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Sustainable development and industrial development: Manufacturing environmental performance, technology and consumption/production perspectives

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SUSTAINABLE DEVELOPMENT AND INDUSTRIAL DEVELOPMENT: MANUFACTURING ENVIRONMENTAL PERFORMANCE, TECHNOLOGY AND CONSUMPTION/PRODUCTION PERSPECTIVES

M. Mazzanti*, F.Nicolli+, G. Marin+, M. Gilli*

Abstract

The aim of this paper is to analyse the environmental performances of manufacturing sectors and their main drivers, (economic factors, technology, trade). We analyse the dynamic development of environmental performances, in absolute terms and in 'productivity' terms, through both decomposition and econometric analyses. The analysis aims to highlight differences over time, across geographical areas, by country income categories and by sector technological classes. Strong emphasis is assigned to the comparison of consumption and production perspectives.

Keywords: Environmental Performance, Sustainability, Consumption and Production perspective

JEL Classification: E21, O11, Q56

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1. Introduction

The work aims at analysing the environmental performances of manufacturing sectors and their main drivers, namely economic factors, technology, trade among others. We analyse the dynamic development of environmental performances, both in absolute terms and in 'productivity' terms, through both decomposition and econometric analyses. The analysis aims to highlight differences over time, across geographical areas, by country income categories and by sector technological classes. Strong emphasis is assigned to the comparison of consumption and production perspectives.

We here first describe the performances of countries and sectors in terms of carbon dioxide emissions and environmental productivity performances, namely economic value on CO_2 (Gilli et al. 2014)[1]. Here and in the more analytical investigations below, the framework of reference is based on the Environmental Kuznets curve (EKC) approach and the IPAT (Impact Population Affluence Technology) identity, the latter being to some extent a broader conceptual framework that embeds the former. Both paradigms allow investigating how environmental performances are (dynamically) affected by population (Martinez-Zarzoso et al. 2007), GDP, technology (Vollebergh & Kemfert 2005), composition effects, trade among the most relevant determinants (Mazzanti & Montini 2010; EEA 2013; EEA 2014; Levinson 2009, for a discussion of the role of trade, composition and technology as drivers of a country environmental performance).

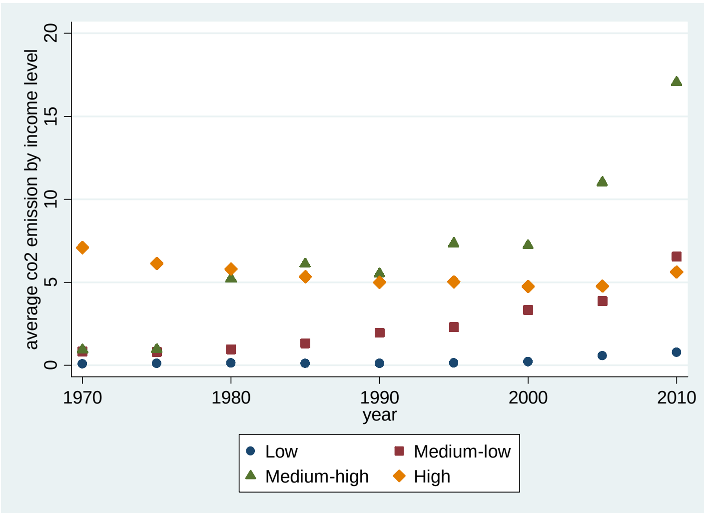
The dynamics of CO_2 by country income categories (Figure 1), outlines that high income countries – in their aggregate figure – have slightly reduced their direct emissions in manufacturing sectors overall (Musolesi et al. 2010), while both medium low and medium high income groups have witnessed increases. The depicted situation clearly shows that there is still an increasing production of carbon dioxide worldwide. It is worth noting that there could be a 'link' between the higher elasticity of carbon dioxide to income in medium low and medium high income groups and the role of trade (e.g. moving production abroad, off-shoring and out-sourcing production of heavy manufacturing as key examples), which explains part of the emission reduction in high income countries. Worldwide emissions in manufacturing sectors are somewhat increased by the natural demanufacturing of more advanced countries, if the goods are produced at higher CO_2/value added intensity in emerging countries (e.g. toys, hardware, etc.). Being such demanufacturing a natural evolution of economic systems, environmental and innovation policies should target technological

[1] The evidence in this work is circumscribed to manufacturing.

transfers, in addition to the aim of minimising environmental regulations costs in the short run, when the two aspects may be in conflict.

Figure 2 complements the income-related analysis by sector-oriented insights. Again, in coherence with what said above, medium technology sectors have contributed more than others to the increase in emissions. Low technology sectors are largely present in medium low and low-income countries with specialisation in manufacturing goods of low and medium technological content, while on the contrary high income countries are specialised in high tech sectors[2]. The share of medium tech sectors appears to be constant across income group, especially in the last decades (See Table 1). Figure 3 gives additional evidence on the closer link between CO_2 and income in medium technology cases, compared to high technology sectors. High tech sectors do not present a meaningful correlation between carbon dioxide emissions and value added.

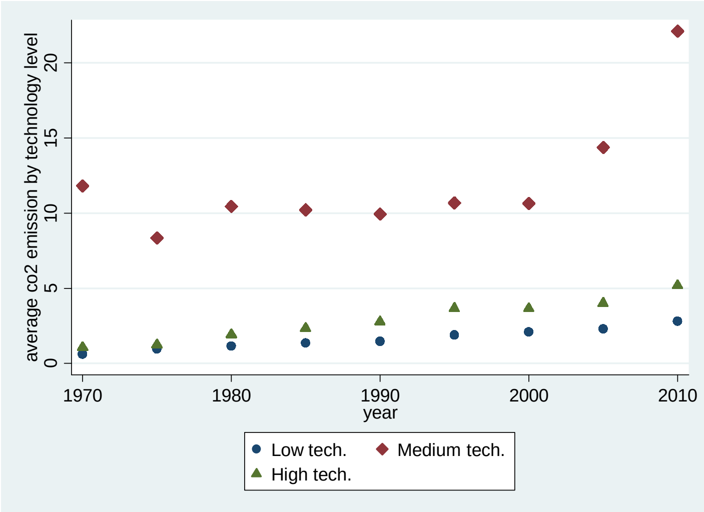
Figure 1 – CO_2 emissions by income level (World Bank categories)



Source: own elaboration on the UNIDO-INDSTAT2 and IEA databases.

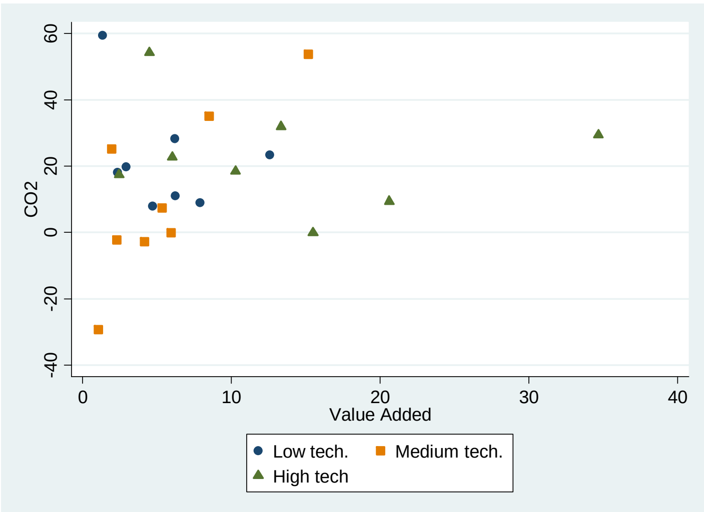
[2] Figures A4 to A7 in Appendix A allow a more detailed perspective, showing the evolution of CO2 emission and environmental productivity from 1970 to 2010.

Figure 2 - CO_2 emissions by technology classes (UNIDO categories)



Source: own elaboration on the UNIDO-INDSTAT2 and IEA databases.

Figure 3 - CO_2 emissions and value added



Source: own elaboration on the UNIDO-INDSTAT2 and IEA databases.

Table 1: Distribution of value added (VA) across technological groups

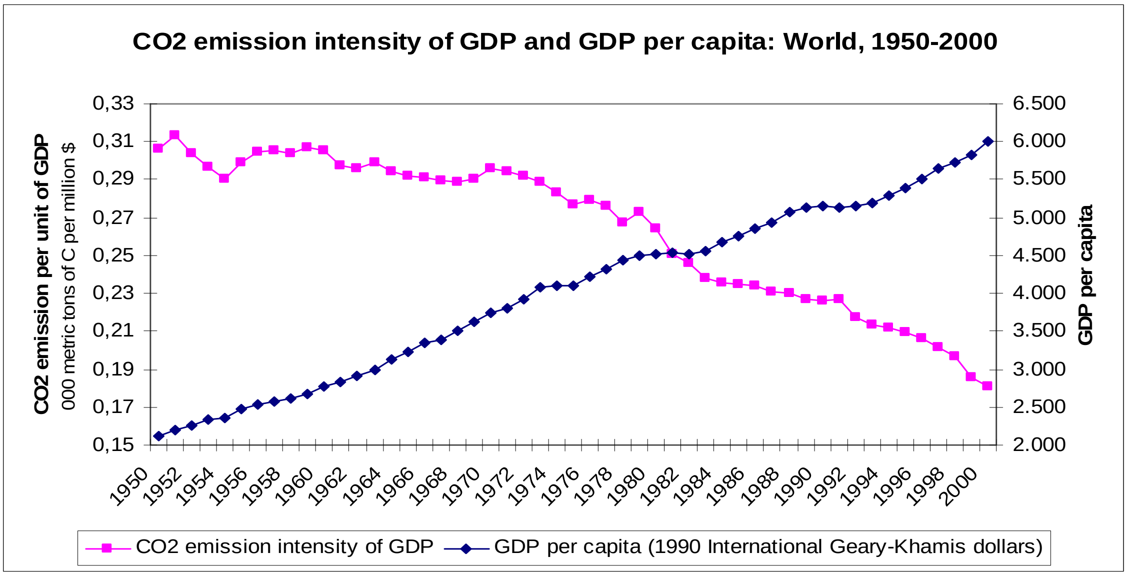
		%			
		Low income	**Medium-low income**	**Medium-high income**	**High income**
1970	**Low tech**	79.39	52.95	45.10	33.39
	Medium tech	5.83	17.39	23.00	19.81
	High tech	14.77	29.66	31.91	46.80
1980	**Low tech**	64.59	47.73	38.45	31.93
	Medium tech	10.39	16.96	25.00	19.85
	High tech	25.02	35.31	36.54	48.22
1990	**Low tech**	63.92	45.13	28.82	30.24
	Medium tech	10.69	20.25	22.69	19.65
	High tech	25.39	34.63	48.48	50.11
2000	**Low tech**	68.37	42.88	35.40	26.60
	Medium tech	8.02	18.37	21.74	19.80
	High tech	23.62	38.75	42.86	53.60
2010	**Low tech**	59.57	32.80	28.48	22.95
	Medium tech	19.28	22.82	25.80	21.16
	High tech	21.15	44.38	45.72	55.89

Source: own elaboration on the UNIDO-INDSTAT2 database.

These empirical facts shortly but coherently narrate pieces of a Kuznets-like dynamics: high technological intensity and high value added specialisations allow reducing emissions, then trade development (e.g. increased net imports of polluting goods) may further contribute to this reduction[3], making necessary to explore both production and consumption perspectives (Marin et al. 2012; EEA 2014) along the evolution of economic systems. It is worth noting the *joint* role of economic value and technology to generate emission reductions: those are two factors that are characterised by dynamic co-causations, one being the driver of the other and vice versa (Costantini & Mazzanti 2012; Costantini et al. 2013). Nevertheless, only a robust technological progress may reverse the CO_2 increasing trend: Figure 4 shows how the significant increase in CO2/GDP levels was not to sufficient to outweigh the GDP scale effect.

[3] The role of Trade is often complex for what it concerns its dynamic relationship with environmental performances: trade flows embody (increase) emissions but also technological flows.

Figure 4 – CO_2 emission intensity and GDP trends in the post second world war period



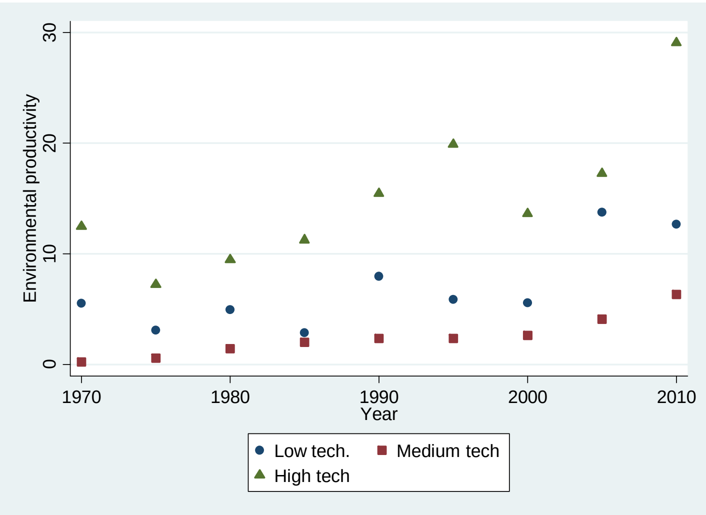
Source: World Bank.

Environmental productivity (EP) is the factor I/A within the IPAT framework[4]. We here define EP as economic value over CO2 emissions (similarly to labour productivity which is defined as VA[5]/L): the investigation becomes more complex since EP is composed of two latent trends regarding carbon dioxide and economic values. The key element is anyhow the elasticity of carbon dioxide to income, when GDP either increases or decreases. Figure 5 show the increase in CO_2 related EP: high technology sectors are associated with the most robust performance, in dynamic (trend) and comparative terms[6]. The gap with low tech sectors shrunk over 2000-2005, then re-increased. It is worth noting that the gap increases – in favour of high tech sectors – over 2005-2010, a peculiar period which is difficult to assess taken as a whole. 2005-2007 was a period of high growth, then the world economies collapsed in 2008-2009, slightly recovering in 2010. All in all, data tell us that the turmoil of high growth combined with a crisis produced an improvement in the EP indicator for sectors which are able to produce higher value added out of their inputs. The gap increased in the last period but was historically always significant: technology, income and environment may move together to increase the chances of our economies being sustainable. The issue is nevertheless how to increase the EP performance in medium technology sectors, which are an example of possibly less affected by international trade – to increase value - and international policy pressures to reduce emissions.

