it provides a counterbalance to technological unemployment.

Inflationary tendency in the short term

Suppose that in an economy with (m-1) sectors, the macroeconomic condition would have been fulfilled if the new sector had not appeared:

$$\sum_{i=1}^{m-1} c_i\,(t-\theta)e^{(r_{i*})\theta} l_i(t-\theta) = 1 \qquad \text{(VIII.47)}$$

Now, with the emergence of the new sector m, this relation becomes:

$$\sum_{i=1}^{m} c_i\,(t)l_i(t) = \sum_{i=1}^{m-1} c_i\,(t-\theta)e^{(r_{i*}-r_{im})\theta} l_i(t-\theta) + c_m(t)\ l_m(t) \qquad \text{(VIII.48)}$$

Assume that after the emergence of m, the impact in the consumption of other products in terms of substitution and complementarity is negligible ($r_{im} \to 0$). Then the relation becomes:

$$\sum_{i=1}^{m} c_i\,(t)l_i(t) = \sum_{i=1}^{m-1} c_i\,(t-\theta)e^{(r_{i*})\theta} l_i(t-\theta) + c_m(t)l_m(t) =>$$

$$=> \sum_{i=1}^{m} c_i\,(t)l_i(t) = 1 + c_m(t)l_m(t)$$

$$=> \sum_{i=1}^{m} c_i\,(t)l_i(t) > 1 \qquad \text{(VIII.49)}$$

Eq. (VIII.49) is described in Pasinetti (1993) as resulting in a tendency for inflation. Note that the higher the originality of the new product, the more negligible the substitution effects on the existing products are and the stronger the inflationary tendency will be.

Counterbalance to technological unemployment

Again, suppose that in an economy with (m-1) sectors the macroeconomic condition would be fulfilled as presented in Eq.(VIII.47) if the new sector had not appeared. Total employment would be given by:

$$E(t) = N(t-\theta)e^{g\theta}\sum_{i=1}^{m-1} c_i\,(t)l_i(t) = N(t-\theta)e^{g\theta} \quad \text{(VIII.50)}$$

Now, assume that after the emergence of m, the impact in the consumption of other products in terms of substitution and complementarity is negligible ($r_{im} \to 0$).

Total employment is given by:

$$E(t) = N(t-\theta)e^{g\theta}\sum_{i=1}^{m} c_i\,(t)l_i(t) \quad \text{(VIII.51)}$$

Considering the inequality (VIII.49), the total employment will by:

$$E(t) > N(t-\theta)e^{g\theta} \quad \text{(VIII.52)}$$

Equation (VIII.52) shows that there is a potential for increase in total employment with the appearance of commodity m. The higher the originality of commodity m in terms of the services that it provides, the lower is the possibility of substitution effects and the higher the tendency of increasing employment in the economy. Therefore, novelty with diversification of the economy avoid technological unemployment when there is the appearance of a new commodity m in which its effect on the demand (r_{im}) for every previously existing commodity i tends to zero.

8.4 Summary

This chapter explores the role of diversification within the theoretical framework of structural economic dynamics proposed by Pasinetti (1993). The discussion focused on the effects of diversification in relation to technological unemployment.

The model presented adopts the assumptions that are common to the empirical literature on economic complexity in which products require a specific set of capabilities to be produced. In that regard, production sectors are assumed to be characterised by the network of technologies used in the production. We assume that there are three ways in which a new sector could appear in the economy: through division of labour, variations in labour-embodied technologies and combination of existing technologies.

In terms of the dynamics of technological change, the labour coefficient associated with a particular sector is a function of the network of technologies used in the production and each labour coefficient remains the same as in the time of the sector's emergence. This is a major departure of this model from the original Pasinetti's model. As a result of the assumption of constant labour coefficients, the price of each product would not change over time.

Changes in consumption coefficients are the result of exogenous factors and the effect of the appearance of a new sector in the economy. The appearance of a new commodity has an impact on the demand of other products because of the potential for substitution or complementarities. Such an effect will be reflected in changes in consumption patterns (Gualerzi, 2012). Therefore, the dynamics of the quantities produced of each product are governed by three components: the rate of population growth, a structural component that is specific to each sector given by the exogenous rate of change in consumption patterns, and another structural component driven by the appearance of a new product.

The structural dynamics of prices and quantities affects the dynamics of macroeconomic magnitudes of employment and total output in the economy. Changes in employment and output in each sector would depend on the balance between the effect of the new product in the demand for the other products and the combination of population growth and exogenous change in consumption patterns.

The discussion in this chapter contributes to the literature by showing that novelty without diversification results in increasing purchasing power of the population in the short term, but it also drives the economy towards technological unemployment and lower per capita income in the long term. On the other hand, novelty with diversification results in an inflationary tendency in the short term, but it provides a counterbalance to technological unemployment.

The next chapter continues the theoretical exploration of diversification and structural change by formalizing Pasinetti's framework of international relations considering the possibility of diversification.

9

Diversification and trade: overview of the model

This chapter continues the investigation of diversification and structural economic dynamics. The study focuses on the process of economic diversification of trading economies. The basic framework is based on Pasinetti's (1993) model and the World Trade Model proposed by Duchin (2005) with respect to the short-run allocation of labour, Andersen (2001) regarding the dynamics of technological change, Clower (1965), Pasinetti (1993), and Gualerzi (2012) with respect to the dynamics of changes of consumption patterns, and on Kauffman (2008) regarding the way to formalize path dependency in the process of diversification. This chapter introduces the main elements of the model without resorting to formulas or equations to give the reader a broad picture of how the model works.

9.1 Introduction

The discussion in the previous chapter has focused on diversification and structural economic dynamics within Pasinetti's (1993) framework of countries in autarky. This chapter extends that discussion by considering diversification of trading economies.

The chapter starts by presenting the basic elements of the model, including how the world is described in terms of countries that trade with each other, how the economy is comprised of several sectors, how these sectors are defined and the relationships between labour, consumption, prices and quantities of products in the economy. The chapter then discusses the dynamics of the model: how the changes of productivity and consumption patterns in each country, combined with the possibility of countries trading products, affect the structure of each economy in terms of employment and income across sectors.

The possibility of creation of new products is a key element. Economic diversification is considered endogenous to the model, meaning that it not only affects the dynamics of the economies but it is also the result of these dynamics. The final part of the chapter briefly discusses how diversification comes about. New products emerge as the result of the combination of labour-embodied technologies available in the economy.

9.2 Basic elements

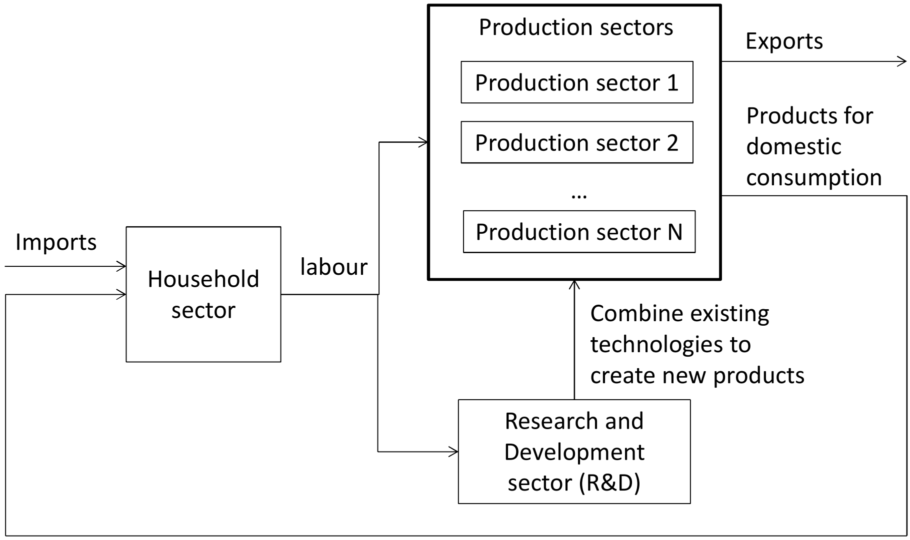
In the model, the world is composed of a number of countries, each producing a variety of products and trading with each other. As in Pasinetti (1993), labour is the only factor of production. The units of the analysis of the model are the sectors that constitute an economy.

The economy of each country is composed of one household sector, many production sectors, and one research and development sector (R&D) (Figure 9.1).

In each country, the household sector provides labour to other sectors and consumes products, some of which are produced domestically and some of which are imported. Each production sector produces a single type of product, which could be consumed domestically and/or exported. A production sector is defined by the set of labour-embodied technologies that are used in the production process. If the demand for domestic products is not enough to utilize all labour available in the economy, the model results in unemployment. The R&D sector creates processes and products that are new to the world or to the country, which gives rise to more productive or new production sectors when they discover a new useful combination of the technologies that already exist in the country's economy.

The following sections describe the various sectors of the economy in more detail and discuss how markets and trade between countries is modelled.

Figure 9.1. Diagram of sectors within a country



9.2.1 Household sector

The modelling of the household sector follows Pasinetti's (1993) multi-sector model of structural economic dynamics. The sector comprises the population of the country. As mentioned, this sector has two roles. First, it consumes commodities that are produced domestically or abroad. The consumption per capita of each commodity is given by a consumption coefficient. Second, the household sector provides labour to produce and to create new products.

Labour is uniform in quality, so that each unit of labour is equivalent as a means of production. Labour is also homogenous across production sectors, so it could be used in the production of any product. It is also assumed that labour is mobile between production and R&D, but it is not mobile between countries (no migration).

In each period and in each country, a proportion of the population is engaged in the production sectors. The share of the population that is not engaged in the production is either engaged in the research and development process (R&D) or is unemployed. Each unit of labour is remunerated by a uniform wage rate.

9.2.2 Production sectors

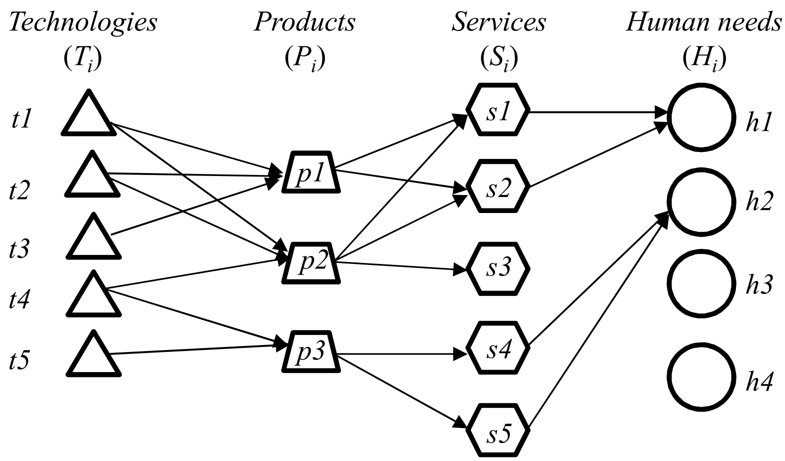
Each production sector produces one single good and labour is the only factor of production. As in the household sector, the basis for the modelling of the production sectors is Pasinetti's (1993) model. The simplification of considering labour as the only factor of production helps us to focus on innovation - the key processes of learning, combination and discovery of new techniques to be able to produce goods - instead of focusing on capital and its accumulation.

All products are final goods, meaning that they are all goods that are to be consumed, such as food, clothes, appliances, etc., and not to be used as inputs for the production of other goods, such as machines or parts of electronic products.

Labour productivity levels in each production sector are given by labour coefficients, which reflect the amount of labour required to produce one unit of product. Usually, countries can only produce the quantity of goods implied by sectoral labour productivity levels and the total amount of labour available in the economy. Occasionally, production sectors can resort to overtime to meet surges in demand.

As described in section 7.3.2, production sectors are characterized by a specific set of labour-embodied technologies. As defined in Chapters Seven and Eight, technology is defined as a mean to fulfil a human purpose (Arthur, 2009). It can be a device, a method, or a process. The framework adopted in the model links production and demand (Gualerzi, 2012; Saviotti and Pyka, 2017) by connecting technologies to products, products to services, and services to human needs. Figure 9.2 illustrates this characterization of sectors by showing that products require a specific set of technologies to be produced; they provide a specific sect of services that fulfil human needs.

Figure 9.2. Links from technologies to human needs



9.2.3 R&D sector

Each country has one R&D sector in which workers search for combinations of technologies that result in products that fulfil human needs. Mainly for simplification, the model considers that there is only one R&D sector instead of various R&D sectors linked to specific production sectors.

In the R&D sector, workers are remunerated to search for new processes and products. The wage of the workers is funded by the production sectors through the price markups of their products. Thus, the number of people engaged in the R&D sector is constrained by the total sum of the markups in the production sectors. We further assume that the number of people engaged in R&D is also limited by the number of people not employed in the production sector and that can be directed to product innovation efforts. Other models sometimes consider an exogenously given minimum share of labour force dedicated to R&D, say at least 2% of the labour force. However, in this model we assume that an economy in full employment in the production sectors does not have labour available to be engaged in product innovation or emulation.

9.2.4 Market setup

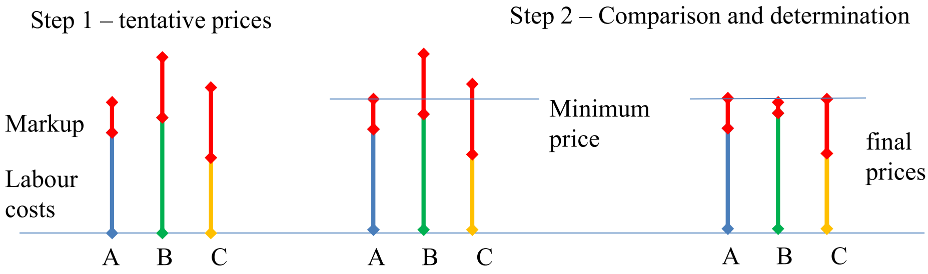
We assume monopolistic competition in domestic and international markets, which means that each sector is composed of a large number of firms that compete with each other but that produce slightly different products (see, e.g. Krugman, 1979). In each sector, there is a markup for the products. We do not model firms themselves, but just the result of that monopolistic competition (the existence of markups).

The price of products is given by the amount of labour required for the production times the wage rate multiplied by the markup of the sector.

The mechanism to determine markup prices is comprised of two steps that are carried out during the transition from one time phase to the next. This mechanism is illustrated in Figure 9.3 for three countries (A, B, C) and a single sector. In the figure, a red line represents a markup. Labour costs in each country are represented by the colours blue (country A), green (country B) and yellow (country C).

The first step is the setup of tentative prices by each sector in each country and targeting each market. These tentative prices are the sum of the labour cost of production and the markup in the previous unit of time. The second step is the comparison and determination of price, in which sectors compare their prices with their competition from other countries and, if the latter have lower prices, reduce the markup to match the competitor's price.

Figure 9.3. Illustration of mechanism to determine markups



9.2.5 *International trade*

All products are considered to be tradable. Therefore, in this model, economies do not have (non-tradable) services sectors such as restaurants, hotels or retail.

Countries can trade freely without trade costs. All output is produced and consumed globally simultaneously. As shown in Figure 9.1, domestic production can be consumed domestically, exported or both. Domestic consumption is the sum of the domestic consumption of the commodity that is locally produced and of the commodity that is imported.

We assume that the total exports of a given country do not need to match the total imports of that country. The balance of payments of countries, which can here be considered as the trade deficit, is not necessarily balanced at each point in time.

In the short-run, the model determines which country specializes in which products based on the demand, prices of products and the amount of labour available for production.

In addition to the markup mechanism described above, which results in more than one country selling products for the same price, the model also adopts a linear programming approach inspired by the World Trade Model proposed by Duchin (2005). It accounts for incomplete specialization of production and trade, due to the limit in labour available for production. In this model, specialization is driven by prices and production is located in countries in which the productivity is higher. Duchin's (2005) model minimizes the factors of production, including labour, under certain constraints such as the limited amount of labour available. Duchin uses the minimization of factors of production as a normative objective to make the model suitable to address policy questions related to sustainable development.

In the model presented here we use a similar mechanism, but we adopt the traditional economic assumption that people prefer to pay the lowest possible price for the products that they consume. This preference for minimizing expenditure drives the production towards the countries that sell at the lowest prices. It is expected that the country that produce a product, say a car, with the lowest price would be the only one to produce and export cars, because all consumers would prefer that lower priced car.

However, countries produce many other products and sometimes there are just not enough people to produce all the goods demanded. This phenomenon of insufficient labour available could happen even with intersectoral labour mobility. In that case, the country that could produce a product for the second lowest price would also start to produce and export that product. Similarly, if that country also runs out of labour to produce all the products that consumers demand, the country with the third lower price will start to also produce and export that product, and so on. That mechanism is implemented using linear programming. The linear programming character of the model resembles a situation in which a broker for the global economy arranges the transactions that allocate production subject to consumer preferences and the constraints of total labour available.

Therefore, trade specialization is determined by consumers with defined demand preferences seeking to minimize their expenditure when purchasing goods from production sectors, which in their turn are jointly constrained by the total amount of labour available in the economy. Therefore, the model does not assume *ex-ante* full specialization and also allows for situations in which similar products with different labour costs coexist in the global market.

9.3 Structural dynamics

As in Pasinetti (1993) the economy changes with: a) changes of consumption patterns and b) technical progress. However, different from Pasinetti's framework, both changes are endogenous to the model. Economies could also change due to changes in the size of the population that affect the total quantities that are demanded of each commodity produced and the total labour available for production. For simplification, in the discussion of the model proposed here we consider that population sizes are constant.

9.3.1 Changes in demand

Similar to Pasinetti's (1993) framework, consumption patterns change according to a generalized version of Engel's law that can be summarized by the following the three empirical regularities:

> *"(i) as per-capita real income increases (whatever the price structure), a marked tendency emerges, for each consumer, not to increase proportionally the demand for the various goods, but rather to follow, in satisfying the various needs, a certain hierarchical order, by first satisfying essential needs and then gradually moving on to the satisfaction of those needs that are less and less essential;*
> *(ii) the variation in the composition of consumption may well occur independently of the increase in income and of the changes in prices, as a*

consequence of the appearance on the market of newly invented goods and services;
(iii) there is no good for which the consumption of an individual can increase indefinitely. A saturation level exists for the consumption of any good and service, even if this saturation level may be reached at different speeds for different goods or at different levels of per-capita income."
(Pasinetti, 1993, pp.39-40)

Pasinetti (1993) uses these three facts as guiding principles; his model, however, does not formalize that framework. It does not: (i) enforce a hierarchical order on the rate of satisfaction of needs, (ii) formalize changes in consumption due to appearance of new products; or (iii) enforce saturation of consumption. Pasinetti adopts a more flexible formulation and describes changes in consumption patterns using an exponential function for each country and sector that can represent any movement of demand over time. Pasinetti (1993) also assumes that the rates of change of consumption in each country and sector are given exogenously.

Many multi-country models of structural change follow Pasinetti's (1993) approach and do not implement those empirical regularities or endogenous change of consumption (Reati, 1998; Araujo and Teixeira, 2004; Araujo, 2013; Araujo and Trigg, 2015). For example, Araujo and Teixeira (2004) and Reati (1998) adopt an exponential formulation similar to Pasinetti (1993). Araujo (2013) and Araujo and Trigg (2015) adopt the same formulation for changes in the domestic consumption of domestic products, while for changes in foreign demand they adopt an export function following Thirlwall (1979) in which change in demand depends on price differentials between domestic and foreign production and price elasticity of demand for exports.

An exception is the model presented in Andersen (2001). The model adopts the abstraction of a country being represented by a "Robinson Crusoe" economy composed of only one person to describe structural economic dynamics in open economies and to consider economic diversification. This model formalizes Pasinetti's (1993) generalized version of Engel's Law in a simplified way in which the hierarchy of preferences of commodities is strictly enforced by making the consumption of a product start only after the consumption of the product immediately higher in the hierarchy is completely satiated. The change in consumption is such that the demand of that product is assumed to be the amount produced in the previous period plus the amount that could have been produced if all unemployed labour had been engaged in the production of that good, up to the saturation level. Andersen (2001) also proposes an endogenous mechanism for change in consumption in the context of multiple "Robinsonian" open economies, but in each country at each point in time only the consumption of one product changes in relation to the pattern of consumption in the previous period.

The model presented in this chapter follows Andersen's (2001) lead in the sense that it formalizes the three empirical regularities presented and it also adopts an endogenous change of consumption. However, the model is more flexible because it does not adopt the restrictions in terms of strict sequencing of consumption of products (i.e. the consumption of a new product only starts after the consumption of existing products is satisfied).

In summary, we assume that consumer demand follows a certain hierarchical order in which they tend to try to satisfy essential needs first and then gradually satisfy needs that are less and less essential. As a result, if consumption increases, it will increase faster for the products that satisfy the more essential needs, except in the case that demand for these is saturated. On the other hand, if consumption decreases, the consumption of those more essential products will reduce slower than of less essential products, because people would rather give up a higher amount of less essential goods than of more essential goods. When the consumption of a more essential good reaches a saturation point, any additional increase in the overall consumption would not change the level of consumption per capita of that product, and other products that are less essential now start to have their consumption increasing faster. The saturation point of each product does is not correlated with the hierarchy of essential goods. A less essential good could reach its saturation point earlier than a more essential product.

Another difference in relation to Pasinetti (1993) and Andersen (2001) is in the assumption related to the level of employment. As discussed previously, Pasinetti's formulation adds the assumptions of full employment and complete expenditure of income in each period. Those assumptions are relaxed here to allow for the investigation of the effects of diversification on the level of employment at the aggregate and sectoral levels.

Here we adopt the Keynesian view of consumer demand. More specifically, we adopt a mechanism similar to Clower's (1965) "dual-decision hypothesis", in which households use a two-step decision process and decide on their demand for goods only after their actual incomes are known. The mechanism works as follows. Firstly, households receive their income and, based on that and on the current prices of products, decide on consumption preferences for the next period. If the income received is lower than the latest expenditure, then people will have a lower expectation related to the extent to which their incomes will be able to fulfil their consumption in the next period, and they would decide to consume less as consequence. If, on the other hand, the income received is higher than latest expenditure, then people will have a higher expectation for the purchasing power of their income in the next period and would decide to consume more. When households actually consume in the following period, firms decide on the level of employment to fulfil that demand, which determines income in the next period. In the model, the actual consumption change for each product is given stochastically, based on a uniform distribution, but the direction of the change is determined by this "dual-decision hypothesis" process and, therefore, it is endogenous to the model. By adopting this hypothesis, we assume that consumers decide on consumption of the immediate next period based on their current income. This mechanism is similar to that proposed by Fusari and Reati (2013) in which the rate of growth of consumption is a function of the ratio of the expected and realized consumption.[1]

In addition, we follow the principle in the agent-based literature (as discussed in Backhouse and Boianovsky, 2013) that consumers show heterogeneous behaviour and follow rules of thumb. Therefore, we consider that the aggregated result of the behaviour described in the paragraphs above is a stochastic change in consumption per capita.

The second process that results in consumption change is the appearance of new products (Gualerzi, 2012). For example, when cars were introduced in an economy the demand for saddles and horseshoes was reduced, while the demand for tyres increased. The way that such process is implemented in the model is through a one-time change in consumption of all other products in the economy due to complementarity and substitution effects, similar to the way it was modelled in section 8.2.3. The degree of substitution or complementarity among products is exogenous to the model (i.e. stochastically determined at the beginning of each run). The appearance of a new product also changes the saturation point of the existing products (Saviotti and Pyka, 2017). People may demand more and more of a product and less and less of others. The magnitude of those changes is also considered to be exogenous but its timing is endogenous to the model - it is when the new product is created.

9.3.2 Technical progress

In the literature, many models that endogenize technical change in a multi-sectoral model, for simplification, do not consider the introduction of new products (Los, 2001; Los and Verspagen, 2006; Araujo, 2013; Araujo and Trigg, 2015). Many of those models use the Kaldor-Verdoorn mechanism, or some variation of it, to represent learning by doing and opportunities for specialization

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[1] In Fusari and Reati (2013), the expected consumption increases with the level of income, is negatively affected by the levels of prices of products, and takes into account the mismatch between consumption and production by increasing when there is an oversupply and reducing when supply is low. If the expected consumption is higher than the actual consumption, then it is assumed that there is margin for further increases in consumption and the rate of growth is positive. On the other hand, if the expected consumption is lower than the actual, then it is considered that consumption should be reduced to a level closer to the expected and the rate of growth of consumption is negative.

of workers as result of output growth. The use of that mechanism creates a positive feedback in which high output growth result in higher productivity growth. For example, in Araujo (2013) and Araujo and Trigg (2015) the growth rate of productivity – the inverse of labour coefficients - is given by sectoral Kaldor-Verdoorn laws, which are assumed to reflect dynamic economies of scale that are the result of increasing specialization of labour provided by market growth. Los and Verspagen (2006), in the context of two countries trading, model two regimes: a leader industry that has lower labour coefficient than its foreign competitor, and lagging-behind regime that has a higher labour coefficient. In the leader industry regime, technological progress is modelled through two mechanisms: a constant exogenous productivity growth reflecting labour saving effects of innovation, and a Kaldor-Verdoorn mechanism that represents learning by doing and opportunities for specialization of workers as result of output growth. In the lagging-behind regime it is assumed that learning by doing (i.e. the Kaldor-Verdoorn mechanism) is at play and that the technological gap to the leader industry also give opportunities for catching up, for example by imitating the production technology of the leader.

Following a different approach, Reati (1998) introduces long waves into Pasinetti's model and considers that process innovation is driven by the pattern of diffusion of technological revolutions, which are radical process and product innovations. Fusari and Reati (2013) follow this framework and endogenize technical change including process and product innovation in a multi-sectoral model. They also further classify innovations as radical – concerning to a completely new process or product – and incremental innovations – related to an already existing process or product.

Some models add a stochastic element to process innovation. For example, Los (2001) models stochastic arrivals of innovation in an intersectoral model in a single-country context. In his framework, technological progress is a function of an industry-specific number of process innovations occurring at a point in time, the proportional increase in labour productivity implied by each innovation with innovations arriving at stochastic intervals following a Poisson process, which is dependent on the total resources dedicated to R&D with diminishing returns of R&D intensity. Andersen (2001) models both process and product innovation as Poisson processes in which the arrival rate of an innovation is a function of the share of the time spent in each activity.

The model presented here follows Andersen's (2001) mechanism. Moreover, similarly to the previous chapter, technical progress that results in diversification is assumed to be the result of combination of existing technologies to create a new sector. The two processes that are assumed to use that mechanism of combination of technologies, namely process and product innovations, are formalized in the model. In addition, the emulation of production that already exists in other countries is also included in the model, to account for technology transfer and international learning of production. For simplification, the model does not include other forms of technological change discussed in the previous chapter, namely division of labour and variation of technologies.

Process and product innovation and emulation

We model process innovation, product innovation and emulation following mechanisms similar to those adopted in Andersen (2001). Both process and product innovations, which create a set of technologies that is new to the world, are assumed to be less frequent events than emulation, which is an innovation that creates a product or a process that is new only to the country. The reason for that is because those that try to emulate have more information about the potential new product than those that try to create a product that is new to the world. Emulators may not know at the beginning how to produce the new product, but they know the services that it provides and the human needs that it fulfils; and they know that there is demand for the product.

Apart from this distinction, we assume that innovation and emulation are performed by the same national R&D sector. We assume that there are knowledge spill-overs between countries, in which the emergence of new processes or products in one country triggers the effort of emulation in other countries. There are also knowledge spill-overs between sectors in a sense that the technologies used in the production of a product in one sector can be combined to technologies of other sectors to create new processes and products.

The division between the shares of people that are dedicated to innovation that result in a new process and innovation that result in a new product altogether is determined by the level of employment in the economy. The closer the economy is to full employment, the higher is the effort towards process innovation to reduce the labour requirement in the existing production base. Similarly, the higher the level of unemployment, the higher is the effort towards product innovation to create new sources of demand and employment.

Of the total number of people dedicated to process innovation, part of them are dedicated to process innovation that is totally new to the world and the remaining are dedicated to emulation of process innovation that happened in other countries. The allocation between these two groups is determined by the backwardness of the production base. The higher the share of sectors that uses technologies that are not at the frontier (i.e. have lower productivity than the same sector in other countries), the higher the share of people dedicated to process innovation that is engaged in emulating the most advanced technologies.

As for product innovation, the share of people dedicated to finding new to the world innovations and the people dedicated to emulation is given by the level of diversification of the economy. If the economy is less diversified, there are many opportunities for imitation of the production that already exist in more diversified countries. Thus, more people will be engaged in the emulation process than in the creation of products that are totally new to the world. On the other hand, if an economy is already much diversified, there are fewer products in the world that are not already produced by that economy, and as consequence fewer people will be engaged in the emulation of production and more people will be trying to innovate. Thus, the higher the diversification the higher the share of people engaged in product innovation instead of emulation, and vice versa.

In the case of product emulation, the effective arrival rate of a product is also affected by the attractiveness of the sector to be emulated in terms of increasing demand. Sectors that are rapidly expanding attract more emulation efforts than sectors that are expanding slowly or declining.

We assume that the mechanism that dictates these distributions is set by a central planner in the R&D sector, who compares the production sectors of countries.

All other things equal, countries in which more people are dedicated to innovation will create more processes and products. More people dedicated to innovation, however, does not automatically guarantee faster creation of new processes and products. Given the mechanism of path dependency (described below), the evolution of the economies is not driven by their scale in terms of population size; a populous country such as the United States does not necessarily discover a higher quantity of new products than a less populous country such the Netherlands just because it has more people involved in R&D. The concentration of R&D affects the number of innovations. Another consequence of such a mechanism is that a less diversified country producing less sophisticated products, say handmaid potato chips, cannot leapfrog and innovate to produce much sophisticated products, say microchips. [2] Another consequence is that some countries may have a production base that is more conducive to further innovation than others. To use an example to illustrate, imagine a country that has a production base that is strong in electronics, computer sciences and bio-engineering; it may have more opportunities for innovation than another in which production is concentrated in fuels and minerals. Even when countries have production bases in similar broad areas, say electronics, the actual production may result in different potential for innovation depending on the technology required for the production of the different types of products.

Path dependency

In the model, the evolution of economies is path dependent (Gerschenkron, 1962; Dosi, 1982, 1988; Hausmann and Klinger, 2007; Hidalgo and Hausmann,

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[2] Transplanted industries (foreign direct investment) can achieve such jumps in production but these are not considered in the model.

2009). The goods that a country is able to produce at any point of time affect what the country will be able to produce next. To implement the mechanism of path dependency, we add to the model the concept of adjacent possible as proposed by Kauffman (2008) and introduced in the previous chapters.

We suppose that in each period and in each country, there is an adjacent possible of potential new sectors that could be created by the permutation of the existing set of technologies. Therefore, the result of product innovation and of emulation has to be part of the adjacent possible of the country.

We consider that some of the potential new products in the adjacent possible of a country are not relevant solutions. They may be a combination of technologies but they do not fulfil any human need at that point in time. Therefore, only a subset of the adjacent possible would result in a new process or product through process innovation, product innovation or emulation.

In the model, we assume that each time that a potential new product is included for the first time in an adjacent possible of any country, a decision is made to randomly assign the potential new product to the subset of products that fulfil or to the subset of products that do not fulfil a human need. We assume that this decision is taken by people based on how they perceive the usefulness of the new product.

This mechanism is implemented in a way that if a potential new product is considered not useful when it is a member of an adjacent possible of a country, then it will also be considered not useful in the adjacent possible of other countries. This mechanism is similar to a percolation process and creates different paths of technology development, some of which may lead to dead ends - the subset of the adjacent possible in which no potential new product has a use to fulfil a human need.

9.4 Summary

This chapter described the key elements of the model being proposed in this book in broad terms. It is a multi-country and multi-sector model in which the process of economic diversification results from and affects the structural dynamics of the economies. To try to present the backbone of a diversification model, we adopt several simplifications such as the assumption that labour is the only factor of production and that economies have no services sectors. The basic units of analysis are the sectors that together constitute national economies: a household sector, production sectors, and an R&D sector.

The next chapter formalizes the functioning of the model. That will help us to check its logical consistency and to derive conclusions about the effects of diversification on structural economic dynamics.

10

Formal description of the model

Following the overview provided in the previous chapter, this chapter presents a detailed description of a model of structural economic dynamics that considers diversification and trade. The model addresses the crucial short-run determination of which country produces which product. For the long-run, the model determines the economic dynamics over time due to trade, changes in consumption patterns and technical progress.

10.1 Short-run

This section focuses on the description of the model in the short-run. The model assumes international trade between R countries, which together produce m different types of commodities. Each country's economy is composed of a household sector, m production sectors and one R&D sector. For simplification, in this section we will focus on the household and production sectors. We will introduce the R&D sector formally in the following sections that deal with the dynamics of the model.

Each sector produces only one kind of product, by means of labour alone. The household sector provides labour to the production sectors and consumes the products produced by them. The characteristics of a specific type of commodity produced by different countries are assumed to be similar but slightly different.

Hence, they can be recognizable by their country of origin through a brand or another product characteristic (e.g. Krugman, 1979). Consumption demand can be met by domestically produced and/or by imported commodities.

In each period and each country, a set of endogenous variables is determined on the basis of exogenous and state variables (Table 10.1).

The exogenous variables are: the total population in country k (N_k) and the total amount of labour available in the country for the production sectors (L_k).

The first set of state variables ($l_{j,k}$) represents the quantity of labour in country k required to produce one unity of product j. Labour is assumed to be homogenous and workers can move freely from one sector to another, but labour is immobile between countries. The second set of state variables ($c_{j,k}$) reflects the demand pattern of consumers in country k and represents the average per-capita quantity of product j that is demanded by the population in that country. Note that it is possible that a country produces a commodity j but its population does not consume that product. Similarly, it is possible that the population of a country consumes a commodity j and the country does not produce that good. The third set of state variables ($MK_{j,h,k}$) is the markup added to the price of commodity j produced in country k and consumed in country h.[1] The other state variable is the nominal wage rate (w_k) of country k expressed in the currency of country 1 ($w_1 = 1$).

Table 10.1. Variables of the model

Exogenous	
N_k (*k*=1,..,*R*)	total population in country *k*
L_k (*k*=1,..,*R*)	total labour available for production sectors in country *k*
State variables	
$l_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	labour coefficient (labour input per unit of output) to produce commodity *j* in country *k*
$c_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	coefficient of consumption per capita of commodity *j* in country *k*
$MK_{j,h,k}$ (*j*=1,..,*m*; *h*,*k*=1,..,*R*)	proportional markup added to the price of commodity *j* produced in country *k* and consumed in country *h*

[1] As discussed in the previous chapter (section 9.2.4), prices for a given good and producing country might differ between countries, reflecting the results from the empirical literature on markup prices, which shows that markups are a function of destination markets, in addition to other firm specific characteristics. For a literature review of markup and export prices see for example Gullstrand, Olofsdotter and Thede (2014).

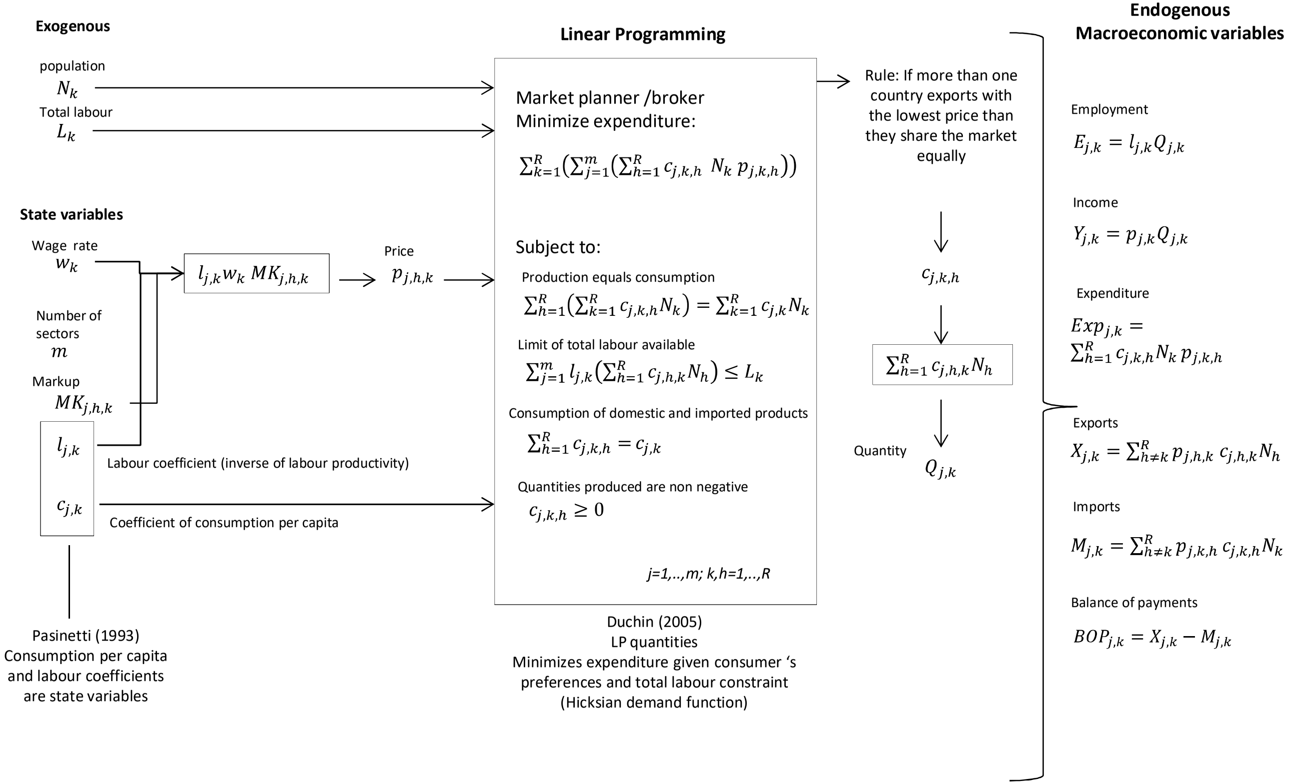
w_k (*k*=1,..,*R*)	nominal wage rate in country *k*
Endogenous	
$p_{j,h,k}$ (*j*=1,..,*m*; *h*,*k*=1,..,*R*)	price of commodity *j* produced in country *k* and consumed in country *h*
$c_{j,h,k}$ (*j*=1,..,*m*; *h*,*k*=1,..,*R*)	coefficient of consumption per capita in country *h* of commodity *j* produced in country *k*
$Q_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	quantity of commodity *j* produced in country *k*
$E_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	employment in sector *j* in country *k*
E_k (*k*=1,..,*R*)	total employment in country *k*
$Y_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	output of sector *j* in country *k*
Y_k (*k*=1,..,*R*)	total output in country *k*
y_k (*k*=1,..,*R*)	output per capita in country *k*
$Exp_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	household expenditure in sector *j* in country *k*
Exp_k (*k*=1,..,*R*)	total household expenditure in country *k*
exp_k (*k*=1,..,*R*)	per-capita household expenditure in country *k*
$X_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	exports of sector *j* in country *k*
X_k (*k*=1,..,*R*)	total exports of country *k*
$M_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	imports of products produced by sector *j* in country *k*
M_k (*k*=1,..,*R*)	total imports of country *k*
$BOP_{j,k}$ (*j*=1,..,*m*; *k*=1,..,*R*)	balance of payments related to trade of product *j* in country *k*
BOP_k (*k*=1,..,*R*)	balance payments of country *k*

Figure 10.1 presents a schematic description of the model in the short-run.

