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Technology foresight and industrial strategy

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ABSTRACT

When Technology Foresight (TF) began to be adopted in industrial countries, it tended to be still somewhat a marginal activity in developing countries. Today globalization radically transformed the range of economic activities that developing countries can perform. Production is fragmented and organized along global value chains. Dense flows of knowledge and technology are available, but need to be fully employed in the framework of coherent industrial strategies.

This paper examines how and to which extent TF programs are needed in developing countries given the new prevailing global context. It argues that the TF and industrial strategy are and must be mutually consistent and they need to be taken seriously, coherently designed and implemented in light of their role to shape and economic growth. We provide preliminary support to this argument by discussing the theoretical foundations and justification of TF and industrial strategy, and then reviewing some relevant examples from Brazil, Chile and South Korea.

1. Introduction

Technology Foresight (TF hereafter) represents a systematic exercise aimed at looking into the longer-term future of science technology and innovation (S&T) in order to make better-informed policy decisions (Irvine and Martin, 1984). Since its early inception, pioneered in Japan, TF has tried to help societies and economies to define strategic areas where the future of science and technology would lead.

During the last few decades the practice of TF diffused through a wide range of developed countries as well as regions, large companies and other organizations. A growing number of developing countries have undertaken TF exercises too. But to what extent does TF really reflect their different condition of developing countries trying to catch up with more advanced ones?

Given their scarcity of resources and lower levels of technological development, developing countries are facing remarkable constraints to catch up with developed countries. Industrial and TF strategies are of crucial importance to this aim since they both pursue the same scope which needs to be consistent with and help strengthen the National Innovation System (NIS). Thus, TF needs to go beyond a pure speculation of where the future will lead and instead foster large-scale efforts to align stakeholders' interests towards the common agreed vision of the future.

This paper addresses this central question and analyzes to what extent TF exercises are essential parts of wider industrial strategies in developing countries by first reviewing and discussing the theory and then analyzing three examples from three countries. Firstly, we examine the case of a now-developed country, South Korea, where clever industrial policies combined with a foresighted national vision clearly contributed to achieve a well-defined and unprecedentedly fast economic growth. Secondly, we analyze the case of a developing economy, Brazil, where the fusion and mutual reshaping between industrial strategies and TF exercises is demonstrating the country's ability to fully understand the new dynamics of Global Value Chains (GVC). Finally, we focus on the institutional development in another developing country, Chile. Here the government set up an institutional framework embodied by the National Council for Innovation and Competitiveness (CNIC) that would appear to favor the coherence and close connection between industrial strategy and TF with a long-term perspective.

2. What is technology foresight?

An essential fact characterizing today's economic development is the speed of technological change which brought about unprecedented levels of productivity growth (Baumol, 1986). As a consequence, industrial and trade structures are continuously being reshaped towards

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more complex sets of activities, that often follow a logic of vertical and horizontal fragmentation within global value chains, with room for outsourcing by multinational companies (MNCs) and foreign buyers that drive the process and ensure its internal coherence (Baldwin, 2011, Cattaneo et al., 2013, Gereffi, 1999). This opens up a new window of opportunities in terms of strategic investments that developing countries may follow to move closer to the technological frontier.

TF represents the concrete effort to overcome this emerging complexity since it systematically embodies a set of programs to study innovation plans and priorities to foresee, shape and direct potential future orientation of technological change (Martin, 1995). Its essential feature stems from the active involvement of a variety of actors such as government, experts, industry and civil society that gather together in order to define a joint vision of the future (Miles, 2010). Among TF participants the role of experts from science/academia and the private sector is of crucial importance since they might have better insights on technological issues with respect to policy makers and hence help reduce the uncertainty brought about the unprecedented speed of technological change (Hilbert et al.2009:882). The rationale behind these "exercises" is to generate positive sum games whose outcomes are expected to be more effective in terms of technological advancement, but also more sustainable in terms of socio-economic benefit than those of isolated initiatives taken by each actor.

Relevant literature refers to TF as to an exercise encompassing a wide range of activities, including: anticipation, forecasting, systematic looking ahead, forward looking activities, strategic intelligence, futures research, technology roadmapping and prognostic among others (Miles, 2010 and Phaal et al. 2004). The pioneering country in TF was Japan that in the 1970s used to call its national technology planning studies "forecast activity" despite the fact that what it was actually performing was "technology foresight" and perhaps in one of the most refined manners (Miles, 2010). It was later in middle 1980s thanks to Irvine and Martin (1984) seminal work inspired by the long Japanese tradition in S&T and TF, that we now call these "forecasting" activities "foresight". The difference is not trivial. On the one hand, forecasting activities, which are typically performed by closed-circles of experts, provide a mere prediction of future contingencies founded on deterministic precision. Their outcome reflects a specific vision of the world, with a single point of view. On the other hand, TF embraces a broader view of the world that is synergistically integrated with policy strategy. Its outcome sketches insights for forward looking S&T policies that "create" rather than "predict" the future (Miles, 2010) by placing emphasis on the learning processes (van Dijk, 1991) as well as the dialog among different disciplines and actors (Elzinga, 1983).