[4] I≡POP*A/POP*I/A, where A stays for GDP.
[5] Value added
[6] Figures A1 to A3 in Appendix A, offers further insights showing a more detailed sectorial perspective.

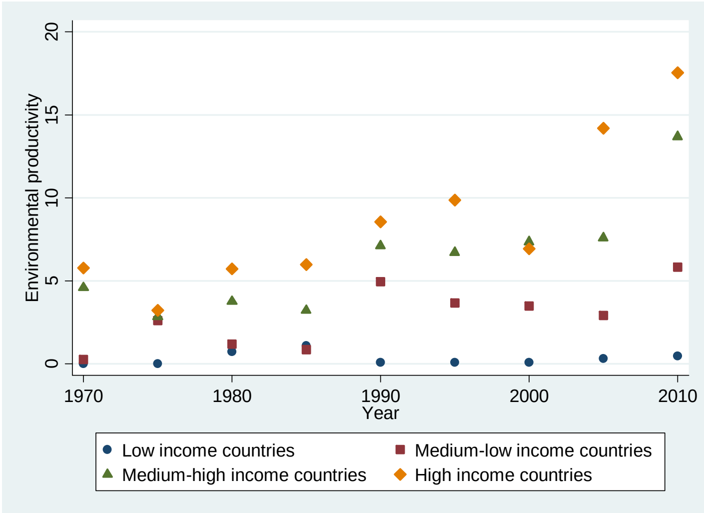
Regarding countries categories by income (Figure 6), it is clear from the observed trends that there is a potential convergence, possibly mediated by trade integration and increasing techno-economic relationships, between high income and medium-high income countries. Two different 'trends' of EP appear: a stagnating path for low and medium low income countries and an increasing one for medium high and high income areas. Increasing environmental productivity, as it is well known, is a necessary but not sufficient condition to achieve a full decoupling. We have observed some 'positive' trends that are nevertheless confined to some world areas and sectors. A risk we highlight is a potential divergence between EP performances, which may be driven by technological divergences across sectors. Again, policies should pay attention to innovation diffusion and to the integration of trade and technological aspects.

Figure 5 – Environmental productivity (VA/CO2) by technology classes (UNIDO categories)



Source: own elaboration on the UNIDO-INDSTAT2 and IEA databases.

Figure 6 - Environmental productivity (VA/CO2) by income level (World Bank categories)



Source: own elaboration on the UNIDO-INDSTAT2 and IEA databases.

Technological progress will be investigated in the following quantitative analyses as a key driver of increased environmental performances. In the IPAT Identity, technological progress T is the factor, which compensates for population P and affluence A (scale) effects on I (environmental impact). Vollebergh and Kemfert (2005) observe that for Carbon dioxide emissions decoupling is not yet apparent and that radical changes in energy technologies are essential. They conclude that: '*directed technological change conveys a positive message i.e., that shifting away from polluting technologies towards non- or less polluting technologies seems both possible and manageable through environmental policy (...). A widespread belief seems to exist that environmentally induced technological change would yield a double dividend*' (p. 144). Technology and time-related effects deserve careful attention. Mazzanti & Musolesi (2013) in fact find that: '*country-specific time related factors weight more than income in driving the northern EU Environmental Kuznets. Overall, the countries differ more on their carbon-time relation than on the carbon-income relation which is in almost all cases monotonic positive*' (p.1).

Trade issues will be also carefully scrutinised in the more analytical sections, namely the role of trade openness and 'production vs consumption' perspectives (e.g. increased net imports of polluting goods) to explain dynamic environmental performances by countries and world areas. The core hypothesis that regards trade and country emission performances revolves around a couple of critical points. On the one hand the pollution haven hypothesis suggests that more stringent regulations in high income countries move emission intense production abroad; on the other hand we should be aware that environmental regulations costs are only a fraction of total costs and, in addition, rich countries could still have price unrelated (non Ricardian) competitive advantages (motivated by the Heckscher Ohlin theorem), which relate to the abundance of (emissions heavy) capital (Wagner & Timmins 2008). Empirical evidence should provide guidance and shed light on the role of trade. Levinson (2009) concludes for the US: '*For the typical pollutant, increased international trade explains less than one-third of the pollution reductions from composition changes in US manufacturing, and only one-tenth of the overall pollution reductions from manufacturing. By far the most important contributor to reducing manufacturing pollution has been technology*'. We here focus on carbon dioxide emissions and not pollutants as such. The evidence on the role of technology, income and trade is geographically and temporally specific. In the following, we offer a macroeconomic glance with a focus on main world areas.

The following sections convey new evidence on the income, trade and technology drivers of carbon dioxide emissions produced by industrial development. We will present insights based on econometric and input output analyses, which touch both the production and consumption side of environmental performances. *Section two* presents two exercises of decomposition analysis of worldwide manufacturing CO_2 emission, one through time and one across countries. *Section three* presents empirical exercises aimed at testing for the presence of a non-linear EKC path, accounting for the role of technological change, while *Section four* extends previous works, comparing direct and indirect emissions performances. Finally, *Section five* lists the main highlights and original outcomes.

2. Decomposition analysis of emissions in the manufacturing sector

In this section, we present two different exercises of structural decomposition analysis. The first one (index decomposition analysis) exploits the time dimension of the panel of data, allowing to study how scale, technological and composition effects influence aggregate emission performances of manufacturing sectors worldwide; the second one relies on the geographical dimension only (shift share analysis), by comparing each country with the world-average and the geographical and income-class average.

2.1 Index decomposition analysis

The aim of the first analysis, presented in the table below, is to decompose CO_2 emission into its three main components, i.e. *technological effect, scale effect and composition effect*. According to the Environmental Kuznets curve framework (See among others Grossman & Krueger, 1995), environmental performances depend on these overlapping forces: on one side, the scale of the economy exerts a negative effect on environmental performances, reflecting the effect of the growth in anthropogenic pressure due to population and affluence growth; on the other side, the advancement in technological capabilities and a change in the composition of the economy have a positive effect on overall environmental performance. In particular, the effect of a change in composition is non-trivial. Standard economic theory refers here to a shift towards a service-based economy, which is generally seen as favourable for the environment given the general low level of direct emission of services sectors. There are however at least two argument against this theory: firstly, the so called "cost disease theory" (Baumol 1967) suggests as in services there are generally lower opportunities for innovation with respect to manufacturing, with a consequent lower opportunity for efficiency gain in the medium run, also in terms of improved environmental performance (Cainelli & Mazzanti 2013). Secondly, many sectors, despite having low direct emissions rely heavily on several industrial and high polluting inputs, which partially offset the environmental gains of a service-based economy. In this specific work, however, we focus on manufacturing sectors only and, consequently, the composition effect reflects here the composition of the manufacturing (refer to Appendix C for further methodological details). In particular, the figures below reflect the role played by the shift in the macro composition of the manufacturing sector, i.e. the share of high, medium and low tech sectors (and is represented by the red bar in the graph). Similarly, the green bar in the graph represents the role played by the shift in the composition within the macro sectors, or alternatively the sub-sector composition. With this approach, we focus more heavily on industrial production and the composition effect has to be interpreted accordingly. Finally, the technological effect is very straightforward to interpret, and is intended as the efficiency gain due to green technological change, which is supposed to increase environmental productivity, i.e. the relationship between the output produced and the level of emission, or alternatively between output and input used in production. In the figure this effect is proxied by "emission intensity of value added", the blue bar. Finally, the purple bar reflects the change in emissions due to the change in the scale (Value added) of the manufacturing sector as a whole. From a methodological perspective, it has to be noted that the scale of the figure reflects percentage changes, and that, by construction, each of these four effects has to be considered holding the others constant[7].

[7] For instance, in the first graph for Low income countries, the last diagram on the right means that a change in the volume of the manufacture (purple bar) has been responsible, over the period 2005-10 of about the 400% increases in CO_2 emission, holding the composition and the emission intensity of the sector constant. Similarly, the blue bar means that the technological effect, which finds proxies here by emission intensity, has been responsible for about a 200% decrease in CO_2 emissions, holding composition and scale effects constant.

Comparing the four graphs of Figure 7, which represent respectively Low, Mid-Low, Mid-high and High income countries it is possible to have a quick comparison of time decomposition of CO_2 emission across these different aggregates[8].

The first striking evidence relates to the size of the effects. As can be seen in comparing the scale of the four graphs, the magnitude of the four effects decreases when moving from low income (which range from -10 to +15) to high income countries (associated with a range of variation between -3 and + 3). This effect is due partially to the different scale of the economy between the four income groups. The percentage variation is in fact much more sensible to subtle increases/decreases when the scale of the economy is small. Secondly, high income countries tend to have a more stable economic system characterised by more stable economic and environmental trends. More interesting evidence can however be found by comparing the four trends. If we consider, for instance, the technological effect only, comparing the four graphs a clear tendency emerges. Technology played a relevant role for high income countries until the 1990s, being the main driver of emission reductions, as shown by the graph in the bottom right position. The technological effect in this group is always negative as expected but its magnitude shrunk. This is probably due to the increasing trend of marginal cost of abatement, which this group experienced in the last decades. On the contrary, for the other groups the technological effect seemed to be reinforced in the last two decades, due to a mixed set of factors, like economic growth, compliance with international environmental treaty (like the Kyoto protocol and the Montreal protocol before it) and a general more widespread awareness about environmental protection.

This first result suggests two orders of conclusions. On the one hand, high income countries in order to face the stringent CO_2 abatement targets proposed for instance in the EU have to cope with increasing marginal cost of abatement in manufacturing sectors, which can make costs of compliance with environmental regulations much higher. On the other hand, this result suggests that there is substantial room for action for environmental policies in the other income groups. This result is even more interesting if we read it together with the purple bar, i.e. the one referring to the value added of the industrial sector. The evidence here is very straightforward to interpret. The importance of the scale effect is decreasing through time in high-income economies, due to a general decreasing share of manufacturing activity in the economy, while on the contrary it is getting always bigger in the other groups due to the stronger industrialisation in these areas. Overall the scale effect is always positive in the analysed period. Finally, it can be noted that both the macro

[8] Comparison of different time period in the same country group has to be taken with care, as due to data constraint not all the time periods have the same number of countries. Has a consequence these graph have to be considered as an overall description of the phenomena more than a precise quantification of the effects.

sector and the sub-sector composition effect tend to be of a low magnitude, being responsible only for a small fraction of total CO_2 emissions (Levinson 2014).

Finally, Figure 8 presents the same analysis for some selected big countries. It is interesting to notice as the main conclusion drawn before for the aggregate income group holds also in this case. If we consider for instance two high income countries, such as France and the United states, they have been characterised by a relevant role of the emission intensity component in reducing emissions up until the beginning of the 1990s, but after that date the technological effect tends to lose relevance. Similarly, the scale effect is initially big and positive, and then starts to decline in the last two decades. On the contrary, India and especially China show the opposite evidence, having the increasing trend of the scale effect linked to the strong industrialisation experienced in the last decade by these two countries and being associated by an increasingly relevant role of the emission intensity component in mitigating the scale effect.

2.2 Shift share analysis

Shift share analysis is a common tool in regional and urban economics (e.g., Esteban 2000): it is employed when researchers have interest in decomposing the factors characterising different growth or intensity differentials between a single region (or a single country) and a benchmark (for instance the country in which the region is contained or, in our case, the countries with respect to the world average). Concisely, the technique decomposes the growth or intensity differential between each regional and the national average into its two main factors: the region performing generally better than average or a regional specialisation in fast growing sectors. In the present paragraph, we adopt the shift-share analysis to decompose the total emission efficiency differentials into three components, called structural (M), differential (P) and allocative (A), which can be interpreted as follows[9] (refer to Appendix D for further methodological details):

1. The differential factor (P), which reflects that part of differential emission due to environmental efficiency. The index assumes positive (negative) values when the country is less (more) efficient in term of emissions, under the assumption that the country mix is the same.
2. The structural factor (M) reflects a country sectorial mix, and indicates the environmental efficiency share due to a particular sectorial combination in a country with respect to the world average. This value assumes positive (negative) value if the region is specialised in more (less) polluting sectors (according to the chosen indicator).

[9] In doing so we follow Mazzanti & Montini (2010) and Gilli et al. (2013) to which we refer for further details on this techniques.

3. Finally, the last factor, called allocative component (A) is calculated as the covariance between the previous two components, and represents the contribution to the emission differential between the country and the world average given by its specialisation in more environmental efficient sectors. A positive (negative) value would mean that country is specialised in more (less) polluting sectors, which are less (more) efficient with respect to the world average.

It is relevant to notice that the sum of these three components gives the exact emission efficiency differential between the country and the world average. As a consequence, the analysis coefficients reported in the following tables are very straightforward to interpret, and a negative sign always means a better than average performance, and a positive sign a worse than average performance. Finally, we note that also in this case the analysis has been conducted on manufacturing sectors only.

Table 2 below presents the first aggregate evidence, in which the performance of the four different income groups is compared with the world average. Several interesting differences emerge across the groups. Firstly, it can be noted as the sectorial mix is a relevant factor only for low income and high income groups, which appear to be specialised in less polluting sectors with respect to the world average. This result can be derived by the coefficient of the M component, which is negative for these two groups. The opposite evidence can be found for mid-low and mid-high groups, which detain the core of heavy polluting manufacturing sectors. By contrast, the only income group that shows a negative and below the average value of the differential factor is high income, that is always environmentally more efficient than the other groups. This result is perfectly in line with environmental Kuznets curve framework, which is based on the assumption that being environmental protection a normal good, its demand increases with the income level. Finally, the last component shows an interesting evidence. Low and mid-low income countries tend in fact to have all negative values in the covariance component, which means in other terms that they are specialised in sectors in which they are more environmental efficient than average. This is an interesting result, which underlines that despite these countries tend to be, on average, less environmental efficient than the world level, they nevertheless have a sort of 'green specialisation'. Finally, it is interesting to notice that these cross sectional decomposition do not change in a significant way across time, and all considerations made above tend to hold over the entire analysed period. This main evidence is confirmed in Table 3, which presents the same analysis but at country level. If we consider for instance the differential factor (P), several high income countries present higher than average performances, which means that they are more environmental efficient than average. This is for instance the case of Austria, Australia, Italy and the USA.