Following Pasinetti (1993), the sets of state variables are assumed to be given at the beginning of each period in the model in the short-run. However, different from Pasinetti's framework, in the model presented in this book these state variables are determined endogenously in the dynamic part of the model as presented in the next sections.

Figure 10.1. Description of the model in the short-run

Time = t



Note: The figure refers to decision-making in one period, during which the state variables remain constant.

As mentioned, several macroeconomic variables are determined endogenously in each period. The first set of endogenous variables determined by the model is the set of prices of products. Pasinetti's (1993) classical framework assumes a separation between the price and the quantity systems, which is also adopted in the model presented here. In Pasinetti (1993) prices are proportional to labour coefficients, while quantities are proportional to consumption coefficients.[1]

Here, prices are assumed to reflect labour costs and markups. For each commodity j produced in country k and consumed in country h, we assume that the price of the commodity ($p_{j,h,k}$) is given by the amount of labour employed in its production multiplied by the wage rate (w_k) and the markup in that particular market:

$$p_{j,h,k} = l_{j,k} w_k \, MK_{j,h,k} \qquad j=1,..,m;\ h,k=1,..,R \qquad \text{(X.1)}$$

Now let us turn to the determination of the quantities produced. Following Pasinetti's quantity system, if country k was in autarky, the physical amount produced of each good j would be directly determined by the demand ($c_{j,k}$), subject to the constraint of the total amount of labour available in the economy.

In the case of trade between countries, each consumer in each country has the choice to buy a product j from any country that produces that commodity. Note that the preferences of a representative consumer of a country k are already defined by the coefficients of consumption per capita $c_{j,k}$ ($j=1,...,m$). In other words, her overall consumption of each good j ($j=1,\ldots, m$) is already determined. What is not determined is the demand of that good j that is produced in a particular country h ($h=1,\ldots,R$). We represent this demand by $c_{j,k,h}$.

The consumption per capita of a commodity j in country k is the sum of the domestic consumption of commodity j that is locally produced ($c_{j,k,k}$) and of commodity j that is imported:

[1] This reflects is the classical flavor of Pasinetti's model. It echoes Smith's pure labour theory in the price system given that prices are only proportional to the quantities of labour and "do not express *market* prices (that would inevitably depend on the temporary whims of market supply and demand). They express those prices which the classical economists called 'natural prices' – a more fundamental notion of price, which reflects permanent and fundamental determinants." (Pasinetti, 1993, p.19). In the quantity system, physical quantities are determined following the Keynesian principle of effective demand: "The production is, in this sense activated, or, as is also said, generated by effective demand. And it is in this way that the Keynesian principle of effective demand here emerges, we might say, in its pure form." (Pasinetti, 1993, p.20)

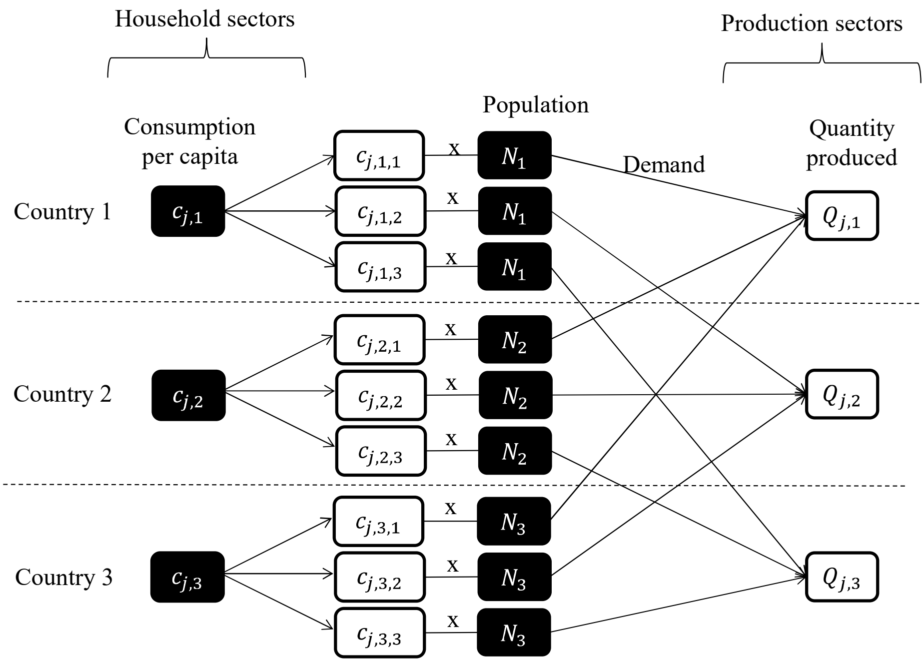
$$c_{j,k} = c_{j,k,k} + \sum_{h \neq k}^{R} c_{j,k,h} \quad =>$$
$$c_{j,k} = \sum_{h=1}^{R} c_{j,k,h} \quad (X.2)$$

On the production side, the quantity of commodity j produced domestically in country k is equal to the domestic and foreign demands, and is given by:

$$Q_{j,k} = \sum_{h=1}^{R} c_{j,h,k} N_h \quad (X.3)$$

Figure 10.2 illustrates the flow of commodities represented by equations (X.2) and (X.3).

Figure 10.2. Illustrative diagram of the flow of commodities



The diagram represents a simplified setup with three countries and only one product: commodity j. The left side of the figure represents the household sectors of the three countries represented in the diagram, while the right side represents the production sectors. The black boxes represent the given state variables of consumption per capita ($c_{j,k}$) and the exogenous variables representing total population (N_k), the clear boxes represent the consumption per capita of domestic and imported products ($c_{j,h,k}$) and the quantities produced by each sector ($Q_{j,k}$), and the symbol 'x' in the diagram represents multiplication. For example, the consumption per capita of commodity j in country 1 ($c_{j,1}$) is divided in consumption per capita of domestic varieties of that product ($c_{j,1,1}$) and of varieties imported from countries 2 ($c_{j,1,2}$) and 3 ($c_{j,1,3}$), which aggregated by the population (N_1) contributes to the demand for the production in each country. There are many possible ways to divide the consumption per-capita of commodity j ($c_{j,k}$) into the consumption of domestic and imported varieties of that product. Therefore, the model has to answer how the consumption per capita of a commodity in a country is divided between varieties produced domestically and varieties that are imported from the different countries.

A usual approach is to assume that the consumption of the different varieties is driven by the relative competitiveness of the countries in that sector, which are determined by the prices of the products. Different solutions are advanced in the literature. Some models follow Ricardo's (1821) principle of comparative advantage by considering *ex-ante* full-specialization in which the country that produces with the lowest *relative* price (relative to the other products) is the only producer and exporter of the product (e.g. Andersen, 2001; Araujo and Teixeira, 2004).[3] Other models use different mechanisms to allow for non-full-specialization, such as the use of export function following Thirlwall (1979) in which shares of domestic and imported goods are a function of the ratio of the prices in each country.[4,5]

Here I do not follow these approaches because the former results in full-specialization of exports, which does not replicate the empirical pattern of diversification, and the latter is used in models with two countries,[6] as opposed to

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[3] These models assume that if two countries produce with the same lowest price, then both countries produce that product but do not trade.

[4] For example, Araujo (2013) assumes that, in the context of two countries trading, domestic consumption of domestically produced goods does not depend on the relative prices of varieties produced in each country, but consumption of imports will only exist if the foreign price is lower than the domestic price. Araujo and Trigg (2015) adopt a similar assumption with the difference that imports are consumed if the foreign price is lower than or equal to the domestic price.

[5] Los and Verspagen (2006), also in the context of two countries trading, assume that the shares of consumption of domestic and foreign goods are determined by the relation between the ratio of domestic and foreign prices using an inverted logistic curve. The setup allows for a situation in which both countries produce and export varieties of a commodity even when they have different prices. That same mechanism, however, could not be implemented to determine bilateral flows in the context of many countries because it uses information on the price ratio of two just countries.

[6] Also used in models that consider one country and the rest of the world.

a multi-country model that can be used to study the pattern of diversification of several countries trading.

I adopt two mechanisms to avoid *ex-ante* full-specialization. The first is the markup prices discussed previously, which is consistent with producers that have different labour costs. They compete in the same market by adopting markups that ensure that they meet the prevailing market price. The second mechanism is inspired by the World Trade Model proposed by Duchin (2005), which allows for non-full-specialization based on comparative advantage and considers multiple regions, goods and factors of production.[7] Duchin's model adopts linear programming to determine the quantities produced for domestic and foreign consumption, world prices and scarcity rents, under the constraint of limited availability of factors of production.[8] Trade is based on direct price comparisons and the country with the lowest price will produce and export the product. However, if there is not enough labour or another factor of production in the country to produce the quantity demanded in the domestic and foreign markets, then the country with the second lowest price would start to also produce and export that product to fulfil that demand.

Following Duchin (2005), we assume that there is a broker for the global economy, who has the task to minimize worldwide expenditure given consumer preferences, by allocating the production of each commodity *j* to the country that has a comparative advantage in producing that good, subject to the constraint related to the total amount of labour available in each economy.

The following linear programming is used to determine quantities:

$$\text{Minimize} \quad \textstyle\sum_{k=1}^{R}\left(\sum_{j=1}^{m}\left(\sum_{h=1}^{R} c_{j,k,h}\ N_k\ p_{j,k,h}\right)\right) \tag{X.4}$$

subject to:

a) The sum of quantities of a commodity *j* produced in all countries is the same as the sum of the quantities of that commodity consumed in all countries:

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[7] Hammer Strømman and Duchin (2006) extend the model to include transportation costs, which allows for the determination of bilateral trade flows.

[8] The World Trade Model uses linear programming to determine quantities and prices. One motivation for its use for price determination is to determine scarcity rents of fully utilized unpriced factors of production, such as water in water-stressed regions. Here we use it to determined quantities only – through the determination of the coefficients of consumption per capita of domestic and imported products – and we use Eq. (X.1) to determine prices, given that the only factor of production in the model is labour.

$$\sum_{h=1}^{R}\left(\sum_{k=1}^{R} c_{j,k,h} N_k\right) = \sum_{k=1}^{R} c_{j,k} N_k \qquad \text{(X.5)}$$

b) The total labour employed in each country is lower than or equal to the total labour available in that country:

$$\sum_{j=1}^{m} Q_{j,k}\, l_{j,k} \leq L_k \qquad k=1,\dots,R$$
$$\sum_{j=1}^{m} l_{j,k}\left(\sum_{h=1}^{R} c_{j,h,k} N_h\right) \leq L_k \qquad k=1,\dots,R \qquad \text{(X.6)}$$

c) For each country k the per capita consumption of a commodity j is the sum of the domestic consumption of commodity j that is locally produced and of commodity j that is imported as formulated in Eq. (X.2). It is rearranged and restated below for convenience:

$$\sum_{h=1}^{R} c_{j,k,h} = c_{j,k}$$

d) All quantities are non-negative numbers:

$$c_{j,k,h} \geq 0 \qquad j=1,..,m;\ h,k=1,\dots,R \qquad \text{(X.7)}$$

The linear programming above does not provide a unique result when two or more countries offer the same good at exactly the same lowest price and they are not constrained by the amount of labour available. In this situation, any combination of quantities of that good results in the lowest expenditure. To address this situation, we assume that the exporting countries have the same market share for this product.[9]

Let us now consider the underlying principle of microeconomic behaviour of the model, which is not explored by Duchin (2005). We assume that consumers show a rational behaviour and prefer the lowest-priced bundle of domestic and imported goods that match their given preferences $c_{j,k}$ ($j=1,...,m$).[10] Therefore, the optimization problem that the representative consumer has to solve is to find demand $c_{j,k,h}$ ($j=1,\dots m;\ h=1,...,R$) that minimizes her expenditure while delivering her overall demand preference given by $c_{j,k}$ ($j=1,...,m$). This is an expenditure

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[9] This particular situation is sometimes considered in the literature to result in no trade in that commodity (e.g. Pasinetti, 1993) when considering trade between two countries.

[10] There are many factors that influence consumer behaviour, and prices are considered to be a cue to the customer about the quality and cost of the product. Nevertheless, the tendency for minimizing expenditure is a common finding in the literature (For examples see De Paredes, Cárdenas and Garcés, 2013; Danziger, Hadar, Morwitz, 2014; Grewal, Roggeveen, and Nordfält, 2014).

minimization problem that is related to the Hicksian demand function, which is the demand of a consumer over a bundle of goods that minimizes her expenditure that yields a fixed level of utility. The Hicksian demand function is considered a mathematic dual to the Marshallian demand function. While the former deals with the expenditure minimization problem, the latter deals with the utility maximization problem. [11]

Therefore, we assume that the central market authority, acting as a broker, aggregates the Hicksian demand functions of all representative consumers (one for each country) subject to the constraint of the production sectors of maximum labour available in each economy. A more formal discussion of the expenditure minimization behaviour of consumers is presented in Annex X.1.

The other endogenous macroeconomic variables of the model: employment, income, expenditure and balance of payments, also follows Pasinetti's (1993) framework.

For each country k, employment in each sector j is equal to the labour required to produce the quantity of commodity j produced domestically:

$$E_{j,k} = l_{j,k} Q_{j,k} \qquad j=1,..,m;\ k=1,\dots,R \qquad \text{(X.8)}$$

At the macroeconomic level, total employment is the sum of employment in each sector of the economy:

$$E_k = \sum_{j=1}^{m} E_{j,k} \qquad k=1,\dots,R \qquad \text{(X.9)}$$

The output value of sector j in country k ($Y_{j,k}$) is given by the price of the commodity multiplied by the quantity produced:

$$Y_{j,k} = \sum_{h=1}^{R} c_{j,h,k} N_h\ p_{j,h,k} \qquad j=1,..,m;\ k=1,\dots,R \qquad \text{(X.10)}$$

Total output of the economy k is, therefore, the sum of the outputs of the individual sectors:

[11] Here we adopt the Hicksian approach because, following Pasinetti's (1993) framework and Clower's (1965) dual-decision hypothesis, consumer preferences are state variables in each period of time and therefore would only change (endogenously) during the passage of one period of time to the next, while expenditure is endogenous in the short run. The Marshallian approach would require to make the symmetrical assumption and to treat consumer preferences as endogenous variables in the short-run and expenditure as a state variable (endogenous in the dynamic part of the model).

$$Y_k = \sum_{j=1}^{m} Y_{j,k} \qquad k\text{=}1,\ldots,R \qquad \text{(X.11)}$$

Which divided by the population gives the output per capita in that country:

$$y_k = \frac{Y_k}{N_k} \qquad k\text{=}1,\ldots,R \qquad \text{(X.12)}$$

Similarly, expenditure in country k on commodity j ($Exp_{j,k}$) is given by the consumption of domestic and imported varieties of the commodity multiplied by their prices:

$$Exp_{j,k} = \sum_{h=1}^{R} c_{j,k,h} N_k \, p_{j,k,h} \qquad j\text{=}1,..,m;\ k\text{=}1,\ldots,R \qquad \text{(X.13)}$$

Total expenditure in country k is the sum of the expenditure on all products:

$$Exp_k = \sum_{j=1}^{m} Exp_{j,k} \qquad k\text{=}1,\ldots,R \qquad \text{(X.14)}$$

The per-capita expenditure in country k is obtained by dividing the total expenditure by the population of the country:

$$exp_k = \frac{Exp_k}{N_k} \qquad k\text{=}1,\ldots,R \qquad \text{(X.15)}$$

The following set of equations is related to value of the quantities traded between countries. They are basically accounting equations. For each country k and sector j, exports and imports by sector are given by the price of the product multiplied by the quantity exported or imported:

$$X_{j,k} = \sum_{h \neq k}^{R} p_{j,h,k} \, c_{j,h,k} N_h \qquad j\text{=}1,..,m;\ k\text{=}1,\ldots,R \qquad \text{(X.16)}$$

$$M_{j,k} = \sum_{h \neq k}^{R} p_{j,k,h} \, c_{j,k,h} N_k \qquad j\text{=}1,..,m;\ k\text{=}1,\ldots,R \qquad \text{(X.17)}$$

Total export and import by country are given by the sum of the exports and imports by sectors, respectively:

$$X_k = \sum_{1}^{m} X_{j,k} \qquad k\text{=}1,\ldots,R \qquad \text{(X.18)}$$

$$M_k = \sum_{1}^{m} M_{j,k} \qquad k\text{=}1,\ldots,R \qquad \text{(X.19)}$$

And the values of the balance of payments by sector and in total for country k are given by the differences between exports and imports:

$$BOP_{j,k} = X_{j,k} - M_{j,k} \qquad j=1,..,m;\ k=1,\dots,R \qquad (X.20)$$

$$BOP_k = X_k - M_k \qquad k=1,\dots,R \qquad (X.21)$$

This concludes the description of the model in the short-run. Its functioning is illustrated in detail with some numerical examples in Annex X.2.

10.2 Wage rate

To start the discussion of the dynamics of the state variables, we assume that nominal wage rates are endogenous and reflect the average productivity of the economy. In the model, we take the wage rate of one of the countries as the unit and then we measure all the prices and wage rates in that currency. This arrangement follows the simplification proposed in Pasinetti (1993) in which gold is used as medium of exchange between countries and the sector that produces gold in each economy has labour productivity equal to the average productivity of that economy.

Given that assumption, considering the currency of country 1 as the baseline, in each period the wage rates in other countries are given by the wage rate of country 1 multiplied by the ratio of average labour coefficients in both countries weighted by the employment shares:

$$w_k = w_1 \frac{\left(\sum_{j=1}^{m} l_{j,1} E_{j,1} / E_1 \right)}{\left(\sum_{j=1}^{m} l_{j,k} E_{j,k} / E_k \right)} \qquad k=\{2,3,..,R\} \qquad (X.22)$$

10.3 Change in markups

As mentioned in the previous chapter, in the model we assume monopolistic competition in domestic and international markets (e.g. Krugman, 1979). We assume the existence of markups over production costs. These could be different per sector, country, and market.

The mechanism of setting markups is implemented in the model through the following algorithm:

1. Initial markups are given for each market. We consider that markup of exports are higher than for selling in the domestic market:[12]

$$MK_{j,k,k}(0) < MK_{j,h,k}(0) \qquad j=1,..,m;\ h,k=1,\dots,R;\ h\neq k \quad \text{(X.23)}$$

2. At the start of a period, sectors initially set their tentative markup for each market as the same as in the previous period:

$$MK_{j,h,k}(t) = MK_{j,h,k}(t-1) \qquad j=1,..,m;\ h,k=1,\dots,R$$

3. Sectors calculate their tentative prices following (X.1) (the labour component of the price may have decreased due to changes in the exchange rate, which affect the relative wage rates, or due to changes in the labour coefficient as a consequence of, for example, process innovation).

4. Sectors of different countries compare prices and try to match the lowest tentative price by reducing their markups:

$$MK_{j,h,k}(t) = {\min(p_{j,h,g})}\Big/{l_{j,k}w_k} \qquad j=1,..,m;\ g,h,k=1,\dots,R;\ g\neq k \quad \text{(X.24)}$$

5. Sectors for which the labour costs are higher than the lower price are forced out of the market.

10.4 Technological change

This section focuses on the analysis of changes in technical knowledge. Technical progress is assumed in the model to be the result of four different processes: 1) introduction of new techniques in the production of an existing product (process innovation); 2) production of a new good that does not yet exist in any country (product innovation); 3) the introduction of techniques that are new

[12] This assumption is based on the empirical literature on markup prices that shows that exporters charge on average higher markups than non-exporters of the same products (e.g. De Loecker and Warzynski, 2012). However, it would not make a difference in the main results of the model if we do not make this assumption because the model assumes different markups in different markets for the same product and producing country, and the dynamics of the model makes these initial markups to change in response to technology change and competition.

to the country's production but not new to the global economy (process emulation); and 4) introduction of a product that is new to the country but not new to the world (product emulation).

For simplification, we assume that population sizes remain constant. Furthermore, we do not model other forms of technical change discussed in chapter Eight (i.e division of labour and variation of technologies), since they do not result in diversification.

We assume that within each period, the composition and number of sectors in the economy remains constant. The emergence or disappearance of economic sectors is therefore restricted to the moment of passing from a given phase to the next. This does not mean that every passing of time would carry a change in the number of commodities.

The next subsection describes the algorithm used to implement the concept of adjacent possible, which creates path dependency in all four forms of innovation.

10.4.1 *Adjacent possible for creation of path dependency of innovation*

As discussed in the previous chapter, we adopt the concept of adjacent possible as proposed by Kauffman (2008) to create the path dependency in the innovation process. Suppose at each passage of time there is an adjacent possible (AD_k) of potential new products or processes that could be created by the combination of existing set of technologies in country *k*.

Using an example to illustrate, suppose country *A* produces three products, in which the first is characterized by technology *a*, the second by technology *b* and the third by technology a*b*. The adjacent possible of country *A* is therefore a set of six products, each one characterized by one of the following technologies: *aa*, *aab*, *bb*, *ba*, *bab*, and *abab*. Any new process or product to be created by the R&D sector of that country has to be composed by one of those six technologies. For example, suppose that a country *B* has developed a new commodity through product innovation, the R&D sector of country *A* would be able to introduce that same product through product emulation only if that product is characterized by one of those six technologies.

In the model, we assume that there is a parameter *u* that represents the probability that the potential new product is useful to fulfil a human need. A value of 0.4 for example would indicate that 4 out of 10 potential new products are useful. A list of useful potential products (List 1) and a list of potential products that are not useful (List 2) are randomly generated. These lists are identical for all countries. If a potential new product *j* is considered not useful when it is a member of an adjacent possible of a country *k*, then it will also be considered not useful in the adjacent possible of other countries.

The algorithm used to implement these steps for each country k at the start of each period is the following:

1. Generate full adjacent possible (AD_k);
2. For each potential new product in the adjacent possible, add it to the effective adjacent possible if that potential product is in List 1;
3. If, on the other hand, that potential product is in List 2 discard it;
4. If the product is not yet in either list, then it will be assigned to List 1 or List 2 (stochastically), and the algorithm returns to step 2 above.

The inclusion of the adjacent possible in the model is essential to implement the path dependency of economies, but it is very demanding in terms of data processing. At each time phase, for each country, the set of technologies used for the existing production has to be combined to generate the adjacent possible, and for each potential new product in that set, a search has to be performed to verify if that product is part of the subset of useful products or not. Higher order combinations are possible in this framework, in which different technologies that are components of various products are combined to create a new product. To keep the computer simulation manageable, we assume that potential new products are the result of combination of only two technologies already used in the production. Therefore, we do not implement combinations of three or more technologies in one step.

10.4.2 R&D sector

We assume that process and product innovation and emulation are the result of the active search for new products in the adjacent possible of a country. That activity is considered to be carried out through R&D and is assumed to be funded by the sum of the markup over production costs of the commodities produced in the country. Therefore, the number of people engaged in R&D is constrained by the surplus obtained by the production sectors in selling products with markup (SP). This arrangement creates a strong tendency for increasing returns. If productivity in the country is higher than in the other countries and high markup profits are obtained, then the productive sectors can fund a large R&D effort. When productivity is low and the country's exports are small and with a lower markup, then the R&D effort is necessarily limited.

$$SP_k(t) = \sum_{h=1}^{R} \sum_{j=1}^{m} \big((p_{j,h,k}(t) - l_{j,k}(t) w_k(t)) Q_{j,k}(t) / w_k(t) \big)$$

$$SP_k(t) = \sum_{h=1}^{R} \sum_{j=1}^{m} \big(l_{j,k}(t) (MK_{j,h,k}(t) - 1) Q_{j,k}(t) \big) \tag{X.25}$$

The number of people engaged in R&D is also constrained by the availability of labour to participate in this activity (LA), which equals the labour that is not engaged in production:

$$LA_k(t) = L_k(t) - E_k(t) \quad \text{(X.26)}$$

The share of labour engaged in R&D (ϵ_k) is then given by:

$$\epsilon_k(t) = \frac{min(SP_k(t), LA_k(t))}{L_k(t)} \quad \text{(X.27)}$$

We assume that a share of these R&D workers is devoted to research towards a new product (either to the country or to the world) ($\partial_k^{product}$) and another share is devoted to finding new and more productive ways to produce existing products ($\partial_k^{process}$):

$$\partial_k^{product}(t) + \partial_k^{process}(t) = 1 \quad \text{(X.28)}$$

$$0 \leq \partial_k^{product}(t) \leq 1;\ 0 \leq \partial_k^{process}(t) \leq 1 \quad \text{(X.29)}$$

We assume that the shares of research dedicated to finding a new product or to finding a new process are endogenous to the model and a function of the share of the labour force that is employed. The assumption is that R&D efforts towards process innovation increase with the employment rate to reduce the labour requirement in the existing production base. On the other hand, the effort towards product innovation increases when labour participation has declined, to create new sources of demand and employment:

$$\partial_k^{process}(t) = E_k(t)/L_k(t) \quad \text{(X.30)}$$

$$\partial_k^{product}(t) = 1 - E_k(t)/L_k(t) \quad \text{(X.31)}$$

In the group of people engaged in finding new products, some of them are devoted to research towards product innovation ($\sigma_k^{product}$ denotes this share) and the rest is devoted to emulation ($\sigma_k^{product\_emulation}$):

$$\sigma_k^{product}(t) + \sigma_k^{product\_emulation}(t) = 1 \quad \text{(X.32)}$$

$$0 \leq \sigma_k^{product}(t) \leq 1;\ 0 \leq \sigma_k^{product\_emulation}(t) \leq 1 \quad \text{(X.33)}$$

We assume that the shares of research dedicated to product innovation and emulation are endogenous to the model in the following way:

$$\sigma_k^{product}(t) = m_k(t)/m(t) \quad \text{(X.34)}$$

$$\sigma_k^{product\_emulation}(t) = 1 - m_k(t)/m(t) \tag{X.35}$$

Where m_k is the number of types of commodities produced in country k and m is the combined number of different types of commodities traded by all countries. Therefore, research related to finding new products will be totally devoted to product innovation if a country already produces all types of commodities that exist.

Similarly, a share of the researchers working to discover a more productive process of production is devoted to research towards process innovation ($\sigma_k^{process}$) and another share is devoted to process emulation ($\sigma_k^{process\_emulation}$):

$$\sigma_k^{process}(t) + \sigma_k^{process\_emulation}(t) = 1 \tag{X.36}$$

$$0 \le \sigma_k^{process}(t) \le 1;\ 0 \le \sigma_k^{process\_emulation}(t) \le 1 \tag{X.37}$$

The shares of research dedicated to process innovation and process emulation are assumed to be endogenous:

$$\sigma_k^{process}(t) = TF_k(t)/m_k(t) \tag{X.38}$$

$$\sigma_k^{process\_emulation}(t) = 1 - TF_k(t)/m_k(t) \tag{X.39}$$

TF_k is the number of sectors in production in country k that are operating at the technological frontier, meaning that they have the highest productivity when compared with similar sectors in other countries. Therefore, if all sectors are operating at the technological frontier, its research related to finding more productive processes will be totally devoted to process innovation.

10.4.3 Process innovation

Process innovation, product innovation and emulation are included in the model using a mechanism similar to that proposed by Andersen (2001). In the case of process innovation, in each country k the outcome of the work of one person engaged towards process innovation takes the form of a Poisson process with the arrival rate of new process given by $\lambda_k^{process}$.

The effective arrival rate of a new process in country k and sector j is a function of the number of people in the R&D sector of that country engaged in process innovation ($\epsilon_k \partial_k^{process}\ \sigma_k^{process} N_k$). The effective arrival rate is also a function of the share of employment in that sector ($E_{j,k}/E_k$), which is assumed to create an incentive to augment labour.

Therefore, in each country k and sector j, the number of new processes in each period is given by:

$$X_{j,k} \sim P(\epsilon_k \partial_k^{process}\ \sigma_k^{process} N_k (E_{j,k}/E_k)\ \lambda_k^{process}) \tag{X.40}$$

When process innovation happens in a sector j, we assume that the labour coefficient of that sector is reduced by a factor ($0 < rdc_{j,k} < 1$):

$$l_{j,k}(t) = rdc_{j,k}\ l_{j,k}(t-1) \tag{X.41}$$

For simplification, we assume that $rdc_{j,k}$ is drawn from a uniform distribution:

$$rdc_{j,k} \sim U(\beta_1, 1\ ), \quad 0 < \beta_1 < 1 \tag{X.42}$$

Where β_1 is a parameter of the model.

10.4.4 Process emulation

Process emulation is modelled in way similar to process innovation. We consider that one person engaged in process emulation in country k would find a new process according to a Poisson process with an arrival rate of $\lambda_k^{process\_emulation}$.

The effective arrival rate of a new process through emulation in country k and sector j is a function of the number of people in the R&D sector of that country who are engaged in process emulation ($\epsilon_k \partial_k^{process}\ \sigma_k^{process\_emulation} N_k$) and the share of employment in the sector ($E_{j,k}/E_k$). A sector would only focus on process emulation if it is lagging behind the technological frontier.

Therefore, in each country k and sector j, the number of new processes through process emulation in each period is given by:

$$X_{j,k} \sim \begin{cases} P(\epsilon_k \partial_k^{process}\ \sigma_k^{process\_emulation} N_k (E_{j,k}/E_k)\ \lambda_k^{process\_emulation}) & \text{if lagging behind} \\ 0, \text{otherwise} \end{cases} \tag{X.43}$$

When process emulation happens in a sector j, we consider that the sector adopts the technologies of the frontier country. Hence, the labour coefficient takes the value of the coefficient in the country h and sector j that was emulated:

$$l_{j,k}(t) = \ l_{j,h}(t) \tag{X.44}$$

10.4.5 *Product innovation*

Regarding product innovation, we assume that in each country k the outcome of the work of one person engaged towards product innovation takes the form of a Poisson process with the arrival rate of new sector given by $\lambda_k^{product}$.

The effective arrival rate of new products in the economy is rescaled by the number of researchers that are engaged in product innovation; hence is given by: $\epsilon_k \partial_k^{product} \sigma_k^{product} N_k \lambda_k^{product}$.

Therefore, in each country k the number of new products in each time phase is given by:

$$X_k \sim P(\epsilon_k \partial_k^{product}\ \sigma_k^{product} N_k \lambda_k^{product}) \tag{X.45}$$

In the case that a new product emerges in this Poisson process, we assume that a new production sector could be established to produce this commodity. We assume that the labour coefficient of the new sector (l_{new}) is given by the average of the labour coefficients of the production sectors in activity in the economy in the previous phase:

$$l_{new,k}(t) = \frac{\sum_{j=1}^{m_k} l_{j,k}(t-1)}{m_k(t-1)} \tag{X.46}$$

Note that although the new product is created, it does not mean that a new sector will automatically be created to produce it. A new sector will start to operate if there is already a potential demand for the new product. In other words, a new sector starts if there is at least one country in which the level of income per-capita is sufficient to allow a potential demand for that new product. If no potential demand exists then production of the new product will be on hold waiting for demand.[13]

10.4.6 *Product emulation*

Product emulation is the innovative research and development process required to imitate and adapt a product that already exist in another country to domestic conditions. Similar to product innovation, we assume that in each country k the outcome of the work of one person engaged towards emulation takes the form of a Poisson process with the arrival rate of new sector given by $\lambda_k^{emulation}$. The effective arrival rate of a new emulation in the economy is rescaled by a share φ of the number of researchers that are engaged in the process of emulation, which total is given by ($\epsilon_k \partial_k^{product}\ \sigma_k^{emulation} N_k$).

The share φ is assumed to be proportional to the emulation opportunity of the sector, which is defined here as the increase in the share of the demand in that

[13] The determination of the consumption coefficients of the new product is discussed later in the chapter.

sector in the total demand for products that are new to the country. The idea is that the higher the increase in demand, the higher the opportunities for new entrants to position themselves in the market. Therefore, if there are two products for which the country can engage in emulation, the higher share of the researchers will be working towards the emulation of the production of the sector that is experiencing the higher increase in demand. The share φ is calculated as follows:

$$\varphi_{j,c}(t) = \frac{\sum_{k=1}^{R} Y_{j,k}(t-1) - \sum_{k=1}^{R} Y_{j,k}(t-2)}{\sum_{i=1}^{m}\sum_{k\neq c}^{R} Y_{i,k}(t-1) - \sum_{i=1}^{m}\sum_{k\neq c}^{R} Y_{i,k}(t-2)} \tag{X.47}$$

$\sum_{k=1}^{R} Y_{j,k}$ is the total output in monetary terms of production of commodity *j*, which is the same as the total demand in monetary terms, and $\sum_{i=1}^{m}\sum_{k\neq c}^{R} Y_{i,k}$ is the sum of output of the *m* sectors that are the result of product innovation in countries other than country *c* and are not produced in that country. The rule above describes an economic incentive that directs the emulation efforts.

For the process of emulation to start, it is necessary that a new product has previously emerged elsewhere in the world. That would trigger the research towards emulation taking the form of the Poisson process. Thus, in each time phase and in each country *k* the number of emulations of a particular new sector *j* is given by:

$$X_{j,k}(t) \sim \begin{cases} P\left(\epsilon_k \partial_k^{product}\ \sigma_k^{emulation} N_k \varphi_{j,c} \lambda_k^{emulation}\right), & \text{if } j \text{ is a new sector in any other country} \\ 0, & otherwise \end{cases} \tag{X.48}$$

For every country *k* and for every emulated sector *j*, we assume that its labour coefficient at the time of the emulation (t'') is the same as the labour coefficient of that sector at the time that it was created (t') in the economy of country *h* that initially introduced the commodity:

$$l_{j,k}(t'') = l_{j,h}(t') \tag{X.49}$$

Once an emulation of a sector occurs in the economy, we assume that no other product emulation will be attempted in that sector in that country in the future.

10.5 Change in consumption patterns

This section describes the dynamics of the model focusing on changes in consumption. Let us start the discussion of change in consumption patterns by looking at Pasinetti's (1993) model, which formalizes these changes in a general form:

$$c_{j,k}(t) = c_{j,k}(t-1)e^{r_{j,k}} \tag{X.50}$$

In which $r_{j,k}(t)$ is the rate of change in consumption, which, as mentioned above, is assumed to be constant during that time phase.

To implement the Engel's law-related fact (i) listed in the previous chapter (section 9.3.1) related to the hierarchy of preferences of consumption, we assume that the commodities are ordered from those that satisfy the most to those that satisfy the least essential needs.

Therefore, we enforce a decreasing order on the rate of changes ($r_{j,k}$) in each country in each period:

$$r_{1,k} \geq r_{2,k} \geq \cdots \geq r_{m_k,k} \tag{X.51}$$

Note that such ordering implies that when consumption is increasing, it will increase faster for the more essential goods. On the other hand, when consumption is decreasing, it will decrease faster for the less essential goods. The hierarchy of consumption preferences does not emerge naturally from a Pasinettian formulation; it has to be enforced. The formalization above is more flexible than the one proposed in Andersen (2001) because it allows for changes in consumption in all products.

To implement the empirical fact (iii), related to saturation of demand, we assume that for each commodity j there is a maximum quantity of per capita consumption given by $maxc_j$. For simplification, we consider that such maximum value is the same in all countries. Therefore, in each country k, the consumption per capita $c_{j,k}$ of commodity j cannot grow beyond $maxc_j$ and the equation (X.50) is rewritten as:

$$\forall j \ \exists \ maxc_j, \ c_{j,k}(t) = \min(c_{j,k}(t-1)e^{r_{j,k}}, maxc_j) \tag{X.52}$$

For the computer-based implementation of the model, we assume that $maxc_j$ is higher than the maximum value of the actual per capita consumption at time 1 of commodity j in any country (here represented by a new variable MAX_j):

$$maxc_j > MAX_j = \max(c_{j,1}(1), c_{j,2}(1), \ldots, c_{j,m_k}(1)) \tag{X.53}$$

For simplification, we assume that $maxc_j$ is drawn from a uniform distribution:

$$maxc_j \sim U(MAX_j, \beta\, MAX_j) \tag{X.54}$$

Where β is a parameter that represents the maximum increase that the consumption per capita may take. For example, if at time 1 the maximum value of consumption per capita of commodity j is 10 units ($MAX_j = 10$), and if the parameter β is set to the value 2, then the saturation point of that commodity ($maxc_j$) will be a stochastic value between 10 and 20 units.

Equations (X.51) to (X.54) formalize the Pasinettian framework, the next step is to endogenize the change of total consumption expenditures. As mentioned, we adopt Clower's (1965) dual-decision hypothesis and the stochastic aggregated behaviour of heterogeneous consumers who follow rules of thumb. The result is that when income is higher than expenditure in the previous time phase, the aggregated behaviour of consumers is to increase their consumption in the current time phase, and vice versa.

Therefore, we assume that the signal (positive or negative) of the growth rate of consumption r is determined endogenously and it is given by:

$$\begin{cases} r_{j,k}(t) > 0, if exp_k(t-1) < y_k(t-1) \\ r_{j,k}(t) < 0, if exp_k(t-1) > y_k(t-1) \end{cases} \tag{X.55}$$

For simplicity, we also assume that r is drawn from uniform distributions:

$$\begin{cases} r_{j,k} \sim U(0, \max(r)), if exp_k(t-1) < y_k(t-1) \\ r_{j,k} \sim U(-\max(r), 0), if exp_k(t-1) > y_k(t-1) \\ r_{j,k} = 0, \ if exp_k(t-1) = y_k(t-1) \end{cases} \tag{X.56}$$

Where $\max(r)$ is a parameter that indicates the maximum absolute rate of change r in all sectors and in all countries.