Irvine and Martin's (1984) work did not only provide the definition and understanding of TF as we conceive it today, but also spurred the proliferation of TF exercises around the world. Right after Japan, France started to perform foresight exercises during the 1980s, followed by Sweden, Australia and Canada (UNIDO, 2005). However, it was during the 1990s that TF gained momentum, expanding also within the UK, the US, The Netherlands and Germany: if one country engaged in foresight activity, others decided to pursue the same exercises too in order to remain competitive (UNIDO, 2005). TF in fact was appreciated as a valuable tool to identify fast, market-oriented and forward-looking innovation policies agreed by the government and the private sector. Recently foresight has also spread to developing countries as a strategic tool to narrow their competitive gap with the technological frontier (see Section 4). The narrow indication that cutting edge technology productions are only a concern to industrialized countries has gradually been overcome, and the literature in this regard has often used the language of "leap-frogging" (Perez, 1983).

From our perspective, the most distinctive features of TF are the following:

1) In its attempt to predict the future, TF has the potential to influence technology direction and hence to "make the future happen" (Miles, 2010). In fact, by fostering a participatory approach and boasting a strong legitimacy which helps building consensus, TF increases awareness, accountability, transparence, predictability of future technological developments and also provide ownership and responsibility (Elzinga, 1983);
2) At the same time, a participatory approach ensures the inclusion of new actors who can expand the range of possible strategies beyond the narrow interests of single individuals. For instance TF can significantly facilitate the strategic decision faced by stakeholders to "make or buy" new technologies considering the local knowledge endowments and organization (Lall, 2004).
3) TF can be pursued at various levels: organizational, local, regional, national or supranational.[1] All these levels of foresight aim to manage both demographic and socio-economic heterogeneity faced by actors involved in the analysis.
4) For its effort to try to link and reorient science and innovation on a national and regional scale, TF is inherently linked with the NIS. TF seeks to foster economic impact by "wiring up" the network between industries, university, governmental bodies as well as the society at large (*e.g.* aging societies, education and training) (Martin and Johnston, 1999, and Andersen and Andersen, 2014).

A number of "failures" intrinsic to innovation activities and S&T policies are usually tackled by TF exercises, such as:

- coordination failures among NIS stakeholders that often have different views on the importance of S&T. The balancing of such interests is crucial to wipe out rent-seeking behaviors and bounded rationality (Schlosstein and Park, 2006);
- communication failures, especially when different actors from distinct disciplines (*i.e.* specialized in different subject-languages and forms of communication) express diverging interests and are convened together in order to define a common strategy;
- market failures, since usually S&T programs require a long-term investment that should be weighed against the possibility of temporary short-term losses; and

political failures since governments too should adopt a long-term perspective on innovation which might not coincide with the political perspective of maximizing consensus in the short-term political interest for the upcoming election (this is often called "dynamic inconsistency").

3. How is technology foresight related to industrial strategy?

Nowadays globalization, increased complexity of manufacturing and services, stronger competition and faster technical change have radically transformed the range of economic activities that developing countries can perform. Production is internationally fragmented and organized along GVCs. Dense flows of knowledge and technology are available, but need to be fully exploited and employed within coherent industrial strategies. A specialization by technology and learning is becoming the dominant paradigm and developing countries need to detect opportunities for future technological and productive specialization in order to catch up and forge ahead.

Therefore individual isolated responses cannot be sufficient to address these complexities and guarantee that countries develop and catch-up. The interdependencies emerging from a globalized competitive setting makes it imperative to devise and follow an appropriate "strategy" to orchestrate responses from the Government, the private sector, and research organizations (Lall, 2004).

However, TF exercises often do not go hand in hand with the concrete identification and design of a policy strategy to promote catch up.

[1] For a comprehensive review of the various methodologies that can combine both quantitative and qualitative methods of TF, see Ciarli et al. (2013).

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The central argument we develop in this paper is that TF exercises need to be mutually consistent with industrial development strategies since both pursue essentially the same objective of industrial development *via* technological catching up. In the following section we briefly describe how the concept of industrial strategy has evolved over time, and how it needs to take into account the more recent changes to the international organization of industry, the emergence of GVCs and the role of innovation.

3.1. Different conceptions on industrial policies

Industrial policies have been the object of vivid debates expressing radically diverging views both in the literature and political arena.

Traditionally, the liberal approach argues that the best policy for all countries and in all situations is to liberalize, as free markets dynamics will let countries identify their comparative advantage. The underlying assumption behind this rationale is that products' markets provide the correct signals for investments to which actors respond accordingly. Governments' single duty would be to provide a stable macroeconomic environment with clear rules of the game along with the provision of essential public goods. Any further intervention is not required and would distort the already optimal allocation of resources. The weakest aspect of this approach is that it overlooks the existence of widespread market failures (Stiglitz, 1989), which tend to be especially pronounced in the field of knowledge and innovation, and that in turn have a central influence on the long-term growth of productivity and income (Hall and Jones, 1999, Griliches, 1979).

In stark contrast, the literature on technological capabilities maintains that technological change is crucial to emerging countries' economic development, but it is hindered by market failures (Bell and Pavitt, 1993; Katz, 1984; Lall, 1992, 1996, 2001 and Westphal, 2002). According to this approach, countries' industrial success largely depends on their capacity to adopt and master existing technologies, even by not being at the technological frontier (Nelson and Winter, 1982). Due to market failures, technology is not freely available and cannot be absorbed without costs or risks. Conscious and purposive efforts to invest in technology specific learning processes and building technological capabilities are essential for firms (Lall, 1992; Pietrobelli and Battisti, 2000 and Lall, 2004:12).