Figure 7 – Decomposition of CO_2 emissions from manufacturing sectors (own elaboration on IEA and INDSTAT data)

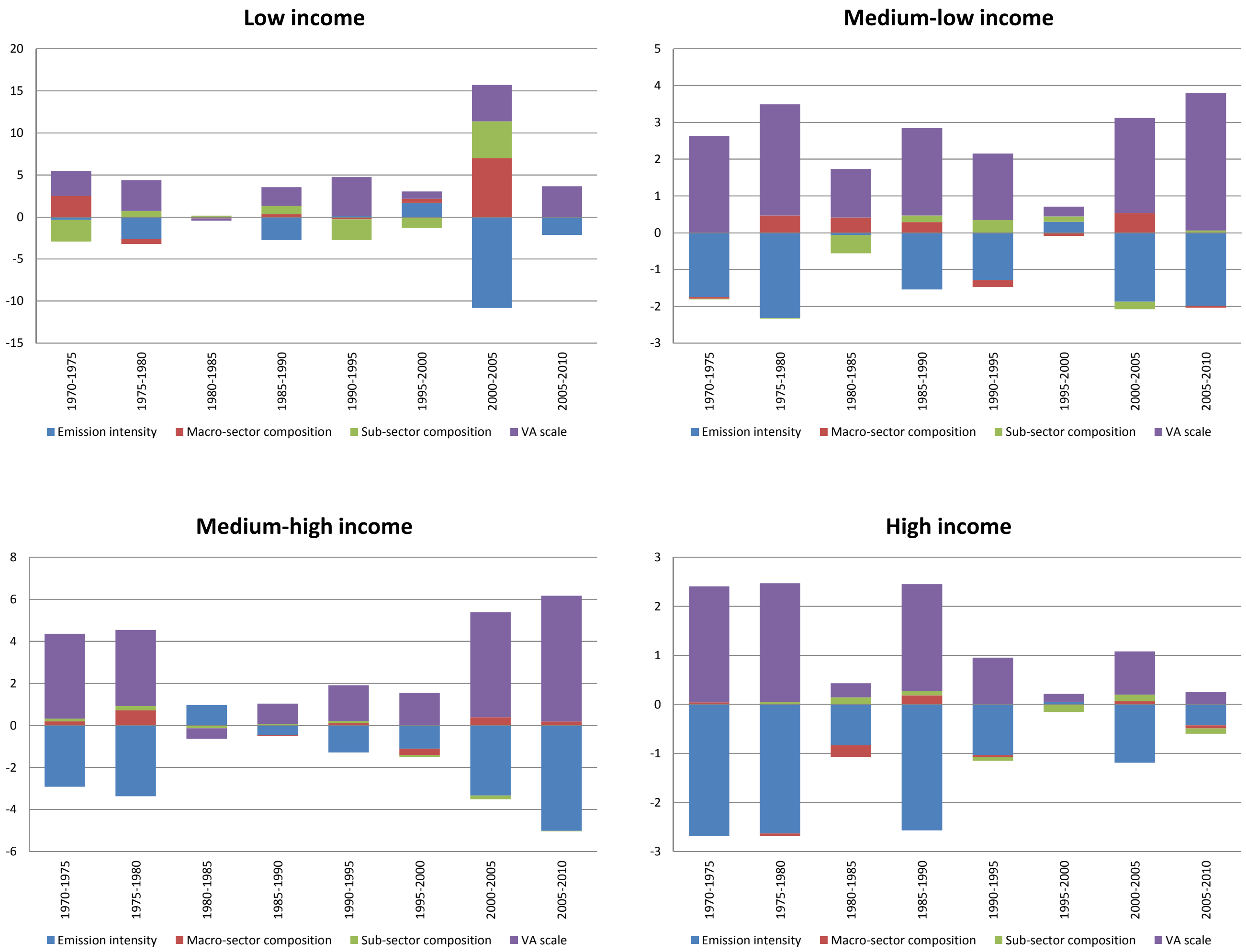


Figure 8 – Decomposition of CO2 emissions from manufacturing sectors in selected countries (own elaboration on IEA and INDSTAT data)

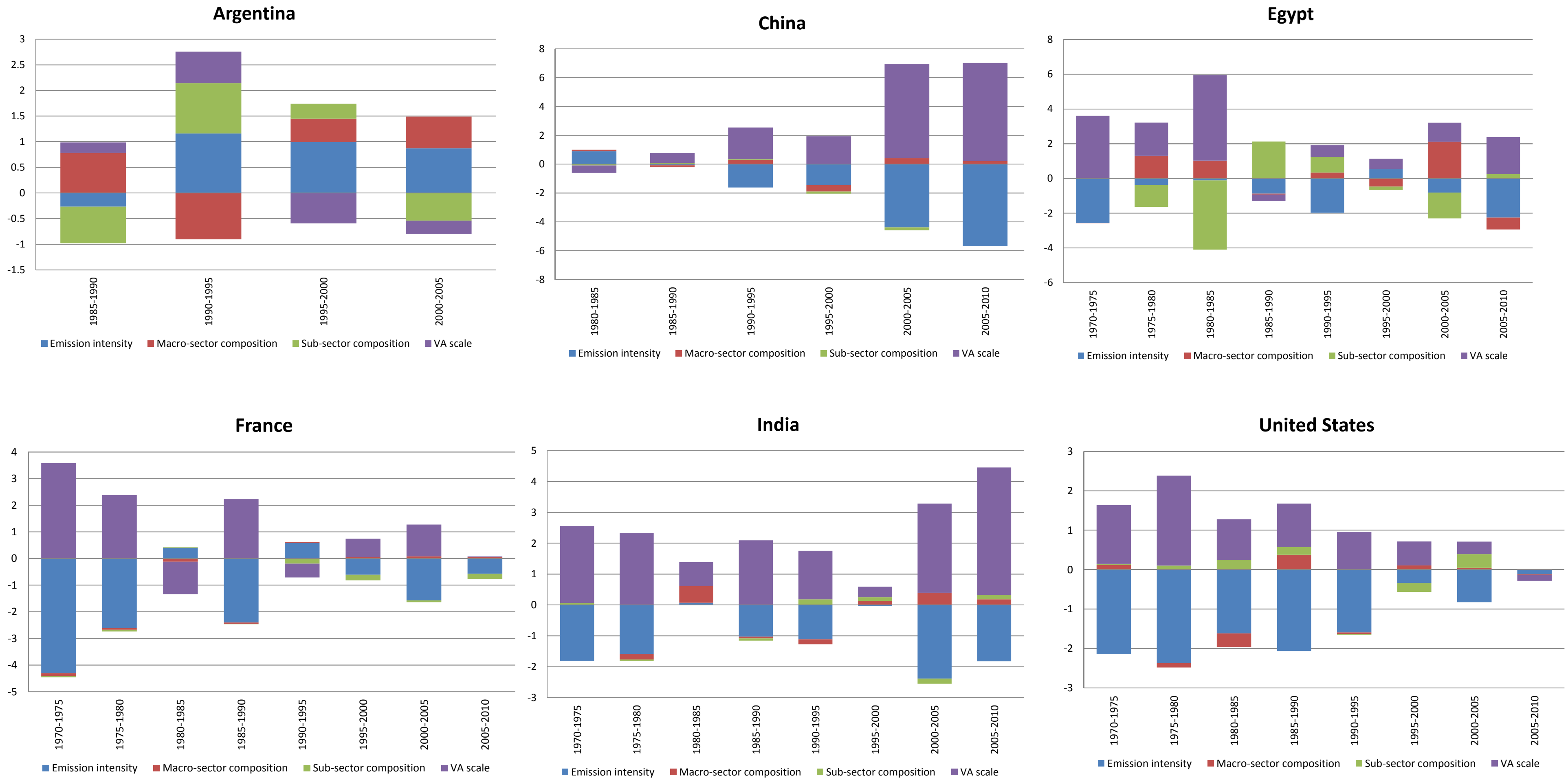


Table 2 – Shift share analysis (CO_2/VA, compared with world average – own elaboration based on IEA and INDSTAT data)

Income group	Component	1970	1975	1980	1985	1990	1995	2000	2005	2010
Low income	P	12.13	2.88	2.08	1.9	1.41	3.58	6.57	0.76	0.34
	M	**-2.13**	**-0.55**	**-0.42**	**-0.22**	**-0.13**	**-0.11**	**-0.03**	0.12	0.05
	A	**-9.52**	**-1.37**	**-1.29**	**-1.13**	**-0.77**	**-3.46**	**-6.35**	**-0.81**	**-0.45**
Medium-low income	P	8.8	6.57	3.25	3.91	3.71	2.48	2.88	2.28	1.55
	M	**-0.67**	**-0.31**	**-0.18**	0.1	0.06	0.11	0.13	0.13	0.07
	A	**-0.94**	**-1.59**	**-0.66**	**-0.99**	**-0.94**	**-0.49**	**-0.55**	**-0.43**	**-0.28**
Medium-high income	P	1.93	1.34	3.66	3.62	1.58	1.64	1.37	0.99	0.25
	M	0.2	0.08	0.16	0.22	0.14	0.14	0.16	0.12	0.1
	A	0.18	0.04	**-0.04**	0.11	**-0.24**	0.04	0.11	**-0.02**	0
High income	P	**-0.2**	**-0.17**	**-0.45**	**-0.43**	**-0.27**	**-0.27**	**-0.25**	**-0.27**	**-0.22**
	M	0.01	0	**-0.01**	**-0.02**	**-0.02**	**-0.02**	**-0.02**	**-0.03**	**-0.06**
	A	0	0	0	0.01	0.01	0.01	0.01	0.01	0.03

Table 3 – Shift share analysis (CO_2/VA, compared with world average – own elaboration based on IEA and INDSTAT data)

Country	1970			1990			2010		
	A	M	P	A	M	P	A	M	P
ARG				**-0.49**	0.1	0.35	**-0.31**	0.5	0.4
AUS	0.2	**-0.5**	0.83	0.7	0.11	**-0.19**	**-0.5**	0.4	**-0.4**
AUT	0.1	0.62	**-0.66**	0.2		**-0.43**		**-0.1**	**-0.29**
AZE							**-0.5**	0.1	1.35
BEL	0.42	0.53	0.97	**-0.1**	0.12	**-0.15**	0.1	**-0.2**	**-0.17**
BGD	**-9.52**	**-2.13**	12.13	**-1.86**	**-0.17**	2.29	**-0.45**	0.5	0.34
BGR									
BIH				**-0.1**	0.6	0.69			
BOL				**-1.15**	0.2	2.6			
BRA				**-0.21**	0.19	**-0.51**			
CAN	0.1	**-0.1**	0.6	0.3	**-0.2**	**-0.11**			
CHL	**-3.14**	2.54	**-1.5**	**-0.68**	0.3	0.29			
CHN				0.41	0.12	8.24	0.3	0.12	0.23
CIV				**-0.62**	0.23	**-0.24**			
COL	**-1.75**	**-0.87**	5.2	0.19	0.3	0.57	0.1	0.7	**-0.7**
CRI				0.8	**-0.1**	**-0.18**	**-0.17**	**-0.3**	**-0.1**
CZE									
DEU							0.2	**-0.11**	**-0.24**
DNK	0.17	**-0.51**	**-0.46**	0.6	**-0.5**	**-0.51**	0.5	**-0.7**	**-0.35**
DOM									
DZA	0.57	**-0.89**	**-2.93**						
ECU	0.22	**-1.7**	**-0.16**	**-0.18**	0.8	1.64	**-0.14**	0.4	0.2
EGY	**-12.22**	**-1.22**	22.74	**-1.34**	0.14	14.64	**-3.75**	0.28	5.1
ESP	0.34	0.89	1.58	0.2	0.3	**-0.29**	0.1	**-0.1**	**-0.18**
FIN	**-0.35**	**-1.4**	2.3	0.1	**-0.9**	**-0.24**	0.7	**-0.8**	**-0.27**
FRA	**-0.1**		**-0.3**		**-0.4**	**-0.3**		**-0.7**	**-0.21**
GAB									
GBR	0.1	**-0.9**	**-0.18**	0.1	**-0.4**	**-0.38**	0.5	**-0.9**	**-0.22**
GHA	**-1.52**	**-0.25**	0.35						
GRC	**-0.22**	**-0.12**	0.9	0.13	0.7	0.12	**-0.2**	0.5	**-0.17**
GTM	0.1	**-0.51**	0.56						