Note that the difference between total income and total expenditure is the same as the value of the balance of payments of an economy. Therefore, this mechanism also serves the function to keep the balance of payments moving towards zero in the long run. With this mechanism, the model does not need to enforce balance-of-payment equilibrium by adding constraints to consumption or supply levels in each economy.

It is also important to note that the model described in this chapter continues to follow Pasinetti's (1993) general framework in the sense that quantities and prices are determined in the short-term through two different systems. In other words, general levels of consumption in a given time period are not directly determined and do not directly affect prices in that period. Note that given that we are dealing with open economies, the determination of quantities produced in each country takes prices in consideration to determine patterns of specialization, which is formalized using the linear programming described in the previous sections. However, this does not result in prices determining overall quantities consumed by a representative agent in each country.

Now let us get back to the empirical fact (ii) in Pasinetti's (1993) framework discussed in the previous chapter (section 9.3.1). It states that variations in the composition of consumption may occur as a consequence of the introduction of new products. First, we assume that the consumption of a new commodity *j* will only occur if the level of income per capita is higher than a certain value (α), below which there is no consumption of that commodity. We assume that this floor in relation to the demand of a particular commodity is the same in all countries. Thus, the consumption of a new commodity *j* will start at a time (t''), at the same time as or posterior to the creation of the new product at time (t'), according to:

$$c_{j,k}(t'') \quad \begin{cases} > 0, if\ y_k(t''-1) \geq \alpha \\ = 0\ ,\ \ otherwise \end{cases} \tag{X.57}$$

We assume that the emergence of a new commodity results in an exogenous small one-time change in the pattern of consumption of all other commodities, due to the complementarities or substitutions that the new product allows. This is the "creative destruction" process in action. Let us define $s_{i,j}$ as the substitution and complementarity effect of the emergence of the new product *i* on the consumption of an existing commodity *j*. For simplicity, we also assume that $s_{i,j}$ is drawn from a uniform distribution with the maximum change given by the parameter κ:

$$s_{i,j} \sim U(1-\kappa, 1+\kappa) \tag{X.58}$$

This implies that in each country *k*, by the time of the introduction of the new product *i*, the coefficient of consumption of existing product *j* is affected in the following one-time change (revising equation X.52):

$$c_{j,k}(t) = \min(s_{i,j}\ c_{j,k}(t-1)e^{r_{j,k}}, maxc_j) \tag{X.59}$$

Similarly, the saturation point of commodity *j* is affected by the change (Saviotti and Pyka, 2017):

$$maxc_j(t) = s_{i,j}\ maxc_j(t-1) \tag{X.60}$$

10.6 Demand higher than production possibilities

The emergence of a new product may generate more demand for labour than the total labour available in the economy. That would be more likely to be the case when the substitution effect of the new product is low and its complementarity effect is high. In such scenario, in addition to the need for labour to be engaged in the new production sector, more labour would also be drawn to some of the existing sectors to fulfil the new demand created by complementarity effects.

When such scenario of surge in demand for labour occurs, then the physical system hits the constraint of the maximum amount of labour available given the existing level of technical knowledge. In that case the linear programming problem set by equations X.4 to X.8 become unsolvable. Given that an objective of the model proposed here is to also be used for investigations through computer simulations, we assume that if the sum of the amount of labour required for production is higher than the sum of the labour available then production sectors will resort to overtime to produce enough products to meet the demand.

That rule is implemented by evaluating the result of the linear programming problem set by equations X.4 to X.8 to verify if it had become unsolvable. In that case, the linear programming problem is changed by revising equation (X.6) as follows:

$$\sum_{j=1}^{m} l_{j,k}\left(\sum_{h=1}^{R} c_{j,h,k} N_h\right) \leq (1+\vartheta) L_k \qquad \text{(X.61)}$$

Where $0 < \vartheta < 1$ is an exogenously given coefficient that represents the amount of overtime as a share of the total amount of labour available for the production sectors. Equation (X.61) states that the total labour employed in each country has to be lower or equal than the total labour available plus the overtime.

As soon as the demand for labour returns to below the total labour constrain, equation (X.6) returns to be used in the model. The mechanism that may make the level of labour return to a lower level is the competition in the international market that affects the market shares (and therefore the level of employment required for production) in all sectors. That competition is enabled by the capacity of other countries to emulate the production of new sectors as well as to increase market share by reducing prices through process innovation.

10.7 Summary

This chapter presents the formalization of a model of structural economic dynamics with international trade that considers economic diversification. The model can be divided into two main parts: short-run and dynamic equations.

In the short run, the model determines prices of products, quantities produced by each sector and country and targeting domestic and export markets. Many basic elements of the model in the short-term follow the Pasinetti's (1993) framework and the World Trade Model proposed by Duchin (2005). A critical element of the model is the way that production sectors are characterized - by the set of labour-embodies technologies that is used in the production.

On the dynamics of the model, we consider that structural dynamics is the result of changes in consumption patterns and technological progress, which are both partly endogenous to the model. The model follows Andersen (2001) in the dynamics of technological change, Pasinetti (1993), Clower (1965) and Gualerzi (2012) in the dynamics of changes of consumption patterns, and Kauffman (2008) in the way to formalize path dependency in the process of diversification. Economic diversification comes about through product innovation or product emulation, and it is considered to be path dependent. New products are created by the combination of existing labour-embodied technologies.

Annex

X.1. Expenditure minimization behaviour

The expenditure minimization problem is related to the Hicksian demand function, which is given by:

$$h(p,\overline{U}) = \arg\min \textstyle\sum_j p_j\, q_j \qquad j\text{=1,..,}m \qquad \text{(X.1.1)}$$
$$\text{subject to: } U(q) \geq \overline{U}$$

where U is the utility function, $\overline{U}$ is the given utility level, p is the set of prices and q is the set of quantities of goods in the economy.

In the present scheme, the given utility level $\overline{U}$ of the representative consumer in country k refers to utility derived from the set of consumption per capita:

$$\overline{U} = U(c_{j,k}), \qquad j\text{=1,…,}m \qquad \text{(X.1.2)}$$

The bundle that minimizes expenditure must have the same total quantity of each good in $c_{j,k}$ (*j=1,...,m*) because that is the given preference of the representative consumer, the only variation possible is in the combination of domestic and imported goods constrained by Eq. (X.2) (i.e. any combination of domestic and imported varieties of a good *j* has to total the exact amount of the consumption per capita of that good).

Therefore, the Hicksian demand function of a representative consumer of country *k* is given by:

$$\arg\min \textstyle\sum_{j=1}^{m} \sum_{h=1}^{R} p_{j,h} c_{j,k,h} N_k \qquad j\text{=1,..,}m;\ h\text{=1,…,}R \qquad \text{(X.1.3)}$$

subject to:

a) The consumption of a commodity *j* is the sum of the domestic consumption of commodity *j* that is locally produced and of commodity *j* that is imported:

$$\textstyle\sum_{h=1}^{R} c_{j,k,h}\, N_k = c_{j,k} N_k \qquad j\text{=1,..,}m \qquad \text{(X.1.4)}$$

We are interested to find the Hicksian demand function of a representative consumer of the whole economy comprised by all countries. In that regard, noting that representative consumers of each country are independent from each other (consumer demand decisions in one country are not influenced by the decisions of another consumer in another country given that their preferences are already set by coefficients of consumption per capita of each country), the Hicksian demand function of the representative consumer of the whole economy is the summation of the individual Hicksian demand functions of the representative consumers of each country.

Therefore, the Hicksian demand function of a representative consumer of the whole economy is given by:

$$\sum_{k=1}^{R} \arg\min \sum_{j=1}^{m} \sum_{h=1}^{R} p_{j,h} c_{j,k,h} N_k \tag{X.1.5}$$

Given that all representative consumers have equal access to the same goods, their behaviour is affected by the same set of prices. Therefore, the set of prices that minimizes the expenditure of one representative consumer has to be exactly the same set of prices that minimizes the expenditure of other representative consumers. Hence, Eq. (X.1.5) can be reformulated as:

$$\arg\min \sum_{k=1}^{R} \sum_{j=1}^{m} \sum_{h=1}^{R} p_{j,h} c_{j,k,h} \ N_k \tag{X.1.6}$$

That minimization is subject to:

a) In each country *k* the consumption a commodity *j* is the sum of the domestic consumption of commodity *j* that is locally produced and of commodity *j* that is imported:

$$\sum_{h=1}^{R} c_{j,k,h} N_k = c_{j,k} N_k \qquad j=1,..,m;\ k=1,\dots,R \tag{X.1.7}$$

Which can be aggregated as follow:

$$\sum_{k=1}^{R} \sum_{h=1}^{R} c_{j,k,h} N_k = \sum_{k=1}^{R} c_{j,k} N_k \qquad j=1,..,m \tag{X.1.8}$$

Which indicate that the sum of quantity produced of a commodity *j* in all countries is the same as the sum of the quantity consumed of that commodity in all countries.

b) And all quantities are non-negative numbers:

$$c_{j,k,h} \geq 0 \qquad j=1,..,m;\ k,h=1,\dots,R \tag{X.1.9}$$

If the model had assumed unconstrained labour, the linear programming described above would be sufficient to determine quantities produced. However, here we consider that there is the possibility that a country is not able to meet demand because of the limit of labour available. Given that the representative consumer of the whole economy does not have access to the information regarding the amount of labour available to each production sector, we therefore assume the existence of a broker that intermediates the relation between consumers and producers. The broker has access to the preferences of each representative consumer and to the amount of labour available to each production sector as described below.

The possible quantities produced by each sector in each country are limited by the amount of labour available in each economy to carry out the production in that sector. The labour available to produce the quantity of goods of a sector j in a country k (quantity that is represented by $Q_{j,k}$) cannot be higher than the total labour available in the economy, represented by L_k, minus the amount of labour employed in the other sectors. Mathematically:

$$Q_{j,k} l_{j,k} \leq L_k - \sum_{i \neq j}^{m} Q_{i,k}\, l_{i,k} \quad , \quad j=1,..,m \tag{X.1.10}$$

The economy-wide constrain derived from Eq. (X.1.10) is given by the equation below. It indicates that the sum of the labour used in each sector of an economy k is limited by the total amount of labour available in the economy:

$$\sum_{j=1}^{m} Q_{j,k}\, l_{j,k} \leq L_k \qquad k=1,\ldots,R \qquad =>$$
$$\sum_{j=1}^{m} l_{j,k} \left(\sum_{h=1}^{R} c_{j,h,k} N_h \right) \leq L_k \qquad k=1,\ldots,R \tag{X.1.11}$$

Therefore, Eq. (X.1.11) is added to the linear programming.

It is possible to build another mechanism that would not require the existence of a broker. If we assume that each representative consumer makes one purchase order at a time and only make new purchase orders when the previous was fulfilled by the producer, and assuming that the order of purchases of each representative consumer is such that goods are ordered from those that have the highest price difference (between the cheapest to the second cheapest), to those that have the lowest difference. After each order, the production section ether fulfil the order (if it has the amount of labour required to produce) or it sends a message back to the consumer informing that it can only fulfil partially the order (informing how much of it the sector can fulfil and delivering that amount). In the latter case, the consumer then would make another order with the producer that has the second lowest price, and so on.

X.2. Analysis of numerical examples of the model in the short-run

This section details the model in the short-run by using a simple example. As in Pasinetti (1993), here we consider the international economic relations of two countries, *A* and *U*. We assume that the medium of exchange in both countries is anchored to an international currency and the exchange rate between the two domestic currencies is fixed so that the prices of all commodities in both countries are the same in terms of that currency. We also assume that both countries produce the same set of four products, and that average productivity in A is higher than in U. Also for simplification, we consider that the labour force in each country is the total population of 100 people, and that markups prices of each country and sector is 1. Let us assume that the initial values of the exogenous and state variables are given by:

- Total labour force in each country: $L_U = L_A = 100$
- Labour coefficients in country A: l_A = {1,1,1,1}
- Labour coefficients in country U: l_U = {2.2,2.4,2.6,2.8}
- Mark up prices: $MK_{j,h,k} = 1$ (j=*1,..,4; h, k*={*A,U*})
- Coefficients of consumption per capita in country A: $c_A = \{0.25, 0.25, 0.25, 0.25\}$
- Coefficients of consumption per capita in country U: $c_U = \{0.1, 0.1, 0.1, 0.1\}$
- Wage rate in country A: $w_A = \$\ 1$
- Wage rate in country U: $w_U = \$\ 0.4$

Table 10.2 presents the key variables of the model for the countries in autarky.

Table 10.2. Two countries in autarky, numerical example

	(1) *l* *(people/unit)*		*(2)* *c* *(unit/people)*		*(3)* *p* *($)*		*(4)* *Q* *(units)*		*(5)* *E* *(people)*		*(6)* *Y* *($)*	
Products	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*
1	1	2.2	0.25	0.1	1	0.88	25	10	25	22	25	8.8
2	1	2.4	0.25	0.1	1	0.96	25	10	25	24	25	9.6
3	1	2.6	0.25	0.1	1	1.04	25	10	25	26	25	10.4
4	1	2.8	0.25	0.1	1	1.12	25	10	25	28	25	11.2
Total									100	100	100	40

Note: wage rate in *A* is $1 and wage rate in *U* is $0.4.

To facilitate the analysis of the table, Columns (*1*) and (*2*) shows respectively the state variables of labour coefficients and coefficients of consumption per capita in each country and sector. Column (*3*) presents the prices, which are calculated based on the labour coefficients and the wage rates. The prices of products in country *A* are all equal to $1, which is the product of the labour coefficients (1 people/unit of product) by the wage rate ($1), while the prices of commodities produced in country *U* vary from $0.88 to $1.12, given the different productivity in the different sectors. Column (*4*) shows the quantity of each good produced in each country. Given that we have assumed the two countries in autarky, the amount produced in each country is equal to the consumption in that country: the consumption per capita of each product multiplied by the number of people in the population (100 people). It results that the quantity produced of each product in country *A* is 25 units and in country *U* is 10 units. Column (*5*) shows the number of people employed by sector in each country. The example was set up to result in full employment in each country. Employment is equally divided by sectors in country *A* (25 people per sector) and varies in country *U* from 22 people in the more productive sector (sector 1) to 28 people in the least productive sector (sector 4). The final column (*6*) presents the output by sector in each country. The more productive country *A* generates an output of $100 while country *U*'s output is $40. In this case of countries in autarky, output (income) is equal to expenditure because all production is consumed domestically. Note that if people in these countries were allowed to trade, and assuming that people in both countries would prefer to buy the cheaper goods 3 and 4 produced in *A*, and the cheaper goods 1 and 2 produced in country *U*, then production in country *A* would tend to specialize in products 3 and 4, and production in country *U* in commodities 1 and 2.

Now let us allow countries to trade.[14] The linear programming minimizes the expenditure simultaneously in countries *A* and *U* under the following constraints:

(i) Total labour employed in each country has to be lower or equal than the total labour available, which for each county is 100 people;

(ii) For each country the consumption per capita of each commodity is the sum of the domestic consumption of products that are locally produced and that are imported;

(iii) The sum of the quantity produced of a commodity in both countries is the same as the sum of the quantity consumed of that commodity in both countries, which in this example are 35 units of each product; and

(iv) All coefficients of consumption per-capita are non-negative numbers.

The results of the linear programming are shown in Table 10.3. To facilitate the discussion, we repeat some of the information provided in the previous table: column (*1*) lists the prices of the commodities produced in each country, with the lowest prices of each commodity indicated in bold, and column (*2*) presents the coefficients of consumption per capita of each commodity in each country. Columns (*3*) and (*4*) show for each country and sector the coefficients of consumption per capita of domestically produced and imported commodities, respectively. Observing columns (*2*) and (*3*) in relation to country *A*, we see that people in that country consumes products 2, 3 and 4 that are produced domestically. Column (*4*) shows that people in country *A* imports products 1 and 2. In the case of country *U*, people in that country consumes products 1 and 2 produced locally and import products 2, 3 and 4.

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[14] We implement the model's equations using the linprog() function in MATLAB R2014a with the interior-point solver.

Table 10.3. Consumption of domestic production and of imports, result of linear programming, numerical example

Products	(1) p ($)		(2) Domestic+imports $c_{j,k}$ (unit/people)		(3) Domestic $c_{j,k,k}$ (unit/people)		(4) Imports $c_{j,k,h}$ (unit/people)	
	A	*U*	*A*	*U*	*A*	*U*	*A*	*U*
1	1	**0.88**	0.25	0.1	0	0.1	0.25	0
2	1	**0.96**	0.25	0.1	0.1762	0.022	0.0738	0.078
3	**1**	1.04	0.25	0.1	0.25	0	0	0.1
4	**1**	1.12	0.25	0.1	0.25	0	0	0.1

Therefore, as initially expected based on people's preferences for buying products with the lowest price, people in both countries prefer to buy products 3 and 4 from sectors in country *A* and products 1 and 2 from sectors in country *U*. However, because of the constraints listed above, country *U* is not able to meet all the demand of product 2 and country *A* also produces and exports that commodity.

More specifically, the limit of the labour available in each economy is the constraint that prevents the full specialization of country *U* in the production of commodity 2. That can be verified in Table 10.4, which shows the values of quantities produced, employment, output and expenditure for each country and sector. Column (*1*) shows the quantity produced of commodities by sector and by country as result of the demand for the products listed in Table 10.3, and, therefore, it shows the pattern of specialization discussed above.

Column (*2*) lists the employment by country and sector that is required to produce the quantities listed in column (*1*). The values for employment are calculated based on those quantities and the values of labour coefficients by country and sector. These results show that 77 people from country *U* engages in the production of commodity 1, the product for which the difference of price between country's *A* and *U* production is the largest (see column *1* in Table 10.3). The rest of the labour force, 23 people, is engaged in the production of commodity 2, the product with the second largest price difference. However, 23 people can produce only 9.6 units of product 2, which is not enough to meet even its own domestic demand for that product. Therefore, country *A* would produce 25.4 units to contribute in meeting the total demand of 35 units.

It is important to consider the structural change resulting from the opening to trade. In the underdeveloped country *U*, employment and production shift to the sectors in which gaps in productivity are narrower, and also the benefits are lower for improving productivity through learning by emulating country's *A* production. More importantly, the sectors where such opportunity for learning are the highest, sectors 3 and 4, disappear from the economy of country *U*. Country *A* in its turn, shift production to the sectors where its productivity differentials are larger.

Table 10.4. Main economic variables, numerical example

	(1) Q (units)		(2) E (people)		(3) Y ($)		(4) Exp($)	
Products	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*
1	0	35	0	77	0	30.8	22	8.8
2	25.4	9.6	25.4	23	25.4	9.2	24.7	9.9
3	35	0	35	0	35	0	25	10
4	35	0	35	0	35	0	25	10
Total	95.4	100	95.4	100	95.4	40	96.7	38.7

Columns (*3*) and (*4*) in Table 10.4 show the income and expenditure per sector and country. Total income in country *U* is the same amount as in the case of autarky ($40), but in country *A* the total income ($95.4) is lower than the autarky-level ($100). In both countries, total expenditure *Exp* is lower than in the case in autarky, not only that, they are the lowest values possible as the result of the linear programming. Income is higher than expenditure in country *U* and is lower than expenditure in country *A*.

The differences between income and expenditure are the same as shown in the balance of payments (*BOP*) as presented in Table 10.5.

Table 10.5. Export, import and balance of payments, numerical example

	(1) X ($)		(2) M ($)		(3) BOP=X-M, ($)	
Products	*A*	*U*	*A*	*U*	*A*	*U*
1	0	22	22	0	-22	22
2	7.8	7.08	7.08	7.8	0.72	-0.72
3	10	0	0	10	10	-10
4	10	0	0	10	10	-10
Total	27.8	29.08	29.08	27.8	-1.28	1.28

Column (*1*) presents the values of exports by sector and country. It shows that country *A* exports $7.801 of product 2, and $10 each of products 3 and 4; while country *U* exports $22 of product 1 and $7.089 of product 2. Column (*2*) presents the values of imports per sector and country. Because there are just these two countries trading, the values of imports in country *A* are the same as the values of exports of country *U* and vice-versa. Column (*3*) shows the balance of payments in each sector and country. The result shows that country *A* imports more than it exports and balance of payments is $-1.288, while country *U* exports more than imports at exactly the same amount and its balance of payment is $1.288.

Gains from trade

We should note that both countries gain from trade according to Ricardo's (1817) principle of comparative advantage given that they both save labour when trading.[15] In his famous example of trade between England and Portugal the gains from trade in Ricardo's view are the following: England exports the equivalent to the labour of 100 of its men and receives in return the equivalent to the labour of 120 of its men, while Portugal exports the equivalent of the labour of 80 of its men and receive in exchange the equivalent to the labour of 90 of its men.[16] We can

[15] That principle is presented in the following passage of Ricardo's Principles of Political Economy and Taxation (1817):
"7.14 The quantity of wine which she shall give in exchange for the cloth of England, is not determined by the respective quantities of labour devoted to the production of each, as it would be, if both commodities were manufactured in England, or both in Portugal.
7.15 England may be so circumstanced, that to produce the cloth may require the labour of 100 men for one year; and if she attempted to make the wine, it might require the labour of 120 men for the same time. England would therefore find it her interest to import wine, and to purchase it by the exportation of cloth.
7.16 To produce the wine in Portugal, might require only the labour of 80 men for one year, and to produce the cloth in the same country, might require the labour of 90 men for the same time. It would therefore be advantageous for her to export wine in exchange for cloth. This exchange might even take place, notwithstanding that the commodity imported by Portugal could be produced there with less labour than in England. Though she could make the cloth with the labour of 90 men, she would import it from a country where it required the labour of 100 men to produce it, because it would be advantageous to her rather to employ her capital in the production of wine, for which she would obtain more cloth from England, than she could produce by diverting a portion of her capital from the cultivation of vines to the manufacture of cloth." (Ricardo 1817, p. 82)

[16] According to The Princeton Encyclopedia of the World Economy: "These paragraphs contain four numbers denoting the amounts of labor needed to produce wine and cloth in England (120, 100) and Portugal (80, 90). International trade textbooks interpret them as constant labor coefficients per unit of output of wine and cloth, and deduce from them linear production possibility frontiers and complete specialization in both countries (unless one of them happens to be

repeat the same method to verify if there is gain from trade in the numerical example presented in the previous section. The result is shown in Table 10.6 and Table 10.7, which shows for countries *A* and *U*, respectively, the maximum and minimum gains from trade depending on the bundle of commodities that we consider in the terms of trade.

Table 10.6. Gains from trade in country *A*, Ricardian version

Country *A*

	Max						
Products	*X*	*M*	*QX*	*QM*	*l*	*LX*	*LM*
1	0	22	0	25	1	0	25
2	7.8	5.8	7.8	6	1	7.8	6
3	10	0	10	0	1	10	0
4	10	0	10	0	1	10	0
Total	27.8	27.8				27.8	31
Gain from trade (*LM-LX*)							3.2

	Min						
Products	*X*	*M*	*QX*	*QM*	*l*	*LX*	*LM*
1	0	20.8	0	21.7	1	0	21.7
2	7.8	7	7.8	7.3	1	7.8	7.8

''large'' and remains nonspecialized). Ruffin (2002) and Maneschi (2004) show that this interpretation is incorrect. A close reading of the first three paragraphs of the foregoing passage reveals that the two numbers relating to each country refer instead to the amount of labor embodied in its total exports and the amount it would require to produce its total imports of the other commodity. In the second paragraph, Ricardo is able to assert which commodity England exports before even mentioning the two numbers relating to Portugal." According to Meoqui (2011): "He [Ricardo] indicates rather precisely the gains from trade for each country — unlike the imprecise speculations about the division of these gains between the two countries in what contemporary textbooks refer to as the Ricardian model. They are the result of a simple subtraction. For England (Portugal), the gains from trade are given by the difference between the number of men, 100 (80), she currently employs to produce the quantity of cloth (wine) exported to pay for the importation of wine (cloth), and the number of men she would need, 120 (90), to produce the wine (cloth) internally. England saves the labor of 20 men, whereas Portugal saves the labor of 10 men. The additional quantity of commodities or services that these men could produce would be the gains from trade in terms of an increase in the amount of commodities and services available."

3	10	0	10	0	1	10	0
4	10	0	10	0	1	10	0
Total	27.8	27.8				27.8	29.5
Gain from trade (*LM-LX*)							1.7

Note: *X* – value of exports; *M* – value of imports; *QX* - quantity exported; *QM* - quantity imported; *LX* – labour required to produce the quantity exported; *LM* – Labour required to produce the quantity imported.

Table 10.7. Gains from trade in country *U*, Ricardian version

Country *U*

	Max						
Products	*X*	*M*	*QX*	*QM*	*l*	*LX*	*LM*
1	22	0	25	0	2.2	55	0
2	5.8	7.8	6	7.8	2.4	14	18.7
3	0	10	0	10	2.6	0	26
4	0	10	0	10	2.8	0	28
Total	27.8	27.8				69	72.7
Gain from trade (*LM-LX*)							3.7

	Min						
Products	*X*	*M*	*QX*	*QM*	*l*	*LX*	*LM*
1	20.8	0	23.6	0	2.2	51.9	0
2	7	7.8	7.3	7.8	2.4	17.5	18.7
3	0	10	0	10	2.6	0	26
4	0	10	0	10	2.8	0	28
Total	27.8	27.8				69.4	72.7
Gain from trade (*LM-LX*)							3.3

Note: *X* – value of exports; *M* – value of imports; *QX* - quantity exported; *QM* - quantity imported; *LX* – labour required to produce the quantity exported; *LM* – Labour required to produce the quantity imported.

Country *A* exports the equivalent of the labour of 27.8 of its people and that is sufficient to import the equivalent of the labour of its people ranging from 29.5 to 31. In the case of country *U*, it receives imports equivalent to labour of 72.7 of its people by exporting the equivalent of the labour of its people ranging from 69 to 69.4. Therefore, trade is beneficial for both countries according to Ricardo's version of "gains from trade." Country *U* has a higher gain than country *A* because through trade it saves more labour that the latter. In fact, this is the same result that

Ricardo gets in his example, because here country U is in the same position of England, it has absolute disadvantage in all products but is the country with the highest gain from trade.

Effect of different levels of diversification

As noted in Pasinetti (1993, p.155), a usual simplification in examples similar to that presented in the previous sections is the assumption that both the advanced and underdeveloped countries have the same productive sectors. That assumption is relaxed in the following example, in which we assume that country A is more diversified than country U.

The initial setup assumes that country A produces commodities 1 to 8 and country U produces commodities 1 to 4, thus the labour coefficients related to products 5 to 8 in country U are set to infinity. For simplification, we assume that both countries have the same population size (100 people). Table 10.8 shows the initial values of the exogenous coefficients of consumption per capita and labour coefficients, as well as the values of prices, quantities, employment and output for the case of the two countries in autarky. Prices for the commodities produced in countries A and U are the same as in the previous example, and consumption per capita was adjusted so that both countries have full employment in autarky.

Table 10.8. Two countries in autarky, example different number of sectors

	l		*c*		*p ($)*		*Q (units)*		*E (people)*		*Y ($)*	
Products	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*
1	1	2.2	0.125	0.1	1	0.88	12.5	10	12.5	22	12.5	8.8
2	1	2.4	0.125	0.1	1	0.96	12.5	10	12.5	24	12.5	9.6
3	1	2.6	0.125	0.1	1	1.04	12.5	10	12.5	26	12.5	10.4
4	1	2.8	0.125	0.1	1	1.12	12.5	10	12.5	28	12.5	11.2
5	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
6	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
7	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
8	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
Total									100	100	100	40

Note: Wage rate in A is \$1 and wage rate in U is \$0.4.

The result of the model for the case of trade between A and U is shown in Table 10.9. The pattern of specialization for the products that both countries produce follows the same pattern as in the previous example in which both countries have the same number of sectors. Country U specializes in products 1 and 2 and country *A* in products 3 and 4, but the latter also produces and exports product 2 to fulfil the total demand that is not met by country *U* due to the limit on the total of labour available. Country *A* also remains the only producer of products 5 to 8.

The shift of labour between the autarky and trade scenarios in both countries only happens in sectors from 1 to 4. Thus, half of the people in country *A* were spared from the shifts of labour between sectors. In effect, the more diversified the advanced country, in comparison with the underdeveloped one, the higher the number of its workers that would not be affected in that way by free trade.

In country *U*, when compared with the example in which both countries have the same number of sectors (Table 10.4), the pattern of specialization in terms of number of workers per sector is less concentrated in sector 1 because the coefficients of consumption per capita in country *A* have changed. Now about half of the workers are employed in sector 1 and the other half in sector 2.

In this example, employment in country *A* reduces from 100 people in autarky to 96.5 people in the open economy scenario. However, employment would increase if people in country *U* start to consume products 5 to 8. In fact, with increase in income in country *U*, if people in that country follow a consumption pattern similar to that of country *A*, they would consume more of products 1 to 4 and start to consume products 5 to 8.

Table 10.9. Trade between more diversified country *A* and less diversified country *U*, example different number of sectors

	l		*c*		*p ($)*		*Q (units)*		*E (people)*		*Y ($)*	
Products	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*
1	1	2.2	0.125	0.1	1	0.88	0	22.5	0	49.5	0	19.8
2	1	2.4	0.125	0.1	1	0.96	1.5	21	1.5	50.5	1.5	20.2
3	1	2.6	0.125	0.1	1	1.04	22.5	0	22.5	0	22.5	0
4	1	2.8	0.125	0.1	1	1.12	22.5	0	22.5	0	22.5	0
5	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
6	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
7	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
8	1	∞	0.125	0	1	∞	12.5	0	12.5	0	12.5	0
Total									96.5	100	96.5	40

Note: wage rate in *A* is $1 and wage rate in *U* is $0.4.

Impact of population size

The previous examples have illustrated the effect of the constraint of maximum labour available on the pattern of specialization of two countries of same population size trading based on comparative advantage. Here we examine the pattern of specialization that emerges when the two countries have different population size and different levels of productivity.

Two examples are considered. Firstly, country *A* has population of 100 people and country *U* has population of 1,000 people. For comparison, the number of sectors, coefficients of consumption per-capita and labour coefficients of both countries are the same as in the first example in this annex. This example illustrates the trade between a less populous and more technologically advanced country with a more populous underdeveloped country; similar to that between countries in Europe and large developing countries in South Asia. The second example assumes that country *A* has population of 1,000 people and country *U* has population of 100 people. That example illustrates trade between a large and technologically advanced country with a less populous underdeveloped country; a pattern that is similar of the trade between the US or countries in Europe with small island developing states in the Caribbean or in the Pacific. The results are shown in Table 10.10.

Table 10.10. Effect of population size on pattern of trade, numerical example

					Example 1				*Example 2*			
	(1) *l*		(2) *c*		(3) *Q (units)*		(4) *E (people)*		(5) *Q (units)*		(6) *E (people)*	
Products	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*	*A*	*U*
1	1	2.2	0.25	0.1	0	125	0	275	220	40	220	88
2	1	2.4	0.25	0.1	0	125	0	300	260	0	260	0
3	1	2.6	0.25	0.1	0	125	0	325	260	0	260	0
4	1	2.8	0.25	0.1	100	25	100	70	260	0	260	0
Total							100	970			1000	88

Note: In the scenario 1 the size of population in country *A* is 100 people and in country *U* is 1,000 people. In scenario 2 the size of population in country *A* is 1,000 people and in country *U* is 100 people.

The columns (*3*) and (*5*) of Table 10.10 shows the quantity produced under examples 1 and 2 respectively. When country *A* has population of smaller size than country *U*, the former specializes in product 4, the one in which it has the larger technological advantaged. Country *U* specializes in products 1, 2 and 3, and also produces and exports product 4 to meet the demand that is not fulfilled by country *A*. When country *A* has a larger population than country *U*, the former specializes in the production of commodities 2, 3 and 4, and it also produces and exports product 1. Country *U* specializes on the production of product 1, which is produced in the sector with the narrower technological gap but also the lower margin for improvement in productivity to reach the technological frontier.

Employment by sector follows the same pattern, as shown in columns (*4*) and (6). In example 1, employment in country U is higher in the sectors with the larger technological gap. Considering that an important component of technological progress is learning by doing, that pattern of employment would be conducive for a faster catch up of country U. On the other hand, in example 2, employment in country U is concentrated in sector 1, with smaller margin for catch up. Moreover, production in other sectors is discontinued and the economy becomes reliant in a single commodity.

Different from the case in which both countries have the same population size (Table 10.4), in both examples the total employment in country U reduces and country A reaches full employment. Unemployment is a bigger problem in country U under example 2 with 12% of the population unemployed compared with 3% under example 1.

The example above is very simplified for analytical purposes but it illustrates the disadvantage of less populated underdeveloped countries in terms of the potential for learning of technical knowledge.

Example with three countries trading

Let us now consider an example in which three countries trade: country A the more advanced, and countries B and C, both underdeveloped, but country C has one of its sectors producing at the frontier of the technological knowledge. Such example simulates a country that has one of its sectors setup through foreign direct investment and transplantation of the production structure from a more advanced country.

Let us assume that the initial values of the exogenous variables are given by

- $L_A = L_B = L_c = 100$
- $l_A = \{1,1,1,1\}$
- $l_B = \{2.2,2.4,2.6,2.8\}$
- $l_C = \{2,2.4,2.6,1\}$
- $c_A = \{0.25, 0.25, 0.25, 0.25\}$
- $c_B = \{0.1, 0.1, 0.1, 0.1\}$
- $c_c = \{0.125, 0.125, 0.125, 0.125\}$
- $w_A = \$\ 1$

Here we set the values of the labour coefficient and the coefficients of per capita consumption in a way that all economies are in full employment in autarky. Again, for simplification, we assume that the medium of exchange between countries is gold and in each country it is produced by a sector with productivity that is the same as the simple average of the productivity of the economy.

Note that as shown in Table 10.11 the average value of the labour coefficient in country C is lower than in country B. Therefore, wage rate in C (\$0.5) is higher than in B (\$0.4) and consequently the prices of the commodities produced in both countries with the same labour-embodied technology (products 2 and 3) are higher in the former than in the latter. Even product 1, for which labour coefficient in C is lower than in B, has a higher price in C than in B.

Table 10.11. Three countries *A*, *B* and *C* in autarky, numerical example

	l(people/unit)			*c(unit/people)*		
Products	*A*	*B*	*C*	*A*	*B*	*C*
1	1	2.2	2	0.25	0.1	0.125
2	1	2.4	2.4	0.25	0.1	0.125
3	1	2.6	2.6	0.25	0.1	0.125
4	1	2.8	1	0.25	0.1	0.125
Average	1	2.5	2			

	p (\$)			*Q (units)*			*E (people)*		
Products	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
1	1	0.88	1	25	10	12.5	25	22	25
2	1	0.96	1.2	25	10	12.5	25	24	30
3	1	1.04	1.3	25	10	12.5	25	26	32.5
4	1	1.12	0.5	25	10	12.5	25	28	12.5
Average							100	100	100

Note: wage rate in A is \$1, in B is \$0.4 and in C is \$0.5.

When trade is allowed between these three countries, country A specializes in products 2 and 3, country B in product 1 and country C in product 4 (Table 10.12). Given the amount of labour available, people in country B are not able to produce commodity 1 in enough quantity to meet the domestic and foreign demand, thus people in country A and country C also produce and export product 1. The effect on employment is very distinct between these countries: country B continues in full employment and country A reduces employment for a small margin, but employment in country C reduces by half. Table 10.13 presents the exports, imports and balance of payments of these countries, which shows that both A and B have positive balance of payments while C has it negative.

Table 10.12. Trade between countries A, B and C, numerical example

Products	l(people/unit)			c(unit/people)		
	A	*B*	*C*	*A*	*B*	*C*
1	1	2.2	2	0.25	0.1	0.125
2	1	2.4	2.4	0.25	0.1	0.125
3	1	2.6	2.6	0.25	0.1	0.125
4	1	2.8	1	0.25	0.1	0.125
Average	1	2.5	2			
Total						

Products	p ($)			Q (units)			E (people)		
	A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
1	1	0.88	1	0.4	45.5	1.6	0.4	100	3.2
2	1	0.96	1.2	47.5	0	0	47.5	0	0
3	1	1.04	1.3	47.5	0	0	47.5	0	0
4	1	1.12	0.5	0	0	47.5	0	0	47.5
Average									
Total							95.4	100	50.8

Table 10.13. Balance of payments of trade between countries A, B and C, numerical example

Products	X ($)			M ($)			BOP=X-M, ($)		
	A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
1	0	31.2	0	21.6	0	9.6	-21.6	31.2	-9.6
2	22.5	0	0	0	10	12.5	22.5	-10	-12.5
3	22.5	0	0	0	10	12.5	22.5	-10	-12.5
4	0	0	17.5	12.5	5	0	-12.5	-5	17.5
Total	45	31.2	17.5	34.1	25	34.6	10.9	6.2	-17.1

What this example suggests is that an increase in the average productivity of a country, when it is transmitted to international prices through the exchange rate, may not be beneficial to the country if it is not broad based through the result of increase in productivity in a large share of the sectors of the economy.

11 Dynamics of endogenous change of consumption patterns

This chapter initiates the analysis of the model to study diversification, structural economic dynamics and trade. As described in the previous chapter, the dynamics of the model are assumed to be the result of changes in consumption patterns and technological progress. Here we focus on the former and study the interrelationship between changes in specialization and consumption patterns in open economies, considering, for simplification, that there is no technological progress. The chapter shows how changes in consumption are linked to the trade balance of two economies trading with each other. The chapter sets the stage for the analysis of the full model in the next chapter, which focuses on technological progress that results in economic diversification.

11.1 Introduction

This chapter presents an initial analysis of the model focusing on the dynamics of consumption and specialization patterns. For simplification, we assume that there is no technological progress and the set of goods produced remains constant. The chapter illustrates the model's endogenous mechanism for changes in consumption patterns that follows Clower's (1965) dual-decision hypothesis in which the household sector decides on consumption in the next period based on current income, while production sectors determine the level of employment based on the demand. It also shows the implementation of Pasinetti's (1993) framework of consumption change that is based on a generalized version of Engel's law.

We start the following section with a very simple set up that does not yet include all elements of the model related to hierarchy and saturation of consumption. These assumptions will be introduced in the subsequent sections. The example in the next section also seeks to verify if the model can generate the expected result of inequality of income and consumption levels of two open economies with different levels of productivity. The subsequent sections show the linkage between sectoral productivity, changes in consumption and the trade balance.