The technological capability approach offers government a platform that indeed justifies policy action in a functional and selective manner. Selectivity is crucial, since the cost of offering uniform support to all industrial sectors would be too high and probably not effective given the fact that the learning processes differ by technology (Lall, 2004). Some simple activities require minimal protection and support if the learning period is relatively brief and the information is easily accessible. Conversely, within more complex activities characterized by high entry costs and externalities, newcomers might never enter unless specific policies are implemented to incentivize them to do so.

However, the existence of market failures does not alone establish a case for intervention: interventions are costly and risky and a careful assessment of costs and benefits and long-term impacts is required.

This policy learning and capacity development process requires interaction between government and firms involving mutual learning and experimentation within an institutionalized process (Rodrik, 2007; Rodrik et al., 2004; Morris, 2010; Kaplinsky and Morris, 2008; Sabel and Zeitlin, 2011). This process is essential both for industrial strategy and for TF exercises and worked extremely well in the successful experiences of some East Asian economies.

3.2. Lessons from the East-Asian "tigers"

The experience of the East-Asian "Tigers" (*i.e.* Hong Kong, Singapore, Taiwan and South Korea) offers a solid example of how an active industrial strategy mutually consistent with a TF framework promoted fast industrialization and technological development. Even though the Asian Tigers are far from having followed the same development model, some major common features of their industrial strategy can be identified (Lall, 1996).

First of all, selective and horizontal policies have been used interchangeably and simultaneously in each country (with the exception of Hong Kong). For example all countries have been investing to create advanced human technical skills, whilst also selectively supporting some sectors with innovation and export subsidies and protection of the domestic market. Secondly, the capability development that they pursued actively took place within a long time frame. Thirdly, FDI has been used differently by each country. The countries wanting to promote local capabilities development restricted foreign entry and directed their activities to exploit spillover effects and hence they favored indigenous companies over foreign ones (South Korea and Taiwan). Conversely, those countries relying on MNCs to promote technology development, targeted foreign investors to persuade them to engage in more complex and technology-intensive functions (Hong Kong and Singapore).

The success of these policies may be explained by some significant principles guiding their implementation. East Asian tigers have been constantly selecting and targeting those activities offering better opportunities for learning, technological benefits and linkages. The importance attributed to fostering learning (Lall, 1987, Lall and Pietrobelli, 2002) implied massive investment in skills generation through education and infrastructures. Learning also extended to strategy formulation and implementation in order to discover the lessons from past mistakes and improve upon them (Amsden, 1989). Such policy learning and flexibility in the strategic decision-making systematically endorsed the private sector, supported by an active role of public institutions to fill in gaps in unusually risky areas (Lall and Teubal, 1998). Finally, exports have been constantly used as a discipline to force early entry in the world markets.

3.3. The role of industrial policies is changing with the emergence of GVCs

Since the early 1990s the twin forces of technology and globalization have led to the geographic fragmentation of industries, where value is added in multiple countries, together with vast improvements in the functional integration of these activities. This process created what is currently known as Global Value Chains. Today it is difficult to imagine a production that is entirely carried out in just one country (Gereffi and Sturgeon, 2013, Milberg and Winkler, 2013). In 2009 world exports of intermediate goods surpassed that of the combined export values of capital and final goods (WTO and IDE-JETRO, 2011:81).

These developments pose remarkable challenges as well as opportunities for developing countries' firms and governments. A large body of evidence indicates that despite the potential presence of certain barriers in some markets and value chains, the interaction between global actors and local suppliers can be a conduit of knowledge and learning experiences that foster processes of learning and capability acquisition, and spill over to other firms not engaged in the same value chain (Pietrobelli and Rabellotti, 2007). This, however, does not suggest that an initial contact between a local supplier and a global buyer is enough. For instance, a minimum of previous accumulation of skills is typically required for a supplier to engage in contract manufacturing with a global buyer (Morrison et al., 2008) and there are certainly cases in which existing contracts were terminated because the supplier was not capable to increase its capabilities to the levels initially expected. Therefore various countries have developed different programs targeted at local firms to support their efforts to become suppliers of global firms. Within this new setting the case for industrial policy and for TF exercises, got elevated to a great prominence (Gereffi and Sturgeon, 2013; Pietrobelli and Staritz, 2013; Sturgeon et al., 2013). The point is not only to find the country's competitive advantage, but also to tailor it to the requirements of these GVCs.

In the challenge to define multifaceted policies and programs coherent with GVC organization and requirements, careful consideration of the systemic nature of GVCs is needed. In this regard, an explicit account of the local innovation system (IS) and its interaction with GVCs is necessary (Morrison et al., 2008; Pietrobelli and Rabellotti, 2011,2012). Indeed, the relationship between IS and GVCs is two-way, as GVCs, and in particular lead firms, may support firm learning and innovation as well as improve local IS (Morrison et al., 2008) but may also block them. Similarly, the IS also influences the capabilities, performance and functions of local firms within GVCs. The effective combination of technological efforts and absorption capabilities of local firms and public support may in turn raise the interest of lead firms to support upgrading processes, locate higher value activities and source higher value products locally (Pietrobelli and Rabellotti, 2011).

What is the economic rationale for value chain-related policies? The debate on public policies in the context of GVCs is part of the broader debate on the role of states and markets in the development process, and the existence of market and coordination failures we discussed above. These issues are particularly problematic in the area of technology, innovation and learning where the contribution of internationalization through integration into GVCs may be most fruitful. The following policy justifications are especially relevant in the context of GVCs. First of all, externalities on other firms are likely to emerge, once one firm signals the potential and the means required to integrate in a GVC. Secondly, in presence of coordination failures, suppliers would not invest to upgrade their production, and lead firms would not support them either. In the absence of long-term contracts, coordination and trust lead-firms and suppliers may engage in learning and upgrading activities to a lesser extent than would be socially desirable. Thirdly, the distribution of rents along GVCs is affected by substantial market failures and entry barriers in specific segments (*e.g.* branding and product conception) (Pietrobelli and Staritz, 2013).