Country	1970			1990			2010		
	A	M	P	A	M	P	A	M	P
HKG				0.21	**-0.12**	**-0.53**			
HND				**-0.4**	**-0.2**	1.35			
HRV				0.6	**-0.5**	**-0.2**			
HUN	**-0.75**	1.26	**-0.85**	0.13	0.11	0.96		**-0.14**	**-0.14**
IDN				**-0.42**	0.1	1.69	**-0.41**	**-0.8**	1.1
IND	2.34	**-0.16**	9.94	**-0.12**	0.11	5.68	**-0.1**	0.16	1.88
IRL	0.67	**-0.55**	0.87	**-0.37**	**-0.9**	0.4	**-0.37**	**-0.4**	0.3
IRN	**-18.47**	**-1.68**	27.57	**-5.9**	0.27	8.74	**-2.54**	0.3	3.62
IRQ				**-5.7**	**-0.26**	6.8			
ISR	0.24	0.15	**-2.2**	0.13	**-0.13**	**-0.39**	0.11	**-0.8**	**-0.42**
ITA	0.1	0.58	**-0.25**	**-0.6**	0.3	**-0.18**	0.2	**-0.6**	**-0.26**
JOR				**-1.48**	0.34	2.75			
JPN				0.2	**-0.4**	**-0.43**	0.3	**-0.7**	**-0.24**
KEN				0.14	**-0.5**	0.71			
KGZ							**-12.98**	1.6	13.63
KOR	**-1.52**	**-0.49**	7.77	**-0.1**	0.1	**-0.21**	0.3	**-0.6**	**-0.26**
LKA	0.14	**-0.33**	**-0.41**	**-0.31**	**-0.16**	0.18	0.1	**-0.8**	**-0.29**
LTU									
MAR				**-3.12**	0.1	3.68	**-0.61**	0.13	0.65
MEX				**-0.9**	0.8	1.48	**-0.3**		**-0.1**
MKD						0.4	**-0.4**	0.4	0.47
MLT									
MNG							**-24.67**	0.15	26.71
MYS	5.79	1.85	2.96	0.27	0.5	0.49	0.12	**-0.3**	0.9
NGA	0.74	**-1.19**	**-1.32**						
NIC	0.48	**-1.56**	**-1.67**						
NLD	0.61	**-1.6**	0.7	0.12	**-0.9**	**-0.23**	0.4	**-0.8**	**-0.14**
NOR	**-0.66**	0.4	0.7	0.8	**-0.4**	**-0.35**			
NZL	0.32	**-0.83**	0.12						
PAK	**-0.33**	**-1.73**	4.19	**-2.99**	0.3	6.2			
PAN	0.17	**-0.68**	**-0.84**	**-0.7**	**-0.9**	0.36			
PER				**-0.38**	0.23	0.17			
PHL	**-2.13**	**-0.99**	4.76	**-0.3**	**-0.7**	0.3	0.5	**-0.12**	0.22
POL	**-0.8**	**-0.48**	1.86	0.3	0.6	0.87			
PRT	0.44	**-0.62**	**-0.11**	0.7	**-0.1**	**-0.2**	0.7	**-0.3**	**-0.26**
PRY	**-1.55**	**-2.49**	1.34						
ROU				**-2.51**	0.23	5.47			
RUS									
SAU				**-3.46**	0.43	6.2	**-0.37**	0.7	1.8
SEN									
SGP	0.22	0.15	**-2.84**	0.26	**-0.28**	**-0.65**			
SLV	0.15	**-1.39**	**-0.36**	**-1.24**	**-0.13**	1.79			
SVK									
SVN				**-0.4**	0.6	**-0.29**			
SWE	0.28	**-0.53**	**-0.98**	0.3	**-0.8**	**-0.37**	0.6	**-0.11**	**-0.32**
THA				**-0.12**	0.3	**-0.13**	**-0.2**	**-0.11**	0.44
TUN				**-2.2**	0.25	2.16			
TUR	**-1.5**	**-0.29**	1.43	**-0.48**	0.11	0.76	**-0.7**	0.3	0.7
TWN				**-0.17**	0.12	**-0.7**			
TZA				**-3.8**	**-0.11**	5.31			
URY	0.7	**-0.53**	**-1.37**	0.4	**-0.1**	**-0.39**	**-0.3**	**-0.12**	**-0.12**
USA	0.6	0.2	**-0.52**	0.5	**-0.3**	**-0.26**	0.3	**-0.4**	**-0.22**
VEN	**-0.17**	**-0.19**	1.65	0.17	0.28	2.33			
VNM									
ZAF	1.72	0.4	3.87	0.54	0.15	0.77	0.4	0.8	0.45
ZMB				**-2.93**	**-0.19**	3.78			

3. Environmental Kuznets Curves: achieving decoupling through Industrial development and technology

The aim of the section is to analyse the impact of income and technological factors on the environmental performance of developed and developing countries over time. We adopt as model of reference the consolidated Environmental Kuznets curves framework, which then links to the IPAT identity (Musolesi et al. 2010; Mazzanti & Musolesi 2013a; Musolesi & Mazzanti 2014; Marin & Mazzanti 2010).

We analyse EKC dynamics by using an unbalanced panel dataset which runs over 8 periods from 1975 to 2010, thus covering the era of oil shocks, the 1992 Rio Convention, and the post Kyoto Protocol period. We estimate EKC in a simple IPAT inspired reduced form – by fixed effects panel model - with the aim of testing non linearity with respect to GDP and the role of additional factors.

The estimated equation in a panel setting (i,t) is:

$$\frac{CO2}{POP} = \beta_{0} + \beta_1 \left(\frac{GDP}{POP}\right) + \beta_2 \left(\frac{GDP}{POP}\right)^2 + \beta_3 (TECH) + \beta_4 (Z) + \varepsilon$$

Where CO_2 is the amount of CO2 emissions from manufacturing sectors (from the EORA database, refer to Appendix B for further details). We will scrutinise both production, namely direct emissions produced by economic activities, and consumption perspectives (refer to Appendix B for further methodological details), namely direct and indirect emissions released to satisfy domestic final demand for manufacturing goods, to shed light on 'sustainable consumption and production' issues (EEA 2014). POP is population, GDP the income factor. Technological elements (TECH) are proxied given data availability by: the flow and stock of national patents (PATc, PATs) and spillovers (SPILL), constructed as the average patenting intensity in neighbouring countries. Z hosts additional relevant factors such as trade openness (TRADE) and inequality indexes (GINI). We use a parsimonious approach and include in the regression the factors one by one in addition to the GDP-only baseline regression, even though the correlation matrix highlights that most pair wise correlations are under 0.25. We will finally include time dummies and comment on the role of temporal (fixed) effects; to verify whether the significance of given factors (e.g. TRADE) is explained and absorbed by simple temporal contents. Descriptive statistics are presented in the appendix (table B.1).

We present estimates for the whole sample of countries and – to offer more interesting and eventually differentiated evidence by world areas: Europe, Asia, Africa, America[10]. The drawback is a reduction of observations.

3.1 Whole sample[11]

The aggregate evidence for production perspective CO2 emissions of manufacturing sectors does not reject the hypothesis of a Kuznets like inverted U shape relationship, with a turning point GDP level between the average and a maximum GDP observed in the sample (Table 4). The evidence is robust to the inclusion of temporal effects, which further show that the decade after 2000 is especially linked to increasing CO2 per capita trends, while the 80s witnessed emission reductions driven by temporal effects, which capture unobserved heterogeneity (institutional and policy effects, energy mix changes, etc.) [12]. We note that cubic specifications are not significant here and for sub samples of countries.

While technological variables are not significant[13], both TRADE and Inequality appear to impact negatively on emissions. The role of trade openness may reflect the condition by which smaller economies have tended to relocate heavier productions elsewhere. This gives relevance to the consumption perspective. Inequality is more puzzling, since emissions per capita appear lower when inequality is higher.

The evidence regarding technology deserves a comment. First, in the EKC relevant literature, the inclusion of specific technological variables is rare; the main reason is the merger with innovation and technology data tend to shrink the panel dataset. Technological variables are often captured by fixed effects in different econometric contexts (Musolesi & Mazzanti 2014; Galeotti et al. 2006; Vollebergh et al. 2009). Among EKC studies, we note Bouvier (2004), who find, for European and North American countries for the period 1980-1986, that the scale effect outweighs the composition and technology effects in the cases of carbon dioxide and volatile organic compounds, contrary to sulphur dioxide. More recent evidence is provided by Auci & Trovato (2011) and Auci & Becchetti

[10] Since only eight countries from Oceania continent are included in the full sample, the restriction of the analysis to the Oceania subsample would lead to biased and thus uninformative estimates. Therefore, it has not been possible to narrow the EKC analysis to this area.

[11] The size of the panel considering all available countries, namely countries that present a reasonable coverage over time (not all periods) and over the considered variables, is 1325.

[12] The evidence is in line with the insights provided by Mazzanti and Musolesi (2014).

[13] In addition to patents, the share of R&D on GDP is also introduced as alternative covariate (results available on request). R&D is similarly not significant across all specifications, and as expected it is positively correlated to patents. There is some similarity with the methodological oriented evidence provided by Eberhardt et al. (2011), who highlight the significance of factors which capture unobserved effects over R&D in the estimation of production functions. Technological (and policy) factors are highly related to time events and dynamics. The inclusion of temporal effects often brings about the irrelevance of those factors.

(2006): the latter paper 'adjusts' the EKC through including the energy supply infrastructure and the industry mix. Though technology is explicitly considered, its empirical inclusion finds proxies in the two mentioned factors. The former paper, which analyses 25 EU countries over 1997-2005, is instead one of the few that includes technological factors, namely R&D. Authors state that: '*As regards the influence of structural national or sectoral factors, considering per capita GDP as an endogenous variable, the signs obtained are as we expect (…) Technological progress induced by private R&D expenditure has a positive sign while the sign of public R&D expenditure shows a puzzle result*'. R&D is used as an instrument to make GDP endogenous.

Another issue is that we can only include total patents, not green ones. Total patents capture the overall innovation capacity, both brown and green economy. It would be nevertheless un-correct to include green patents even if they were available, since green patents are defined only for green sectors[14].

In addition, we note that overall worldwide evidence can hide heterogeneous conditions across areas and countries. Policy implications are also more difficult to draw, without more specific insights (Musolesi & Mazzanti 2014). On the role of unobserved heterogeneity factors see again Eberhardt et al. (2012), who show that taking into account heterogeneity and cross section dependence shrinks and nullifies the role of factors such as R&D.

As far as the EKC non-linear evidence is concerned, it is worth noting that panel estimators that assume slope homogeneity as fixed effects may capture non linearity even due to a small subset of outliers. Homogeneous slope estimators might then capture nonlinear EKC shapes due to the presence of some outliers. But they may hide the average structural relationship characterising the countries/sectors. The use of heterogeneous slope estimators is here undermined by the nature of data. In a sector-based datasets too many groups are present to estimate SURE or Swamy random coefficients model[15] (Mazzanti & Musolesi 2013b). Homogeneous slope estimators nevertheless generally provide better fits.

The consideration of a 'consumption' perspective, where an alternative dependent variable is adopted, shows a different outcome: the nonlinear path is characterised by a U shape, with a strong relevance of time effects, which for example turns TRADE from significant (negative) to not

[14] The reconstruction of green patents for brown sectors (say, automotive) should involve a specific data and time intensive research project.

[15] Random coefficients models were actually implemented to check non linearity shapes in that context. The hypothesis of parameter constancy is rejected. Nevertheless, the number of sector groups makes difficult to properly estimate the model. As intuition, the basic model does provide best outcomes in the linear specification, with a CO2-GDP elasticity of about 0.2. The implementation of additional models that capture slope heterogeneity is scope for further research, but with focus on countries or limited number of aggregated sectors.

significant (Table 5). The U shaped relationship between income and 'consumption perspective' emissions, evidences the lack of decoupling when considering overall footprint of the consumption of manufacturing goods, that is in line with the idea that affluent countries offshore polluting productions with little shift to the consumption of goods characterised by a small footprint. If, on the one hand, affluent countries prefer a clean environment at home because environmental quality is considered as a normal good, on the other hand, affluence increase the demand for goods that are increasingly produced abroad.

Table 4 – EKC analyses (all countries)

Variable	A	B	C	D	E	F
lnGDP	1.370***	1.625***	1.373***	1.331***	1.398***	1.035*
$lnGDP^2$	-0.083***	-0.092***	-0.083***	-0.078***	-0.085***	-0.045
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		-0.167**				
lnSPILL			4.471			
lnGINI				-2.350***		
lnPATc					-0.00000014	
lnPATs						0.00000002

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level.

Table 5 – EKC Consumption perspective (all countries)

Variable	A	B	C	D	E	F
lnGDP	-0.314**	-0.024	-0.316**	-0.471***	-0.313**	0.685
$lnGDP^2$	0.030***	0.038***	0.031***	0.043***	0.037***	-0.019
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		0.068				
lnSPILL			-3.897			
lnGINI				1.247***		
lnPATc					0.0000001	
lnPATs						-0.0000002

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level.

3.2 Europe

The turning point of the EKC for the European sub sample is within the range of observed GDP levels as well. We note that the EKC shape weakens when time dummies are introduced. Temporal effects seem to capture a large part of emission reduction since the mid-80s (Table 6).

Regarding the other potential drivers of emission reduction, trade openness, inequality and technological factors are all relevant, though only TRADE maintains significance –and a negative sign of the coefficient - when temporal dummies T_i are introduced. Thus, we may preliminary affirm that temporal effects may capture exogenous technological change, which spreads over all countries and eventually the increasing policy stringency over time. Specific technological effects at country level do not pass through the test of including time effects.

The consideration of a 'consumption' perspective in Europe, is different in terms of evidence with respect to the other countries: the most robust specification is linear, with a positive elasticity coefficient of 0.277 (Table 7). Again, this highlights the absence of decoupling in terms of overall footprint of consumed manufacturing goods for European countries.

Table 6 – EKC analyses (European countries)

Variable	A	B	C	D	E	F
lnGDP	1.041***	1.488***	0.967**	1.157**	0.972*	1.035*
$lnGDP^2$	-0.046*	-0.075***	-0.040	-0.053*	-0.041	-0.045
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		-0.694***				
lnSPILL			-51.102			
lnGINI				-0.764		
lnPATc					0.00001	
lnPATs						0.00000002

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level.

Table 7 – EKC Consumption perspective (European countries)

Variable	A	B	C	D	E	F
lnGDP	0.272***	0.273***	0.277***	0.288***	0.342***	0.329***
$lnGDP^2$						
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		-0.209*				
lnSPILL			-10.772			
lnGINI				-0.348		
lnPATc					0.00000002	
lnPATs						-0.0000002

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level. $lnGDP^2$ is not significant.