11.2 Initial analysis of the model

In this section, we discuss an example of a simulation run of the model (called Example 1 in this chapter). The setup of the simulation is the following: we consider two countries (country A and country U) trading four products (products 1 to 4). Let us assume that at the start of the simulation both countries have the same level of consumption per capita:

- Coefficients of consumption per capita: $c_A = c_U = \{0.05, 0.05, 0.05, 0.05\}$

Their labour force and population have the same size:

- Total labour force in each country: $L_A = L_U = 100$

Productivity in country A is higher than in country U in all sectors, but the productivity gaps vary across products:

- Labour coefficients in country A: $l_A = \{1,1,1,1\}$
- Labour coefficients in country U: $l_U = \{2.2,2.4,2.6,2.8\}$

The relative wage rate is measured in the currency \$ of country A, and reflects the relation between average productivity in each country. Therefore, given that production in country A is on average 2.5 times more productive than in country U, the wage rate in country A is 2.5 times the wage rate in country U:

- Wage rate in country A: $w_A = \$ 1$
- Wage rate in country U: $w_U = \$ 0.4$

The model is set up assuming the following:

- No trade costs
- No saturation of consumption
- No hierarchy of consumption
- No technological progress
- No markup (prices equal production costs)
- The maximum possible values of the rate of change of the coefficient of consumption (r): max(r)=0.01, which means that the maximum rate at

which consumption per capita of a commodity can increase or decrease in each period is 1%.

The initial setup of the simulation described above is such that if the countries were in autarky their income per capita would be the same, although the level of employment in country *U* would be higher than in country *A*:

- Income per capita in autarky: *A*=\$0.2; *U*=\$0.2.
- Employment in autarky: *A*=20 people; *U*=50 people;

A simulation run of the model of 2,000 periods is shown in Figure 11.1.[1] The figure shows 12 panels in two columns. This arrangement will be used throughout the figures describing simulation runs in this chapter. The first two panels (first row) show the labour coefficients in all sectors in countries *A* and *U*, which are assumed to be constant during the run. The second row shows the panels with the dynamics of consumption per capita, which are assumed to be the same for all products in both countries at the beginning of the run. The panels show that consumption per capita in country *A* increases and consumption per capita in country *U* decreases during the run. The direction of the change in consumption is determined endogenously in the model, but the rate of change is stochastic. The panels in the third row show the prices of products in both countries, which remain the same, throughout the run, given the absence of technological progress and markups. Panels in the fourth row show the evolution in the quantities produced in each sector of country *A* (panel on the left) and country *U* (panel on the right). In the fifth row, the panel on the left shows the evolution of the level of employment in each country. Employment rates in both countries vary throughout the run (there is no assumption of full employment). The panel on the right in the fifth row shows the income per capita in real terms. The sixth row shows the balance of payments (panel on the left) and the evolution of the relative wage rates in real terms (panel on the right).

The results of the simulation run can be described as follows:

Specialization: At the beginning, country *U* exports products 1 and 2 and country *A* exports products 3 and 4. This pattern of specialization changes the average labour coefficient in each economy, since the employment shares of sectors change. This causes changes in the wage rate of country *U*, measured in *A*'s currency. The change in wage rate changes the pattern of comparative advantage. The result is that country *U* specializes in product 1 and country *A* produces all products. Note that the sectors with lower productivity in the less productive country (*U*) are exactly those sectors that disappear.

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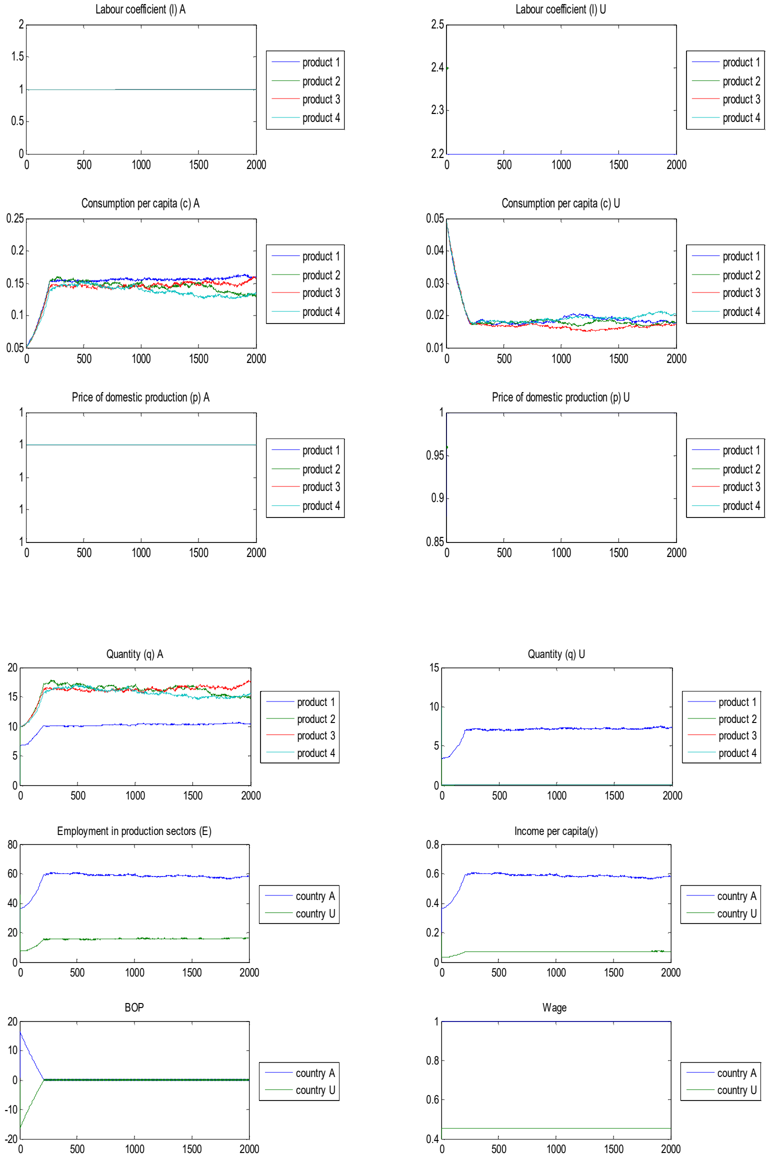
[1] The model is implemented in MATLAB R2014a and the linear programming was implemented using the function linprog with the interior-point solver.

Figure 11.1. Example 1



Dynamics: At the beginning of the run, income in country *A* increases with trade and the resulting expansion of the market for the goods produced in that country. Expenditure for the same basket of products remains the same, given that there is no technological progress. As result, income is higher than expenditure and consumers decide to increase their consumption for all products.

At the beginning of the run, income in country *U* is restricted by the fact that only sector 1 is producing, while expenditure remains the same (for the same basket of products). Thus, expenditure is higher than income and consumers reduce their expenditures. Consumption in the country decreases for all products.

Consumption in country *A* increases at an average rate that is similar to the rate of reduction of consumption in country *U* (maximum of 1% in each period). However, the increase of consumption in country *A* is larger in absolute terms than the decrease in country *U*. Therefore, the effect of trade is that global consumption increases.

The increase of consumption of country *A* results in growth of production and income in that country. However, production and income do not grow as rapidly as the decline in consumption in country *U*, which causes slower growth of production in country *A*. On the other hand, the net increase of consumption of product 1 results in increase of production in both countries, given that both produce that good. As a result, production and income in country *U* also increase.

Over time, this pattern brings the trade balance close to zero. After that point, increases in consumption in a country have a high probability to create a negative trade balance, which triggers a subsequent reduction in consumption. Thus, the trade balance gravitates towards zero.

The result when comparing with the start of the run is the following:

a) Employment increases in both countries;
b) Income per capita increases in both countries;
c) BOP fluctuates around zero;
d) Consumption is higher in country *A* and lower in country *U*. For all products, consumption per capita is higher in country *A* than in country *U*;
e) In terms of country's *A* currency, wage rates remain constant in country *A* by default (the country is the benchmark) and increase in country *U* because, at the end of the run, the most productive sector 1 is the only sector in operation.

When we compare that result with the scenario of the two countries in autarky, the differences are the following:

a) Employment increases in country *A* and decreases in country *U*;
b) Income per capita increases in country *A* and decreases in country *U*;

c) For all products, consumption per capita is higher in country *A* with trade than in autarky. For country *U* is the opposite; consumption per capita is lower with trade.
d) In terms of country's *A* currency, wage rates remain constant in country *A* by default and increase in country *U* because, at the end of the run, the most productive sector 1 is the only sector in operation.

The simulation run of the model, therefore, shows that even when starting with the same levels of consumption per capita, countries with different average productivity levels will have different levels of consumption in the long-run. Moreover, the country with the higher labour productivity (lower labour coefficient) reaches higher levels of consumption in the longer run.

Sensitivity tests presented in Annex XI.1 show that these results are not affected by changes in initial parameters such as relative wage rates (reflecting the exchange rate between the two currencies), initial levels of consumption per capita (which affect the initial level of the trade balance between the countries), or the stochastic change in consumption that occurs in different runs of the simulation.

The conclusions of that exercise are the following. If there is no technological progress:

a) In the long run, the pattern of specialization, levels of income and employment, and levels of consumption are determined by the levels of productivity in each economy;
b) In the aggregate, trade results in the increase in the physical quantity consumed (and therefore produced) of all products;
c) However, the distribution of that increase is uneven. The country with higher productivity (country *A*) increases consumption, income and employment. On the other hand, the country with lower productivity (country *U*) ends up with lower consumption and employment than would be the case if the country was in autarky.

These results are very relevant and the first two are in line with the mainstream economic theories. The third one, however, shows the critical possibility that a country could be better off in autarky than if it trades with another country. The example describes how that happens: with trade, it is cheaper for consumers in country *U* to buy most of the products that they demand from country *A*. The production base of the former reduces to a single sector. Demand in this sector increases but this is not enough to absorb the people in other sectors who lose their jobs. As a result, total employment, income per capita and consumption get reduced to below autarky levels.

This example is of course a simplification and very particular. For example, the two countries have different levels of productivity but initially produce the same number of products, while in reality more productive countries are also more diversified and not all products are produced in all countries. Nevertheless, the results are important because they imply that trade is not necessarily beneficial to all countries in the absence of technological progress. This result echoes the conclusions of Pasinetti (1993) in relation to international trade. He considers international learning (which allows emulation and technological progress of less productive and diversified countries) as the primary source of gains from trade.

The next section explores the causal link between productivity and the pattern of specialization.

11.3 Productivity and the pattern of specialization

This section shows that the patterns of specialization and the trade balances presented in the previous examples are related to the productivity levels in each country, more specifically the differences in the range of productivity levels within each economy. The analysis suggests that countries that have a large variation of productivity across its economic sectors would be at a disadvantage when trading with a country that produces the same products but with a lower variation of productivity, in the absence of technological progress.

When two countries trade, the country with the narrower range of labour coefficients (in terms of the ratio between highest to the lowest labour coefficient) has a positive trade balance. For example, in the simulation discussed above, the narrower range of labour coefficients in country *A* means that the relative technological gap (in terms of ratio of labour coefficients: l_A/l_U) between countries *A* and *U* is narrower for the products with low labour coefficients in country *U* (higher productivity sectors) and is larger for the products with higher labour coefficients in country *U* (lower productivity sectors).

This relation is critical because the wage rate of country *U* in terms of country *A*'s currency is given by Eq. (X.22):

$$w_U = w_A \left(\sum_{j=1}^{m} l_{j,A} E_{j,A} \Big/ E_A \right) \Bigg/ \left(\sum_{j=1}^{m} l_{j,U} E_{j,U} \Big/ E_U \right)$$

where E_A and E_U are the total employment levels in *A* and *U*, and $E_{j,A}$ and $E_{j,U}$ are the employment in sector *j* in these countries.

In the specific case of Example 1, the ratio of the weighted averages of labour coefficients is lower than the ratio of labour coefficients of sector 1:

$$\frac{\left(\sum_{j=1}^{m} l_{j,A}E_{j,A}\Big/_{E_A}\right)}{\left(\sum_{j=1}^{m} l_{j,U}E_{j,U}\Big/_{E_U}\right)} < \frac{l_{1,A}}{l_{1,U}} \tag{XI.1}$$

Therefore, for sector 1 with its relatively smaller technological gap, the relation between prices in country A and country U is the following:

$$p_{1,U} = l_{1,U}w_U = l_{1,U}w_A \frac{\left(\sum_{j=1}^{m} l_{j,A}E_{j,A}\Big/_{E_A}\right)}{\left(\sum_{j=1}^{m} l_{j,U}E_{j,U}\Big/_{E_U}\right)} < l_{1,U}w_A \frac{l_{1,A}}{l_{1,U}} = l_{1,A}w_A = p_{1,A} \tag{XI.2}$$

For sectors in which the technological gap is smaller (lower labour coefficients implying higher productivity sectors in country U) the prices of goods produced in country U are lower than the price of products produced in country A. Therefore, country U will specialize in these sectors with lower labour coefficients and its average labour coefficient will decrease, which will increase the wage rate of country U (expressed in international prices). In the long run, country U will either produce only the product with lower labour coefficient, or will stop production all together, depending on the specific labour coefficients.

Therefore, the pattern of specialization is not related to average productivity, but to the spread of productivity levels across each economy. We can illustrate this result using a counter example (called Example 2) in which the level of productivity in country U is higher than in country A, but the spread of productivity levels in country U continues to be larger than in country A.

Example 2

The initial setup of the run is the same as Example 1 but with labour coefficients as follows:

- Labour coefficients in country A: $l_A = \{1, 1,1,1\}$
- Labour coefficients in country U: $l_U = \{0.6,0.7,0.8,0.9\}$

Wage in country U is set to reflect the productivity level in the country at the beginning of the run: $w_U = \$\ 1\ .3333$

This initial setup indicates that country U is more productive than country A in all products. The initial prices of each commodity in each country are the following:

- $p_A = \{1, 1,1,1\}$

- $p_U = \{0.8, 0.9, 1.06, 1.2\}$

If the countries were in autarky their levels of employment and income per capita would be the following:

- Employment in autarky: A=20 people; U=15 people;
- Income per capita in autarky: A=\$0.2; U=\$0.2.

The simulation run shows the same pattern of specialization as in Example 1. At the beginning of the run, country U has a comparative advantage in products 1 and 2 and country A in products 3 and 4. This initial pattern of specialization reduces the average labour coefficient of country U. As a result, the wage rate in country U increases and the country loses the comparative advantage in product 2, which is then produced only by country A. With that change, the average labour coefficient of country U decreases to the level of the labour coefficient of sector 1. This further increases the wage rate of country U measured in the currency of country A. Such increases again change the pattern of comparative advantage with both countries producing product 1 at the same labour costs. The result is the pattern of specialization that remains throughout the simulation: countries U and A producing and exporting product 1 and country A exporting the other products as well.

The result of the simulation is presented in Figure 11.2. In the long-run, this example produces the same results as Example 1: country A has a positive trade balance and, as result, consumption increases, with the opposite happening in country U. Therefore, the trade balance and pattern of specialization are not causally linked to the average productivity levels.

Note that the scenarios in Examples 1 and 2 are somewhat special because country A always has the narrower range of labour coefficients. If we make the range of labour coefficients of country U as narrow as that of country A, identical prices for all products in all countries should emerge. Both countries produce all products, and the change in consumption pattern will only follow a random walk. This is confirmed in annex XI.2. This annex also shows the same result for the case in which labour coefficients are different in all sectors and in both countries, but the range of labour coefficients are the same in both countries.

Now, to verify the result that a narrower range of labour coefficients would make a country have a positive balance of trade, and vice-versa, let us consider an example (Example 3) in which country U has a narrower range.

Example 3

- Labour coefficients in country A: $l_A = \{0.8, 0.9, 1.1, 1.2\}$
- Labour coefficients in country U: $l_U = \{1.7, 1.8, 2.2, 2.3\}$

The result is a positive initial trade balance for country U and the resulting higher consumption levels in that country in the long run in relation to consumption in country A. The graphs representing the simulation of that example in Figure 11.3 confirm this result.

Figure 11.2. Example 2

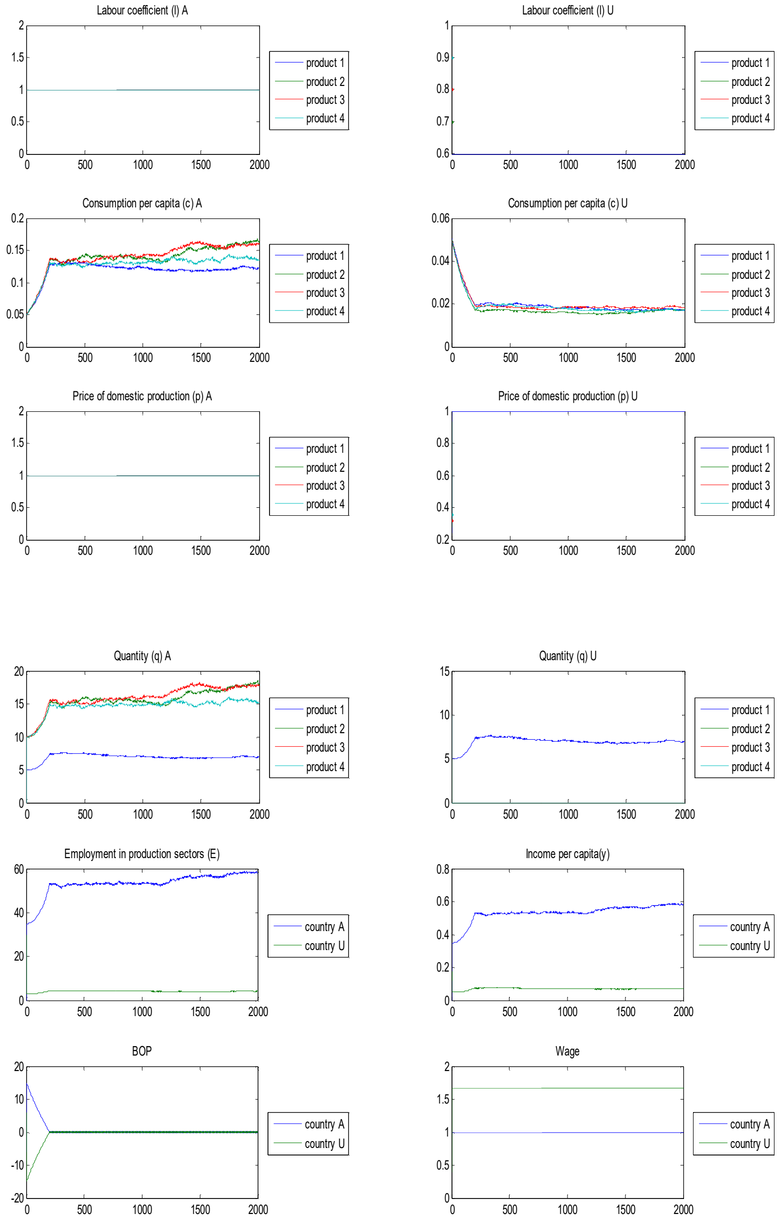
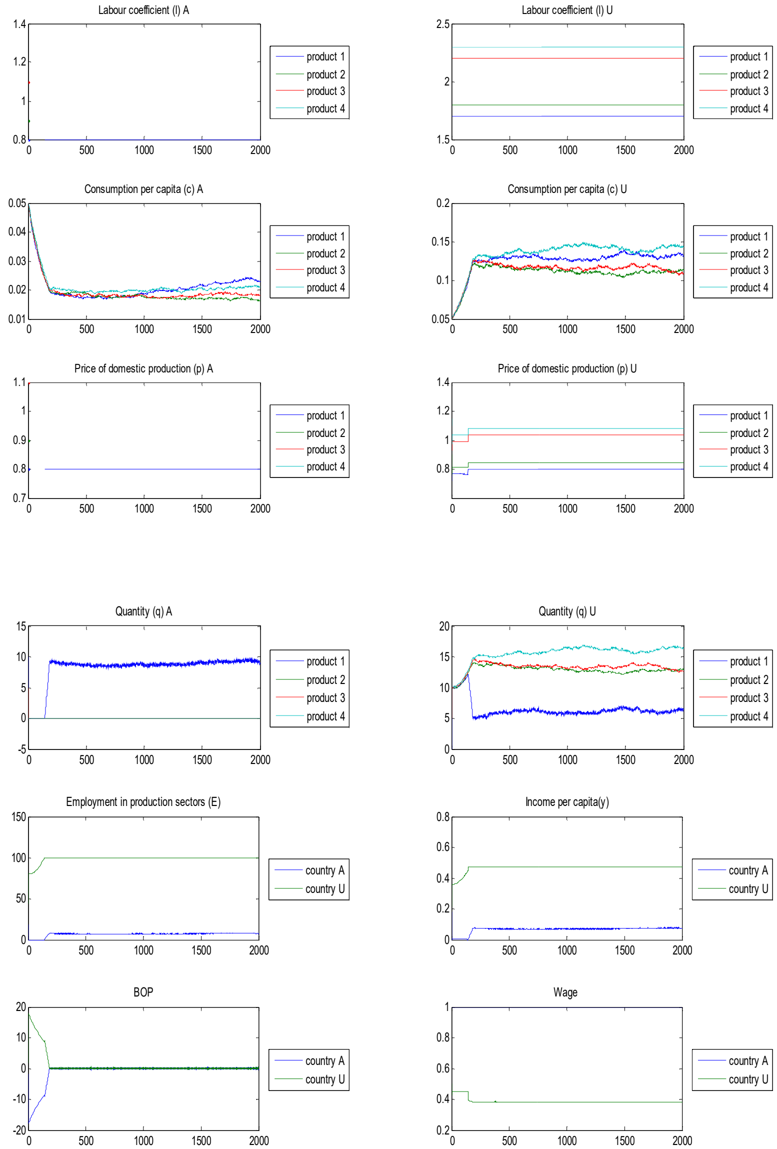


Figure 11.3. Example 3



These examples show that, in the absence of technological change, a country will have a lower consumption level in the long run if it has the larger range of labour coefficients.

Empirical analysis (McMillan, Rodrik, and Verduzco-Gallo, 2014) reveals that countries with lower average productivity indeed have a larger range of labour coefficients (and labour productivity) than more productive countries (as measured by the ratio between the higher to the lower labour coefficients in each economy). [2] In more productive countries, all sectors are relatively more productive. Even more traditional sectors of the economy have benefited from innovation and technological change and have reached a level of productivity that is relatively higher than in other countries. As a result, the gap in productivity between the different sectors in the economy is relatively narrow. In less productive countries, on the other hand, the differences between the more traditional and the modern sectors of the economy are relatively higher. Traditional sectors continue to use less productive technologies (such as in the agricultural sector in poorer countries) while modern sectors use relatively more productive technologies (for example in transplanted industries established through foreign direct investment).

These results should be seen as stressing the importance of technological progress and not the potential negative effects of trade in a stylized example. To illustrate this, we could look at the patterns of specialization seen during the nineteenth century associated with the origins of the "great divergence" in standards of living between the rich core and poor periphery countries (Williamson, 2011). In a simplified example, suppose England and India trading two products, textiles and agricultural commodities, before the industrial revolution with the same productivity levels (represented by the following labour coefficients: 1.2 for commodities and 1 for textiles). With the onset of the industrial revolution, the productivity of the textile sector in England increases. Suppose its labour coefficient decreases to 0.8, which increases the range in productivity in England and the country experiences a negative trade balance. In the absence of technological progress, England would be worse off, but with technological progress the resulting pattern of specialization was that England specialized in manufacturing (textiles), with high potential for process and product innovation, while India specialized in agricultural commodities, and ended up de-industrializing.

[2] Table 1 in McMillan et al. (2014) lists the labour productivity of the most and least productive sectors in a selection of developed and developing countries. The analysis of the table shows that the relative technological gap between developed and developing countries is higher for more productive sectors and lower for less productive sectors.

In summary, the analysis presented in this and the previous section shows that, if there is no technological progress, then when two countries trade, the country with the narrower productivity range in the sectors of the economy will achieve the higher consumption level in the long run and will be better off than in autarky, and vice versa.

11.4 Hierarchical order of preference and saturation of demand

This section presents an analysis of the model considering the generalized version of Engel's law as presented in Pasinetti's (1993) framework, in terms of a hierarchical order of preferences and saturation of demand. The discussion focuses on the results of a simulation run of the model (Example 4) that has the same initial setup as Example 1.

We assume that consumers in both countries have their preferences of consumption decreasing from good 1 to 4. Therefore, in both countries, when consumption increases it would increase faster for product 1 than for product 2; and so on with the slowest pace of increase for product 4. On the other hand, in both countries, when consumption decreases it would decrease slower for product 1 and so on. We also assume that all sectors have points at which consumption becomes saturated. These are exogenously given and are not higher than 100% above the initial consumption per capita ($\beta = 2$).

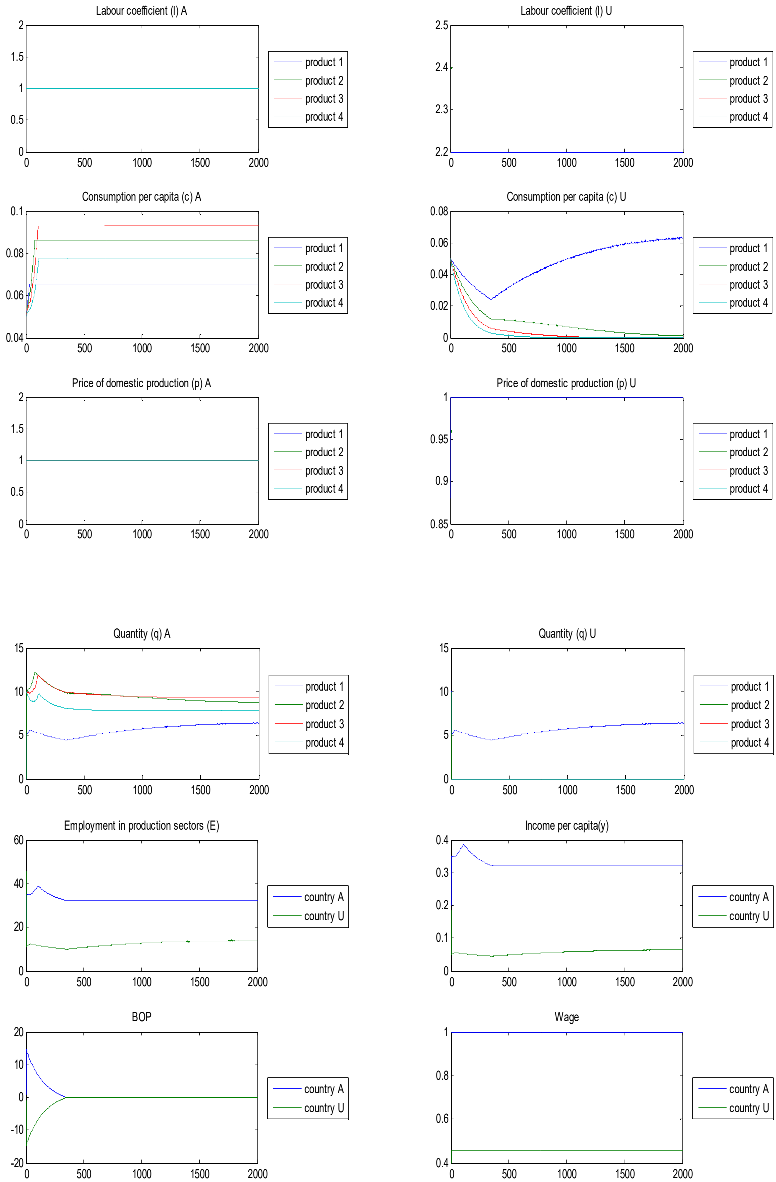
Figure 11.4 shows the result of Example 4 for 2,000 periods. The result shows that the pattern of specialization follows the comparative advantage in the prices of products: *U* specializes in product 1 and country *A* produces all products.

In general, the results of the simulation are similar to those without the assumption of hierarchy of preferences and saturation of consumption (Figure 11.1) in the sense that in the long run country *A* has higher consumption, employment and income per capita levels than country *U*. However, there are some notable differences in the rate of change of consumption of particular sectors.

The final result in terms of consumption patterns is that consumption in country *A* is higher in the long run for all products, while in country *U* only the consumption of product 1 is higher than at the beginning of the simulation. Consumption in country *A* reaches saturation levels in all products, which are different for each sector. In country *U*, consumption initially decreases for all products (at a rate that becomes faster from good 1 to 4 as discussed above) while the country was experiencing a negative balance of payments. When the trade balance starts to gravitate towards zero, consumption of product 1 in country *U* starts to increase, while consumption of the other products decreases.

Production reflects the saturation of consumption in country *A* and reduction of consumption for most products in country *U*. Initial increases in production in sectors 2, 3 and 4 in country *A* disappear over time, as consumption of the products of these sectors stabilizes. Production of good 1 in both countries starts to recover after countries balance their trade.

Figure 11.4. Example 4



In the long run, employment and income per capita are higher in country *A* than in country *U*, but the difference is lower than in the case of no hierarchy of preference and saturation of consumption.

To test whether these results are driven by the stochastic nature of the change in consumption per capita, results from 50 simulation runs were collected. These again cover 2,000 periods and had the same initial configuration as the simulations in Example 4. The summary statistics of the resulting macroeconomic variables are presented in Table 11.1. It shows that the results of Example 4 are consistent with the average values of key variables from the simulation runs: employment in country *A* is on average almost twice the size of employment in country *U*, income per capita in country *A* is over four times higher than in country *U*, wage rates converge to values reflecting the average productivity of the production sectors in each country, and the balance of payments tends to zero.

Table 11.1. Model with hierarchy of preferences and saturation of consumption - macroeconomic variables, summary statistics

	Employment		Income per capita		Wage rate		BOP	
Country	Mean	Std	Mean	Std	Mean	Std	Mean	Std
A	30.38	2.86	0.30	0.03	1	0	0.01	0.01
U	16.79	3.09	0.07	0.01	0.45	0	-0.01	0.01

Table 11.2 presents the results of the simulations in each country in terms of final consumption per capita and of quantity produced by each sector. The table shows that Example 4 illustrates the usual result of a simulation run with the same initial setup: consumption in country *A* is higher than in country *U* for all products but product 1 (the one with higher consumer preference) and the pattern of specialization is such that country *A* produces and exports all products and country *U* specializes in the production and export of product 1.

This highlights once again that if trade is not accompanied by opportunities to learn how to improve production methods to increase productivity and expand the range of products that a country can produce, trade may not necessarily be advantageous for both countries, and in particular not beneficial for the country with lower levels of productivity. This point was emphasized by Pasinetti (1993) as one of the two conditions that he identifies as needed to be satisfied for both countries to benefit from trade.[3] The other condition is that other sectors could

[3] According to Pasinetti: "It is only when all possible efforts to increase learning have been made (i.e. all possible efforts have been made to take advantage of the primary source of international gains) that an underdeveloped country can hope to obtain further gains from international trade. In other words, possible benefits from international trade are subordinated to the benefits from international

absorb workers who lose their jobs, such as in the case of workers in sectors 2, 3 and 4 in country *U*. From the simulations above we conclude that the sectors in which the country specializes may not be able to absorb all the displaced workers (as in the case of sector 1 in country *U*), depending on the level of consumption and the level of saturation of demand for their products.

Table 11.2. Model with hierarchy of preferences and saturation of consumption - consumption per capita and quantity produced, summary statistics

		Mean				Std			
	Country	prod 1	prod 2	prod 3	prod 4	prod 1	prod 2	prod 3	prod 4
Consumption per capita	*A*	0.07	0.08	0.08	0.07	0.01	0.01	0.01	0.01
	U	0.07	0.02	0.02	0.01	0.01	0	0	0
Quantity produced	*A*	7.63	7.43	7.54	7.77	1.40	1.50	1.54	1.34
	U	7.63	0	0	0	1.40	0	0	0

11.5 Summary

Through the analysis of a series of examples of simulation runs, the chapter discusses several results related to trade specialization and its long-term effects on employment, consumption and income. First, the model replicates the fact that countries with different levels of average productivity will have different levels of consumption in the long-run, with the country with the higher labour productivity having the highest consumption, even when they start with the similar levels of consumption per capita. This result is not affected by initial levels of the exchange rate (i.e. under- or over-appreciation of a national currency).

The discussion also highlighted that the changes in consumption are linked to the trade balance, which is shown to be a function of the differences in the range of productivity within each economy, not a function of the average level of productivity. If the technological gap between two countries is larger for the higher productivity sectors and narrower for the lower productivity sectors, then the

learning. In this sense, international trade, aimed at taking advantage of differences in comparative costs, emerges as a subordinate source (subject to the conditions that employment be safeguarded and that all efforts be made for international learning) and therefore as a secondary source of international gains." (Pasinetti, 1993, pp. 160-161) country with lower productivity level will have a lower consumption in the long run. Empirical data suggest that this is actually the case.

The chapter also presents an analysis of the model considering the implementation of Pasinetti's (1993) framework of consumption change, which is based on two elements of a generalized version of Engel's law: a hierarchical ordering of preferences of consumption and saturation of consumption. That analysis shows that long term disparities between countries in terms of employment, consumption and income are smaller than in the case in which these assumptions are not made. There are also differences in terms of the effects on changes in particular sectors, which emphasizes the importance of sectoral analysis to evaluate the effects of trade.

The next chapter continues the study of structural economic dynamics of open economies by focusing on technological change through product innovation and emulation.

Annex

XI.1. Some sensitivity tests

This section presents some sensitivity tests to verify the results of the simulation using the parameters of Example 1 described in section 11.2.

The first test, which is presented in detail in the next section (Annex XI.1.1), verifies whether the results are driven by differences in relative wage rates (reflecting the exchange rate between the two currencies), which determine the pattern of specialization at the initial of the simulation run. To verify the contribution of that initial set-up for the results, I study the results of two other simulation runs that assume different initial configurations related to the exchange rates between the currencies of the two countries (called Example 1a to describe the case of initial over-appreciation of currency of country *U* and Example 1b to describe initial under-appreciation of that currency). These examples show that, although an initial under- or over-appreciation of currency of country *U* changes the initial pattern of specialization of both countries, in the long-run the result is similar to the example described above if the exchange rate is allowed to vary so that the differences in the wage rates reflect the differences in average productivity of countries.

The second test is to verify whether stochastic changes during a simulation run affect the long-term results of the model. I have executed 50 runs of the model for each example mentioned above for the period of 2,000 periods (the same as those used to generate the graphs). After each run, the values for employment, income per capita, wage rates, and balance of payments were collected and the summary statistics of those are shown in Table 11.3. The summary statistics related to the consumption per capita of each product and production in each sector and country are presented in Table 11.4 and Table 11.5. These tables show that, as discussed above, the average and standard deviations of all macroeconomic variables are basically the same across the different scenarios (examples). That result suggests that the runs of the model are not affected by the changes in the initial values of wage rate in country *U* nor by the stochastics changes during the simulation.

Table 11.3. Macroeconomic variables, summary statistics

		Employment		Income per capita		Wage rate		BOP	
	country	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Example 1	*A*	59.61	3.39	0.60	0.03	1.00	0.00	-0.01	0.06
	U	14.72	0.98	0.07	0.00	0.45	0.00	0.01	0.06
Example 1a	*A*	60.53	4.18	0.61	0.04	1.00	0.00	0.00	0.05

	U	15.18	1.06	0.07	0.00	0.45	0.00	0.00	0.05
Example 1b	*A*	60.35	4.18	0.60	0.04	1.00	0.00	0.00	0.05
	U	14.67	1.15	0.07	0.01	0.45	0.00	0.00	0.05

Table 11.4. Consumption per capita, summary statistics

		Consumption per capita							
		Mean				Std			
country		prod 1	prod 2	prod 3	prod 4	prod 1	prod 2	prod 3	prod 4
Example 1	*A*	0.15	0.15	0.15	0.15	0.01	0.02	0.02	0.02
	U	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
Example 1a	*A*	0.15	0.15	0.16	0.15	0.01	0.02	0.03	0.02
	U	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
Example 1b	*A*	0.15	0.15	0.15	0.15	0.01	0.02	0.03	0.02
	U	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00

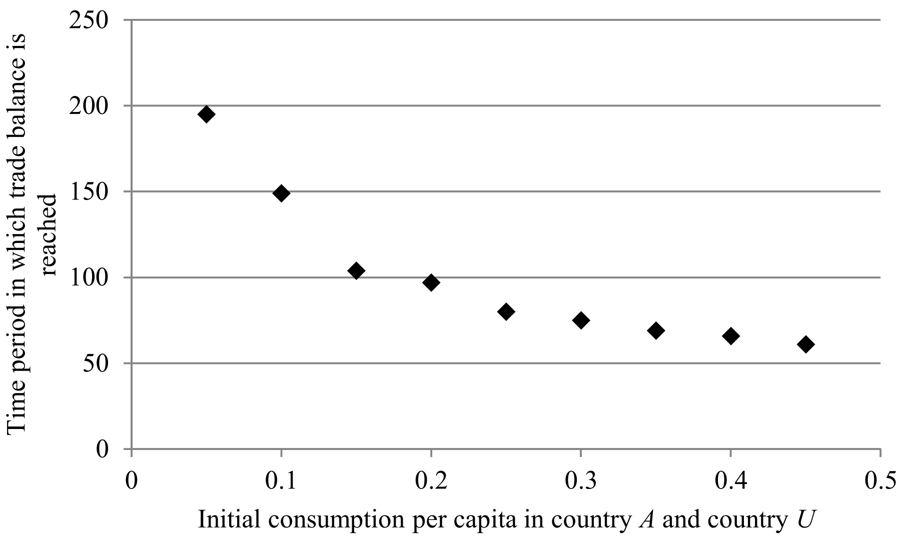
Table 11.5. Production, summary statistics

		Quantity produced							
		Mean				Std			
country		prod 1	prod 2	prod 3	prod 4	prod 1	prod 2	prod 3	prod 4
Example 1	*A*	9.76	16.53	16.80	16.51	0.47	1.77	2.22	1.56
	U	6.69	0.00	0.00	0.02	0.45	0.00	0.00	0.00
Example 1a	*A*	9.87	16.96	17.31	16.39	0.54	1.92	2.40	1.99
	U	6.90	0.00	0.00	0.02	0.48	0.00	0.00	0.00
Example 1b	*A*	9.70	16.45	17.12	17.08	0.58	2.35	2.53	2.28
	U	6.67	0.00	0.00	0.02	0.52	0.00	0.00	0.00

The third test verifies whether the initial level of consumption per capita (and the resulting initial trade balance between the countries) affects the pattern of specialization shown in the previous examples. The motivation for the test is that Example 1 shows that the results in terms of differences in long-term consumption per capita are observed very quickly (compared to the length of the simulations), and that they are crucially related to the period in which the country with high productivity has a positive trade balance. In annex XI.1.2, I explore this question with an example (called Example 1c) and analytically. In the example, the good that country *U* specializes in is given a much higher initial per capita consumption. The effect of increases in the consumption per capita of the product in which country *U* specializes is the decrease in the time that it takes the countries to reach trade balance. The result of these tests is that the positive trade balance is not related to the initial level of consumption of the products in which the countries specialize. In other words, even if the underdeveloped country specializes in a product with initial high total demand, in the long-term it would still end up with a lower consumption per capita.