In sum, the existence of GVCs is raising and reshaping the need for cleverly-designed industrial policies and for their coherence with TF and long-term planning exercises.

4. Why does a clear and planned coherence between technology foresight and industrial strategy matter more for developing countries?

In developing countries the need for coherent TF exercises inherently coupled with industrial strategies is especially strong. First of all, developing countries are often characterized by widespread market failures, poor institutional development (Rodrik, 2000), and a scarce coordination of society and science with public policies, that result in a missing sense of common purpose (Tavares and Wacziarg, 2001). As a consequence, it is unlikely to expect that in such context each actor would naturally and easily align with the vision outlined by the TF. Information does not often flow smoothly and is marked by substantial asymmetries, the rules of the games are not often solid and enforceable as it would be needed, and inter-firm and inter-organization coordination is poor and occasional.

In contrast, more developed countries are generally characterized by better-aligned NIS and actors that are more likely to quickly respond to the incentives launched by the market or by government policies. The simple ‘signaling’ effect of a TF exercise is often sufficient to determine behaviors consistent with its long-term objective.

Secondly, TF exercises in developing countries need to be of a different nature. This is because they are seldom frontier innovators but rather users of technologies developed abroad that need to be adopted and adapted to local contexts and conditions. Provided that their final aim is to promote a catching up process, TF should help searching for existing technologies that could be more appropriate to their needs and level of NIS development, and should be closely related to their industrial strategy to promote the improvement of technologies.

Thirdly, a major issue identified in the literature inherent to developing countries' technological development is the forecast of the timing of *technology realization*. Developing economies are generally lagging behind in technology development, and the adoption of a new technology, either through domestic firms' efforts or through technology transfer, might be retarded by several constraints which can delay the time of the technology realization. These constraints can include the lack of appropriate regulation and policy standards, human and financial resources, and research infrastructure (Chan and Daim, 2012).

Fourthly, when TF are mutually consistent with the industrial strategy, this can help limit the extent of the dynamic inconsistency which is typically stronger in developing countries, whereby the urgency to achieve positive results in the short-run prompts the tendency to overlook the benefits of long-term investments (Ascher, 2009). This shortsightedness can be mitigated and possibly solved through a shared private and public vision for the future and by turning common commitment into actions (Martin and Johnston, 1999). While investing in key strategic sectors of the future, TF and industrial strategy should create, nurture and strengthen the institutional and physical infrastructure that leads to innovation. This latter type of investments can guarantee a country enough flexibility to reorient its policies in the case of failures and mistakes.

4.1. How to achieve a strong link and coherence between technology foresight and industrial strategy?

A careful review of the literature points to some common characteristics between TF exercises and industrial strategies that deserve to be highlighted. First of all private sector involvement is key, and as such it should to occur through a participatory approach. Its scope is twofold: on the one hand it raises the relevance of these exercises by helping defining the content that public policies should have that are often unknown *a-priori* from Government (Hausmann et al., 2008, Hausmann and Rodrik, 2006); and on the other hand, they guarantee ownership, responsibility and accountability throughout the process.

Secondly, it is widely acknowledged that well-organized, competent and effective institutions are the backbone of successful innovation and industrial policies (Crespi et al., 2014). Participation of entities like the Ministries of Industry, Planning, Education, S&T should encourage actors to adopt behaviors that are consistent with the long-term benefits of TF programs. “Innovation councils” for instance can support long-term strategies whose duration exceeds that of the government, and help mitigate governments' tendency to overlook the benefits of long-term investments in favor of short-term gains (Box 1).

A third important condition for TF and industrial policy's success is a thorough understanding of GVCs logic along with their underlying power relationships. Nowadays GVCs represent one of the main sources of information and technology (as well as market access) for developing countries. With GVCs countries can target specialization niches, but in order to do so they need to develop the necessary skills and technologies to deal with powerful large chain leaders.

In the next section we examine three cases (South Korea, Brazil and Chile) where the coherent coupling of TF and industrial strategy has been more evident.

5. Case studies: the link between foresight exercises and industrial policies in developing countries

5.1. South Korea: technology foresight and its overlap with development policies

The most striking aspect of South Korea's industrial development is the radical shift of its economy from low- to high-tech value-added sectors in only a few decades. This was made possible because, over time, TF and industrial policies have become deeply intertwined *via* complex and at time overlapping measures (Chung, 2007). Their main aim has been to respond to the technological challenges raised by global competition.

Box 1
Institutional set up of organizations fostering TF.
One of the major challenges of TF exercises and industrial policies is to overcome the dynamic inconsistency between short-term gains and long-term benefits typically faced by governmental institutions. This is sometimes achieved through the establishment of a more permanent S&T policy body, able to overcome the political and economic cycles with a foresighted vision. The international experience of such S&T councils varies from country to country. Councils should be seen as a source of strategic intelligence for the innovation policy agenda. According to the extent of their influence on government policy planning, three types of councils can be identified:
A *joint planning* model: which draws from the Japanese experience, where councils serve the government as horizontal ministries of innovation by bringing together different actors from different disciplines to pursue joint projects;
A *coordination model*: based on the Finnish experience, in which the council's main goal is to advice the government by communicating across ministries to direct and align innovation policy. Such advice though is not always necessarily binding, like for the Chilean CNIC.
An *advice model*: as the Canadian case, where the government proactively seeks the council's advice though it does not intend to be restricted from it.
Source: adapted from OECD (2009).