3.3 Asia

The evidence presents a robust EKC which still confirms its robustness after the inclusion of time effects. We note that both TRADE and the intensity of patents flow (PATc) are significant in the regression that includes time dummies (Table 8). Both coefficient show a negative sign: in Asian countries, trade openness and technological intensity have both reduced emissions[16]. On the one hand, technology development is a source of emission per capita reduction in emerging export oriented areas. While not always 'green', technology development increases efficiency of production, in first place through energy efficiency investments that present more appropriable returns than actions aimed at mere GHG reductions.

[16] As far as technology is concerned, we recall that patents are total and not green in kind.

On the other hand, the role of trade is more counterintuitive in Asia. It seems that the increase in scale of (carbon intense) export driven emerging economies (China, India) is counterbalanced by other elements. Again, smaller economies tend to be related to lower emissions per capita. In addition, there are also countries (Japan, Malaysia, etc.) whose exports are less dependent on carbon intense inputs. Further analyses could look at even more specific levels, up to the country level. The advantage of working with aggregated datasets – possibly looking at regional macro differences – is the opportunity to exploit robust panel techniques. All in all, the trade and technological dynamics, which are somewhat interrelated by co-causations, have helped Asian manufacturing based economies to move to at least a relative decoupling path, wherein emission increasing scale effects do find some compensations.

The consideration of a 'consumption' perspective is associated to significant evidence from economic and statistical point of views. The U shape we noted worldwide is possibly driven by Asia, for which also other covariates are significant: SPILL (negative); PATs (Positive), GINI (positive). Such evidence is nevertheless not robust to the inclusion of temporal effects (Table 9).

Table 8 – EKC analyses (Asian countries)

Variable	A	B	C	D	E	F
lnGDP	1.240***	1.965***	1.346***	1.580***	1.614***	1.514***
$lnGDP^2$	-0.067***	-0.097***	-0.071***	-0.088***	-0.077***	-0.071***
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		-0.330**				
lnSPILL			39.701			
lnGINI				-1.094*		
lnPATc					-0.0000009*	
lnPATs						-0.0000002*

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level.

Table 9 – EKC Consumption perspective (Asian countries)

Variable	A	B	C	D	E	F
lnGDP	-0.709***	-0.253***	-0.840***	-1.085***	-0.699***	-0.588***
$lnGDP^2$	0.0466***	0.053***	0.051***	0.071***	0.049**	0.042**
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		0.187**				
lnSPILL			-58.578**			
lnGINI				1.805**		
lnPATc					0.00001**	
lnPATs						0.0000003*

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level.

3.4 Africa

As it was expected, Africa does not present EKC dynamics. The CO2-GDP elasticity is between 0.365 (no time effects) and 0.140 (with time effects).The coefficient is not elevated, but a real turning point is absent for the continent. Balancing income and time effects, the driving force of the latter prevails as dynamics behind the increase of CO2 per capita (Table 10).

In addition, while the TRADE element disappears at the introduction of time effects, both GINI and PATs show negative significant coefficients: more unequal countries and countries with higher technological intensity report lower emissions per capita.

The consideration of a 'consumption' perspective does not associate to significant evidence from economic and statistical point of views.

Table 10 - EKC analyses (African Countries)

Variable	A	B	C	D	E	F
lnGDP	0.147*	0.0346***	0.147*	0.122	0.103	0.103
lnGDP^2						
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		0.048				
lnSPILL			8.375			
lnGINI				-2.199**		
lnPATc					-0.00002	
lnPATs						-0.000068**

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level. lnGDP^2 is not significant.

3.5 America

The area presents a within sample turning point for the EKC curve, where nevertheless temporal effects are positive over 90s and in the post 2000 decade[17], As shown in Table 11. The analysis is limited by the difficulty of focusing on South and North America separately, due to constraint related to a minimum number of panel observations.

The consideration of a ‘consumption’ perspective does not associate to significant evidence from economic and statistical point of views.

[17] The application of heterogeneous (slopes) panel models might be a further step to refine the analysis of EKC shapes.

Table 11 – EKC analyses (American countries)

Variable	A	B	C	D	E	F
lnGDP	0.782**	0.520	0.647	1.028***	1.014**	1.029**
$lnGDP^2$	-0.062***	-0.018	-0.054**	-0.059***	-0.083***	-0.084***
year dummies	yes	yes	yes	yes	yes	yes
lnTRADE		-0.023				
lnSPILL			16.484			
lnGINI				-1.533		
lnPATc					0.0000001	
lnPATs						-0.0000002

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level.

3.6 IPAT framework

As a final exercise, we focus on the estimation of a strict IPAT specification, where CO2 levels are explained by population, GDP and technology. We use the stock of patents as a rpoxy of technology, including time dummies in the panel (Table 12).

Estiamtion of IPAT models are less frequent with respect to the related EKC specifcations, at least within social sciences. Results by world areas show some insightful evidence. The population driver is significant in Europe and America, with GDP being the key factor in Asia – a continent that has witnessed high economic growth and mitigated population growth.

It is interesting to note that the technology factor (patent stock) is negatively associated to emissions in 3 cases out of 4, with Europe witnessing a strong significance of temporal effects after the 90's. Other non income effects (not captured by patents) may have driven down emissions over the last two decades (Musolesi & Mazzanti 2014).

Table 12: IPAT related analyses: population, GDP, technology drivers of carbon dioxide levels

Variable	A	B	C	D
lnGDP	0.218***	0.394***	0.097	-0.0415***
lnPOP	1.018**	0.377	0.103	1.391***
year dummies	yes	yes	yes	yes
lnPATs	0.0000001	0.0000003**	-0.00007**	-0.00000009*

Note: The dependent variable is CO_2. Year dummies are five years period dummies in between 1980-2010. All Results are available on request. All presented regressions show F tests that reject the non significance of the overall regression. Constants are included. *** 1% significance; ** 5% significance level. * 10% significance level.

4. Consumption Versus Production perspective

The analysis conducted in the first three chapters, unless when specified (e.g. §3) are conducted using data on direct emissions from manufacturing sectors i.e. environmental pressures directly exerted by the production of manufacturing goods (also known as 'production perspective'). A different and complementary approach can be derived considering, on the other side, the direct and indirect emissions occurring along the supply chain, or the so called 'consumption footprint' or 'consumption perspective'. This second perspective is interesting because it calculates the total environmental pressure corresponding to the final demand for selected consumption categories (here manufacturing goods) of a given country in a given year, tracking all emissions along the entire supply chain. In other terms this means that it considers both direct and induced emissions, net of emission associated to goods/service used as intermediate inputs in other sectors. Operatively, the main complication with this last approach is that often consumption footprints data need to be estimated. In this work, we decided to estimate them relying on environmentally extended input-output (EEIO) modelling starting from the EORA multi-regional input-output database (Lenzen et al., 2013)[18]. Data sources and methodological details are reported in Appendix B. In the following tables, in particular, we compare, for the four income groups first and then for

[18] More details about data and methods for this section are reported in Appendix B.

the single countries, the consumption and the production perspective. In particular, in Table 13, the first five columns represent the ratio of emissions induced worldwide by domestic consumption of manufacturing goods ('consumption perspective') divided by the direct emission of domestic production of manufacturing goods ('production perspective') either consumed domestically or abroad as final goods or intermediates. In other terms, a higher level of this indicator indicates that the analysed country releases more emissions to satisfy the final demand of manufacturing goods as compared to direct emissions released by its manufacturing sector, or in other terms that their consumption footprint of manufacturing goods is greater than their production footprint.

Looking at the results, several important considerations can be drawn. Firstly in low and low-mid income countries, the consumption footprint is much higher than the production footprint, which in other terms means that they are inducing relatively more emissions world-wide with respect to the two other income groups. This is obviously only a relative result, given by the comparison of the coefficient across the group. This evidence does not consider the size of emission of the two income groups. If we look at the right five columns of table 13 in fact, we can easily note that despite their higher consumption footprint, low and mid low countries only account for a small share of total CO_2 direct emission, which increased from the 4% in 1970 to the 13% in the 2000. Even though this result seems to contradict recent evidence about offshoring and carbon leakage, we should bear in mind that for most of these low-income countries the manufacturing sector (and the corresponding emissions) represented only a minor part of their economy and they were importing manufacturing goods from high-income countries (where indirect emissions occurred) in exchange of agricultural products or raw materials (that do not enter our measure of production perspective, that is the denominator of our indicator).

Moving from a cross-country analysis of the data to the time series dimension, some interesting results emerged. The most relevant one is the opposite trends registered by this indicator in high income countries and the three other groups. High income countries are increasing their share of consumption footprint over direct emission, i.e. they depend more on other countries (that are, on average, less environmental efficient) to satisfy the domestic demand of manufactured goods. On the contrary the other three income groups have shown completely different results. The driving forces behind this evidence are manifold. Firstly, an increase in domestic emission efficiency decreases the production footprint for a given level of industrial production, increasing the level of the indicator, which could be one of the factors behind the increasing trend for high income countries. Secondly, also offshoring and delocalisation are two factors which might decrease the production footprint, explaining again the result for high income country. Thirdly, the increasing process of industrialisation experienced by the other three income groups, registered here by an increasing trend in their total direct emissions, is probably the main driver behind their performances. Moving to the second and final table, we can see as this trend is confirmed also when looking at single countries. If we take for instance Germany, Italy and the US, we can see that their consumption perspective has increased significantly with respect to their production perspective. On the contrary, emerging economies like China and India experienced the opposite trend.

Table 13 – Consumption vs production perspective for income group (own elaboration on EORA)

	Consumption perspective / production perspective					**Share of global direct CO_2 emissions (production perspective) in manufacturing**				
Income group (World Bank)	**1970s**	**1980s**	**1990s**	**2000s**	**1970-2009**	**1970s**	**1980s**	**1990s**	**2000s**	**1970-2009**
Low income	14.88	11.51	9.35	9.99	11.13	1%	1%	1%	1%	1%
Lower middle income	6.24	4.39	2.74	2.25	3.05	3%	5%	10%	12%	8%
Low and lower-middle income	*8.13*	*5.73*	*3.37*	*2.84*	*3.96*	*4%*	*6%*	*11%*	*13%*	*9%*
Upper middle income	1.98	1.71	1.54	1.30	1.54	21%	27%	35%	42%	32%
High income	1.43	1.59	2.01	2.27	1.81	75%	67%	54%	46%	59%
High and upper-middle income	*1.55*	*1.62*	*1.83*	*1.81*	*1.71*	*96%*	*94%*	*89%*	*87%*	*91%*
Total	**1.83**	**1.87**	**2.00**	**1.94**	**1.92**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 14 – Consumption vs production perspective for selected countries (production perspective CO_2 emissions for 1970-2009 > 1% of world total – own elaboration on EORA)

	Consumption perspective / production perspective					**Share of global direct CO_2 emissions (production perspective) in manufacturing**				
Country	**1970s**	**1980s**	**1990s**	**2000s**	**1970-2009**	**1970s**	**1980s**	**1990s**	**2000s**	**1970-2009**
Algeria	2.09	1.06	0.77	0.91	1.01	0.12%	0.37%	0.37%	0.30%	0.29%
Argentina	5.88	4.98	4.99	3.23	4.54	0.54%	0.58%	0.59%	0.67%	0.60%
Australia	6.06	6.05	4.56	3.62	4.94	0.94%	0.88%	0.95%	0.85%	0.90%
Austria	1.25	1.66	2.08	2.20	1.83	0.39%	0.32%	0.34%	0.31%	0.34%
Belgium	1.04	1.14	1.64	1.91	1.42	0.86%	0.67%	0.60%	0.50%	0.64%
Brazil	3.24	2.51	2.85	2.27	2.61	1.70%	2.41%	2.83%	3.19%	2.61%
Bulgaria	1.71	1.82	1.17	1.43	1.58	0.35%	0.39%	0.23%	0.16%	0.27%
Canada	0.96	0.99	1.01	1.10	1.02	2.87%	2.91%	3.08%	2.81%	2.91%
Chile	1.70	1.70	1.68	1.72	1.70	0.18%	0.16%	0.24%	0.27%	0.22%
China	1.31	1.16	0.98	0.91	1.02	10.76%	14.40%	20.20%	26.71%	18.97%
Colombia	2.96	2.69	2.58	1.84	2.43	0.30%	0.36%	0.42%	0.39%	0.37%
Croatia	0.76	0.76	1.30	1.64	1.02	0.24%	0.32%	0.14%	0.11%	0.19%
Cuba	1.85	1.88	1.77	2.01	1.87	0.29%	0.31%	0.22%	0.12%	0.22%
Czech Republic	1.08	1.02	1.15	1.88	1.19	1.09%	0.98%	0.48%	0.32%	0.67%
Denmark	2.06	3.14	3.58	4.40	3.18	0.23%	0.14%	0.14%	0.11%	0.15%
Egypt	2.02	1.77	1.37	1.41	1.53	0.28%	0.51%	0.68%	0.76%	0.58%
Finland	1.19	1.10	1.59	1.66	1.42	0.31%	0.35%	0.36%	0.32%	0.34%
France	1.40	1.88	2.85	3.79	2.29	3.31%	2.28%	1.80%	1.24%	2.05%
Germany	1.31	1.73	2.99	3.88	2.21	5.95%	4.33%	2.83%	1.98%	3.55%
Greece	1.56	1.68	2.95	3.68	2.54	0.26%	0.28%	0.26%	0.23%	0.26%
Hungary	1.09	0.98	1.55	2.55	1.37	0.47%	0.46%	0.23%	0.16%	0.31%
India	1.88	1.81	1.49	1.49	1.58	1.77%	2.45%	4.09%	4.99%	3.51%
Indonesia	9.14	4.97	2.38	2.29	2.94	0.24%	0.60%	1.60%	1.77%	1.14%
Iran	2.45	2.31	2.11	1.85	2.07	0.56%	0.63%	0.93%	1.28%	0.89%
Iraq	10.20	5.08	1.67	1.80	3.40	0.09%	0.20%	0.25%	0.18%	0.18%
Ireland	2.25	1.86	2.69	3.46	2.60	0.11%	0.12%	0.09%	0.10%	0.10%
Israel	2.12	2.25	4.04	7.63	4.25	0.10%	0.09%	0.14%	0.09%	0.11%
Italy	1.38	1.91	2.76	3.35	2.29	2.45%	1.86%	1.60%	1.31%	1.74%
Japan	1.27	1.65	2.22	2.71	1.94	6.67%	5.59%	5.43%	3.85%	5.25%
Kuwait	1.38	1.68	1.50	1.38	1.47	0.15%	0.16%	0.21%	0.25%	0.20%
Latvia	0.59	0.56	2.45	0.22	0.49	0.36%	0.45%	0.03%	0.34%	0.29%
Libya	3.93	1.09	0.78	0.63	1.03	0.04%	0.15%	0.16%	0.12%	0.12%
Lithuania	0.77	0.74	2.38	3.32	0.97	1.05%	1.20%	0.10%	0.10%	0.55%
Malaysia	2.44	2.49	2.00	1.27	1.70	0.15%	0.23%	0.51%	0.77%	0.45%
Mexico	1.85	1.60	1.65	2.08	1.79	1.18%	1.75%	1.78%	1.43%	1.54%
Morocco	2.68	2.06	1.75	1.67	1.93	0.08%	0.11%	0.12%	0.12%	0.11%