This is illustrated in Figure 11.5, which shows the change in the time that it takes to reach balance of trade, as a function of the initial consumption per capita of good 1.

Figure 11.5. Relation between consumption per capita of good 1 and time that it takes to reach balance of trade



In summary, the results of the simulation run of Example 1 are not affected by changes in the initial set up of the model.

XI.1.1. Examples with different levels of exchange rate at the beginning of the simulation

This section shows the result of a simulation run (Example 1a) that use the same initial setup as in Example 1 except that the wage rate in country U is initially set at the same value as in country A: $w_U = \$\ 1$. Note that the wage rate is assumed to change during the simulation run following Eq. (X.22). In the long-run, this example produces the same results as Example 1, despite the very different pattern of specialization at the beginning of the run.

If these countries were in autarky, their employment levels and income per capita would be:

- Employment in autarky: A=20 people; U=50 people;
- Income per capita in autarky: A=\$0.2; U=\$0.5.

Note that although the income per capita in country U is more than the double of that in country A, the consumption is the same in both countries. That illustrates that currency of country U is over-appreciated at the beginning of the run.

The result of the simulation is shown in Figure 11.6. The pattern of specialization that develops is the following. At the beginning, the high wage rate in country U, when considering the productivity of both countries, makes that its products have higher prices than those produced in country A. Thus, country A produces and exports all products and country U does not produce any. This pattern of specialization only changes when country A can no longer produce the quantity of goods to meet the global demand due to the limit of labour available in the economy, and country U starts to produce product 1 (the products in which the technological gap is narrower). That changes the average of the labour coefficients in country U, which changes its wage rate expressed in country A's currency. The change in wage rate changes the pattern of comparative advantage. The result is that country U specializes in product 1 and country A produces all products.[4]

Regarding the dynamics of the run, at the beginning, income in country A increases with trade and the resulting expansion of the market for the goods produced in that country, while expenditure remains the same for the same basket of products, given that there is no technological progress. Thus, income is higher than expenditure and consumers increase their consumption for all products. In the case of country U, at the beginning of the run income drops to zero because all sectors stop to produce, while expenditure remains the same for the same basket of products. As a result, expenditure is higher than income and consumers reduce their demand for all products.

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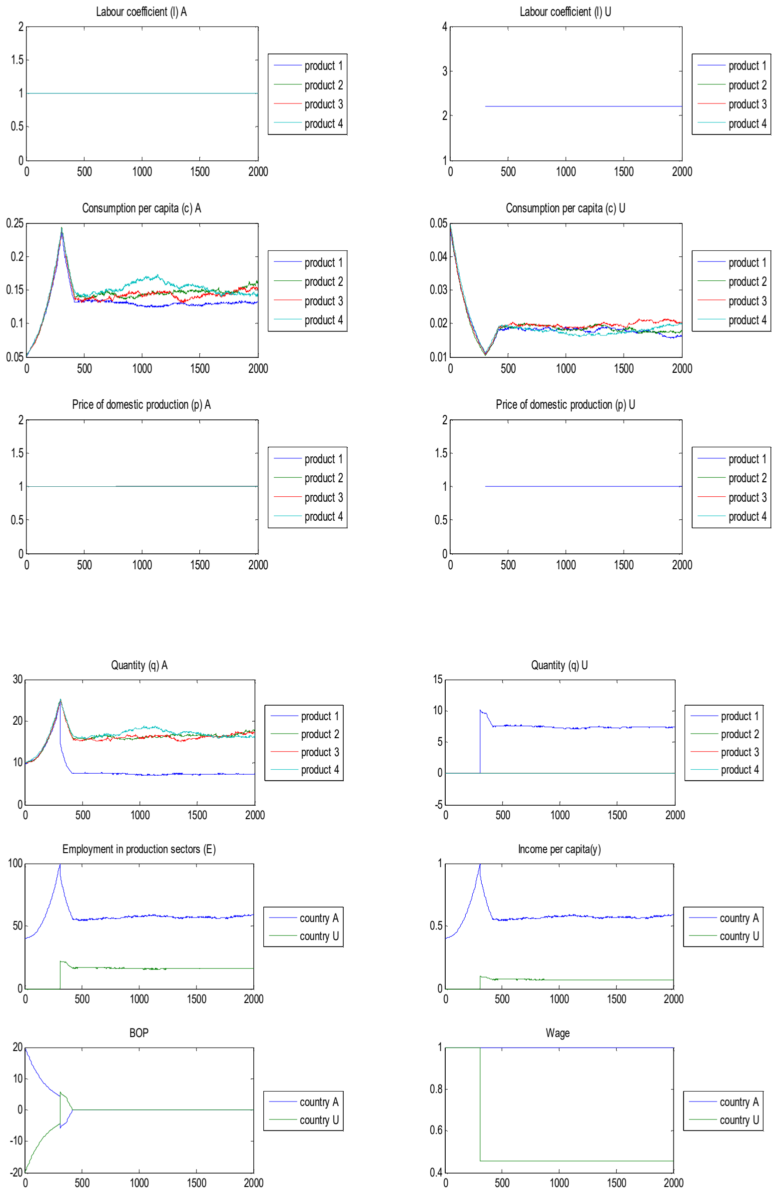
[4] Note that an important working assumption in the model is the following: if a country is not producing any product anymore, then its average labour productivity remains the same as when it stopped the production.

Figure 11.6. Example 1a - initial over-appreciation of currency of country *U*



As in the case of Example 1, consumption in country A increases on average at a rate that is similar to the rate of reduction in consumption in country U, but the aggregate result is a higher increase of consumption in country A than a decrease in country U in absolute terms. Therefore, the net effect of trade is that global consumption increases.

The increase in consumption of country A results in growth in production and income in that country. However, production and income do not grow as fast as the consumption because consumption in country U is decreasing, which causes slower growth of production in country A. Over time, increasing consumption (and expenditure) faster than growth in income in country A and reducing consumption (and expenditure) and no income in country U move the trade balance towards zero. However, before the trade balances, country A reaches full employment and is not able to fulfil the global demand for the goods that it produces. At that moment, country U starts to produce commodity 1 to meet the demand. When production in country U starts, the price of product 1 produced by country U was \$2.2 (result of labour coefficient l=2.2 and wage w=\$1). However, after country U starts production of good 1, the wage rate in the country changes to reflect the average productivity of the economy. This reduces the price of good 1 in the international market to \$1.

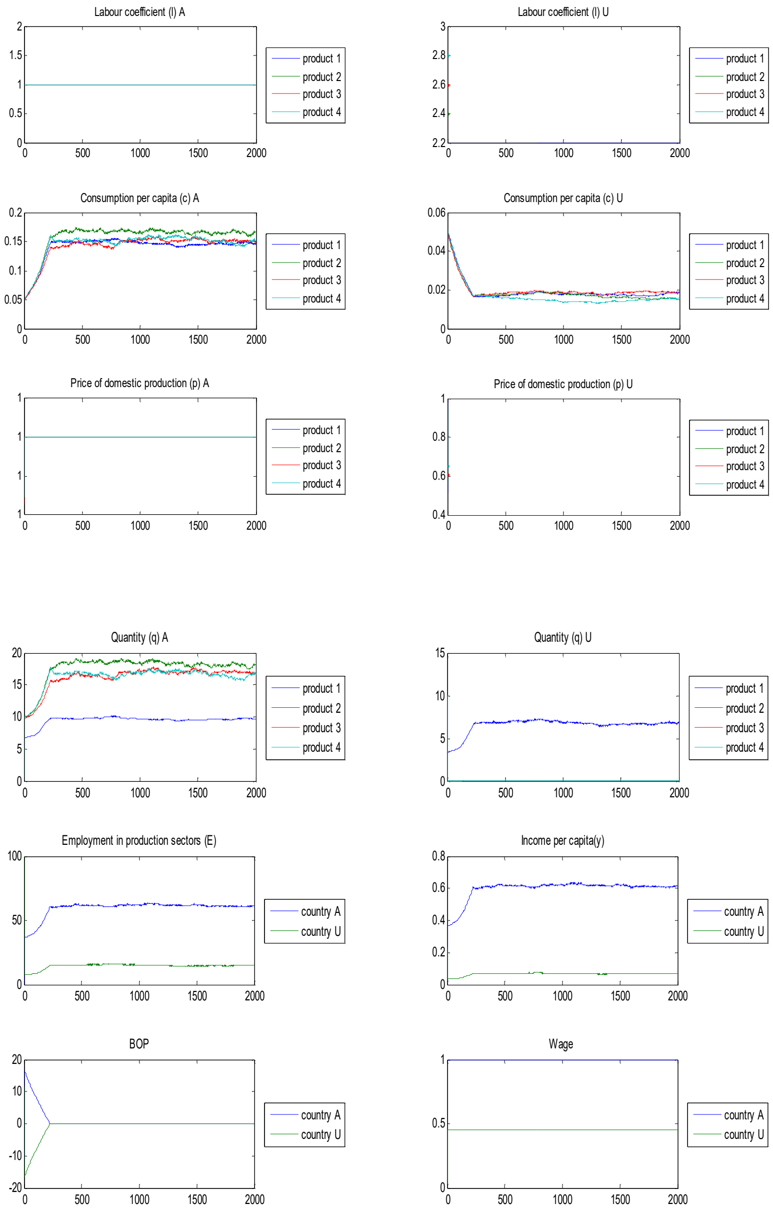
The production of good 1 by country U reduces the production levels in country A and consequently its income. The trade balance shifts and now country U has a positive trade balance and country A has negative net-trade. As a result, consumption decreases in country A and increases in country U. Over time, that moves the trade balance towards zero. Therefore, consumption varies stochastically but keeps about the same level. Production follows demand and is also kept at about the same level.

The final result is the same as in the case of Example 1: higher consumption and income in country A than in country U.[5]

Now let us analyse the case of undervaluation of the currency of country U at the beginning of the run (Example 1b). Again, we assume that the initial setup is the same as in Example 1, but the wage rate in country U is set to a lower value: $w_U = \$\,0.025$. The result of this simulation is shown in Figure 11.7. At the beginning, the low wage rate in country U results in lower prices of its products as compared with those produced in country A. Therefore, country U produces and exports all products and country A do not produce any.

[5] Note that this result holds even if we assume that there is saturation of consumption, in which case country A would not reach full employment and country U has no opportunity to re-start production. The final result would be the same in terms of higher level of consumption in country A than in country U.

Figure 11.7. Example 1b – initial under-appreciation of currency of country *U*



Assuming that the wage rate is allowed to change to reflect the average productivity of each economy, the wage rate in country U increases and reaches \$0.4. The change in wage rate changes the pattern of comparative advantage. The result is that country U specializes in product 1 and country A produces all products. After the change in the wage rate in country U (measured in country A's currency) the dynamics of the run is the same as in Example 1. Therefore, the initial value of the wage rate in country U does not affect the pattern of specialization and sectoral and macroeconomic variables in the long term.

XI.1.2. Effect of initial level of consumption

This section shows with computer simulations and analytically that changes in the initial levels of consumption of the good in which country U specializes do not change the long-term results shown in Example 1.

We fist analyse, by computer simulation, an example (called in this chapter Example 1c) in which the good that country U specializes in is given a much higher per capita consumption as initial value. Figure 11.8 shows the result of a simulation run of the model with the initial set-up equal to the one discussed in the first example of this section, except by the initial levels of consumption per capita, which are given by:

$c_A = c_U = \{0.20, 0.05, 0.05, 0.05\}$

This setup gives good 1, in which country U specializes, a higher per capita consumption in both countries.

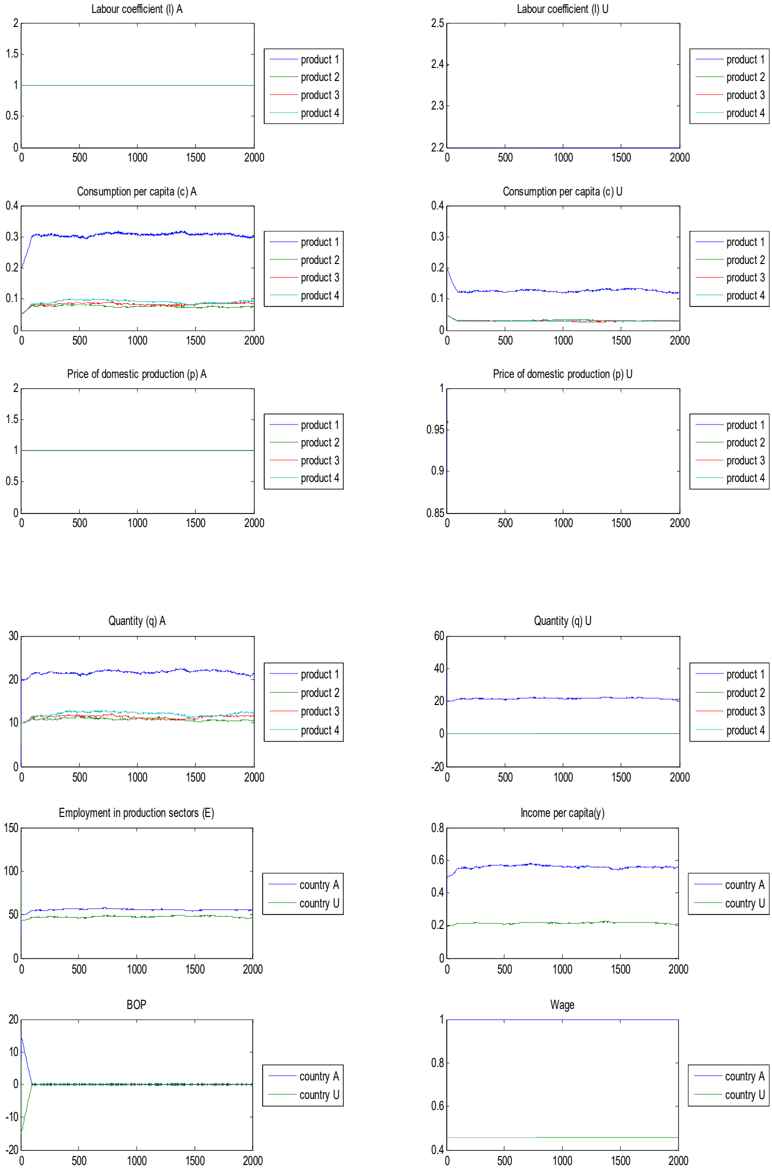
The level of employment and income per capita in the counter example of both countries being in autarky is the following:

- Employment in autarky: A=35 people; U=83 people;
- Income per capita in autarky: A=\$0.35; U=\$0.332.

The simulation run shows a pattern of specialization similar to that of Example 1: countries U and A producing and exporting product 1 and country A exporting the other products as well. Therefore, in the long-run, this example produces the same results as Example 1: country A (high productivity) has a positive trade balance and, as result, consumption increases, with the opposite happening in country U.

The main difference in the simulations in Examples 1 and 1c is in the shorter time that it took the countries to reach trade balance (balance of trade gravitating around zero): around 97 periods in the case of Example 1c instead of 195 periods as in Example 1. In both examples, country U (lower productivity) has a negative trade balance and, as result, consumption decreases, while the opposite happens for country A.

Figure 11.8. Example 1c – higher initial consumption per capita of product 1



Let us now explore analytically the result shown in Example 1c that the level of initial consumption per capita affects the time that it takes for the simulation to reach balance of payments close to zero. That can be illustrated by Table 11.6, which shows the trade balance in countries *A* and *U*.

Let us suppose that the scenario is similar to Example 1, and that the table shows a snapshot of the economy when the long-run specialization pattern is reached (i.e. country *U* and *A* producing good 1 and country *A* producing goods 2, 3 and 4 as well).

The table has one column titled "Set *A*" that represents the set of sectors of country *U* that continue to produce when open to free trade (i.e. sector 1), and a column titled "Set *B*" that represents the sectors that do not produce (i.e. sectors 2, 3 and 4).

Table 11.6. Illustration of the trade balance, beginning of run

country *U*	Set *A* = {1}	Set *B* = {2,3,4}
(1) Income	a	0
(2) Expenditure	a, a > 0	b, b > 0
(3) Income – expenditure	-b < 0 => negative trade balance	

country *A*	Set *A* = {1}	Set *B* = {2,3,4}
(4) Income	a	c + b
(5) Expenditure	a, a > 0	c, c > 0
(6) Income – expenditure	b > 0 => positive trade balance	

Line (1) shows the income in free trade. Let us assume that the global demand for product 1 is ($2a). The assumption used in the model is that if two countries produce a product with the same lowest price, they will share the market, unless one of the countries is in full employment. This is the case in example 1 and therefore the production of that commodity in country *U* is half of that ($a). Since country *U* only produces product 1, the only income is from that sector ($a).

Line (2) shows the expenditure in free trade. The expenditure on the consumption of product 1 is the same as the income ($a), given that both countries have the same consumption. As for the set *B*, the expenditure is represented by $b.

Line (3) shows the trade balance (income – expenditure) which is (- $b), a negative amount.

Now, let us discuss the trade balance in country *A*. Line (4) shows the income in that country, which is $a for the set *A* and is $c+$b for set *B*, where $c is the amount related to the production to meet the domestic demand of country *A* and $b is the amount related to the foreign demand. Line (5) shows the expenditures in country A, which is \$a for good 1 and \$c for the set B, as mentioned above. Line (6) shows the trade balance, which is positive (\$b).

Table 11.7 shows the effect of increasing the initial consumption per capita of good 1 in which U specializes, as in Example 1c. Note that if we represent the change in demand in country U as given by: -\$d1 for set A and -\$d2 for set B, and if we represent the change in demand in country A by: \$d3 for set A and \$d4 for set B, then balance of trade is given by:

Country U: \$ ((d3 + d1)/ 2) + d2 - b

Country A: \$ b - (((d3 + d1)/ 2) + d2)

Table 11.7. Illustration of the trade balance, during run

country U	Set A = {1}	Set B = {2,3,4}
(1) Income	a + ((d3 - d1) / 2)	0
(2) Expenditure	a - d1, a > 0	b - d2, b > 0
(3) Income – expenditure	((d3 + d1) / 2) + d2 - b	

country A	Set A = {1}	Set B = {2,3,4}
(4) Income	a + ((d3 - d1)/ 2)	c + b + d4 - d2
(5) Expenditure	a + d3, a > 0	c + d4, c > 0
(6) Income – expenditure	b - (((d3 + d1)/ 2) + d2)	

Given that the absolute values of the changes in demand are a function of the size of the initial consumption, the higher the value of "a" the higher the values of d1 and d3 and the faster the balance of trade will move towards zero.

In summary, changes in the initial consumption per capita of the good for which country U specializes do not change the pattern of specialization in the log-run (based on the labour coefficients used in examples 1, 1a, 1b and 1c) and the fact that country U has negative trade balance. Changes in initial consumption of good 1 only affect the amount of time that it takes to reach trade balance.

XI.2. Effect of different productivity levels

This section shows the result of simulation runs that have initial setup similar to that of Example 1 but with different values for the labour coefficients of the different sectors.

- Coefficients of consumption per capita: $c_A = c_U = \{0.05, 0.05, 0.05, 0.05\}$
- Total labour force in each country: $L_U = L_A = 100$
- Wage rate in country A: $w_A = \$ 1$
- Wage rate in country U: $w_U = \$ 0.4$
- The maximum possible values of the rate of change of the coefficient of consumption (r): max(r)=0.01.

- No trade costs
- No saturation of consumption
- No hierarchy of consumption
- No technological progress
- No markups over production costs

Example 1d:

- Labour coefficients in country A: $l_A = \{1, 1,1,1\}$
- Labour coefficients in country U: $l_U = \{2,2,2,2\}$

Example 1e:

- Labour coefficients in country A: $l_A = \{1, 1,1,1\}$
- Labour coefficients in country U: $l_U = \{0.5,0.5,0.5,0.5\}$

Example 1f:

- Labour coefficients in country A: $l_A = \{0.8, 0.9,1.1,1.2\}$
- Labour coefficients in country U: $l_U = \{1.6,1.8,2.2,2.4\}$

The results of the simulations of Examples 1d, 1e and 1f are shown in Figure 11.9, Figure 11.10, and Figure 11.11, respectively.

Figure 11.9. Example 1d – country A more productive, same levels of productivity within country, and both countries with the same range of productivity

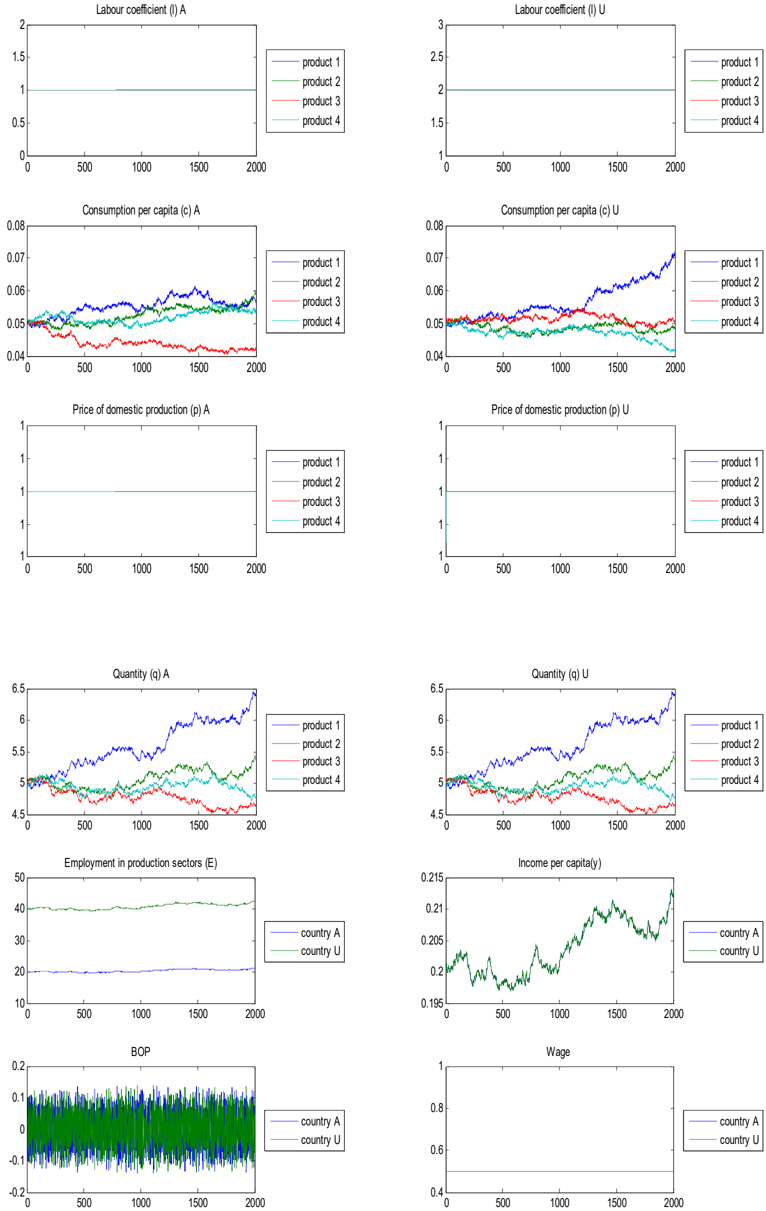


Figure 11.10. Example 1e – country B more productive, same levels of productivity within country, and both countries with the same range of productivity

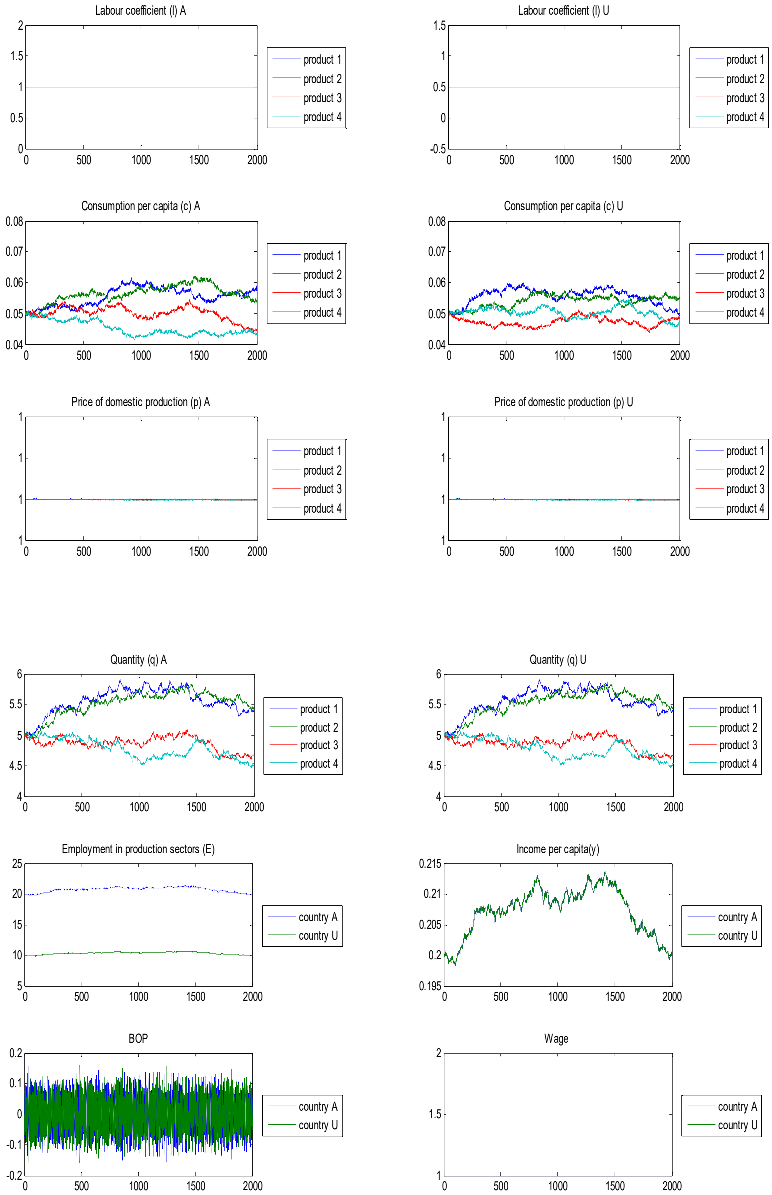
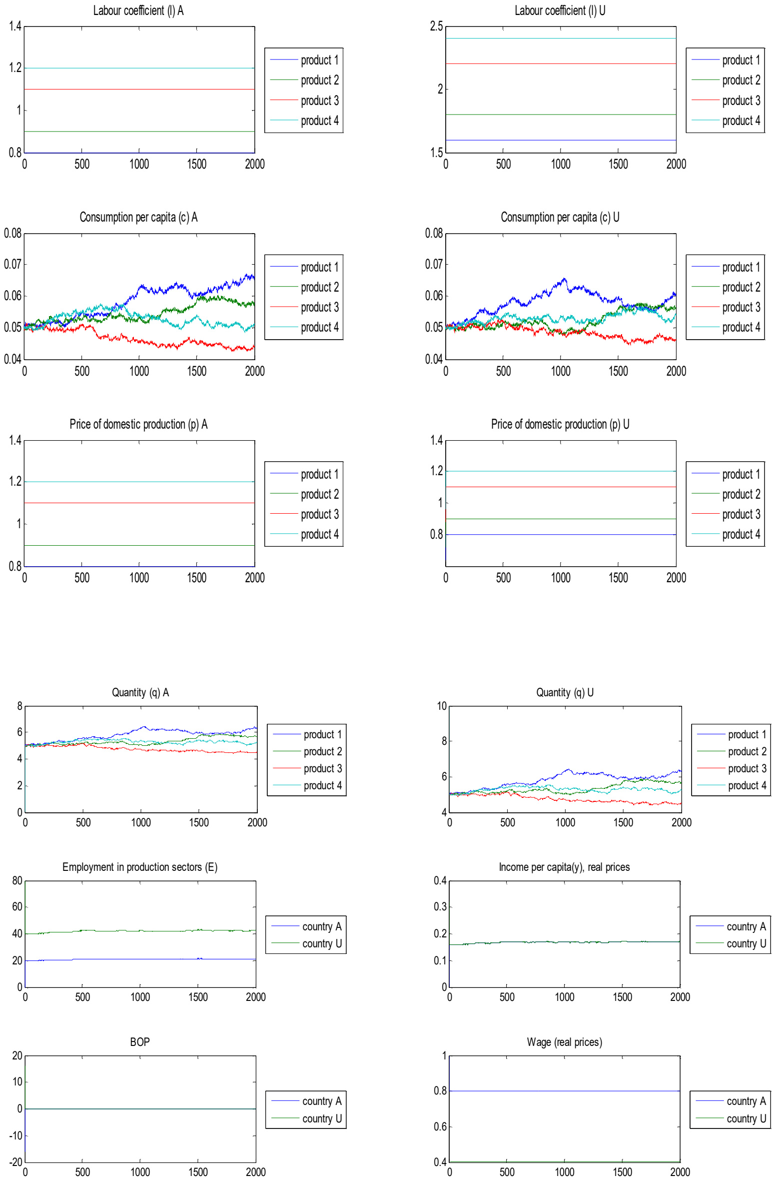


Figure 11.11. Example 1f - country A more productive, different levels of productivity within country, and both countries with the same range of productivity



12 Diversification and technological change

This chapter shows the main results of this dissertation. It presents the analysis of the model to study diversification, structural economic dynamics and trade, focusing on the dynamics due to technological progress. The chapter shows that the model is able to replicate the stylized facts discussed in Chapter Four related to economic diversification. It also presents the result of analysis of the interrelationship between product innovation and emulation and shows how different rates of technological change affect global levels of output and inequality across countries. The chapter also presents the analysis of possible strategies to facilitate the diversification and catch up of poorer economies, and shows the benefits of the strategy adopted in Chapter Six to identify possible products for innovation by targeting potential new products with complexity higher than the country's average.

12.1 Introduction

This chapter presents the analysis of the dynamics of the model that are the result of technological change. The chapter illustrates the main characteristics of the model: the endogenous mechanism for product and process innovation and emulation. As presented at previous chapter, this mechanism follows Andersen's

(2001) model where innovations arrive at stochastic intervals following a Poisson process, which is dependent on the resources dedicated to R&D. This endogenous mechanism also adopts the concept of adjacent possible, which is implemented in the model by assuming that new products are created as the result of the fruitful combination of the labour-embodied technologies that already exist in the economy considered.

The next section illustrates the functioning of the model by using a simple example with two countries and four initial products. The subsequent section shows that the model replicates the stylized facts discussed in Chapter Four by presenting an analysis of simulation runs of the model with a larger number of countries (30) and initial products (10) to facilitate the visualization of the results. The chapter then presents an analysis of the effects of different rates of technological progress, in terms of product innovation and emulation, on global GDP and inequality across countries. The chapter ends by presenting an analysis of possible strategies to facilitate diversification and catch up of poorer economies.

12.2 Illustrative example

This section considers the example of the structural economic dynamics of two countries (*A* and *B*) trading with each other. Both countries have a population of the same size (100 people) and produce the same four products with exactly the same technology. Hence, people in country *A* are as productive as people in country *B*. To facilitate the description of the example, we impose a limit of four new sectors on the maximum number of sectors that could emerge during a simulation run.

Let us assume that the initial values of the exogenous and state variables are given by:

- Population: $Q_{n,B} = Q_{n,A} = 100$
- Labour coefficient of country *A*: $l_A = \{1,2,3,4\}$
- Labour coefficient of country *B*: $l_B = \{1,2,3,4\}$
- Coefficient of consumption per capita in country *A*: $c_A = \{0.05, 0.05, 0.05, 0.05\}$
- Coefficient of consumption per capita in country *B*: $c_B = \{0.05, 0.05, 0.05, 0.05\}$
- Initial wage rates: $w_A = w_B = \$\ 1$
- Initial domestic markups of each sector in each country are taken stochastically, in a range from 2 to 2.5. Markups for export markets are initially up to 0.5 higher than domestic markups.

We assume that the maximum possible values of the rate of change of the coefficient of consumption (r) is given by: max(r)=0.01.

We consider that all sectors have saturation of consumption points that are exogenously given but that are not higher than 100% above the initial consumption per capita:

- $\beta = 2$

In terms of process innovation, we assume that in each country one person engaged in R&D would find a new way to produce an existing product on average once every 50 periods:

- $\lambda_A^{process} = \lambda_B^{process}$=1/50

On the other hand, one researcher engaged in the emulation of a more productive process to produce an existing product would find a new way to emulate a given process once every 25 units of time:

- $\lambda_A^{process\_emulation} = \lambda_B^{process\_emulation} = 1/25$

Regarding product innovation, we assume that in each country one person engaged in R&D would find a new product on average once every 50 units of time:

- $\lambda_A^{product} = \lambda_B^{product}$=1/50

One researcher engaged in emulation would find a new way to emulate a product once every 40 units of time:

- $\lambda_A^{product\_emulation} = \lambda_B^{product\_emulation} = 1/40$

We assume that the maximum overtime is of 50% of the production time:

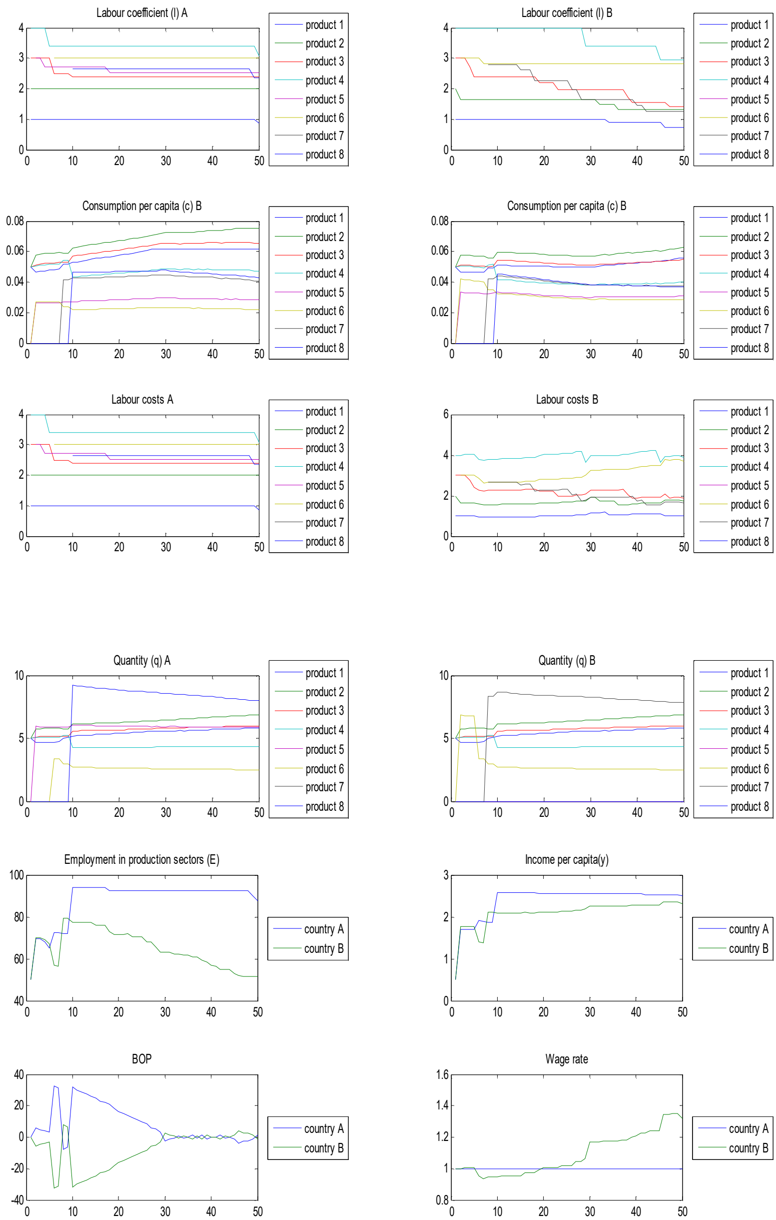
- $\vartheta = 0.5$

Figure 12.1 shows the evolution of the key variables in one run of the model. The first two graphs at the top of the figure show the evolution of the labour coefficients in each country. Both countries produce initially the same four products (products 1 to 4). In period 2 a product numbered 5 emerged in country *A* and a product numbered 6 was created in country *B* (see Table 12.1). In period 6, country *A* emulates the production of sector 6. In period 8, country *B* starts the production of product 7, and in period 14 country *A* starts production in sector 8.

During the simulation, each sector experienced process innovation, which resulted in decreasing labour coefficients as seen in the first two graphs at the top in Figure 12.1. The sectors and period in which these process innovations occurred are shown in the third column of Table 12.1. The simulation also resulted in one process emulation in period 10, when sector 3 in country *A* emulated the production of that same sector in country *B*. As mentioned, for illustration purposes, the simulation was restricted to a maximum of eight sectors. Therefore, after the introduction of these new sectors, technological progress was due to process innovation and emulation only.

Table 12.2 shows the evolution of the set of technologies in country *A* to illustrate the process of combination of technologies that gives rise to technological change. The technologies that represent the first four products are {*a*, *b*, *aa*, *ab*}, respectively. These initial technologies are combined to create new products or new processes.

Figure 12.1. Two countries trading



For example, as mentioned above, in period 2 a new sector (5) emerged in country *A*. That sector emerged as a combination of technologies *ab* and *b* and resulted in *abb*. The same sector experienced process innovation in period 4 and the set of technologies used for production became *abab*, the combination of the technologies of sector 4. This set of technologies combined with the technology of sector 1 (*a*) in period 14 resulted in a new sector (sector 8 with technology set *ababa*). Another example is the process innovation that sector 1 experienced in period 50, in which the technologies of sectors 5 (*baababab*) and 3 (*baaa*) were combined to create a new process (*baababab baaa*) to produce product 1.