South Korea's initial development followed an inward-looking model of technology imports until the 1970s, when the economy specialized in traditional low value-added, labor-intensive light industries (*e.g.* textiles). This specialization soon suffered competition from low-cost productions from other developing countries, and prompted South Korea's commitment to search for an alternative development trajectory (Shin and Kim, 1994). The country's new specialization focused on high-value/capital intensive heavy and chemical industries and high-tech home-grown technologies such as electronics (*e.g.* semiconductors, mobile phones, displays and mobile internet) (Kim and Dahlman, 1992). The presence of large *chaebols*[2] like Samsung, Lucky-Goldstar (LG) and Hyundai represented a key factor in contributing to this radical change in the economic specialization.

The industrial policies implemented by the Korean Government were inherently interventionist, pervasive and sought to promote indigenous technology whilst improving local technological capabilities (Lall, 2004). Vertical policies targeting high-tech niches coexisted with horizontal ones aimed at developing endogenous capabilities, improving local infrastructure and implementing R&D investments across a variety of sectors (Chung, 2007). This unprecedented economic growth would not have been possible without government interventions *via* the six National Development Plans that were designed and implemented between 1962 and 1991. From a careful analysis of these plans some key features of government intervention emerge.

The first is the single-minded objective to pursue economic growth, which has been the foremost goal for all South Korean governments. Such goal prevailed even at the expense of others, like equity or poverty reduction. This attitude turned out to be essential in directing and forging Korean mentality and rejuvenate institutions and leaders (Chung, 2007).

The second feature was that trade policies were complementary to industrial policies and geared towards structural transformation of the economy's specialization. They were oriented to promote capital goods imports (rather than consumer-ones), and FDI was kept out of the picture for many years unless it was deemed essential for accessing new technologies (Lall, 2004). These policies were constantly accompanied by stringent performance requirements and were gradually phased out as companies demonstrated the ability to compete.

The third was the government capacity to engage the private sector in the development process within both TF exercises and development plans stimulating its ownership and responsibility of the TF exercises. Private sector trust in government action was based on the deep-rooted legitimation of the state and on “collectivism”.

Korean foresight exercises date back to the 1990s, after the national development plans had taken off in the 1960s. Foresight activities tended to have a strong technological connotation and so did the earlier national development plans. Despite the different terminology in fact they did the same job. As a matter of fact, national development plans foresaw the future by identifying the strategic sectors in which to invest, and they did so by combining both long and short-term perspectives.

Since the 1990s, TF exercises in South Korea have typically resulted in 5 year-plans targeted to problem solving and to understanding which general-purpose technology was worth investing in. TF results are incorporated in the wider S&T Plans which are usually longer-term (5 to 30 years). The rationale is to better connect targeted on-spot technologies selected during TF exercises with the overall NIS long-term plan and projections (see Yim, 2011 and Shin and Kim, 1994 for a comprehensive review).

The conceptual and practical link between South Korean TF exercises and industrial development makes it a suitable example to follow for other emerging economies (Kim and Dahlman, 1992). During the implementation of TF investment in technology has been visibly supported by the Korean government and became integral part of the 2013–17 S&T Plan where particular emphasis was paid to renewable energies (Yim, 2011). However, the adoption of TF as a strategic tool for policy making did not come without difficulties, and the government repeatedly went through a trial-error process.

The first national R&D plan, which started in 1982, stressed the need to create indigenous capabilities in semiconductors, steel, automobiles and shipbuilding (Hwang et al., 2011). During 1982–1992 a total of 2400 projects received massive government investments (US$ 207 million and more than two/thirds directed to R&D). Many research departments in firms were created (Shin and Kim, 1994) and the private sector R&D investment also increased from about US$ 297 million in 1982 to about US$ 3044 million in 1990. However, in spite of these efforts, R&D projects' commercial performance was rather unsatisfactory. Only about 4% of the 469 R&D projects funded by the government, and only about 30% of the 589 projects jointly financed by the government and the private industry, were successfully commercialized (Shin and Kim, 1994). The lack of expertise in R&D management of Government officials was deemed responsible for this poor performance. This, in turn, motivated the establishment of R&D budgets under the supervision of entrusted specialized organizations for each line ministry (Lee et al. 1996).

The last TF exercise in South Korea was conducted in 2012 and it focused on the “social needs” of the Korean society.The novelty of the exercise lied not only on the new typology of selected sectors (including protecting health with personalized medicine and treatment, model for forecasting health conditions, electric home appliances for future energy saving, among others) but also on the methodology adopted to detect changes in the R&D environment (Kim et al. 2013:72). The New and Emerging Signals of Trends (NEST) developed by the Korea Institute of Science and Technology Information (KISTI) firstly developed 8 years ago, is one of them. By combining quantitative and qualitative methods, NEST seeks to formalize the identification of weak signals[3] and emerging technology trend searches based on massive analysis, inference

[2] *Chaebols* were South Korean private business owned by single powerful families and they comprised several smaller members and units, which all maintained a close connection with the government (Chung, 2007).