	Consumption perspective / production perspective					Share of global direct CO2 emissions (production perspective) in manufacturing				
Country	**1970s**	**1980s**	**1990s**	**2000s**	**1970-2009**	**1970s**	**1980s**	**1990s**	**2000s**	**1970-2009**
Netherlands	0.78	1.05	1.48	2.22	1.38	0.96%	0.73%	0.78%	0.58%	0.74%
New Zealand	2.95	2.82	2.52	2.80	2.75	0.10%	0.11%	0.14%	0.11%	0.11%
Nigeria	20.38	7.77	3.00	3.45	4.63	0.05%	0.12%	0.30%	0.36%	0.23%
North Korea	1.04	1.03	0.82	0.61	0.90	0.68%	0.86%	0.62%	0.35%	0.60%
Norway	0.82	0.95	1.12	1.32	1.06	0.48%	0.40%	0.38%	0.35%	0.39%
Pakistan	5.25	4.33	2.83	2.10	2.89	0.14%	0.21%	0.36%	0.55%	0.34%
Peru	1.43	1.64	2.05	1.28	1.52	0.16%	0.15%	0.12%	0.23%	0.17%
Philippines	3.39	3.73	2.90	4.00	3.48	0.31%	0.27%	0.41%	0.30%	0.32%
Poland	1.72	1.80	1.90	2.23	1.89	1.45%	1.20%	0.81%	0.69%	1.00%
Portugal	1.46	1.69	2.63	3.41	2.45	0.21%	0.22%	0.26%	0.22%	0.23%
Qatar	1.82	0.91	0.59	0.64	0.70	0.03%	0.08%	0.18%	0.29%	0.16%
Romania	1.25	1.14	1.27	1.62	1.27	1.29%	1.54%	0.66%	0.44%	0.93%
Saudi Arabia	2.83	1.75	1.03	1.00	1.25	0.22%	0.59%	0.88%	1.18%	0.77%
Singapore	0.81	1.10	1.58	3.85	1.90	0.24%	0.27%	0.39%	0.22%	0.28%
Slovakia	1.43	1.44	2.12	1.67	1.64	0.39%	0.39%	0.28%	0.22%	0.31%
South Africa	2.47	2.83	3.09	3.07	2.85	1.17%	1.10%	0.87%	0.70%	0.93%
South Korea	1.45	1.62	1.61	2.07	1.79	0.59%	0.90%	1.68%	1.72%	1.29%
Spain	1.68	1.94	2.95	3.59	2.60	1.24%	1.10%	1.06%	1.00%	1.09%
Sweden	0.66	0.91	1.23	1.58	1.07	0.71%	0.51%	0.50%	0.38%	0.51%
Switzerland	2.19	2.78	4.21	5.65	3.57	0.22%	0.18%	0.13%	0.11%	0.16%
Syria	2.13	1.75	1.63	1.58	1.70	0.07%	0.15%	0.15%	0.14%	0.13%
Taiwan	9.88	2.77	1.87	1.29	2.89	0.46%	0.70%	0.87%	0.83%	0.73%
Thailand	3.90	3.26	2.51	1.82	2.37	0.27%	0.40%	0.91%	1.18%	0.74%
Trinidad and Tobago	0.88	0.86	0.47	0.34	0.51	0.11%	0.13%	0.18%	0.33%	0.20%
Turkey	1.69	1.39	1.62	1.83	1.67	0.40%	0.60%	0.89%	0.98%	0.75%
UAE	4.17	1.88	1.60	2.14	2.00	0.05%	0.17%	0.33%	0.39%	0.25%
UK	1.01	1.34	2.37	3.95	1.94	3.30%	2.31%	1.88%	1.19%	2.06%
USA	1.19	1.47	2.20	2.48	1.77	25.49%	19.94%	14.53%	12.59%	17.42%
Venezuela	2.37	2.15	1.51	1.78	1.86	0.56%	0.64%	0.93%	0.83%	0.76%
Viet Nam	9.61	4.37	4.71	2.72	3.76	0.07%	0.12%	0.17%	0.42%	0.22%
Total (selected countries)	**1.54**	**1.65**	**1.87**	**1.86**	**1.75**	**88%**	**85%**	**86%**	**87%**	**86%**

5. Concluding remarks and highlights

The work has used applied economics techniques to offer diverse insights on the relationships between environmental performances and the correlated drivers, taking a new original manufacturing sector perspective. Decomposition analyses, panel econometrics and input output tools have delivered interesting and complementary insights.

- ***The decomposition analysis*** shows that TECHNOLOGY PLAYED A RELEVANT ROLE IN EXPLAINING MANUFACTURING EMISSION REDUCTION IN HIGH INCOME COUNTRIES ONLY UNTIL THE 1990S. After that period its effect diminished. One key driver was the second oil shock, an evidence which is confirmed by other country based studies in the literature[19]. ON THE CONTRARY, FOR THE OTHER INCOME GROUPS, THE TECHNOLOGICAL EFFECT HAS REINFORCED IN THE LAST TWO DECADES. Summing up, it seems that technological development, in this case probably denoting energy efficiency components, helped high income countries and emerging countries in their (different for the timing) development path. The issue for the present and future is the role of 'green' technological development to achieve a full decarbonisation. The increasing trade openness might help accelerating technological transfers and sector's responses through innovation adoption and diffusion.
- Similarly, also THE MAGNITUDE OF THE SCALE EFFECT IS DECREASING THROUGH TIME IN HIGH-INCOME ECONOMIES, DUE TO A GENERAL DECREASING SHARE OF MANUFACTURING ACTIVITY IN THE ECONOMY, while it has been increasing in size in medium-high, med-low and low income countries, thanks to the stronger industrialisation in these areas. This is a structural effect to be taken into account, in light of the (i) manufacturing weight of emerging economies; (ii) the non binding but relevant new EU target towards a newly increased 20% GDP manufacturing share (EEA, 2014); (iii) the higher innovation intensity of manufacturing versus services.

Those facts highlight a KEY EVOLUTIONARY RELATION BETWEEN TECHNOLOGY, COMPOSITION EFFECTS AND INDUSTRIAL DEVELOPMENT. The (intense) role of technology in industry – as a driver for competitiveness and better environmental performances - is the main motivation.

- ***The shift share analysis*** additionally shows that HIGH-INCOME COUNTRIES TEND TO BE GENERALLY MORE ENVIRONMENTALLY EFFICIENT THAN THE AVERAGE AND TEND TO BE MORE SPECIALISED IN HIGH TECHNOLOGY AND GREENER SECTORS, a result which is in line with

[19] This highlights the relevancy of integrating the analysis of market and policy drivers. Even if the introduction of environmental policies, say environmental taxation, should relate to the cost of externalities, it is true that in political economy terms the introduction of environmental taxes is more effective when oil prices are low. Green taxes may compensate the fall in market prices to support technological progress targeted to environmental/resource efficiency.

economic theories and EKC. Along the development path, in high income countries technological and composition effects have (partially) compensated growth-driven emission patterns. This has occurred in various 'times' of the development path: some economies first reacted – even differently – to oil shocks, then de-manufacturing started to show its effects, and finally the remaining manufacturing core sectors provided some 'green innovation' reactions to the policies and challenges originated out of Rio and Kyoto. As a consequence, high technology sectors as expected convey better environmental productivity performances, namely emissions on economic value, with respect to medium-tech sectors. This is a relevant fact to understand the sustainability of the past and future industrial development.

Econometric exercises are aimed at investigating EKC/IPAT patterns from both production and consumption perspectives, and show that:

- The "WORLDWIDE" EVIDENCE DOES NOT REJECT THE EXISTENCE OF EKC PATHS FOR THE 'PRODUCTION PERSPECTIVE', WITH TRADE OPENNESS DECREASING EMISSIONS AND TECHNOLOGY BEING UN-RELEVANT, besides Asian economies. The results for technology are not unexpected and do not contradict previous evidence here and elsewhere: technological development – partially oriented towards energy efficiency – has been relevant to compensate scale effects. Econometric models results nevertheless show, through temporal specific fixed effects, that a LARGE PART OF EMISSION REDUCTIONS (AND INCREASES) WAS CAUSED BY UNOBSERVED FACTORS, such as possibly institutional quality, policy stringency and commitment, energy mix shifts, etc.. Those factors often overtake technological covariates in significance terms; further research should investigate in specific terms the role of those unobserved factors and time-related shocks.
- We note that instead TAKING THE 'CONSUMPTION PERSPECTIVE' INTO ACCOUNT DOES NOT CONFIRM EKC-LIKE DYNAMICS. This is expected, relevant and linked to the role of trade in the production perspective. Nevertheless, we note that the (interconnected) trade and technology dynamics helped compensating growth effects for what emission reductions is concerned in some areas such as Asia.
- IN THE EU, THOUGH A SORT OF EKC SHAPE APPEARS, TEMPORAL EFFECTS SEEM TO CAPTURE A LARGE PART OF EMISSION REDUCTION SINCE THE MID 80'S. TRADE OPENNESS REDUCES CARBON DIOXIDE, CONFIRMING THE IDEA THAT PRODUCTION DE-LOCALISATION IN EMERGING AREAS IS PART OF THE CO_2 REDUCTION in wealthier countries. In fact, the 'consumption based analysis' shows a positive relationship between carbon dioxide and GDP. IN ASIAN COUNTRIES, TRADE OPENNESS AND TECHNOLOGICAL INTENSITY HAVE BOTH REDUCED EMISSIONS. The inverted U

shape EKC in the production analysis turns into a U shape: again, the two analyses look at the economic system from different perspectives and provide complement insights. In Africa, as it was maybe expected, EKC dynamics are not present: the elasticity of carbon dioxide to income is nevertheless below unity, a signal of relative decoupling. In addition, it might be noticed that more unequal countries and countries with higher technological intensity report lower emissions per capita. In the Americas, nonlinear CO_2-income paths are shown, with a strong effect of 'temporal factors' again, that seem to cause an increase in emissions in the last two decades, which is similar to what temporal factors highlight for the EU. This is thus a OECD evidence: after the reactions to oil shocks and the policy intense 90's (Rio Convention, Kyoto Protocol), the decoupling path lost pace.

- To sum up, besides Africa the evidence does not reject nonlinear EKC paths. The hypothesis that technology drives down CO_2 to compensate scale effect is more relevant for developing and emerging economies, while in the EU Trade is a determinant factor. When technology matters, it is not due to spillovers effects, though this is evidence needs further (spatially oriented) research. Temporal related factors often show greater relevance. This opens the way to further analyses and introduction of additional carbon dioxide drivers, e.g. policies.
    - The nonlinear EKC path do not exists when we introduce a consumption rather than a production perspective. In the most relevant cases, the EU presents a positive link between emissions and economic value, while Asia presents a U shape opposite to the EKC hypothesis. This shows that the EKC evidence we may find heavily rely on the 'production oriented approach'.

Finally, regarding the specific comparison between consumption and production sustainability ***through input output techniques***, we further note that the ratio between the footprint of domestic consumption of manufacturing goods and the domestic direct emissions of manufacturing sectors (namely, consumption and production perspectives) is increasing when moving from high-income countries to low-income countries, due to the greater development of the manufacturing sector in high-income countries. However, when looking at the dynamics of this indicator we observe a progressive convergence of low-income countries (due to increased importance of manufacturing in these countries) towards high-income countries, in which a rather stable dynamics of consumption of manufacturing goods has been accompanied by the offshoring of manufacturing activities towards lower-income countries.