Table 12.1. List of changes in technologies

Country	Product innovation	Product emulation	Process innovation	Process emulation
A	5 (2), 8 (14)	6 (6)	1 (50), 3 (6), 4 (5, 50), 5(4, 18), 8 (49)	3 (10)
B	6 (2), 7 (8)		1 (34, 46), 2 (2, 32, 36), 3 (4, 5, 19, 23, 38, 39, 47), 4 (29, 45), 6 (7), 7 (15, 18, 26, 28, 40, 42)	

Note: Numbers in parentheses indicate the period in which the innovation occurred.

The second row of graphs in Figure 12.1 shows the effect of the appearance of the new products in the consumption of existing products, due to complementarity or substitution effects. The third row of graphs presents the evolution of labour costs in each country, which reflect the changes in labour coefficients in each sector and the changes in the relative wage rate in country *B*, given that the wage rate in country *A* is taken as the numéraire throughout the run. The fourth row of graphs shows the evolution of quantities produced in each sector and country. Two notable patterns shown in these graphs are the high level of production of the new sectors, given that each country has in effect a monopoly of production when a new product emerges, and the drop in production in country *B* of product 6 following country *A*'s emulation of the production of that sector in period 6.

Figure 12.1 also presents the evolution of employment in each country and shows that employment levels in country *A* remain higher than in country *B*, due to the higher levels of production of its more diversified economy. Income per capita is also higher in country *A* than in *B*. The balance of payments shows that trade imbalances happen mostly during the emergence of new sectors.

Table 12.2. Evolution of set of technologies, country *A*

time	Products							
	1	2	3	4	5	6	7	8
1	a	b	aa	ab	-	-	-	-
2	a	b	aa	ab	abb	-	-	-
3	a	b	aa	ab	abb	-	-	-
4	a	b	aa	ab	abab	-	-	-
5	a	b	aa	babab	abab	-	-	-
6	a	b	ababbabab	babab	abab	baa	-	-
7	a	b	ababbabab	babab	abab	baa	-	-
8	a	b	ababbabab	babab	abab	baa	-	-
9	a	b	ababbabab	babab	abab	baa	-	-
10	a	b	baaa	babab	abab	baa	-	ababa
11	a	b	baaa	babab	abab	baa	-	ababa
12	a	b	baaa	babab	abab	baa	-	ababa
13	a	b	baaa	babab	abab	baa	-	ababa
14	a	b	baaa	babab	abab	baa	-	ababa
15	a	b	baaa	babab	abab	baa	-	ababa
16	a	b	baaa	babab	abab	baa	-	ababa
17	a	b	baaa	babab	abab	baa	-	ababa
18	a	b	baaa	babab	baababab	baa	-	ababa
19	a	b	baaa	babab	baababab	baa	-	ababa
20	a	b	baaa	babab	baababab	baa	-	ababa
21	a	b	baaa	babab	baababab	baa	-	ababa
22	a	b	baaa	babab	baababab	baa	-	ababa
23	a	b	baaa	babab	baababab	baa	-	ababa
24	a	b	baaa	babab	baababab	baa	-	ababa
25	a	b	baaa	babab	baababab	baa	-	ababa
26	a	b	baaa	babab	baababab	baa	-	ababa
27	a	b	baaa	babab	baababab	baa	-	ababa
28	a	b	baaa	babab	baababab	baa	-	ababa
29	a	b	baaa	babab	baababab	baa	-	ababa
30	a	b	baaa	babab	baababab	baa	-	ababa
31	a	b	baaa	babab	baababab	baa	-	ababa
32	a	b	baaa	babab	baababab	baa	-	ababa
33	a	b	baaa	babab	baababab	baa	-	ababa
34	a	b	baaa	babab	baababab	baa	-	ababa
35	a	b	baaa	babab	baababab	baa	-	ababa
36	a	b	baaa	babab	baababab	baa	-	ababa
37	a	b	baaa	babab	baababab	baa	-	ababa
38	a	b	baaa	babab	baababab	baa	-	ababa
39	a	b	baaa	babab	baababab	baa	-	ababa
40	a	b	baaa	babab	baababab	baa	-	ababa
41	a	b	baaa	babab	baababab	baa	-	ababa
42	a	b	baaa	babab	baababab	baa	-	ababa
43	a	b	baaa	babab	baababab	baa	-	ababa
44	a	b	baaa	babab	baababab	baa	-	ababa
45	a	b	baaa	babab	baababab	baa	-	ababa
46	a	b	baaa	babab	baababab	baa	-	ababa
47	a	b	baaa	babab	baababab	baa	-	ababa
48	a	b	baaa	babab	baababab	baa	-	ababa
49	a	b	baaa	babab	baababab	baa	-	baabababb
50	baabababbaaa	b	baaa	abaabababb	baababab	baa	-	baabababb

The graph at the bottom right presents the evolution of relative wage rates and shows that wages in country B are higher than the wages in country A at the end of the run, which reflects the lower average labour coefficient of that economy (higher average productivity). In this particular run, country A is more diversified but has lower average productivity. However, as shown in the next section, when more sectors are allowed to be created, more diversified economies tend to also be more productive on average.

This illustrative example highlights the Schumpeterian framework of economic dynamics, in which the introduction of technological change puts the economic system in constant flux; the system no longer reaches an equilibrium state. Innovation results in growth in terms of income and employment, which in their turn enable future innovation. Innovation acts as an unsettling force, taking the system to a new configuration from where it starts to move to an equilibrium until it is disturbed again by the next innovation.The example also highlights the path dependency in the innovation process, which constrains the options for future innovation. It gives and enforces the possible directions for technological change. It is, therefore, a key element in the study of economic dynamics. Such path dependency, however, cannot be seen in macroeconomic variables such as output, employment, balance of trade, and wage rates. The model allows us to analyse this process in detail; to see how that path dependency unfolds, as shown in Table 12.2 in the example.

This section also shows that the model follows the requirements discussed in Chapter Seven as important for the study of diversification and structural economic dynamics: it considers the existence of multiple sectors and multiple countries trading with each other, and analyses how this structure changes and affects macro-economic variables (e.g. employment, gross domestic product, total consumption and balance of trade). The next section examines whether the model can replicate the stylized facts related to diversification discussed Chapters Four and Seven.

12.3 Replication of the stylized facts

This section presents the results of a key experiment in this study. It puts the model to a test to verify if it is able to reproduce the patterns of diversification observed in the actual trade data. The section shows that the model indeed is able to replicate the following four stylized facts: (1) diversification is associated with higher total GDP, (2) diversification is associated with lower average ubiquity of exports, (3) opportunities for catching up in terms of diversification are not equally distributed and less diversified countries tend to fall behind, and (4) diversification is path dependent (which is true by design of the model, making technologies emerge through the combination of existing technologies).

To perform this test, we generate simulations with 30 countries, 10 initial products and 100 periods. We run 100 simulations of the model to test different realizations of the stochastic process, with the following set of initial configuration values and parameters:

- labour coefficient $l_1 = l_2 = \cdots = l_{30} = \{0.5, 0.5, \dots, 0.5\}$;
- coefficient of consumption per capita $c_1 = c_2 = \cdots = c_{30} = \{0.01, 0.01, \dots, 0.01\}$;
- wage rate in country 1 $w_1 = \$\ 1$;
- β = 2; saturation of consumption not higher than 100% above the initial consumption per capita;
- $\lambda_k^{product} = \lambda_k^{process} = 1/200$; in any country k (k=1,2,3,…,30) each researcher finds a new product or a new process on average once every 200 periods;
- $\lambda_k^{product\_emulation} = \lambda_k^{process\_emulation} = 1/100$; in any country k (k=1,2,3,…,30) each researcher engaged in emulation finds a new way to emulate a product once every 100 periods;
- u = 0.2; 2 out of 10 potential new products invented as a combination of existing technologies are useful.

The set of figures shown on the next pages presents the results of one of the 100 runs of the simulation. Figure 12.2 shows that the model replicates the stylized fact 1 of the positive association between the level of diversification and GDP. The horizontal axis of the graph shows the diversification of each country at the end of the simulation run (period 100) measured by the number of products exported, and the vertical axis shows the total GDP in each country expressed in the currency of country 1 (the vertical axis is shown in logarithmic scale). Each circle in the graph represents a country. Some circles appear to overlap with each other in the figure (particularly at lower levels of diversification), which indicates that countries have about the same level of GDP for similar levels of diversification. Also noticeable is the large income inequality between more diversified countries and the others. GDP of the two more diversified countries (both exporting 26 products) is 2 to 3 times higher than the GDP of the third more diversified country and 200 to 300 times higher than the less diversified countries (which export the same initial 10 products).

Figure 12.3 shows that the model also replicates stylized fact 2, the negative association between diversification (horizontal axis) and the average ubiquity of the exports of a country (vertical axis). The graph shows that the value of average ubiquity of the exports of the more diversified countries (14) is less than half of the less diversified countries (30), which indicates that on average the more diversified countries face half of the competition faced by the less diversified countries.

Figure 12.2. Association between diversification and GDP

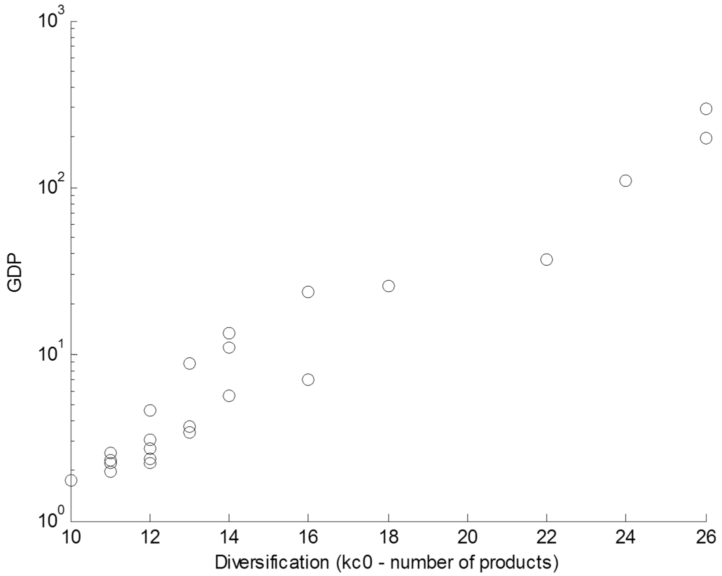


Figure 12.3. Association between diversification and average ubiquity of exports

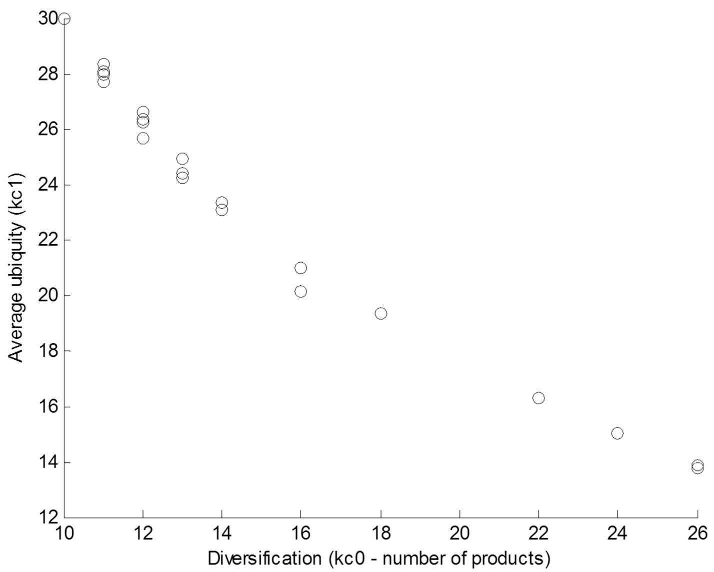


Figure 12.4 shows that diversification is also positively associated with employment levels. The graph presents a pattern that resembles the association between diversification and total GDP (Figure 12.2). This is expected given that total GDP is calculated as the production of a country multiplied by the prices of its products that were sold in each market, and one component of price is the labour cost (the other is the markup). Therefore, the higher the level of employment, the higher the labour income and the higher the total GDP of a country. Note that the employment levels of the two more diversified countries (40 and 35 per cent, respectively) are closer than the GDP levels of these two countries, which indicates that significant contributors for the differences in GDP levels is the differences in wage rates and in average markup levels of the products of each country.

Figure 12.5 presents the positive association between diversification and consumption per capita. It is noticeable that as diversification increases, the differences in the levels of diversification between countries, and consequently the differences in income (as seen in Figure 12.2), result in smaller differences in expenditure. The reason for that is the saturation of demand of commodities in the economy. Above certain levels of income, the consumption per capita of the products that have reached saturation remains constant.

Figure 12.6 shows the negative association between diversification and the average labour coefficient. The circles at the top of the graph represent countries that have not experienced process innovation; the average labour coefficient in these economies has remained at the value of 0.5. Some of these countries have diversified, hence have experienced product innovation, but that has not changed the average labour coefficient due to the simplification adopted in the model assuming that a new sector that emerges through product innovation has an initial labour coefficient equal to the average labour coefficient in the economy. Other circles in the graph represent countries in which sectors have experienced process innovation. The more diversified the country, the higher the level of employment and the higher the share of R&D dedicated to process innovation in comparison with product innovation. Therefore, the higher the probability that more productive sets of technologies are adopted by sectors in the economy, reducing the average labour coefficient. This yields the inverse relationship between average labour coefficients and levels of diversification. This tendency does not preclude the variation of the results shown in the graph for countries that have the same level of diversification. Innovation is the result of a stochastic process; therefore, it is possible that, during the run, process innovation occurs more often in a country and less often in others, all things being equal.

Figure 12.4. Association between diversification and employment

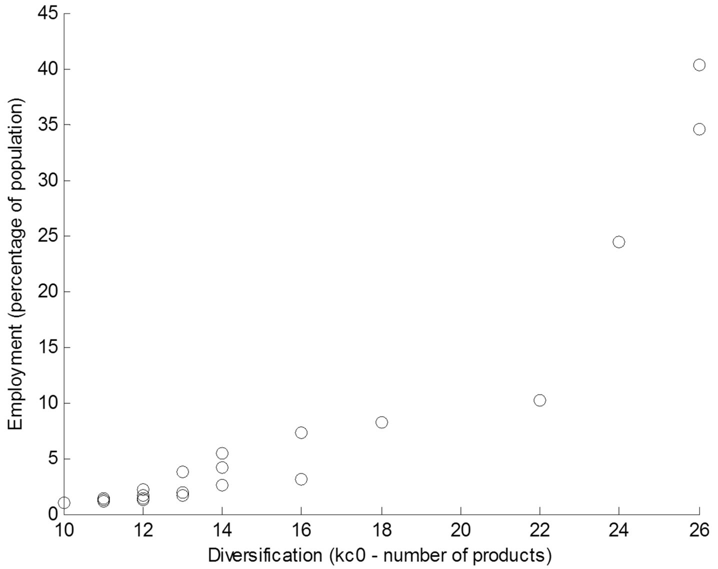


Figure 12.5. Association between diversification and consumption per capita

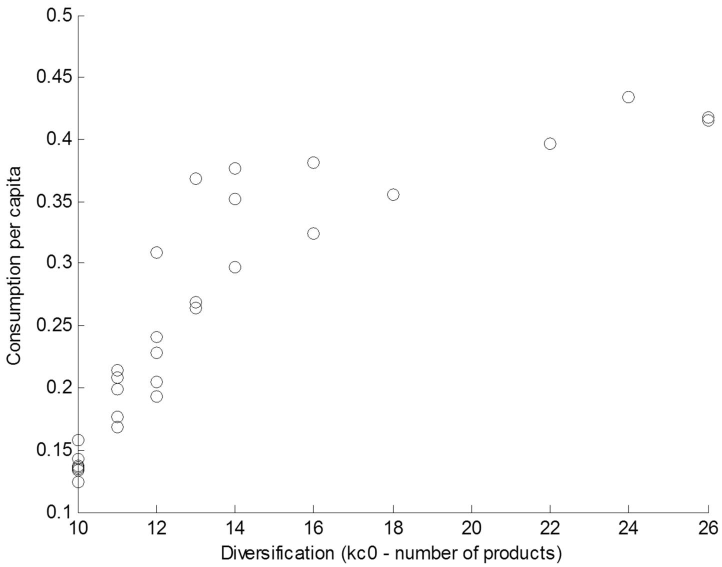
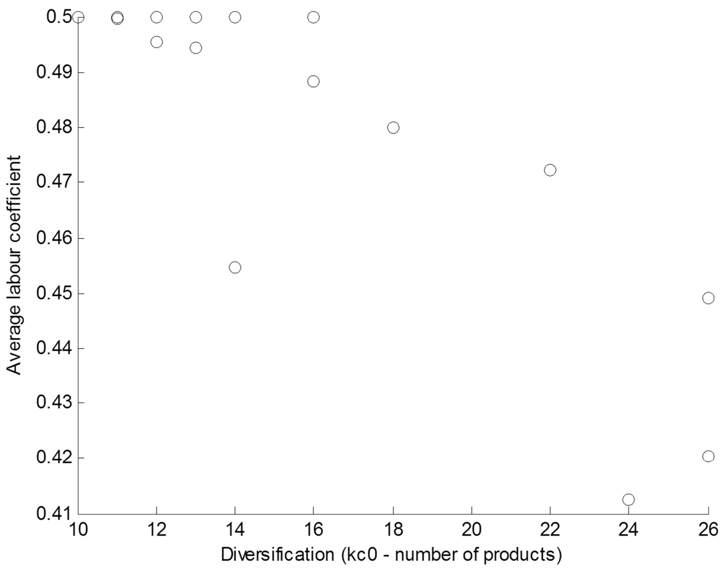


Figure 12.6. Association between diversification and average labour coefficient

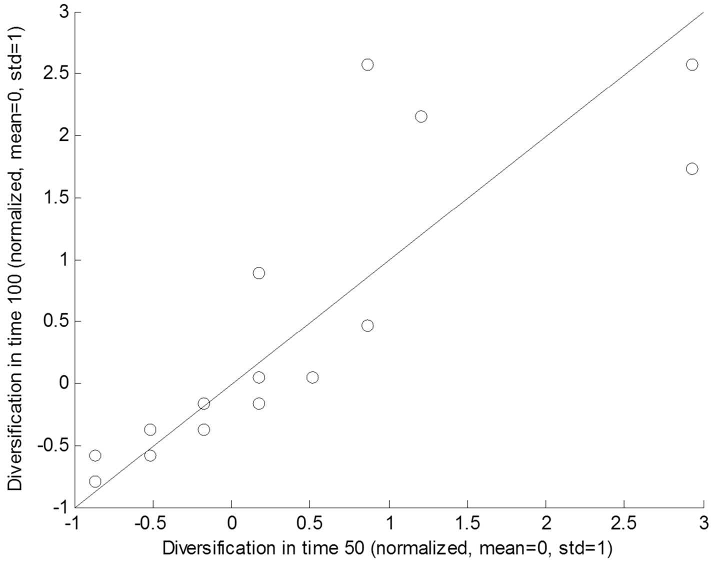


The model also produces a pattern similar to that of stylized fact 3 in which less diversified countries lag behind and countries that are more diversified tend to catch up. This is illustrated in Figure 12.7, which shows the diversification in period 50 along the horizontal axis and diversification in period 100 along the vertical axis. Diversification is normalized so that, on each axis, zero represents the global average diversification and the standard deviation is one. The circles below the diagonal line represent the countries for which diversification has decreased between the two periods and the circles above that line represent the countries for which diversification has increased.

Less diversified countries have a smaller set of technologies from which to create useful new products. Their people are engaged in productive sectors that are frequently observed in other countries as well, which increases competition and reduces the opportunities for higher markups. Their idle labour force could be employed in R&D, but low markups reduce the resources dedicated to this activity. As new products are added in more diversified economies, the resulting changes in consumption patterns of the other products of the economies (due to complementarity or substitution) could reduce the demand for products produced by the less diversified countries, hence further reducing the resources for R&D. These countries become trapped in a vicious cycle.

Countries in the middle group in terms of diversification have a larger set of potential new products in the adjacent possible and are more likely to catch up through emulation. Whenever they emulate the production of a more productive country, their lower wages create a higher price differential that allows for higher markups. These can fund further R&D. Increasing production also increases income per capita. These countries are in a better position to catch up than the less diversified countries.

Figure 12.7. Example of evolution of diversification



The summary statistics of 100 runs of the simulation are presented in Table 12.3. In terms of diversification, the countries that are less diversified at the end of a run of the simulation have generally not experienced any product innovation or product emulation. They have completed the runs with the same 10 sectors that they had at the beginning. The median country on average ends a run with 11 sectors, which shows that half of the countries are not able to increase their diversification substantially. On the other hand, more diversified countries have on average 33 sectors exporting at the end of a run of the simulation.

The table also presents the slope of the least-squares regression line that summarizes the relationship between the logarithm of the level of diversification of a country ($k_{c,0}$) and the logarithm of GDP. The empirical evidence shows a positive slope for that relationship, which is replicated by the model as indicated in the table by the positive value 4.61. Similarly, the table shows the slope of the least squares regression line related to the logarithm of the level of diversification ($k_{c,0}$) and the logarithm of the average ubiquity of exports ($k_{c,1}$). A negative value (-0.85) is consistent with the empirical relationship that a higher level of diversification is associated with a lower average ubiquity of exports.

Table 12.3. Summary statistics of 100 runs of simulation

		Mean	Standard deviation
Diversification			
	Minimum	10	0.14
	Maximum	33	4.56
	Median	11	0.58
Relationship between logarithm of diversification and logarithm of GDP ($\ln(k_{c0})$ x $\ln(GDP)$)			
	Slope	4.61	0.46
	R-squared	0.94	0.03
Relationship between logarithm of diversification and logarithm of average ubiquity ($\ln(k_{c0})$ x $\ln(k_{c1})$)			
	Slope	-0.85	0.03
	R-squared	1	0

12.4 Effect of innovation on output, across-country inequality and diversification

In this section, we study how the macroeconomic results of the model are affected by the choices of parameters related to the arrival rate of innovation. The analysis has two objectives. The first is to show that changing the pace of product innovation and emulation does not change the results of the model related to the stylized facts. The analysis in this section focuses on the stylized facts 1 and 2 related to the association of diversification with GDP and with the average ubiquity of exports.

The second objective is to study how different rates of product innovation and emulation affect the output of countries, the inequality across countries and their levels of diversification. This analysis is closely related to the problem studied in the strand of literature on product cycle models, which has analysed the relationship between innovation, emulation (called imitation) and policies that facilitate or hinder imitation (see Saggi, 2016 for a review of that literature). Key questions in this literature are whether and to what extent developed and developing countries benefit from technology transfer.

This strand of literature is divided mainly in models based on variety expanding innovation and quality ladders. In general, both types of models are used in frameworks that consider only two countries and adopt full specialization of exports. In product cycle models based on variety expanding innovation, products are created in the North through product innovation and, once they are imitated in the South, the production moves from North to South. In the quality ladders framework, a product is created initially in the North through product innovation, then is imitated in the South and production moves to there, but the North can again innovate to create a new vintage of the product, in which case it will be the sole producer and exporter of that latest vintage of the product until the South again imitates the production. There is a full specialization pattern that moves back and forth between North and South.

By using the model proposed in this dissertation, we are able to expand this study to many countries, considering a more realistic framework that replicates stylized facts related to diversification (including the basic fact that more than one country can produce and export the same product), and considering that all countries can engage in product and process innovation and emulation at the same time.

To conduct these tests, we run 100 simulations of the model 100 times with the same set of initial parameters, considering 50 periods to test different realizations of the stochastic process. For this analysis, we consider 10 countries initially trading 6 products. These countries have the same population size (100 people), and labour and consumption coefficients at the beginning of each simulation; therefore, they start with the same productivity, income and consumption levels. We track the results related to diversification and output (GDP) for all countries, as well as inequality across countries.

The initial parameters are as follows:

- labour coefficient $l_1 = l_2 = \cdots = l_{10} = \{0.5, 0.5, 0.5, 0.5, 0.5, 0.5\}$;
- coefficient of consumption per capita $c_1 = c_2 = \cdots = c_{10} = \{0.01, 0.01, 0.01, 0.01, 0.01, 0.01\}$;
- $u = 0.4$; 4 out of 10 potential new products are useful;
- wage rate in country 1 $w_1 = \$\ 1$;
- $\beta = 2$; Saturation of consumption not higher than 100% above the initial consumption per capita.

For each set of simulations, we vary the parameters related to the arrival rate of product innovation ($\lambda_k^{product}$) and product emulation ($\lambda_k^{product\_emulation}$). For example, for a given value of the parameter of arrival rate of product innovation we make emulation be 'very easy', by considering the parameter of the rate of arrival of product emulation as ten times of the rate of arrival of product innovation, and then increase the level of difficulty in equal intervals until product emulation becomes as difficult as product innovation ($\lambda_k^{product\_emulation} = \lambda_k^{product}$). The rate of arrival of product innovation takes the values {1/100, 1/125, 3/500, 1/250, 1/500}. The scenario in which $\lambda_k^{product} = 1/100$ indicates that a researcher finds a new product on average once every 100 periods, while the scenario in which

$\lambda_k^{product} = 1/500$ a new product is expected to be discovered by one researcher once every 500 periods. During the simulations, we consider that process innovation is as difficult as product innovation, and process emulation as difficult as product emulation:

- $\lambda_k^{process} = \lambda_k^{product}$
- $\lambda_k^{process\_emulation} = \lambda_k^{product\_emulation}$

The averages of the results of the 100 runs for each set of parameters are presented in Table 12.4, in relation to the replication of the stylized fact 1. The table shows the slope of the relationship between the logarithm of diversification and the logarithm of GDP. The rows show the different arrival rates of product innovation, while the columns show the arrival rates of product emulation as a multiple of the arrival rate of product innovation. For example, the top right cell of the table shows the result of the simulations in which product innovation and emulation are faster, while the cell at the left and bottom of the table shows the result for simulations with slower innovation and emulation. The table shows that, in all combinations of rate of product innovation and emulation tested, diversification is positively associated with GDP, which replicates stylized fact 1. The slope increases when product innovation is slower (i.e. it increases from top to bottom). The reason is because a slower rate of product innovation implies fewer new products, and consequently fewer products that could be emulated, which reduces the chances for less diversified countries to catch up with the countries that have innovated first. As expected, the slope also increases when emulation becomes more difficult (i.e. from right to left).

Table 12.4. Slope of the relationship between logarithm of diversification and logarithm of GDP (ln(k_{c0}) x ln(GDP))

Arrival rate of product innovation	Arrival rate of product emulation (multiple of the arrival rate of product innovation)									
	1x	2x	3x	4x	5x	6x	7x	8x	9x	10x
1/100	2.78	2.54	2.34	2.17	2.17	2.10	2.04	1.98	1.91	1.91
1/125	2.98	2.65	2.40	2.33	2.21	2.14	2.08	2.04	1.98	2.01
3/500	3.19	2.90	2.64	2.51	2.39	2.27	2.18	2.10	2.10	2.05
1/250	3.67	3.41	3.04	2.80	2.64	2.52	2.38	2.35	2.25	2.19
1/500	4.55	4.25	3.98	3.67	3.47	3.06	3.18	2.90	2.87	3.01

Table 12.5 shows the results related to the negative association between diversification and average ubiquity of exports (stylized fact 2). The table shows that all combinations of arrival rate of product innovation and emulation that were tested result in negative values for the slope of that association, which replicates the stylized fact. The table shows that the slope of the association becomes more

negative when product innovation and emulation become slower (i.e. when one moves from top to bottom and from right to left in the table). Slower product innovation and emulation reduces the chances of less diversified countries to emulate the production of first movers and, as result, the latter benefits from lower competition and lower average ubiquity of exports, which is reflected in a steeper downward slope.

Table 12.5. Slope of the relationship between logarithm of diversification and logarithm of average ubiquity (ln(k_{c0}) x ln(k_{c1}))

Arrival rate of product innovation	Arrival rate of product emulation (multiple of the arrival rate of product innovation)									
	1x	2x	3x	4x	5x	6x	7x	8x	9x	10x
1/100	-0.7	-0.7	-0.6	-0.5	-0.5	-0.5	-0.5	-0.4	-0.4	-0.4
1/125	-0.8	-0.7	-0.6	-0.6	-0.5	-0.5	-0.5	-0.5	-0.4	-0.4
3/500	-0.8	-0.7	-0.7	-0.6	-0.6	-0.6	-0.5	-0.5	-0.5	-0.5
1/250	-0.8	-0.8	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.5	-0.5
1/500	-0.9	-0.8	-0.8	-0.8	-0.8	-0.7	-0.7	-0.7	-0.7	-0.7

In summary, changes in the rate of product innovation and emulation do not affect the results of the model in terms of its capabilities to replicate stylized facts.

Now let us turn to the analysis of the effects of the different rates of product innovation and emulation on world GDP and its distribution over countries, on inequality across countries and on the levels of diversification of countries.

The average of the results related to the global level of GDP of the 100 runs for each set of parameters is presented in Figure 12.8. The figure shows the rate of arrival of product innovation on the vertical axis, which increases from the bottom (arrival rate of 1/500) to the top (arrival rate of 1/100). On the horizontal axis, the figure shows the rate of arrival of product emulation represented as a multiple of the rate of arrival of product innovation. It increases from the left (1x) to the right (10x). The contour lines in the graph join points that represent combinations of rates of product innovation and emulation that result in the same values of global GDP. Different colours in the figure represent different ranges of global GDP.

The figure confirms the general view that the level of global GDP is associated with the level of product innovation. For lower rates of product innovation, this association is mainly independent of the level of product emulation. Intuitively this makes sense, because although emulation reduces the output of the country/sector that was the original product innovator, an equivalent level of output is created by the country/sector that emulates the production. If it is very easy to emulate, many countries may be able to emulate the production of the original product innovator, in which case competition will drive the price of the product down. This could increase consumption of all available products in most countries, increasing total output. In fact, the figure shows that for higher rates of innovation there is a tendency that the easier the emulation, the higher the level of global GDP. This effect of emulation on total GDP is small when emulation is difficult (lower part of the graph), but it becomes evident for faster rates of emulation and product innovation (top right corner of the graph).

Emulation also has a large effect on the distribution of output over countries. To illustrate this, Figure 12.9, Figure 12.10 and Figure 12.11 show how the value of GDP of the poorest, median and richest countries at the end of each run varies with the different parameter values for product innovation and emulation. The GDP values are shown as a percentage of global GDP.

In Figure 12.9 the results vary mainly in the vertical dimension, increasing from the top to the bottom. This suggests that the faster the product innovation, the lower the relative GDP of the poorest country at the end of the period. Intuitively, these countries were not successful in innovating. Therefore, when it is easier for all countries to innovate, other countries benefit the most, and the poorer countries lag further behind.

Figure 12.10 and Figure 12.11 are fundamentally different from the previous one because now the value of GDP varies mainly horizontally instead of vertically. This means that product emulation has a larger effect than product innovation on the relative value of GDP of the median and top countries. Figure 12.10 shows that the easier the emulation for the same level of product innovation, the higher is the relative level of GDP for the median country at the end of the period. Figure 12.11, on the other hand, shows that the country at the top is better off the faster the product innovation and the more difficult the emulation process.

Intuitively, the countries that would tend to benefit first and foremost when emulation is facilitated are the ones that are already somewhat successful in innovating, and have accumulated the set of technologies required to emulate the production of the original innovator. This explains why the relative level of GDP for the poorest country in Figure 12.9 is essentially independent of the level of emulation, while emulation has a big effect on the shares of total GDP of the median and top countries, as shown in the other two figures.

If emulation is facilitated to a degree that even the poorest and least technologically advanced countries would have the opportunity to quickly emulate the production of other countries, then the majority of countries are able to also benefit from technological progress, which is reflected in higher shares of global GDP. The effect is strong for the median country (right side of Figure 12.10), but also to a lesser extent noticeable in Figure 12.9 for the case of the poorest country.

Figure 12.8. Global GDP, ($)

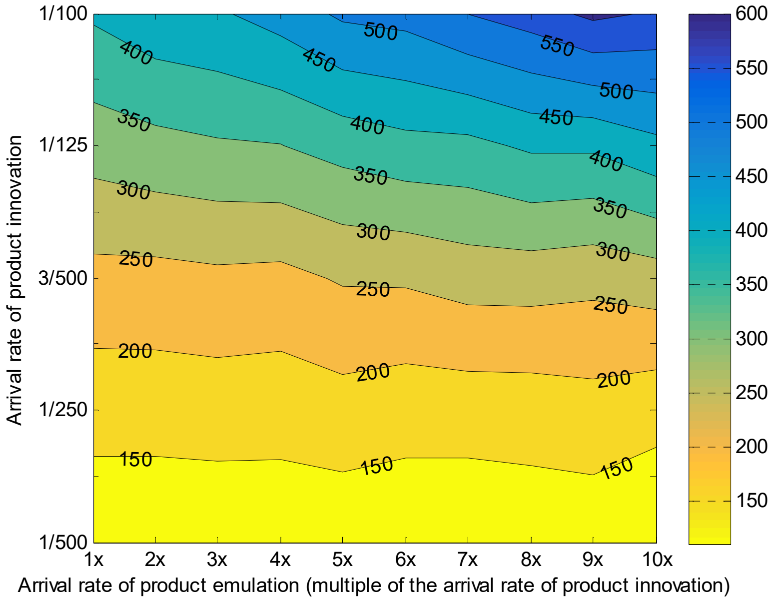


Figure 12.9. Minimum value of GDP, percentage of Global GDP

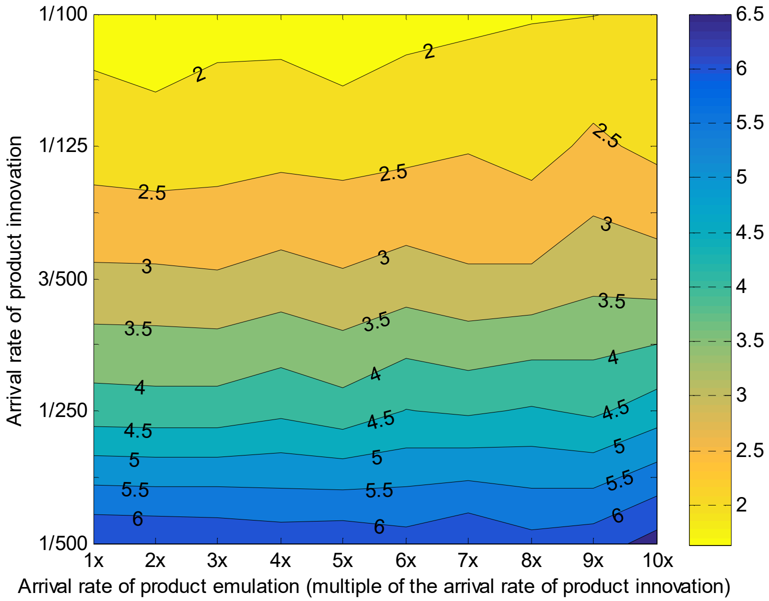


Figure 12.10. Median value of GDP, percentage of Global GDP

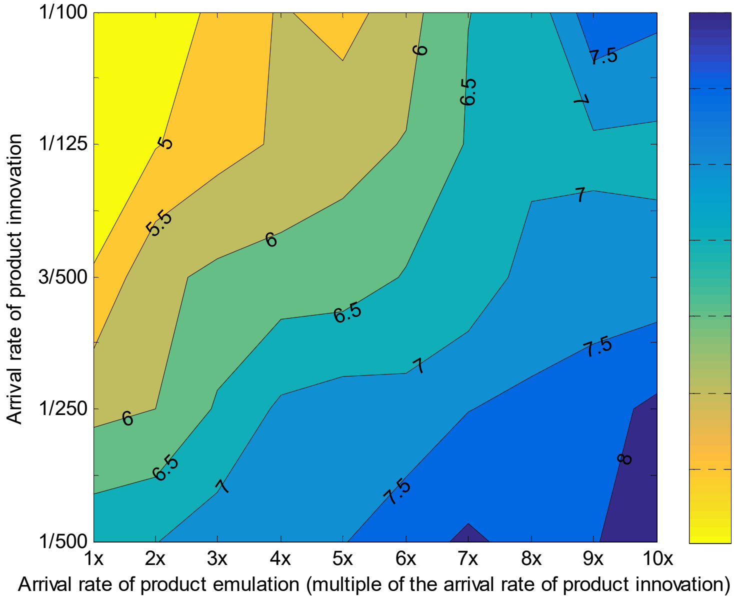


Figure 12.11. Maximum value of GDP, percentage of Global GDP

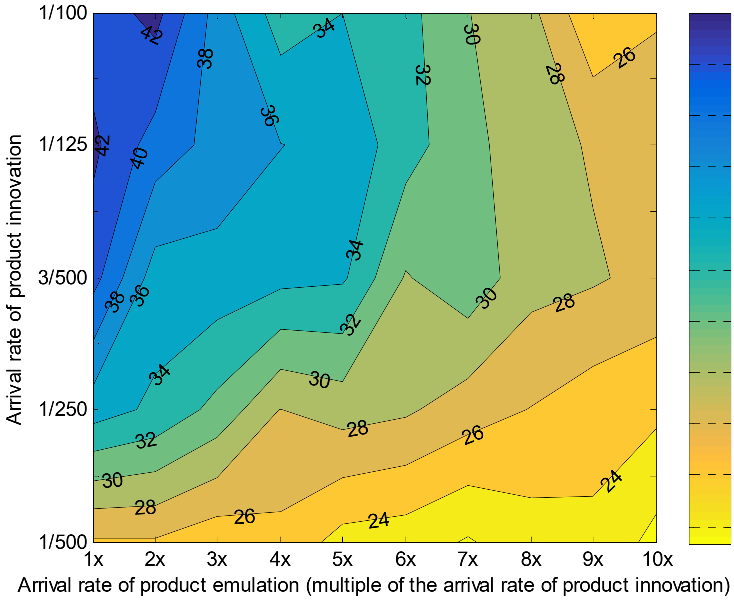
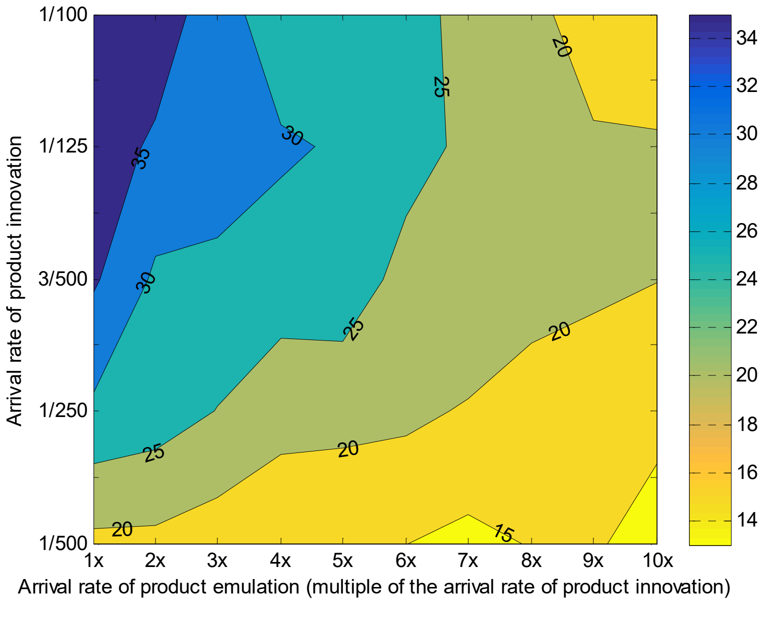


Figure 12.12 and Figure 12.13 summarize the effects of different rates of product innovation and emulation on income inequality between the country at the top and the one at the middle and between the country at the top the one at the bottom in terms of GDP, respectively. The figures show that faster product innovation is associated with higher levels of inequality across countries, but that tendency could be counterbalanced by facilitating emulation.