[3] Weak signals are events, accidents or rare occurrences that are thought to trigger future changes (Kim et al., 2013:52).

techniques, and Delphi studies from worldwide expert networks in order to assist researchers to better perform their research activities. NEST acts as a sort of "unsupervised bottom-up approach" since crucial decisions taken during the process are made by information technology and data mining algorithms. Human expertise is foreseen only during the assessment and at the end of the process (Kim et al. 2013:72).

5.2. Brazil's experience with technology foresight and a value-chain approach to industrial strategy

One of Brazil's many historical challenges has been the diversification of its production beyond natural resources, to raise the technological content of its exports *via* new and higher-productivity industries. Within this context, Brazil has been recently reconsidering its approach to industrial strategy to exploit the potential offered by GVCs.

5.2.1. Technology foresight in Brazil

In Brazil, the proliferation of TF exercises began systematically at a national level in the late 1990s with "Brazil 2020". However, national commitment to S&T policy started much earlier through S&T plans (the first Science and Technology Development Plan took place already in 1973–74) and business-level TF exercises (Popper and Medina 2008, and Chan et al. 2012). During this initial phase, TF exercises were implemented by large banks and companies such as BNDES and PETROBRAS. TF took the form of prospective and extrapolative studies (Porto et al., 2010). Nevertheless, largely because of the tumultuous period of political and economic oil gas crisis, as well as the Brazilian transition out of the military government, these techniques led to miss-specified predictions motivating the inclusion of additional foresight techniques imported from Western countries (such as scenarios) (Porto et al., 2010).

The newly adopted techniques allowed TF exercises to strengthen stakeholders' coordination. They took place every 2 or 3 years and their main goals included:

- the identification of the strategic sectors where to invest as for example with the 2002 Brazilian TF Program, that targeted civil construction, textile and garments plastics, wood and furniture; and
- the strengthening of investment in key infrastructures in order to be able to accommodate and take advantage of technological change, as with "Project Brazil 3 Times" (Mojica, 2010).

Nowadays, the principal institution responsible of TF is the Centre for Strategic Studies and Management (*Centro de Gestão e Estudos Estratégicos* — CGEE). In 2005 CGEE together with FINEP (*Financiadora de Estudos e Projetos*, Research and Projects Financing Corporation) defined the "Brazil 3 Times" project, a strategic study that examined scenarios to characterize the country's future in 2007, 2015, and 2022 respectively. The use of scenarios contributed to raise awareness of the vast amount of local assets and of the huge Brazilian market (Gouvea and Kassicieh, 2005). By acknowledging Brazil's goal to catch up with foreign competition in international markets, this project highlighted the relevance of GVCs for the country's technology policy (CGEE website).

5.2.2. Foresight and GVC-oriented industrial policies in consumer electronics in Brazil[4]

An instructive case of how GVCs intersect with national industrial policies and TF can be found in Brazil's recent efforts to leverage its large and growing internal market to build domestic capabilities in the consumer electronics sector.

Brazil's overall trade performance in the consumer electronics sector recently turned negative, with a decline in exports and a very rapid increase in imports to fulfill the rising demand of the local middle class. These rapid market shifts brought a new set of players to the fore, namely Apple and the many makers of Android-based smart phone handsets, and the contract manufacturers that produce the bulk of these products such as Flextronics (from the USA and Singapore) and Foxconn (from Taiwan). Market growth and access to Mercosur is providing Brazil with the leverage to demand local production and content from consumer electronics and communications GVC lead firms, who in turn have put pressure on their key global suppliers to make investments in Brazil. To do this Brazil is bringing to bear a range of old and new policies aimed at spurring local production in the electronic sector. The key laws and programs to stimulate local production are listed and described in Table 1.

Table 1
Brazil's Electronics-related industrial policies.

Policy mechanism	Details
Informatics law	The Informatics Law of 1991 initially sought to foster local production of electronics and R&D through the use of Basic Production Processes (PPBs) and R&D investment quotas.
Local content incentives	Firms are encouraged to manufacture in Brazil through product-specific PPBs – "the minimum group of operations, within the industrial plan, which characterizes real industrialization of a certain product". PPBs reduce industrial product taxes (IPI) on final products, raw materials, intermediate products and packaging goods associated with the promoted product from 15% to nearly zero. Reduction in ICMS (state VAT) also applies in many states. PPBs are product, not company specific; only those products meeting the PPB's criteria receive benefits. They are defined and monitored by the Ministry of Science, Technology and Innovation (MCTI) and Ministry of Development, Industry and Foreign Trade (MDIC). PPBs set 'nationalization indices' that define how much of the promoted product must be local in content in order to retain the incentives offered. For example, the PPB for computer tablets in 2012 set the nationalization index at 30% and targets to raise it gradually over time.
R&D spending requirements	Firms must invest 4% of gross revenue from promoted products in local R&D. The key stipulation is that R&D must involve the discovery of a new technology or the development of new workforce capabilities, and not simply extend an existing, mature technology.
Incentives for the semiconductor industry	The Brazilian Microelectronics Program, launched by the MCTI in 2002, sought to support segments of IC manufacturing by offsetting exorbitant capital requirements involved in building a foundry with the latest technological capabilities. This focus on microelectronics continued through the 'Política industrial, Tecnológica e de Comércio Exterior' (PITCE) enacted by President Lula in March, 2004. PITCE focused on developing outward-oriented software and integrated circuit industries, among various others. In 2007, the government enacted PADIS, a subset of the broader industrial policy 'Plano Brasil Maior' to develop local semiconductor and display industries by targeting companies investing in R&D and manufacturing capabilities in Brazil.
Plano Tecnologia da Informação TI Maior	Software is the fastest growing IT market segment in Brazil (16% annual growth rate during 2011–15, Business Monitor International 2012). Brazil has long had a viable cluster of software SMEs. Plano TI Maior is the most recent attempt to scale these firms up, the majority of which remain small and unable to compete outside Brazil. The most important component of Plano TI Maior is CTENIC, an equivalent of the PPB for software. This certification is currently under development and will define what constitutes 'Brazilian software'. Explicit efforts to bolster software development in Brazil are important, as software development costs are considerably higher in Brazil than in China and India.