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Appendix A

Table A 1. Sectorial taxonomy by technology group (UNIDO categories)

Sector code	Description	Abbreviation	Technology group
15_16	Food, beverages and tobacco	Food and tobacco	Low tech
17_18_19	Textiles, wearing apparel, fur and leather products; footwear	Textile	Low tech
20	Wood products (excluding furniture)	Wood	Low tech
21_22	Paper and paper products; printing and publishing	Paper	Low tech
24	Chemicals and chemical products	Chemicals	High tech
25_33_36_37	Rubber and plastic products; medical, precision and optical instruments; Furniture and manufacturing n.e.c.	Plastic and precision tools	Medium tech
26	Non-metallic mineral products	Non-metallic minerals	Medium tech
27	Basic metals	Basic metals	Medium tech
28_29_30_31_32	Fabricated metals; machinery and equipment n.e.c. and office, accounting, computing machinery; electrical machinery and apparatus and radio, television, and communication equipment	Fabricated metals and machinery	High tech

Figure A 1 Average CO2 emissions & Environmental productivity (1). Low tech. Sectors

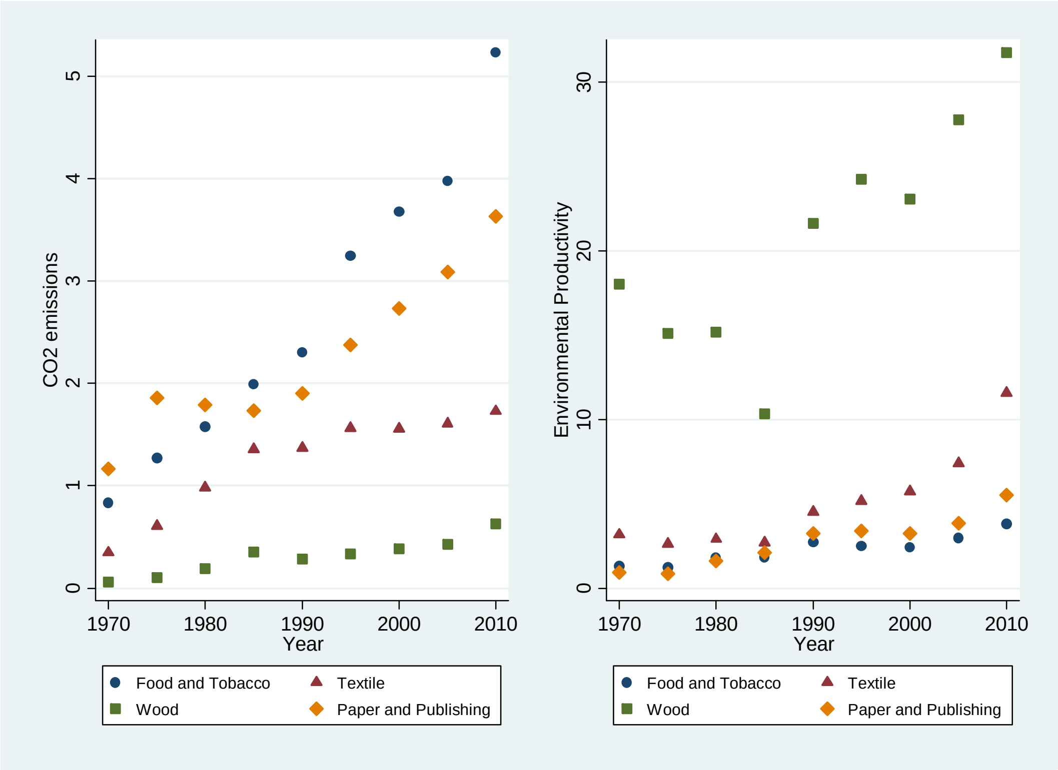


Figure A 2 Average CO2 emissions & Environmental productivity (2). Medium tech. sectors

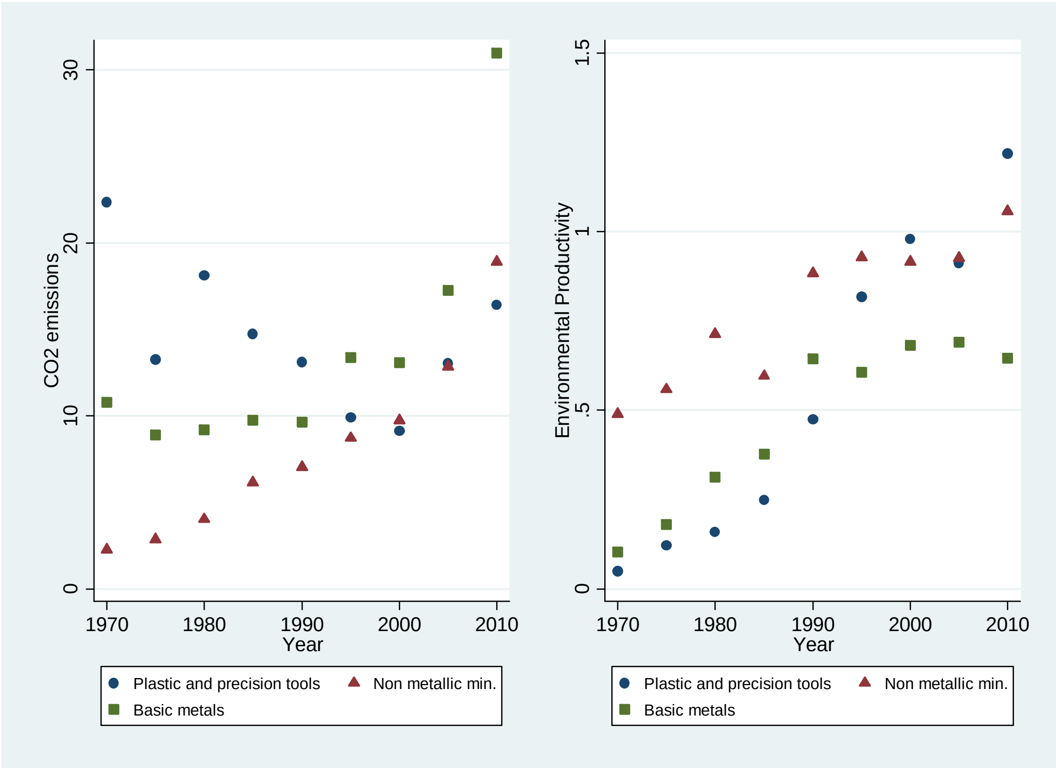


Figure A 3 Average CO2 emissions & Environmental productivity (3). High tech. Sectors

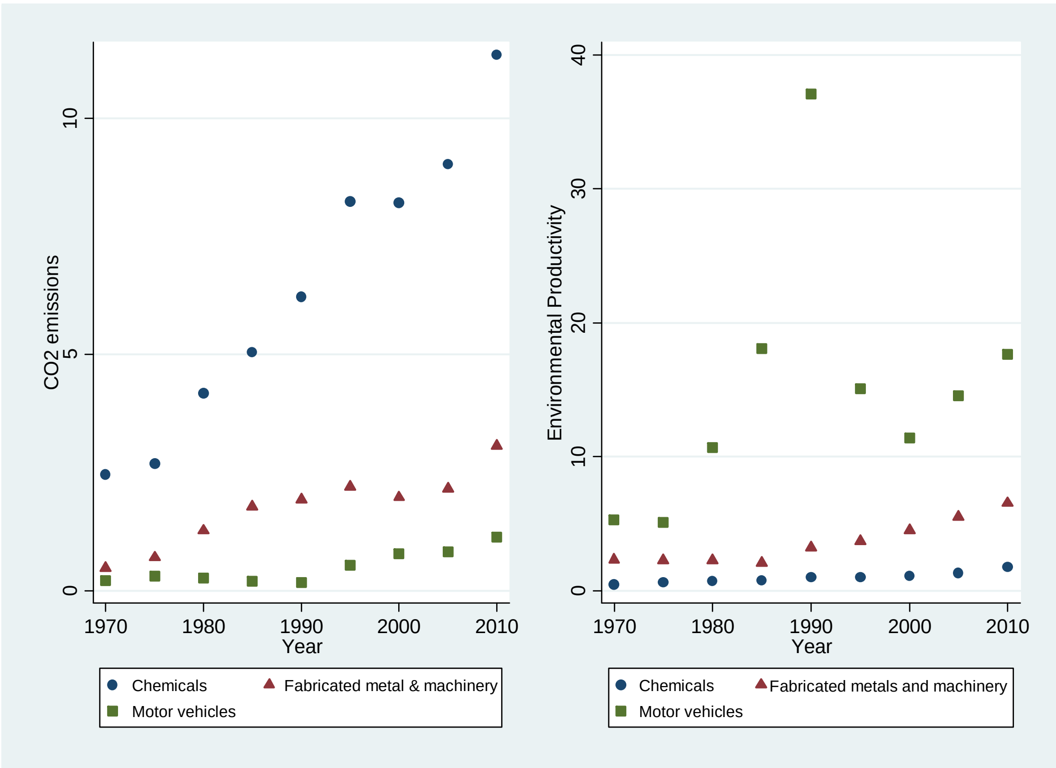


Figure A 4 Average CO2 emissions & Environmental productivity by technology level (1). Low income countries

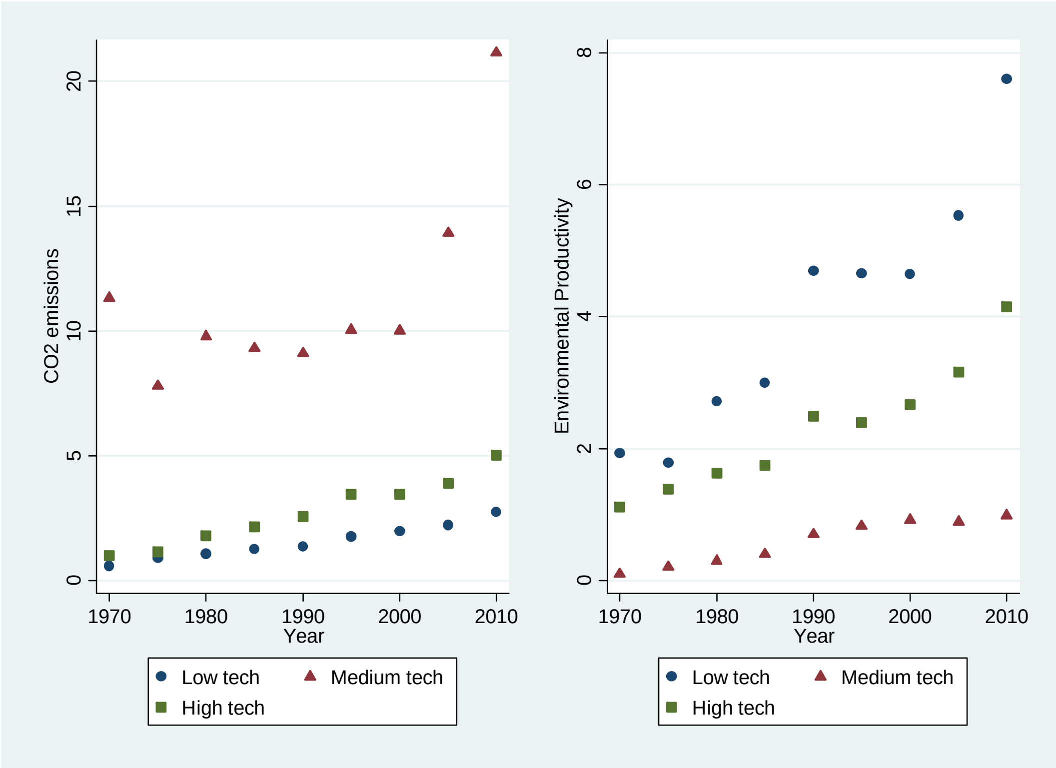


Figure A 5 Average CO2 emissions & Environmental productivity by technology level (2). Medium-low income countries

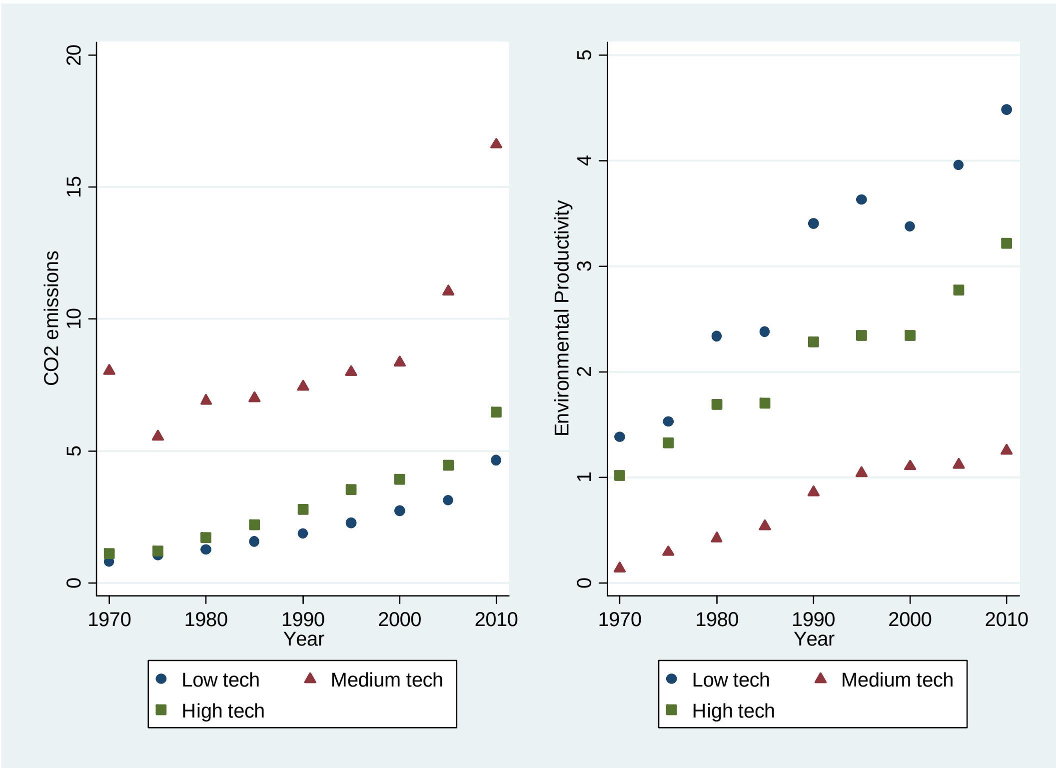


Figure A 6 Average CO2 emissions & Environmental productivity by technology level (3). Medium-high income countries