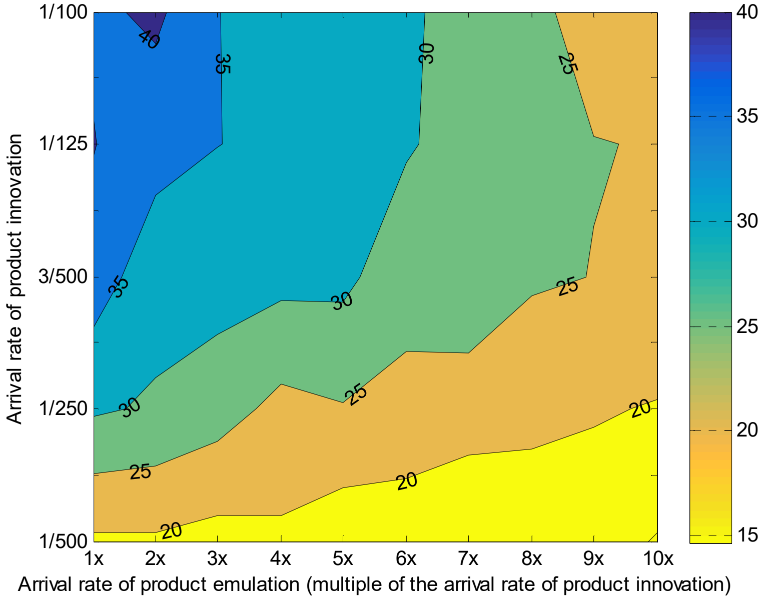
The positive association between product innovation and inequality across countries could be explained by the combinatorial nature of the innovation process, in which new products are created by the combination of existing technologies. Not all possible combinations generate useful products; nevertheless, this process creates increasing returns that makes successful innovators distance themselves in terms of GDP from relatively less innovative countries.

Figure 12.12. Income inequality (Difference between the country at the top and the one at the middle as a percentage of Global GDP)



However, for a given level of product innovation, easier emulation gives countries more chance to catch up with first movers. The latter still benefit from being more successful in product innovation and having a larger set of technologies that could be combined to create even newer products, but the advantage in relation to other countries is reduced by a faster pace in emulation. Whenever a product is emulated, a share of the market, and the associated production to attend that demand, is shifted from the original innovator to the emulator. That process reduces the inequality across countries. These results are in line with the more traditional strand of literature about catching up, which highlighted the positive association between the facilitation of diffusion of knowledge and the pace of catch up of technologically backward countries (e.g. Abramovitz, 1986).

Figure 12.13. Income inequality (Difference between the country at the top and the one at the bottom as a percentage of Global GDP)



At first sight, people in the countries at the bottom and in the middle of the income distribution would prefer to live in a world in which there is fast product innovation and in which technology transfer is facilitated (i.e. emulation is easy to accomplish). In that world they would have higher GDP per capita and the inequality across countries would be reduced. People living in countries at the top, on their turn, would be better off in a world with fast innovation but in which emulation is difficult to be realised. This is a narrative consistent with the prevalent view that more developed countries prefer institutions that provide a strong protection to their original innovation efforts, while developing countries prefer more policy space in which emulation is facilitated.

However, it is important to note that although emulation affects distribution in a way that reduces the share of richer countries in total GDP, the effect on the absolute level of GDP of these countries is less dramatic. The reason is that, as shown in Figure 12.8, there is a tendency for global GDP to increase with faster emulation for a given level of product innovation, which somewhat compensates the reduction in the share of advanced countries in global GDP. Therefore, faster innovation and emulation makes people from poorer and median countries better off without having a large negative effect on GDP per capita of people in richer countries.

Faster emulation has an additional positive effect that is stronger in richer countries. It increases the levels of diversification of countries, increasing the total number of products, which in their turn are used to fulfil a larger set of human needs.

Figure 12.14, Figure 12.15 and Figure 12.16 illustrate this, by showing how the levels of diversification in the country at the bottom, in the middle and at the top, respectively, are affected by the rates of product innovation and emulation. These figures suggest that diversification increases in all countries when there is faster product innovation combined with easier emulation. Not only the countries in the middle and the bottom would benefit, but the result is also very substantial for the most diversified country. Easier emulation can increase the level of diversification of this country over four-fold. These figures also show that even if great effort is put into product innovation, the level of diversification of poorer countries would not improve if technology transfer mechanisms are not in place to assist the emulation of production.

Figure 12.14. Minimum diversification (additional diversification as a percentage of the initial level of diversification)

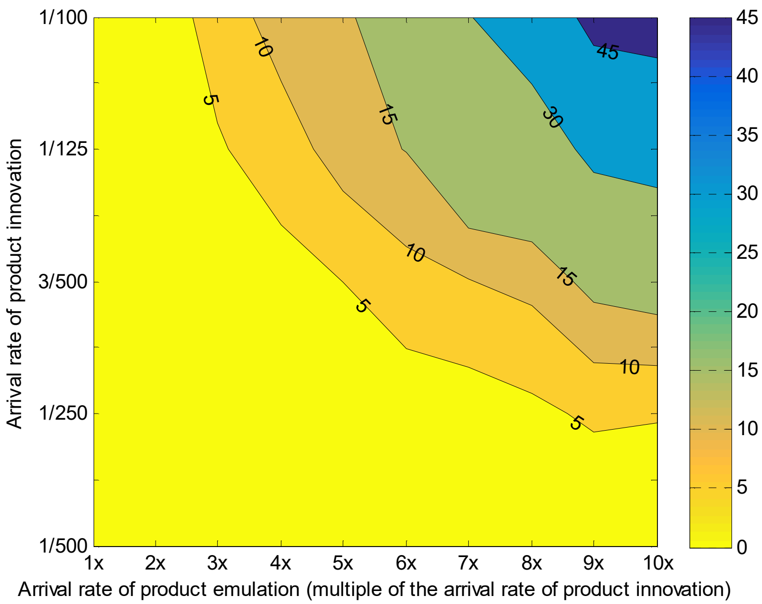


Figure 12.15. Median diversification (additional diversification as a percentage of the initial level of diversification)

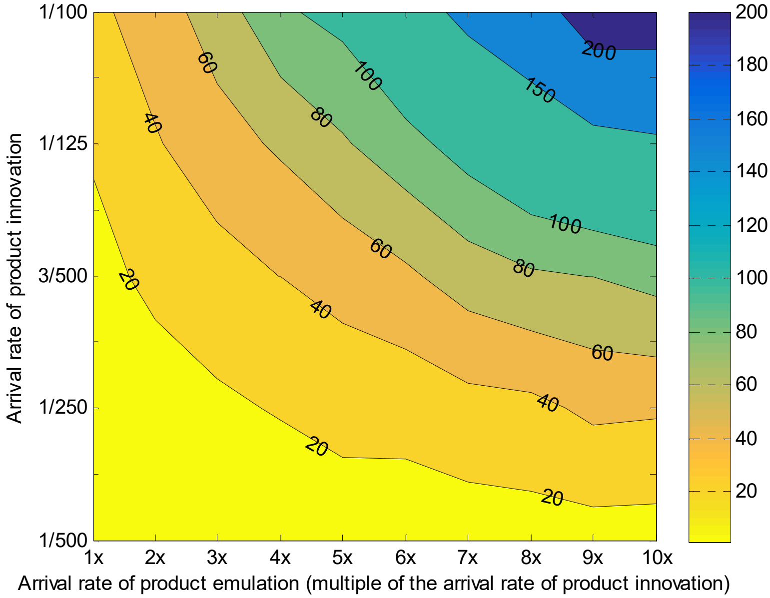
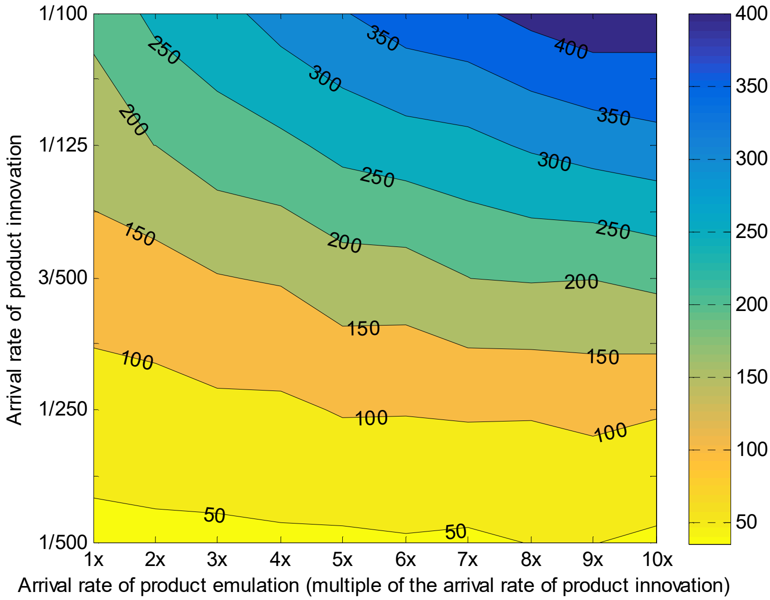


Figure 12.16. Maximum diversification (additional diversification as a percentage of the initial level of diversification)



The stronger positive effect of faster emulation on the diversification of the country at the top could be seen as counterintuitive, given that it results in shorter periods during which the original innovator benefits from Schumpeterian rents - the higher markups due to the advantage of being the only producer of the good. Given that markups are used to finance R&D, that dynamic could result in lower innovation in the countries at the top. However, this narrative misses the point that when emulation is facilitated, countries at the top also benefit by being able to emulate the production of other original innovators. When this happens, they tap into shares of new markets and expand the set of technologies available to them, to generate new product innovation and emulations. That process appears to more than compensate the shorter periods of Schumpeterian rents.

In summary, the simulations of the model suggest that faster product innovation is associated with higher global GDP, which confirms the policy recommendation for higher investments in R&D in all countries. Moreover, global GDP is higher when emulation of production is facilitated. This also leads to lower income inequality across countries and higher number of new products to satisfy human needs. These results show the need for technology transfer between countries not only to facilitate developing countries to catch up but also to increase wealth in developing and developed countries.

12.5 Catch up strategies

This section presents the analysis of possible strategies to facilitate the catch up and diversification of poorer countries. We run 100 simulations of 50 periods for each strategy, with 10 countries, 6 initial products and the same initial configuration as used in the analysis in the previous section. For each run, data was collected at the middle of the run (period=25) and at the end (period=50). The data recorded was related to the country that at period 25 was the least diversified among the 10 countries. A catch up strategy is applied only to that country that was lagging behind, from period 25 to the end of the run, to verify if at the end of the run that country had been able to diversify and catch up with the other countries.

This section presents the results of the analysis of one benchmark strategy and seven catch up strategies (Table 12.6). The benchmark strategy reflects the normal specification of the initial values of the variables and the model parameters, which is used to evaluate the other strategies. The first three alternative strategies are based on focusing in only one process of technological change: the 'focus on emulation' strategy concentrates all the R&D effort in product emulation, the 'focus on product innovation' strategy concentrates R&D on the effort to find a new product; and the 'focus on process innovation' strategy concentrates all R&D on finding a more productive way to produce an existing product.

Table 12.6. Strategies used in the analysis

Strategies	Description
Benchmark	Normal run of the model. It is used as benchmark.
Focus on product emulation	R&D concentrates in product emulation
Focus on product innovation	R&D concentrates in product innovation
Focus on process innovation	R&D concentrates in process innovation
Target more complex products	Product emulation target the products that have higher than average product complexity
Undervalued currency by 10%	The wage rate is reduced by 10% relative to the international currency
Focus on product emulation & Target more complex products	R&D concentrates in product emulation, which target products with above average product complexity
Focus on product emulation & Target more complex products & undervalued	R&D concentrates in product emulation, which target products with above average product complexity, and higher competitiveness created by a 10% undervalued wage relative to the international currency

The fourth strategy is the same used in Chapters Six to identify the products with high opportunities for diversification. For each country, the average product complexity of the production base is calculated. The strategy is to focus product emulation on the products that have complexity above the average levels of the product complexity of the country that was lagging behind. The idea is that the more complex products would offer higher opportunities for further diversification since they are associated with countries that are more diversified and have a less ubiquitous production.

A fifth strategy is to keep the currency of the country that was lagging behind undervalued (by 10%) to increase the competitiveness of its exports, which would increase the revenues and therefore the resources available to finance R&D. This strategy has the objective to illustrate the idea that an undervalued currency benefits poorer countries. That argument has been an important element in the Latin American structuralist literature and also in the context of the analysis of the Chinese growth process (e.g. Rodrik, 2008; Bresser-Pereira, 2012).

The sixth strategy is the combination of 'focus on emulation' and the strategy that targets the emulation of products with above average complexity, while the seventh strategy adds the undervaluation of currency to that mixed strategy.

Each particular strategy was applied in four different model configurations in terms of the rates of arrival of product innovation and emulation. The objective is to show that the results of the different strategies are affected when rates of product innovation increases and emulation is facilitated. The configurations used are as follows:

A. $\lambda_k^{product} = \frac{1}{100}$; $\lambda_k^{product_{emulation}} = \frac{1}{10}$: A researcher working in R&D finds a product innovation on average once every 100 periods and a product emulation once every 10 periods.

B. $\lambda_k^{product} = \frac{1}{200}$; $\lambda_k^{product_{emulation}} = \frac{1}{20}$: A researcher working in R&D finds a product innovation on average once every 200 periods and a product emulation once every 20 periods.

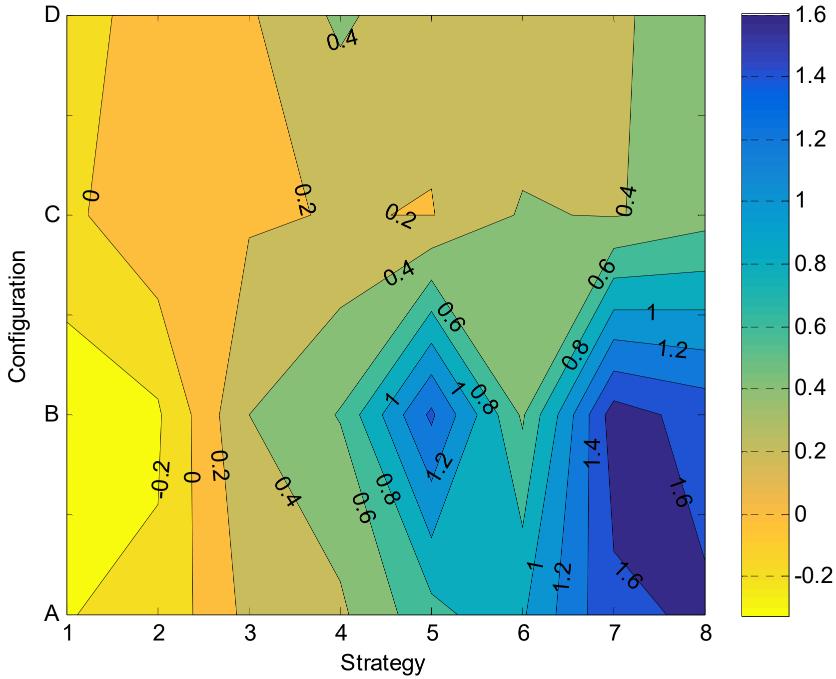
C. $\lambda_k^{product} = \frac{1}{100}$; $\lambda_k^{product_{emulation}} = \frac{1}{50}$: A researcher working in R&D finds a product innovation on average once every 100 periods and a product emulation once every 50 periods.

D. $\lambda_k^{product} = \frac{1}{200}$; $\lambda_k^{product_{emulation}} = \frac{1}{100}$: A researcher working in R&D finds a product innovation on average once every 200 periods and a product emulation once every 100 periods.

Table 12.7 in Annex XII.1 shows the average of the results of all runs of simulations for each of the configurations above. To facilitate the visualization of these results, Figure 12.17, Figure 12.18, and Figure 12.19 present a summary of the effects of each strategy to increase the diversification of the country lagging behind. In these figures the strategies are lined up along the horizontal axis and the configurations along the vertical axis. Both are ordered in a way to make the contours in the figures look smooth, to facilitate the visualization. The order selected for the strategies was to line them up from the worst to the best strategy in terms of diversification at the end of the run, when considering faster product innovation and emulation (i.e. configuration A).

The measure used in Figure 12.17 is the gain in diversification by using a particular strategy, when comparing with the performance of the other countries. The idea is that the strategies that perform better will facilitate the increase of diversification of the poorest countries faster than the increase of the diversification of the average country in the same period. Such strategies would allow the poorest country to catch up with the average country. This measure of relative gains in diversification is calculated by the difference of the normalized measure of diversification in the middle and at the end of the simulation runs (difference between the values in columns four and three in Table 12.7 in Annex XII.1). A value of zero means that at both points in time the country had the same diversification in relation to the global average; hence there was no gain in relative terms. A positive value indicates that the country became more diversified than the average, while a negative value shows the opposite.

Figure 12.17. Comparison of catch up strategies, increase in diversification as compared with the global average



Notes: Strategies:

1 - Focus on process innovation

2 - Focus on product innovation

3 - Benchmark

4 - Undervalued currency by 10%

5 - Focus on product emulation

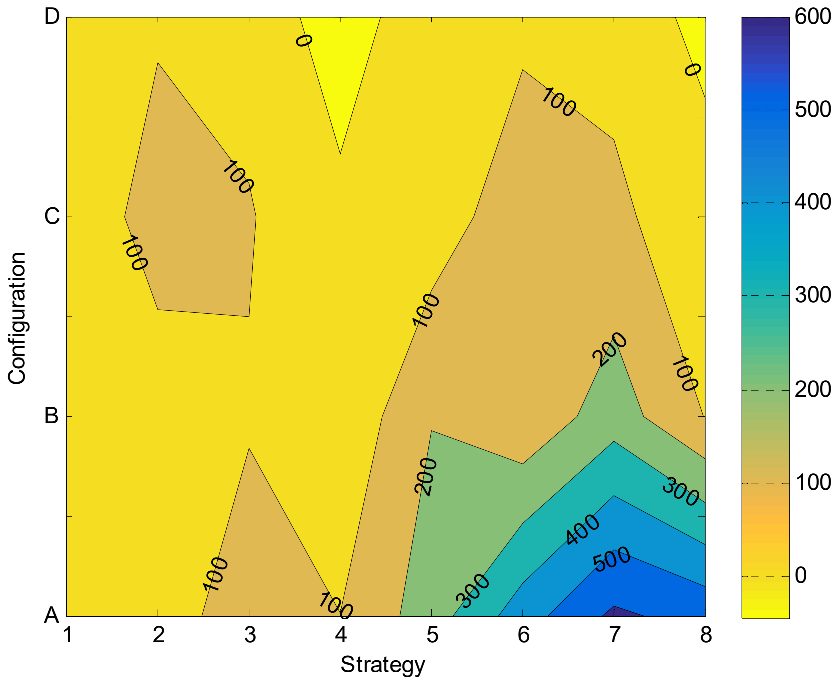
6 - Target more complex products

7 - Focus on product emulation & Target more complex products

8 - Focus on product emulation & Target more complex products & undervalued currency by 10%

Figure 12.18 and Figure 12.19 present the percentage increase in GDP and employment of the initially less diversified country as result of the adoption of the different strategies, respectively.

Figure 12.18. Comparison of catch up strategies, percentage increase in GDP



Notes: Strategies:

1 - Focus on process innovation

2 - Focus on product innovation

3 - Benchmark

4 - Undervalued currency by 10%

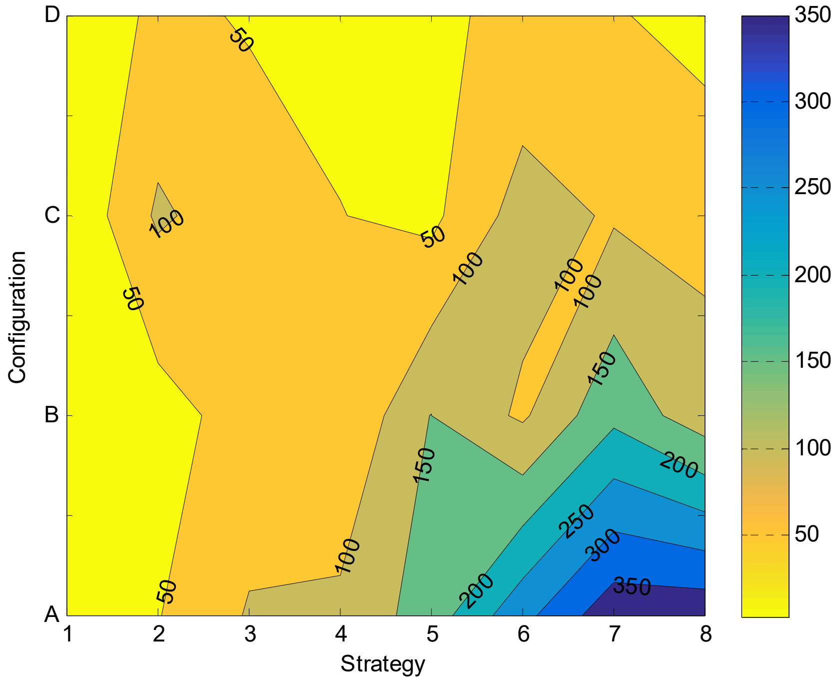
5 - Focus on product emulation

6 - Target more complex products

7 - Focus on product emulation & Target more complex products

8 - Focus on product emulation & Target more complex products & undervalued currency by 10%

Figure 12.19. Comparison of catch up strategies, percentage increase in employment



Notes: Strategies:

1 - Focus on process innovation

2 - Focus on product innovation

3 - Benchmark

4 - Undervalued currency by 10%

5 - Focus on product emulation

6 - Target more complex products

7 - Focus on product emulation & Target more complex products

8 - Focus on product emulation & Target more complex products & undervalued currency by 10%

The figures reveals that the larger variation in the results relate to configurations A and B (more frequent emulation), in contrast to the lower variation shown in the configurations C and D (less frequent emulation). The reason for this pattern is that when emulation is facilitated in the less diversified country (for example through technology transfer), the effects of all strategies that use emulation (i.e. six out of the seven strategies tested not counting the benchmark) are boosted by the increase in the frequency that a new emulation could emerge. This generates the larger variation of results.

When comparing the results related to configuration A and B, larger variation is seen in the results of configuration A (more frequent product innovation) than in those of configuration B (less frequent product innovation). The same pattern is observed when comparing the results of configuration C and D. This happens because the strategies for catch up rely on accelerating technological change in the less diversified countries, and when innovation (and for that matter emulation) happens at a slower pace, these strategies are less effective. These comparisons suggest that the differences among the strategies in terms of promoting diversification are more pronounced when there is more product innovation and emulation is facilitated.

These figures show that two of the strategies perform less than the benchmark scenario: the focus on process and product innovation. The worst strategy is to focus all R&D effort towards process innovation, ruling out all possibilities for diversification. The reason for such a low performance is because all innovation is directed to improve labour productivity of existing products, which reduces prices, output and employment. The reduction in price could lead to higher demand, but this effect is limited by the saturation of consumption and by the shift of demand to new products that are created by other countries (which carry out product innovation and emulation). Even if there is an increase in demand, it may not be all captured by the country that generated the process innovation because other countries may be able to reduce their markup to match the lower international price, keeping market shares unchanged. The result is a decrease in diversification when compared with the global average, and lower GDP and lower employment when compared with the benchmark strategy.

In the real global economy, product innovation is usually carried out in more developed countries anyway, but process innovation is a strategy that we may see associated with industries in less diversified countries, particularly in sectors that are established through foreign direct investment and in which the business model relies heavily in lowering production costs of existing production. In that case, less diversified countries could be paradoxically worse off if its firms engage preferentially in process innovation. Therefore, these results suggest that policies that promote innovation and increase in productivity in less diversified countries may be in fact counterproductive if they target process innovation instead of product emulation as the innovation strategy.

Focusing exclusively on product innovation does not help to catch up either. The economy of the country that is lagging behind is less diversified and has a smaller set of technologies available for combination and generation of new products. Most probably, these new products that could emerge from that combination are not new to the world anyway. Given that all countries in the simulation start with the same set of products and underlying technologies, the adjacent possible of the less diversified country is likely to be composed by potential new products that are only new to the production base of that country; they were already created in other more innovative countries in the past. This strategy only makes these countries persist in a fruitless quest for products that are new to the world.

The other strategies tested are either considerable better or at least as good as the benchmark (strategies 4 to 8 in the figures).

Strategy number 4 is the one that undervalues the currency by 10%. That strategy outperforms the benchmark in terms of increasing diversification, but results in similar levels of employment and lower GDP. An undervalued currency reduces the labour costs of exports and makes the less diversified country more competitive in the products that it is able to produce. Moreover, the country is able to produce and export some additional products that otherwise would have a price higher than the international price. This results in higher diversification than the benchmark scenario. However, the undervalued currency also makes import prices relatively higher than normal. People of the country would have to reduce their consumption, which would also affect the domestic production. Therefore, the gains in employment related to the additional sectors added to the economy are reduced by the lower employment due to lower consumption. The effect in output is negative given that prices of exports are reduced. It is important to note that in these simulations all countries are of the same population size. The strategy could have positive results if the market for the additional sectors of the economy are sufficient large to increase employment and output of the economy, or if imports are curbed in favour to domestic production.

The next best strategy (number 5) is to focus exclusively on product emulation. This outperforms the benchmark scenario because now no R&D efforts are lost in trying to find products that are new to the world, in an adjacent possible that is limited by the reduced set of technologies available in the country. The strategy generates more innovation, a more diversified economy, higher output and employment. Focusing on emulation also outperforms the strategy of undervalued currency in terms of GDP and employment because more new products emerge, production and exports increase, and prices of imports are not negatively affected.

More effective than focusing on product emulation is the strategy of targeting emulation on new products that have above average complexity (strategy number 6). This strategy does not enforce a concentration of R&D on emulation (product and process innovation may coexist), but requires that whenever product emulation is pursued, such emulation targets potentially new products that are in the adjacent possible and that have product complexity above the country's average. Products with above average complexity are produced and exported in relatively fewer countries, hence the competition is lower and market shares and markups are higher. That increases not only output and employment but also makes more resources available for R&D and increases the innovation and the resulting diversification.

The combination of both strategies discussed above is even more effective (Strategy number 7): it dedicates all R&D effort to emulation and targets products with above average complexity. Now the positive effects of these strategies reinforce each other. More innovation is generated and the new products created face lower competition than the average product already produced in the country. Market shares and markups are higher; more resources can be dedicated to R&D, creating a virtuous cycle.

The addition of an undervalued currency (strategy 8) results in higher gains in diversification, but a generally lower performance in terms of GDP and employment, due to the reasons already discussed above related to lower export prices and relatively higher prices of imports.

Therefore, in this simulation experiment, strategy 7 is the one that results in the highest gains in most of the configurations. The gains in following this strategy represented six- to eight-fold increases in GDP and three- to four-fold increases in employment. These results support the relevance and appropriateness of the strategy applied in the second part of this dissertation to identify potential new products with good opportunities for diversification. That strategy also focused on emulation and the targeting of products with above average product complexity.

12.6 Summary

This chapter presents an analysis of the model focusing on the structural economic dynamics and diversification that are the result of technological change. The chapter illustrates the functioning of the model and shows that it can replicate the stylized facts discussed in Chapter Four. The chapter also presents an analysis of the effects of different configurations of the model, in terms of the rate of product innovation and emulation, on global GDP, across country inequality and diversification levels. The chapter also presents an analysis of different strategies for facilitating diversification and shows that the strategy that results in higher increases in diversification is the one that combines a focus on emulation and targeted to products with above average complexity.

Annex

XII.1. Summary of results of catch up strategies

This annex shows the average of the results of the all runs of simulations for each of the configurations considered in the analysis presented in section 12.5. The values in Table 12.7 are obtained as the average over 100 simulations runs. The values in parentheses are the standard deviations. For each indicator, values are presented for the middle and the end of the simulation runs: (1) indicates that the data is related to period 25, and (2) indicates that the data is related to period 50.

The first two columns present the diversification of the lagging country in period 25 and in period 50, respectively. The third and fourth columns show the same information but with the diversification normalized in such a way that the value represents the difference between the diversification of the country and the average diversification of all 10 countries as measured by the standard deviation of that distribution of diversification values. A negative value indicates that the level of diversification of the country is below the global average, and vice-versa. The columns five and six present the value of GDP in each time considered, and columns seven and eight show the level of employment.

For example, Table 12.7 (A) shows the result for the configuration in which there is faster product innovation and emulation. In the benchmark scenario, the diversification at the end of the run of the country that was lagging in the middle of the run was on average 11.82 products, almost the double of the initial number (6) of products of the country in the start of the run. In relative terms, the normalized diversification of the country at the end of the run was -0.97; below the average of the 10 countries in the simulation (represented by the normalized value of zero). The table also shows that global GDP was \$20.93 and total employment as a percentage of the labour force was 7.97% at the end of the run.

In Table 12.7 (A), the strategy that focuses on product innovation results in few new products at the end of the run for the country that was lagging, with an average of diversification of 8.17 products. In normalized terms the result is even worse. It reduces from -1.29 at the middle of the run to -1.46 at the end, further away from the average of the 10 countries. The result is lower GDP (13.67) and employment (5.64%) than the benchmark scenario.

The strategy of focusing on process innovation is even worse, as seen in the fourth row in Table 12.7 (A). The diversification at the end of the run is basically the same as the one in the middle of the run, given that no effort was directed to product emulation or emulation. The small difference is due to a few runs of the simulation in which a new product emerged in the country during period 26 (one unit of time after the middle of the run) as a result of previous R&D efforts that were carried out before the strategy of focusing on process innovation was started. Other indicators reflect that lack of diversification. The normalized diversification is -1.31, global GDP is $8.68, and the employment is 4.02% of the labour force at the end of the run.

Information regarding the results of the other strategies are presented in the other rows of the table.

Table 12.7. Summary of results of catch up strategies

(A) $\lambda_k^{product} = \frac{1}{100}$; $\lambda_k^{product_{emulation}} = \frac{1}{10}$

Strategies	$k_{c,0}$ (number of products)		$k_{c,0}$ normalized (mean=0, sd=1)		GDP ($)		Employment (% labour force)	
	1	2	1	2	1	2	1	2
Benchmark	6.79 (0.91)	11.82 (4.48)	-1.22 (0.37)	-0.97 (0.70)	8.68 (2.62)	20.93 (16.9)	3.91 (0.97)	7.97 (4.89)
Focus on product emulation	6.74 (1.01)	14.90 (7.97)	-1.30 (0.34)	-0.57 (1.11)	8.28 (2.17)	28.94 (26.3)	3.75 (0.83)	10.20 (7.33)
Focus on product innovation	6.74 (0.84)	8.17 (1.96)	-1.29 (0.39)	-1.46 (0.34)	8.48 (2.59)	13.67 (9.64)	3.83 (0.96)	5.64 (2.78)
Focus on process innovation	6.70 (0.79)	6.84 (0.95)	-1.31 (0.33)	-1.52 (0.28)	8.58 (2.88)	8.68 (2.42)	3.86 (1.03)	4.02 (1.03)
Target more complex products	6.93 (1.03)	19.56 (6.52)	-1.27 (0.35)	-0.29 (0.68)	8.81 (3.02)	48.77 (33.3)	3.93 (1.03)	15.12 (7.60)
Undervalued currency by 10%	6.83 (1.00)	12.42 (5.82)	-1.23 (0.35)	-0.87 (0.70)	8.72 (3.26)	17.56 (20.1)	3.91 (1.19)	8.29 (5.68)
Emulation & Target more complex products	6.81 (0.89)	23.68 (6.51)	-1.28 (0.30)	0.28 (0.61)	8.65 (2.61)	62.22 (28.8)	3.88 (0.96)	18.71 (6.64)
Emulation & Target more complex & undervalued currency	6.73 (0.77)	23.22 (7.24)	-1.22 (0.35)	0.41 (0.59)	8.36 (1.95)	55.69 (35.9)	3.78 (0.74)	18.29 (8.01)

(B) $\lambda_k^{product} = \frac{1}{200}$; $\lambda_k^{product_{emulation}} = \frac{1}{20}$

Strategies	$k_{c,0}$ (number of products)		$k_{c,0}$ normalized (mean=0, sd=1)		GDP ($)		Employment (% labour force)	
	1	2	1	2	1	2	1	2
Benchmark	6.12 (0.35)	8.41 (2.08)	-1.05 (0.45)	-0.65 (0.79)	7.17 (0.99)	13.78 (0.99)	3.33 (0.40)	5.7 (2.79)
Focus on product emulation	6.13 (0.34)	11.25 (2.95)	-1.00 (0.51)	0.44 (1.15)	7.22 (0.94)	21.37 (9.99)	3.34 (0.37)	8.35 (3.28)
Focus on product innovation	6.14 (0.35)	6.73 (1.13)	-0.91 (0.54)	-1.14 (0.44)	7.57 (2.10)	10.43 (7.17)	3.48 (0.82)	4.53 (2.31)
Focus on process innovation	6.09 (0.29)	6.13 (0.34)	-1.01 (0.39)	-1.33 (0.33)	7.15 (0.77)	7.62 (0.90)	3.32 (0.31)	3.54 (0.39)
Target more complex products	6.09 (0.29)	9.14 (2.51)	-1.05 (0.38)	-0.48 (0.70)	7.22 (1.37)	15.95 (10.5)	3.34 (0.54)	6.41 (3.20)
Undervalue d currency by 10%	6.13 (0.44)	7.73 (1.94)	-0.98 (0.42)	-0.37 (0.85)	7.25 (1.31)	8.19 (8.97)	3.34 (0.50)	5.07 (2.50)
Emulation & Target more complex products	6.11 (0.31)	12.38 (3.07)	-1.00 (0.49)	0.68 (0.81)	7.19 (1.27)	25.37 (11.6)	3.33 (0.49)	9.55 (3.55)
Emulation & Target more complex & undervalued currency	6.09 (0.32)	10.45 (3.56)	-1.00 (0.46)	0.53 (0.81)	7.48 (2.28)	14.78 (13.9)	3.42 (0.82)	7.54 (3.77)

$$(\mathrm{C})\quad \lambda_k^{product} = \frac{1}{100};\ \lambda_k^{product_{emulation}} = \frac{1}{50}$$

Strategies	$k_{c,0}$ (number of products)		$k_{c,0}$ normalized (mean=0, sd=1)		GDP ($)		Employment (% labour force)	
	1	2	1	2	1	2	1	2
Benchmark	6.08 (0.31)	7.35 (2.46)	-0.80 (0.26)	-0.63 (0.49)	7.34 (2.03)	15.28 (24.4)	3.39 (0.78)	5.84 (6.19)
Focus on product emulation	6.06 (0.24)	7.02 (1.44)	-0.87 (0.28)	-0.68 (0.41)	7.24 (1.63)	10.34 (5.48)	3.36 (0.63)	4.61 (1.94)
Focus on product innovation	6.03 (0.22)	7.15 (2.02)	-0.83 (0.23)	-0.66 (0.42)	6.92 (0.81)	17.61 (23.1)	3.24 (0.37)	6.71 (6.76)
Focus on process innovation	6.07 (0.26)	6.10 (0.30)	-0.81 (0.26)	-0.86 (0.22)	7.26 (1.81)	7.32 (1.38)	3.36 (0.70)	3.46 (0.64)
Target more complex products	6.05 (0.22)	8.44 (2.35)	-0.82 (0.27)	-0.39 (0.47)	7.12 (1.39)	18.97 (16.3)	3.31 (0.56)	7.34 (4.80)
Undervalue d currency by 10%	6.05 (0.22)	7.07 (1.70)	-0.89 (0.33)	-0.68 (0.40)	7.18 (1.67)	8.60 (14.1)	3.32 (0.63)	5.02 (3.86)
Emulation & Target more complex products	6.09 (0.29)	8.71 (2.76)	-0.82 (0.27)	-0.44 (0.49)	7.39 (1.94)	16.20 (12.4)	3.40 (0.71)	6.60 (4.03)
Emulation & Target more complex & undervalued currency	6.06 (0.24)	8.65 (2.67)	-0.81 (0.23)	-0.30 (0.61)	7.40 (2.01)	10.67 (12.9)	3.43 (0.75)	6.37 (3.96)

(D) $\lambda_k^{product} = \frac{1}{200}$; $\lambda_k^{product_{emulation}} = \frac{1}{100}$

Strategies	$k_{c,0}$ (number of products)		$k_{c,0}$ normalized (mean=0, sd=1)		GDP ($)		Employment (% labour force)	
	1	2	1	2	1	2	1	2
Benchmark	6.02 (0.14)	6.70 (1.20)	-0.61 (0.32)	-0.44 (0.63)	7.04 (1.16)	11.16 (8.35)	3.26 (0.44)	4.75 (2.70)
Focus on product emulation	6.01 (0.10)	6.87 (1.10)	-0.68 (0.25)	-0.41 (0.51)	6.96 (0.67)	10.51 (4.52)	3.23 (0.28)	4.62 (1.69)
Focus on product innovation	6.03 (0.17)	6.71 (1.13)	-0.68 (0.32)	-0.53 (0.55)	7.24 (1.79)	13.31 (12.4)	3.34 (0.66)	5.41 (3.45)
Focus on process innovation	6.03 (0.17)	6.04 (0.20)	-0.60 (0.35)	-0.76 (0.27)	7.06 (1.12)	7.39 (1.02)	3.27 (0.43)	3.43 (0.42)
Target more complex products	6.02 (0.14)	6.93 (1.24)	-0.63 (0.30)	-0.39 (0.57)	7.10 (1.42)	12.48 (9.54)	3.28 (0.54)	5.22 (3.06)
Undervalued currency by 10%	6.01 (0.10)	6.45 (0.82)	-0.61 (0.22)	-0.18 (0.62)	6.95 (1.04)	3.91 (6.84)	3.23 (0.41)	4.35 (2.13)
Emulation & Target more complex products	6.01 (0.10)	7.10 (1.34)	-0.63 (0.23)	-0.25 (0.69)	6.92 (1.04)	11.68 (6.07)	3.22 (0.42)	5.00 (2.13)
Emulation & Target more complex & undervalued currency	6.00 (0.00)	6.58 (0.96)	-0.67 (0.26)	-0.21 (0.62)	6.84 (0.36)	4.73 (5.95)	3.18 (0.16)	4.13 (1.50)

13

Conclusions

13.1 Conclusions

This dissertation presented a study of the interrelations between economic diversification, structural change and economic growth. The study was conducted in two stages. First, empirical regularities that highlight those interrelations were compiled and discussed. Then, in a second stage, an economic model was proposed to explain those regularities and describe the channels through which diversification affects and is affected by structural economic dynamics.