Source: adapted from Gereffi and Sturgeon, 2013.

[4] See Gereffi and Sturgeon, 2013, for additional details.

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At first glance Brazil's current industrial policies may appear similar to the old-style import-substitution ones, but they are remarkably different in several aspects. As GVCs bring new actors and industry structures to the fore, the challenges, opportunities, and outcomes related to these policies are different. Reliance on global sourcing implies openness to knowledge and technology from abroad, and this is very different from the past. Moreover old-style protection policies also stifled competition, whilst the global battle to provide global suppliers represents a constant inducement to improve efficiency through the specialization in fine segments of the value chain, reflecting comparative advantage as much as possible.

A centerpiece of Brazil's strategy to increase local production of consumer electronics has been to attract global contract manufacturers, known in the industry as electronic manufacturing services (EMS) providers. As electronic lead firms such as Apple and Hewlett Packard continue to outsource manufacturing, contract manufacturers have become increasingly important players in the component purchasing, assembly, test, and after-sale service functions of electronics GVCs. Seven of the 12 largest contract manufacturers are based in Taiwan, and they all suffer from low profit margins (just 2.4% in 2011) due to intense competition. They fill an increasingly complex role in the electronics GVC since they must not only work closely with lead firms to develop products and meet tight production schedules, but also with a worldwide network of component manufacturers and distributors to ensure that they meet demand and keep their lines operating at, or near, full capacity. They perform an important role of coordination of local suppliers, reducing uncertainty of final consumption by presenting market opportunities and setting, showing the standards to fulfill markets requirements, and making investments with large minimum scale requirements possible.

Thanks to Brazil's industrial policies and direct pressure on the company from policy-makers, Foxconn has begun to assemble iPhones, iPads and most recently iPad minis for Apple in Brazil. While Foxconn currently imports 90–95% of its components, the company is likely to begin to manufacture components, including displays, in Brazil. Recent negotiations for a fifth Foxconn factory in Brazil suggest that once production is at 100% (projected to be 2016), Foxconn will be manufacturing additional components including cables, cameras, touch-sensor glass, LED products, and printed-circuit boards (Taipei Times, 2012).

The story of Hewlett Packard (HP) also offers interesting insights on the integration between foresight and industrial policies in the GVCs. HP uses three global contract manufacturers to produce in Brazil (Foxconn, Flextronics and Jabil Circuit). But hardware production is only part of the picture. In meeting the requirements for local R&D spending (4% of sales), HP Brazil employs 400 engineers and researchers in its lab in Southern Brazil and has contracts with another 1000 collaborators from universities and research centers in the country. It also has four software centers working on local customer-specific applications, while contract manufacturers are being used to help meet the R&D spending requirement. Two of HP's research centers have been set up in collaboration with the Flextronics Institute of Technology's (FIT): the Radio Frequency Identification (RFID) Center of Excellence, which has worked on over 100 RFID-related projects with HP; and the newer Sinctronics IT Innovation Center, which focuses on environmental compliance and product recycling. R&D capacity, just as like the manufacturing capacity of contract manufacturers, can serve multiple lead firms. FIT performs R&D on behalf of competitors like Foxconn and Compal which do not have the R&D facilities in Brazil, and has therefore been able to develop economies of scale in R&D, with remarkable externalities.

The presence of global contract manufacturers in Brazil generates a number of immediate advantages. It creates new jobs — Foxconn currently employs 6000 in Brazil and could add 10,000 more jobs by 2016. Moreover, because contract manufacturers serve multiple customers, their manufacturing capabilities can satisfy local content requirements for multiple brands as production is flexible enough and capacity can be switched towards different product categories and firms.

In sum, the focus of Brazil's industrial policy to attract investments from contract manufacturers, as well as GVC lead firms, signals a sophisticated understanding of the dynamics of the electronics GVCs by policy-makers. Contract manufacturers provide a leading edge, flexible, and scalable platform for local production and R&D. Furthermore, the Brazilian case suggests that learning within GVCs is possible if supported by appropriate policies. Arguably, the government understood that TF needs to be fully inserted into a modern industrial policy approach to strengthen the country's innovation capacity.

5.3. Technology foresight in Chile: CNIC's efforts to foster innovation and address dynamic-inconsistencies

The Chilean innovation system has been suffering from several bottlenecks (OECD, 2013). The most difficult to address has been the poor institutional coordination which inevitably reflected in the low trust that private sector had towards public/private business relations. Nevertheless, the Chilean political will has recently become more supportive of innovation *via* various reforms encouraging firm's R&D investments. TF programs were launched only recently (beginning of 2000) on a national basis and they were adopting Delphi methods to select the key economic activities to promote (Popper and Medina, 2008).

A recent concrete institutional effort towards the strengthening of the NIS, which is key to TF exercises, has been made through the establishment of the National Innovation Council for Competitiveness (CNIC) in 2005, the most important institutional innovation in the last 30 years (Zahler et al., 2014). CNIC embodies a permanent private-public partnership advising the Chilean government on long-term strategies related to innovation and competitiveness. The Council directly responds to the President of the Republic and in fact it should serve as the interface between the President and various Ministries (Finance, Education, Planning, *etc*.).

Inspired by the Finnish experience and hence based on a coordination model (Box 1), CNIC serves as a platform to agree on policy priorities with a clear and consistent consensus. Its guidelines are part of the White Paper (CNIC 2010). Every 4 years CNIC provides an evaluation of the accomplishments achieved, as well as an evaluation of the Chilean Industrial Development Agency (CORFO) and the National Council on Science and Technology (CONICYT). For its inherent nature, CNIC can be regarded as a foresight-oriented organization since it is entrusted directly by the government to define the direction of national innovation strategy.

Along with CNIC, the government also established the Innovation for Competitiveness Fund (FIC) that finances CNIC's decision once they obtain governmental approval. FIC's resources draw from a levy on mining introduced with the mining law (Zahler et al., 2014). The CNIC actively engages with its counterpart in the government, the Ministerial Commission for Innovation (*Comité de Ministros para la Innovación* — CMI) funded in 2007, an implementation body of innovation policies.

CNIC's operative mandate is based on three pillars, namely:

- fostering a high-quality lifelong learning to increase the quality of human capital;
- supporting scientific communication and dissemination aimed at applying knowledge to concrete productive and social needs; and
- enhancing private sector involvement in the design and implementation of foresight exercises and concomitantly fostering internal R&D (Crawford et al., 2010).

One of CNIC flagship programs was the “Cluster Program”, a vertical policy inaugurated in 2007 (and now discontinued) which witnesses the Council's capacity to introduce more selectivity through foresight within innovation policies (Zahler et al., 2014).

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5.3.1. CNIC evaluations and critiques

The international experience of national innovation councils hints by and large to a continuous trial and error process before they set to work efficiently. The Chilean case is not an exception in this regard. The council in fact had to deal with a number of structural problems (*i.e.* the change of government in 2009 discontinued some already initiated programs).

A certain degree of experimentation has been crucial in order for CNIC to adapt to the context in which it operates. Some major bottlenecks have been identified, namely: the role of the Council should be set clearer so to guarantee its neutrality as an advisory body; the council should also improve the communication among different government bodies and agencies so as to generate an efficient and transparent social networking; and the legitimacy of the Council should be founded on clear basis in the parliamentary legislation (and not on a presidential decree) (OECD, 2009).[5] This aspect is especially important for TF policies since a clearer legitimacy can foster the council capacity to solve dynamic inconsistency issues (OECD, 2009).

All these recommendations have to deal with a more sophisticated level of institutional set up required for the CNIC to operate more effectively. They also highlight the fact that technological and economic change need to be sustained by appropriate institutions able to overcome the political dynamic inconsistency that prevents the NIS to flourish. CNIC's institutional answer to foresight policies requires a considerable commitment in many respects. The council should actively engage to align ministries and agencies towards a common vision. Ministries in turn have to give up part of their autonomy in favor of a national innovation policy. Ultimately, the challenge for CNIC is to establish itself as a credible advisor of the government and help systematize competitiveness and innovation policies (OECD, 2009). In addition, a participatory approach should be constantly encouraged. CNIC aims at becoming an arena where critical inputs/information on the Chilean NIS can be discussed, and where a collective and strategic intelligence can be pursued by gathering together different actors with different interests.

In sum, despite significant investments and a favorable macroeconomic environment, Chile has not yet succeeded in becoming an innovation-based diversified economy (OECD, 2013). However, institutions like the CNIC can help tackle and solve Chile's NIS inherently highly fragmented nature. A certain degree of experimentation is still needed to improve its role and functioning, but efforts to learn from past initiatives have been a central and very appropriate feature of its experience.

Two important outcomes emerge from the analysis of the Chilean case. First, CNIC has the potential to act as a key foresight actor within the Chilean NIS since initiated a process to establish an innovation culture in the country with a stronger interaction between the public and private sectors. Second, and consequently, this institutional set up promises to help the country address the typical dynamic inconsistency and distance between TF and an appropriate industrial strategy.

6. Summary and conclusions

In this paper we have argued that the link between TF and industrial development strategy needs to be taken seriously in light of its role to shape technological change and economic growth. Since TF and industrial strategy essentially pursue the same goal and are two sides of the same coin, they need to be coherently designed and implemented. When Technology Foresight began to be adopted in industrial countries, it tended to be still somewhat a marginal activity in developing countries. It was then believed that TF and its prediction of the future was a matter that only highly industrialized countries could endeavor, being more engaged and interested in frontier and "new to the world" innovation.

Today globalization, increased complexity, competition and fast technical change make it imperative for countries to specialize by technology and learning. This new competitive setting offers a window of opportunities for developing countries that need to devise an appropriate industrial strategy to address these complexities and interdependencies.

In addition to providing insights about critical technological areas, TF can prove a valuable instrument to add coherence to S&T policy in developing countries but needs to be designed and implemented together with the country's industrial strategy. The experiences we explore from Brazil, Chile and South Korea, where this coherence has been sought successfully, provide preliminary support to our argument.

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[5] In the UK the council is defined on a parliamentary basis, and a simple ministerial decision is effective in signaling an intention so to align actors towards it.

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