The model proposed is a multi-country multi-sector model of structural economic dynamics with diversification. It assumes endogenous changes in consumption patterns and technological progress. Economic diversification is the result of product innovation and emulation. Each product requires a specific set of technologies and new products are created by the combination of existing technologies in the economy. Process innovation and emulation increase productivity in the sectors in which they are applied by changing the set of technologies used in the production, which affects future product innovation and emulation, and therefore affects the diversification process.

The effect of diversification on structural economic dynamics is not straightforward. Diversification changes the structure of the economy by adding new economic sectors, which provides employment and generates income, but also changes the consumption patterns of other products through complementarity and substitution effects. If the new sector produces a good that is new to the world and that fulfils a need that was not met by existing products, then diversification adds jobs and income. If the new sector produces a good that is already produced in the world, then diversification may add jobs and income to the economy but only by shifting jobs from other countries that compete in the same sector in the global market. Competition drives prices down, which increases real incomes and expenditure, affecting jobs and incomes.

Although the path followed by a particular economy is difficult to predict, the model shows that there are specific patterns of the relationship between economic diversification and total output, employment, consumption per capita, and labour productivity that emerge from the international relations of countries.

The objective of the model was to identify strategies that facilitate the emergence of productive activities in poorer economies and promote economic catch up. A critical element of any such strategy would involve the identification of potential new products for diversification that are more likely to emerge given the current production base and the domestic and global demand for potential new products.

13.2 Contributions to existing literature

This dissertation contributes to the streams of literature on economic complexity, structural economic dynamics, economic development and technological change and innovation.

From a theoretical perspective, the dissertation's main contribution is the multi-country multi-sectoral model proposed in Chapters Nine and Ten. It considers trade and diversification within a framework of structural economic dynamics and is able to replicate empirical regularities related to diversification found in the literature on economic complexity. Therefore, the model links those two streams of literature and can serve as a tool to further explore how the combination of both streams could advance the study of the relationship between diversification and economic development.

The model directly contributes to the stream of literature based on Pasinetti's (1981, 1993) models by formalizing his framework of international trade. Other models have proposed the extension of Pasinetti's models to trade (e.g. Araujo and Teixeira, 2004; Araujo, 2013; Araujo and Trigg, 2015). However, as opposite to the model proposed in this dissertation, they result in full specialization of exports based on prices and are not able to replicate empirical patterns of diversification.

The model also contributes to the stream of the literature on structural dynamics that adopts the Keynes-Kalecki principle of effective demand to determine the output of each sector, as opposed to models that assume that output is determined by full employment of labour and capital based on Say's law and Walras's law. In particular, it adopts and presents a formalization of Clower's (1965) "dual-decision hypothesis", which assumes that households decide their expenditure in the next period based on their income of the current period, and production sectors decide on the level of employment required based on the demand.

The model also contributes to the study of the relationship between innovation and demand (Gualerzi, 2012, Saviotti and Pyka, 2017) by connecting technologies to products, products to services, and services to human needs.

In Chapter Eight, this dissertation also adds to the literature on structural economic dynamics by proposing a formalization of diversification within Pasinetti's (1993) model. This allows for the study of the effects of the change in the number of sectors in the structure of an economy in autarky and the impact on macroeconomic variables of employment and output. The model links this stream of literature to the stream on economic complexity by adopting the usual assumptions of the latter in relation to the network of countries, products and capabilities (e.g. Hausmann and Hidalgo, 2009). The model allows for the study of the different effects of product and process innovation on technological unemployment.

The dissertation also makes several methodological and empirical contributions to the literature. The dissertation adds, in Chapter Three, to the empirical literature that classifies products based on unit value (e.g. Fontagné et al., 2008; Mulder, Paillacar and Zignago, 2009). Similar to Mandel (2010), the methodology proposed in this book also takes into account the fact that the distribution of unit value is fat-tailed, and as in Esposito and Vicarelli (2011), that the outliers in the distribution of unit value are considered as different products. The contribution of this dissertation is to use this information to develop a classification of products differentiated by unit values. The resulting classification is much more disaggregated than the classifications usually used in the empirical literature on economic complexity, which allows for the construction of more detailed product space maps.

The dissertation also contributes to the literature related to the development of measures of diversification (e.g. Felipe et al., 2010, 2012; Anand et al., 2012; Tacchella et al., 2012) based on the method of reflections (Hausmann and Hidalgo, 2009). The productive capacity index presented in Chapter Three was conceived to use all iterations of that method. Combined with more disaggregated datasets produced using the methodology to classify products based on unit values, it allows for the analysis of product capacity of poorer economies such as the least developed countries.

Chapter Four presents contributions to the empirical literature on economic complexity through the discussion of existing and new stylized facts related to diversification, productive capacities and distribution of complexity of the exports of countries. It adds to the empirical studies of diversification within product categories of trade statistics (e.g. Schott, 2003; Hummels and Klenow, 2005; Fontagné et al., 2008) by showing that there is a positive but non-linear relationship between the diversification within and across product categories. This highlights the importance of taking within product category diversification and the need for disaggregated datasets into consideration in the study of economic diversification.

Using the disaggregated datasets developed for the analysis, the dissertation shows a positive association between the export diversification of a country and its total GDP, which is also discussed in Lei and Zhang (2014) but is not highlighted in the empirical literature. This work also detects the negative association between diversification and the average ubiquity of exports discussed in Hausmann and Hidalgo (2009 and 2011), which is also observed in the matrix of exporting countries and exported products.

The dissertation contributes to the research on the use of the methods developed in the economic complexity literature to estimate the economic complexity of countries and product complexity of exports to find new stylized facts (e.g. Freitas and Salvado, 2008; Abdon and Felipe, 2011; Anand et al., 2012;). It shows that the distribution of productive capacities of 220 economies in 2013 is fat tailed: some developed economies have levels of productive capacity that are many standard deviations above the mean, while the remaining economies have levels of productive capacity that are below the global average. The study of the evolution of the productive capacities shows that countries that are less diversified lagged behind from the mid-1980s to the mid-2000s. Countries in which the diversification gap in relation to the more diversified countries was narrower tended to catch up, but countries that were less diversified tended to fall further behind, which resembles findings of Verspagen (1993) in a context in which diversification does not play a role.

The dissertation also contributes to the line of research related to verifying the effect of economic complexity of a country on its level of wealth (e.g Hidalgo and Hausmann, 2009; Anand et al., 2012). It shows that the average complexity of production of 174 economies for which 2010 data is available explains 91% of the variation of their GDP, when controlling for the size of the population and the age dependency ratio. Similarly, a strong association is found between GDP and the maximum complexity of country’s production. This suggests that development is related to the expansion of exports towards products of higher complexity.

Other contributions are related to the study of the properties and structure of the network that connects countries to products that they export and of the product space. This dissertation shows that, for a given country, the products close to each other in product space are also close in terms of level of product complexity (Chapter Four). Therefore, the idea of developing countries leapfrogging by diversifying to a sector that has product complexity much higher than the existing production base seems to be unlikely. This information can be used in the identification of potential new products using the product space map.

Another contribution to the study of product space and diversification is the result in Chapter Five showing that for low levels of diversification the number of potential new products increases sharply with the number of existing products exported. For higher levels of diversification, the number of potential new products decreases with the increase in diversification. This result suggests that countries with less diversified exports have many opportunities to diversify by emulating developed countries; while more diversified countries should gradually combine emulation with product innovation.

In Chapter Five, the dissertation also presents contributions to the stream of literature on industrial policy and developmental state (in particular, to the study of possible binding constraints that prevents firms to innovate to socially desirable levels). Some of the constraints highlighted in the literature include discovery costs, limited access to credit, weak institutions, and barriers to competition and entry of firms in new sectors (e.g. Fisman, 2001; Djankov at al., 2002; Svensson, 2003; Banerjee and Munshi, 2004; Aghion et al. 2005; Hausmann, Hwang and Rodrik, 2007). Following Rodrik (2004) by considering that the objective of industrial policy is to diversify the economy and generate new areas of comparative advantage, this dissertation highlights an additional binding constraint on catching up and shows that industrial policy may also be justified when demand factors are very likely to attract investment to new economic sectors that have product complexity below the country's average. This hinders the prospects of the economy to build productive capacities. The dissertation contributes with a methodology and framework to analyse the likelihood of a country to increase its productive capacities through a laissez-faire approach or selective policies. The results of the analysis show that the majority of poorer economies have to use selective industrial policies to strategically diversify by nudging the private sector and creating incentives towards economic activities with higher complexity.

In Chapter Six, the dissertation contributes to the stream of literature that study methods to identify sectors for economic diversification (e.g. Freitas and Salvado, 2008; Lin and Monga, 2010; Anand et al., 2012; Neves, 2012; Freitas et al., 2013). Similar to Hausmann and Hidalgo (2013), it uses the product space and demand information about potential new products in the analyses of new sectors for diversification. The dissertation also contributes to this literature by identifying sectors for diversification in 36 economies and countries with special needs in the Asia-Pacific region.

13.3 Limitations and suggestions for future research

This dissertation presents new stylized facts within the stream of literature on economic complexity and proposes an initial attempt to explain empirical regularities that result from this literature through a model within the theoretical framework of structural economic dynamics and economics of technological change and innovation. Several areas of work could be explored to address its limitations and further extend the model and the analysis. In this section, I discuss some of these areas and, risking being extremely simplistic but in the spirit of adding some thoughts on how the work could be extended, propose some ways to implement changes in the model and methods presented in this dissertation.

In relation to the empirical analysis presented in this dissertation, similar to large part of the studies in that stream of literature, that analysis is based on trade data to estimate productive capacities of countries and complexity of products. An extension of that work could explore the use of data on services in the analysis and verify how the results compare with the initial analysis as well as with the work in the literature that uses services data (e.g. Anand et al., 2012).

This dissertation presents a framework for identifying potential new products for diversification considering the productive capacities of the economy and the incentives created by foreign and domestic demand. It further shows how other elements could also guide the identification of potential new products, as in the case of considering the existing agricultural production in the identification of potential new agri-business. This analysis could be extended to consider other relevant factors in the identification of potential new sectors, such as the opportunities for job creation, balance of payments considerations, other productive linkages with the domestic economy, the potential pollution impact, the requirements in terms of use of land and water, etc. A way to implement that extension is to apply first the steps described in Chapters 5 and 6 and, based on the resulting list of potential new products, start to apply other criteria for selection of new sectors based on economic, social and political considerations. Once the initial list of potential new products is compiled, any subset of that list will consist of products that have higher likelihood to be successfully emulated and that contribute to increase the productive capacities of the economy.

In relation to the model, it adopts many simplifications to focus the analysis on the relationship between endogenous diversification and the dynamics of change of the structure of trading economies. This naturally limits the use of the model to the analysis of scenarios in which those simplifications do not affect the most relevant elements of study. Future work could be carried out to extend the model by relaxing the following assumptions.

The model assumes that all goods are final, and, therefore, it does not consider intermediate goods. As a result, the model does not allow the study of global value chains and the distribution of tasks in production across countries based on their comparative advantage. Possible extensions of the model to address this limitation could involve the use of input-output modelling. Formalization similar to that used in the primal linear programming of the World Trade Model by Duchin (2005) could be used to revise the short-term equations of the model and add input-output tables to it. I have implemented some elements of that extension in earlier working versions of the model presented in this dissertation. Further work in this direction is an immediate area of future research.

Another possible way to introduce intermediate goods in the analysis is to assume that products are characterized by the combination of existing technologies and existing products, as opposed to the combination of technologies only as in the present model. With that change, countries would need to produce or import the products that are inputs to their production. The decision of how much of different products each sector would demand could be made endogenous in a similar way as the decisions of household consumption, as part of a two decision process (Clower, 1965). An additional mechanism that may have to be considered is the use of stocks to keep track of surpluses in the production sectors.

Another simplification of the model is the assumption that labour is the only factor of production. It does not consider the existence of capital or resources such as energy and water. The addition of resource factors could extend the use of the model to study the effects of product and process innovation and emulation, as well as diversification, on sustainable development. Duchin's (2005) World Trade Model considers multiple factors and a similar formalization could be used to extend the model proposed in this dissertation.

The model also does not consider trade costs, which addition would allow the study of the effects of these costs on diversification. I have implemented trade costs in previous working versions of the model and initial results presented in ESCAP (2014) show that increases in these costs reduce the level of diversification of affected countries. Further work implementing and studying the effects of adding trade costs to the model presented in this dissertation could be another immediate area of future research. In principle, the implementation would require a single change in equation X.1 to include exogenous trade costs. Another possible extension is to add specific transport technologies in the model, which could benefit from process innovation as well as being used in combination with other technologies to create new goods through product innovation. In that way, technological change in the transport sector and the resulting changes in trade costs would be endogenous to the model. Trade costs could be implemented exogenously in terms of taxes and subsidies, which could allow the study of the effect of those in facilitating economic diversification.

Another possible extension of the model is to include national governments that collect taxes and provide public goods. That extension would allow the study of the effects of taxation and provision of infrastructure that could serve as complementary technology in the production. The implementation of such mechanism could, for example, explore the different effects of taxing household income or consumption, or the revenues of the productive sector. Public infrastructure could be included as a public good produced by the national government, and that could be combined with other technologies to produce consumer goods.

A future extension of the model could consider the need of basic specific knowledge for workers to learn a new technology. That would lead to the assumption of a new sector to provide education, which would require workers (teachers) that could be remunerated by the wage rate. The sector could be financed by taxes and provided by a national government. That would allow the study of the effect of education on diversification.

The model assumes that workers can move effortless and immediately between sectors. Another possible extension could relax this assumption and consider that productive sectors require some time to expand employment. This could be implemented by adding a constraint in the linear programming equations that characterize the model in the short-run so that the number of workers employed in each sector would not increase by more than a given percentage in relation to the previous period. Such a mechanism would need to be combined with the relaxation of the assumption related to the equality of market shares for sectors in different countries selling a product by the same international price, because sectors would not be able to expand immediately to attend the demand. The result is that, even with a single international price, sectors in different countries that produce and export the same product may end up with different market shares. The impact on diversification would be channelled through the effect of different market shares on the sum of markup prices and, consequently, on the amount of resources available for R&D.

Another limitation of the model is that it does not consider the existence of non-tradable services, which amount for around 60% of GDP of many economies. One way to extend the model to include services is to create a non-tradable sector in each economy. The existence of such a sector would prevent the situation in which the model results in a country with the entire population unemployed due to prices higher than the international prices in all its production sectors.

The model could also consider the introduction of new technologies through science following Arthur (2009) in which new technologies are created by harnessing physical phenomena (e.g. radio, laser, fiber optics). The implementation of this extension to the model could be carried out by adding a science sector to each country's economy. The workers in that sector could be remunerated by the wage rate as in the other sectors. The sector could be financed by a national government through taxes on household income or consumption, or revenues of the productive sector. The scientific process for discovering a new technology could follow a Poisson process similar to the innovation processes in the R&D

sector. New technologies that emerge in the science sector would be added to the set of technologies available in the national economy to the R&D sector for the creation of new products and processes. An emulation process for science could be also implemented to replicate the diffusion of scientific results across countries. I have implemented such science sector in previous working versions of the model presented in this dissertation and it allows for the study of the effects of investment in science on the levels of diversification of countries. Further work in that direction could create a more descriptive model of national systems of innovation and structural economic dynamics with trade and diversification.

The model deals with inequality across countries but it does not consider inequality within countries, e.g. among workers of different sectors. An extension of the model could address this aspect by, for example, considering that a share of the markup of each sector is redistributed among the workers of that sector. Since different sectors have different markups, the result would be that workers in sectors with higher markup would have higher wages than workers in sectors with lower markups. Such model could explore the effects of trade and technological change on inequality, and would be able to disaggregate those effects to study their contributions and interplay.

A simplification in the simulations of the model presented in this dissertation is that they consider that populations are of the same size in all countries. This assumption can easily be relaxed given that the size of the population is already considered in most equations of the model. However, a revision in the model would be required in relation to the determination of the changes in consumption patterns. To give an example, in the current model, in a scenario of two countries trading (e.g. a populous country A and a less populous country B), the trade balance in country A would trigger a change in consumption per capita in that country somewhat equivalent, but in different direction, to the change in country B. That makes the consumption in the more populous country to be more sensitive in the aggregate to the balance of trade than the aggregate consumption in the less populous country. A possible way to address that would be to make the change in consumption pattern to be inversely proportional to the size of the population. That revision in the model would allow its application in the study of how population size affects diversification and structural economic dynamics, which is of particular interest of less populous countries such as the small Islands developing States.

Another possible extension of the model in relation to population is to consider population growth. This can be implemented, for example, by adding one equation in the model in which the size of the population of a country changes over time based on an exponential function and an exogenous growth rate similar to the formalization adopted in Pasinetti (1993). The model could be further extended to adopt rates of population growth as a function of the level of income per capita, to capture the tendency of smaller families as economies get richer. Another possible way to endogenize the rate of growth would be to assume that the economic life of the share of the unemployed working population above a certain threshold, say any percentage above 50% of the working population, is characterized by subsistence practices in rural areas, and have a rate of population growth higher than the rate applied for the rest of the population. The model could also assign some sectors in each country as agricultural-based productive sectors, which would also be considered rural-based and in which the working population would have the same high level of population growth as in the population in subsistence. Simulation runs could start considering a large share of that population in subsistence and in agriculture. The diversification of the economy and creation of jobs in new productive sectors would reduce the share of unemployed population in subsistence, which would reduce the share of population with high rate of population growth. Similarly, the increase in productivity in the agricultural-based productive sectors would reduce employment in those sectors and consequently the share of the population that experiences the higher rate of population growth. Such extension of the model could also be used to explore the effects of diversification on structural transformation in terms of the move from agriculture to industry and services.

Another possible extension of the model related to the treatment of population would be to consider the possibility of movement of people across countries (e.g. migration). This could be a very fertile area of research by combining structural economic dynamics, trade and diversification with migration studies. A possible and simplistic way to implement this would be to assume that the share of population of a country willing to emigrate is proportional to the share of unemployed population, and assign quotas for immigration for each country, which would indicate how many immigrants they would receive at each unit of time. The model could assume match making mechanism that moves people across countries based on those parameters. Such model would allow the study of the effect of immigration policies in countries at different stages of development on the possibilities for economic diversification.

Similar to the suggestion above, I believe it would be extremely timely and relevant to pursuit a line of research that explore ways to analyse and extend the results of this dissertation in light of sustainable development. I hope this dissertation could represent a stepping stone in this direction.

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Summary

The objective of this study is to verify the relation between economic diversification, structural change and economic growth. There are two main motivations for this research. The first is the relevance of economic diversification for poorer countries. The second motivation is to link the empirical literature on economic complexity, which has uncovered several stylized facts about the pattern of diversification, with the literatures on growth, trade, technology change and structural transformation. A key research question is: Which new economic activities are more likely to emerge given the level of diversification of the current production base and the domestic and global demand for potential new products?

The work is structured in three parts. The first part is comprised of Chapters Two to Four and focuses on empirical regularities related to diversification.

Chapter Two presents a review of the empirical literature on economic complexity. A key message of this research is that what a country exports matters for its current and future levels of wealth. This literature mainly uses methods of network analysis. The underlying assumptions are that: products require a specific set of nontradable capabilities to be produced, countries have a set of those capabilities, and they produce the goods for which they have the required capabilities. Important methods proposed are related to measurement of complexity of countries and products, as well as to the concept of a product space. However, methods developed in that literature have not been applied to the analysis of potential new exports of poorer countries.

Chapter Three presents the method of reflections proposed by Hidalgo and Hausmann, which is extensively used in the literature. The chapter presents the measures of productive capacity and product complexity used in my research. Similar to other studies in the literature, they are derived from measures of

diversification and ubiquity that result from the method of reflections. Ubiquity of a product in this literature means how many countries export that product. To allow for the use of the method for the analysis of poorer economies, I propose to use the method of reflections considering all trade flows and in a more disaggregated dataset. To build this dataset, I follow other studies in the literature and consider the distribution of unit values of different bilateral trade flows to classify products. The novelty of the method is that it takes the fact that the distribution of unit values is fat-tailed into consideration, which results in finer detail in the product classification.

Chapter Four presents stylized facts of the literature on economic complexity using the datasets and the methodologies presented in Chapter Three. The chapter highlights the following stylized facts: a) the level of diversification is positively associated with the total GDP of a country; and b) it is negatively associated with the average ubiquity of exports; c) countries that are less diversified have lagged further behind over the years, while countries that were able to catch up had diversification levels closer to that of more developed countries; c) the average complexity of exports is a good predictor of GDP, and d) development is associated with the expansion of exports towards products of higher complexity. Another pattern highlighted in the chapter is that products that are close in the product space are also close in terms of product complexity. These stylized facts guide the analysis in the second and third parts of the work.

The second part of the dissertation is comprised of Chapters Five and Six and focuses on a methodology to identify potential new products for diversification.

Chapter Five discusses the active role of governments in the diversification process through industrial policy. I use empirical methods to identify the potential new products for diversification given the current production base of a country and the demand incentives created by export and import replacement opportunities. The result suggests that poorer countries have many opportunities to diversify by emulating developed countries. But the effect of demand incentives is to reduce the number of potential new products for diversification with above average complexity. Therefore, the majority of poorer countries would not be able to rely on the market incentives to drive the economy towards increasing productive capacities. This research contributes to industrial policy literature by exploring the use of empirical data and the role of demand to verify the need for selective policies.

Chapter Six applies the methodology to identify potential products for diversification to the group of 36 least developed, landlocked developing and small island developing countries in the Asia-Pacific region. It follows several studies that have used the product space to analyse the possibilities for export diversification of countries. The novelty is the consideration of the demand for possible new products. The objective is to identify the sectors that would maximize the opportunities for countries to build their productive capacities through the emulation of the production of more developed countries. For each of the 36 countries, the chapter presents the top five sectors with higher percentage of potential new products, and the potential new sectors with higher export and import replacement opportunities. The chapter also presents a list of export opportunities in agro-based processing activities that have links with existing agricultural production to create demand and encourage investment in agriculture in Asia-Pacific LDCs. The application of this methodology could assist in the design of industrial and investment policies.

The third part of the dissertation is comprised of Chapters Seven to Twelve and proposes a model of structural economic dynamics with economic diversification.

Chapter Seven presents a literature review of the models that have been proposed to explain the stylized facts discussed in Chapter Four. The chapter identifies two strategies in the literature. The first is to propose theoretical frameworks based on the network connecting countries, capabilities and products. The second uses more traditional economic frameworks, adds assumptions related to capabilities and complexity, and use the empirical data to test predictions of the model. I present two models to illustrate these strategies. These approaches could produce possible explanations for the stylized facts, but they are not particularly grounded in economic theory and therefore there is scope for investigations on the relation between diversification and structural economic dynamics.

Chapter Eight adds diversification to the model of structural economic dynamics of a country in autarky, proposed by Pasinetti (1993). The discussion focuses on technological unemployment. A novelty is that production sectors are characterised by the technologies used in the production. We assume that there are three ways a new sector could emerge: through division of labour, variations in labour-embodied technologies and combination of existing technologies. Out of these three only the combination of technologies results in diversification. The result of the analysis suggests that innovation without diversification has the effect of increasing purchasing power in the short term but results in technological unemployment and a consequent decrease in per capita income in the long term. On the other hand, the emergence of novelty with diversification results in inflation in the short term, but it is a counterbalance to technological unemployment.

Chapters Nine and Ten present the main model proposed in this thesis, which combines diversification, structural change and international trade. Chapter Nine describes in broad terms the key elements of the model. Following this overview, Chapter Ten presents a detailed description of model. In the short run, the model determines prices of products and quantities produced by each sector. Many basic elements of the model in the short-term follow Pasinetti's (1993) framework and the World Trade Model proposed by Duchin (2005). Regarding the dynamics of the model, we consider that structural dynamics is the result of changes in consumption patterns and technological progress, which are endogenous to the model. The model follows Andersen (2001) in the dynamics of technological change, Pasinetti (1993), Clower (1965) and Gualerzi (2012) in the dynamics of changes of consumption patterns, and Kauffman (2008) in the way to formalize path dependency in the process of diversification. Economic diversification comes about through product innovation or emulation, and it is considered to be path dependent. New products are created by the combination of existing labour-embodied technologies.

Chapter Eleven describes the pattern of trade and export specialization given a fixed set of goods. The chapter shows that the model replicates the fact that countries with different levels of average productivity will have different levels of consumption in the long-run, with the country with the higher labour productivity having the highest consumption. The chapter highlights that this result is in fact a function of the differences in the range of productivity within each economy, not a function of the average level of productivity.

Chapter Twelve focuses the analysis on technological progress. The chapter shows that the model is able to replicate the stylized facts discussed in the first part of the thesis. It presents the result of analysis of the interrelationship between product innovation, process innovation and emulation and shows how different rates of technological change affect global levels of output and inequality across countries. The chapter also presents an analysis of different strategies for facilitating diversification. It shows that the strategy that results in higher increases in diversification is the one that combines a focus on emulation, targeted products with above average complexity and supported by a competitive currency. This is the strategy aligned with the discussions in the second part of the work.

The final chapter presents conclusions and discusses possible directions for further research.

Addendum on valorization to the dissertation

This addendum presents how this research creates value by making knowledge suitable and available for social and economic use. It focuses on the main implications, the relevance of the research, and the various forms in which its results have been disseminated.

The main implication of the results of this dissertation is the fundamental notion that economic development happens through the diversification of economies towards more complex products. Development policies should be designed and implemented aiming at facilitating that process. The implementation of such strategic diversification involves the selective promotion of new economic activities over traditional ones through the use of targeted industrial, infrastructure, trade, investment and private sector development policies. A key element in the implementation of these policies is the identification of the appropriate sectors and products to target based on the productive structure of the country and changes in global demand. This dissertation presents methods and strategies that developing countries could use to identify these sectors. This information is a public good that can be used by these stakeholders to facilitate economic diversification. Public policies and private investment can be directed to support the emergence of those economic activities that have a higher potential of success.

The results of this dissertation are also relevant to better target action for the implementation of internationally agreed development goals. For example, the outcome document of the United Nations summit for the adoption of the post-2015 development agenda held in September 2015 (Transforming our world: the 2030 Agenda for Sustainable Development),[69] which agreed on the Sustainable Development Goals (SDGs), explicitly recognizes the importance of economic diversification in two SDG targets. The first is within Goal 8, which focuses on promoting economic growth that is at the same time sustained, inclusive and sustainable, and that is able to generate full and productive employment and decent work for all. Target 8.2 is to "[a]chieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors."

This dissertation supports and provides explanations to the assumptions of the formulation of that target related to the positive association between economic productivity and diversification, and the links between diversification, technological upgrading and innovation. Its implication for meeting the target is that poorer economies have a higher likelihood of benefiting from a particular type of innovation, namely the emulation of the production that already exist in more diversified countries. The dissertation also shows that, in fact, the focus should be on the diversification towards higher-value added sectors. In general, these are sectors that exist in more diversified economies and that have a higher markup because they face relatively lower competition. These characteristics are associated with higher levels of product complexity, and this dissertation shows that a better strategy for diversification is the focus on emulation of sectors with above country's average product complexity.

The SDG target also indicates the need to focus on sectors that, in addition of having a higher-value added, are also labour-intensive. Given that the model presented in this dissertation considers only labour as a factor of production, it does not study the relation between capital and labour of the new sectors during the process of diversification. However, it shows that diversification is positively associated to employment. Therefore, given that the ultimate objective of the Goal 8 is sustainable economic growth with full employment, the diversification strategy proposed in this dissertation would contribute to the achievement of this goal.

The second SDG target related to diversification is under goal 9, which is related to building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation. Target 9.b is to "[s]upport domestic

[69] A/RES/70/1 - Transforming our world: the 2030 Agenda for Sustainable Development.

technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities." This dissertation supports the view that industrial diversification would lead to technological development and that governments have a role to play in ensuring the appropriate policy environment to facilitate such strategic diversification.

The results of this dissertation have been disseminated through several channels to policymakers, government officials, representatives of international organizations, practitioners and academics.

For example, a paper published in the Seoul Journal of Economics applies the same methodology used in chapters 5 and 6 of this dissertation in the analysis of the strategies for structural transformation in South Asian countries (Freire, 2013b). An empirical paper that I co-authored and published in the Journal of Southeast Asian Economies uses the same methodology to identify specific sectors with higher opportunities for diversification in Myanmar (Ayres and Freire, 2014). I have also published a chapter in an academic book on quality innovation presenting the results of that analysis applied to least developed countries (Freire, 2014).

I have had the opportunity to contribute with the results of the empirical part of this research to chapters of the Economic and Social Survey of Asia and the Pacific, a flagship publication of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP, 2011 and 2012). These contributions were related to the stylized facts of diversification, productive capacities of countries, complexity of production, and product space maps. The analysis presented in chapter 6 was also presented in an ESCAP publication regarding the challenges and prospects for economic diversification in Asian landlocked developing countries (ESCAP, 2104), which was ESCAP's analytical contribution to the Second United Nations Conference on Landlocked Developing Countries, held in Vienna in November 2014. The analysis was also presented in a chapter of the first issue of ESCAP's Asia-Pacific Countries with Special Needs Development Report (ESCAP, 2015), which focused on how to build productive capacities through economic diversification to overcome structural challenges of least developed countries, landlocked developing countries and small island developing states.

The empirical analysis presented in chapter 4, on the evolution of the distribution of product complexity of exports, was also presented in a publication of the United Nations Human Settlements Programme (UN-HABITAT) on the role of cities in productive transformation. The analysis presented focused on Dili, Timor-Leste and Ho Chi Minh City, Viet Nam (Freire, Spaizmann and Balac, 2015).

The research was also disseminated in a series of working papers of ESCAP's Macroeconomic Policy and Development Division. These focused on the analysis of productive capacities of countries in Asia and the Pacific (Freire, 2011), on challenges and opportunities for least developed countries in diversifying their economies and building productive capacities (Freire, 2012a), and on the identification of potential new sectors for diversification in Myanmar (Ayres and Freire, 2012). The research was also presented in ESCAP's policy papers series on countries with special needs in a paper focusing on the role of agriculture in closing development gaps of least developed countries (Freire, 2014a), and in a policy brief on policies for balanced development of these countries (Freire, 2014b).

Chapters 10 and 12 were disseminated as part of UNU-MERIT's working paper series (Freire, 2017a) and the working paper series of the United Nations Department of Economic and Social Affairs (Freire, 2017b) focusing on the description of the main model developed in this dissertation and the results of the analysis of strategies for poorer countries to catch up. Similarly, the main findings of Chapter 5 were disseminated in a UNU-MERIT working paper (Freire, 2017c), which discusses the need for strategic diversification to promote structural transformation.

The results of the research were also disseminated through presentations in several national and international conferences, seminars and meetings, including:

- Fourth South Asia economic summit (SAES IV) on "Global recovery, new risks and sustainable growth: repositioning South Asia", which was held in Dhaka, on 22 and 23 October 2011, with a presentation on building productive capacities of the least developed countries;
- UNCTAD's senior experts meeting of least developed countries (LDCs) on "Challenges and opportunities for LDCs: Graduation and structural transformation," which was held in Addis Ababa from 28 February to 1 March 2012, with a presentation focusing on opportunities and key challenges for least developed countries in building productive capacities, facilitating structural transformation and successful graduation from the LDCs' status;
- Presentations at the National University of Sciences and Technology (NUST), Islamabad on 10 May 2012 and at the Pakistan Institute of Development Economics (PIDE) on 11 May 2012, focusing on challenges and opportunities for Pakistan in building productive capacities through economic diversification;
- Fifth South Asia economic summit (SAES V), held in Islamabad from 11 to 13 September 2012, with a presentation focusing on the role of

diversification and structural transformation for growth with welfare in South Asia;

- Tenth international conference of the global network for the economics of learning, innovation, and competence building systems (GLOBELICS), held in Hangzhou, China from 9 to 11 November 2012, with a paper focusing on diversification and productive capacities in least developed countries (Freire, 2012b);
- United Nations ESCAP expert dialogue on the quality of growth, held in Bangkok, from 14 to 16 November 2012, with a presentation on diversification and structural change for growth with quality;
- ESCAP capacity building workshop on agricultural policy analysis for food security and poverty reduction, held in Bogor, Indonesia, from 26 to 30 November 2012, with a presentation describing the methodology presented in Chapter 6 of this dissertation for selecting agro-industries for production and export diversification, and discussing policies and strategies for facilitating the emergence of more productive agro-industries;
- UNDESA – ESCAP – ILO – UNEP expert group meeting on green growth and green jobs for youth, held in Bangkok, on 12 and 13 December 2012, with a presentation on strategies for facilitating the emergence of more productive and greener jobs;
- Capacity building workshop on agricultural policy analysis, food security and poverty reduction through sustainable agriculture, which was organized by United Nations CAPSA in Bangkok, in April 2013, with a presentation on economic diversification, structural transformation and poverty reduction;
- United Nations CAPSA capacity building workshop on agricultural policy analysis, food security and poverty reduction through sustainable agriculture, held in November 2013 in Dili, Timor-Leste, with a presentation on agribusiness opportunities in Timor-Leste;
- Stakeholder's consultation on inclusive growth and structural transformation in Lao People's Democratic Republic, which was organized by CAPSA in Vientiane on 29 November 2013, with the presentation on emerging economic activities with potential to contribute to higher productivity and structural transformation in Lao People's Democratic Republic;
- Asia-Pacific regional workshop on graduation strategies from the least developed country category as part of the implementation of the Istanbul programme of action for the LDCs, which was held in Siem Reap, Cambodia on 4 December 2013, with a presentation on promoting

productive capacity development in the LDCs through economic diversification;

- United Nations ESCAP expert group meeting on macroeconomic outlook and challenges and regional connectivity for shared prosperity in the ESCAP region, held in Bangkok on 16 and 17 December 2013, with a presentation on the diversification towards agribusiness to close development gaps of LDCs;
- World Urban Forum 2014, networking event on the role of cities on equity and productive transformation policies in Africa, Asia and Latin America, in Medellin on 9 April 2014, with a presentation via video on productive transformation of cities based on Asia-Pacific case studies;
- ESCAP side event at the second UN conference on landlocked developing countries, which was held in Vienna in November 2014, with the presentation of the ESCAP's report that I authored titled "Economic Diversification in Asian LLDCs;"
- United Nations expert group meeting on macroeconomic outlook and challenges, held in Bangkok in December 2014, with a presentation on the role of economic diversification for building productive capacities of countries;
- High-level Asia-Pacific policy dialogue on the implementation of the Istanbul programme of action for the least developed countries for the decade 2011-2020, which was held in Siam Reap, Cambodia, from 4 to 6 March 2015, with a presentation on the role of economic diversification for building productive capacities in the Asia-Pacific least developed countries.

I also had the opportunity to present to the Ministry of Finance of Timor-Leste the results of the analysis presented in Chapter 6 related to the identification of potential new products for diversification in that country. That work was part of the ESCAP project entitled "Capacity building for implementing the Timor-Leste's Strategic Development Plan 2011-2030 focusing on inclusive development and job creation." I presented the project to the Prime Minister and the Finance Minister of Timor-Leste at ESCAP on 25 August 2013. Following that presentation, I conducted missions to Timor-Leste in September 2013 and March 2014 to hold consultations with government officials of the Ministry of Finance, Ministry of Industry, Commerce and Environment, Ministry of Tourism, Ministry of Foreign Affairs and Prime Ministry's Office, and to provide technical assistance to the staff of the Ministry of Finance of Timor-Leste in the preparation of a report to identify practical policies that the Government could implement to diversify the country's economy.

I plan to continue to disseminate the results of this dissertation to policymakers, government officials, practitioners and other stakeholders from civil society through my work at the United Nations.

Curriculum Vitae

Clovis Freire Junior was born in Fortaleza, Brazil on 30 May 1973. He is an Economic Affairs Officer at the Division for Sustainable Development of the Department of Economic and Social Affairs of the United Nations, in New York.

A Computer Engineer by training, he started his career in 1997 in Brasilia as Lieutenant Engineer of the Brazilian Air Force, where he worked on computer networks and network security for five years. During that period, he also taught Computer Sciences at the UPIS University in Brasilia. After that, he managed the department of technology development of an ICT consultancy firm in Brasilia. In 2003 he joined the United Nations as Computer Network Engineer at the Headquarters in New York, and in 2005 he moved to Bangkok to work in the area of ICT for socioeconomic development at the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). From 2005 to 2010 he worked in the areas of space applications for development, reduction of risk of natural disasters, and assessment of progress towards the achievement of the Millennium Development Goals (MDGs). In 2010 he joined the Macroeconomic Policy and Development Division of ESCAP working in the areas of poverty reduction, economic growth and structural change, particularly in least developed, landlocked developing and small island developing States. In 2015 he returned to the United Nations Headquarters in New York to work in support to the achievement of the Sustainable Development Goals (SDGs) through science, technology and innovation.

Clovis holds a Computer Engineer degree from the Instituto Tecnológico de Aeronáutica (ITA), Brazil, a Master’s degree in Computer Sciences from the

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Clovis is married to Odalea Novais Freire and they have a son (Alvaro, 15 years old) and a daughter (Alicia, 10 years old).

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