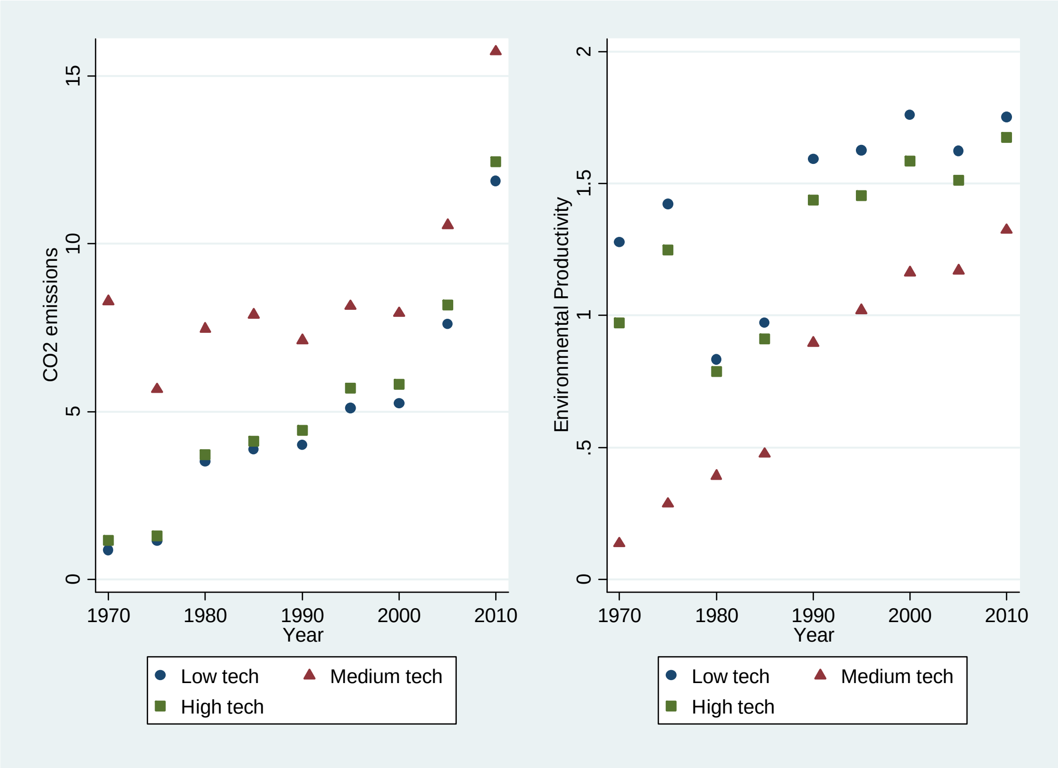
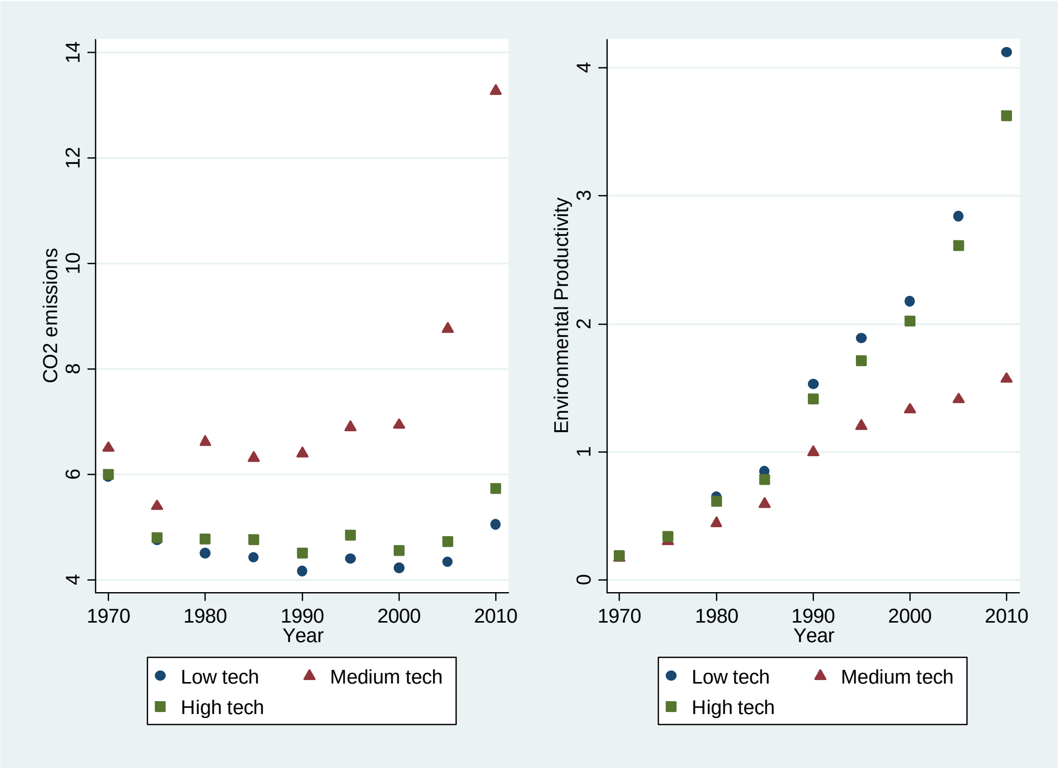


Figure A 7 Average CO2 emissions & Environmental productivity by technology level (4). High income countries



Appendix B: Consumption perspective and the EORA database

Information on CO2 emissions used in analysis of sections 3 and 4 is based on the EORA (http://worldmrio.com/) database (Lenzen et al. 2012; Lenzen et al. 2013). The database provides estimates of sectoral direct CO2 emissions together with year-specific world input output tables for 187 countries, 26 sectors (7 of which pertaining to manufacturing sectors) over the period 1970-2011.

We build two different indicators of emissions based on this base of data. The first is labelled as 'production perspective emissions' and refer to direct emissions by manufacturing sectors due to their production activity. This indicator reflects the pressures exerted by the manufacturing sector as a whole no matter where the goods produced are then consumed and with no consideration of indirect emissions (i.e. from other sectors and, eventually, other countries) occurred along the supply chain to produce these goods.

The second indicator, labelled as 'consumption perspective emissions', measures the amount of emissions needed (directly and indirectly, at home and abroad) to satisfy the domestic demand for manufacturing goods. The indicator is built by exploiting the information from the world input output tables of EORA that allow to account for emissions occurring along the whole world supply chain of domestically-consumed manufacturing goods. We adopt the common approach described by Serrano & Dietzenbacher (2010), based on the Leontief input output model, to compute 'consumption perspective emissions'.

The world totals for the two indicators would not necessarily coincide. This is because while 'production perspective emissions' only consider direct emissions from manufacturing sectors, 'consumption perspective emissions' include indirect emissions that occur in other relevant sectors (e.g. the power generation sector) and are embodied in manufacturing goods while it excludes emissions corresponding to those manufacturing products that are used as intermediate inputs for other non-manufacturing sectors.

Variable	Description	Observations	Mean	Std. Dev.
CO2	Direct co2 emissions (5 year average) in metric tonnes	1512	36,383.05	152,710.2
POP	Population in millions of inhabitants	1456	28.6 millions	110 millions
GDP	Gross domestic product in millions of dollars	1440	138,000 millions	691,000 millions
PATc	Flows of national granted patents	1219	2,382.66	10,776.63
PATs	Stock of national granted patents starting from 1960	1219	13,932.21	51,186.49
SPILL	Average patenting intensity in neighbouring countries	1512	2,373.861	1,689.164
TRADE	Ratio of a country's total trade on GDP	1032	0.73	0.84
GINI	Measure of inequality among country's GDP	1272	39.34	9.73

Table B.1 – Descriptive Statistics - Econometric analysis

Appendix C: Index decomposition analysis

We decompose the overall time change in sectoral CO2 emissions into four components:

- Emission intensity component;
- Macro-sector composition;
- Sub-sector composition;
- VA scale.

Total CO2 emissions by manufacturing sectors may be calculated according to the following identity

$$E = \sum_i \left(\frac{E_i}{VA_i} \times Macrosect\_comp_i \times Subsect\_comp_i \times Scale \right)$$

where $\frac{E_i}{VA_i}$ represents CO2 emissions per real value added of sector i, $Macrosect\_comp_i$ represents the value added share of the macro-sector (either high, medium or low technology) to which sector *i* belongs over total manufacturing value added, $Subsect\_comp_i$ represents the value added share of sector *i* over the total value added of its corresponding macro-sector, $Scale$ represents the overall size of the whole manufacturing sector in terms of value added.

The emission intensity component is measured as the relative change in total CO2 emissions from manufacturing sectors that would have occurred in a 5-years period if, leaving the structure and scale of the manufacturing sector unchanged (in terms of real value added) at its average, emission intensity of value added (E/VA) of each sector *i* would have had the observed change in the same period. This indirectly measures changes in production technology and in emission efficiency of production.

$$EI\ component = \sum_i \left(\Delta \frac{E_i}{VA_i} \times \overline{Macrosect\_comp_i} \times \overline{Subsect\_comp_i} \times \overline{Scale} \right)$$

The macro-sector composition component describes the role played by shifts in economic activities across macro-sectors. The progressive specialisation of the manufacturing sector of a country in macro-sectors characterised by different emission intensities has an influence on total emissions of manufacturing sectors.

$$Macro - sector\ component = \sum_i \left(\overline{\left(\frac{E_i}{VA_i}\right)} \times \Delta Macrosect\_comp_i \times \overline{Subsect\_comp_i} \times \overline{Scale} \right)$$

Similarly, the sub-sector composition component measures the extent to which changes in the composition of macro-sectors influences emissions for given vectors of emission intensity, macro-sector composition and overall scale.

$$Sub - sector\ component = \sum_i \left(\overline{\left(\frac{E_i}{VA_i}\right)} \times \overline{Macrosect_{comp_i}} \times \Delta Subsect\_comp_i \times \overline{Scale} \right)$$

Finally, the scale component measures the contribution of changes in the overall scale (in terms of real value added) of the manufacturing as a whole to total manufacturing CO2 emissions.

$$VA\ scale = \sum_i \left(\overline{\left(\frac{E_i}{VA_i}\right)} \times \overline{Macrosect_{comp_i}} \times \overline{Subsect\_comp_i} \times \Delta Scale \right)$$

All components are divided by the initial level of total manufacturing CO2 emissions and should be interpreted as relative changes.

Appendix D: Shift-share analysis

The shift-share analysis is a useful tool, because it allows decomposing the emission efficiency differential between a country y and a benchmark (in this case, the world average) into its three main components: the country's industrial composition, the country specialisation in more environmental efficient sectors and the covariance between these two factors. These components are generally called in literature structural (M), differential (P) and allocative (A) (Costantini et al. 2011).

If for instance, we take the world average indicator of emission intensity CO2/VA as the benchmark and the value of $CO2_y$/ VA_y for country y, the total indicator can be decomposed as the sum of (E^S /VA^S)*(VA^S /VA), where E^S is the sectorial emission level and VA^S/VA is the share of sectorial value added on total value added for sectors s, where s ranges from 1 to j (j is the number of manufacturing sectors included in our dataset, see Table A1 for the full list of sectors included in the analysis). As a consequence, referring to the following notation:

- X is the emission intensity index (where X=CO2/VA for the world average and $X_y = CO2_y$/ VA_y for country y), and X^S is the sectorial emission intensity. This can be also written as: $X = \sum_S P^S X^S; X_y = \sum_S P_y^S X_y^S$.
- P^S is the sectorial value added and is defined as $P^S = VA^S/VA$

The emission efficiency differential of country y, defined as X_y-X, can be decomposed into its three component M, P and A according to the following formulas (For an economic interpretation of the indexes see the main text):

1. The structural factor (M), or country sectorial mix, is calculated for country y as:

$$M_y = \sum_S \left[X^S(P_y^S - P^S)\right]$$

2. The differential factor (P), is calculated for country y as:

$$P_y = \sum_S \left[(X_y^S - X^S)P^S\right]$$

3. The allocative component (A), is calculated for country y as:

$$A_y = \sum_S \left[(X_y^S - X^S)\right]\left[(P_y^S - P^S)\right]$$

Appendix E: IEA and INDSTAT databases

The empirical analysis reported in section 1 and 2 of the current chapter is based on two different databases. CO2 air emissions deriving from the combustion of fossil fuels are retrieved from the corresponding database maintained by the International Energy Agency (IEA). Emissions are reported in millions of tons. However, where emissions are smaller than 100,000 tons, they are rounded to zero. For simplicity, with little influence on results, we set these values to 50,000 tons given that for both the decomposition analysis and the shift share analysis values for emissions should be strictly positive. In any case, being aggregate results weighted by the size of sectors and countries, these assumptions have little influence on aggregate results. To increase the time and country coverage, we linearly interpolated information on emissions given that decomposition exercises require that information is available for all sectors in a countries for two different points in time.

Real value added in US dollars by manufacturing sectors (ISIC Rev 3.1) come from the INDSTAT2 database maintained by the UNIDO. Value added in nominal terms by sector, for which we have the greater coverage in INDSTAT2, is deflated to 2005 prices (US$) using the deflator for manufacturing industries provided by the United Nations Statistics Division[20]. Also for what concerns value added, we perform linear interpolations to increase the coverage.

Finally, to increase coverage and reduce the potential issue of measurement errors, we do not use yearly information but five years windows, in which the value of value added and emissions for the specific year (e.g. 1980) is computed as the simple average of all available years between 1978 and 1982.

To combine the two datasets and to cover a sufficient number of countries and time period, we aggregate sectors as follows:

[20] http://unstats.un.org/unsd/snaama/dnllist.asp

Table A 2. Sectoral classification used in the IEA-INDSTAT2 dataset

ISIC Rev 3.1 (and UNIDO taxonomy of macro-sectors in parenthesis)	Macro-sector
15 (L), 16 (L)	Low-technology
17 (L) 18 (L) 19 (L)	Low-technology
20 (L)	Low-technology
21 (L) 22 (L)	Low-technology
24 (H)	High-technology
25 (M) 33 (H) 36 (L) 37 (L)	Medium-technology
26 (M)	Medium-technology
27 (M)	Medium-technology
28 (M) 29 (H) 30 (H) 31 (H) 32	High-technology
34 (H) 35 (H)	High-technology

While the match between our aggregation and the low-technology aggregate is good (all subsector where classified in the UNIDO taxonomy as low-technology sectors), we could not perfectly match our aggregation to the taxonomy proposed by UNIDO for medium and high technology sectors. What we define 'high-technology' macro-sector also includes sector 28 which is classified as medium-technology sector, while what we define 'medium-technology' macro-sector also includes sector 33 (high-technology), sector 36 (low-technology) and sector 37 (low-technology).

Table A3 describes the coverage by country and year of the IEA-INDSTAT2 merged database.

Table A 3. Coverage of the IEA-INDSTAT2 database

Income group	ISO	Country	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
Low income	BGD	Bangladesh		X	X	X	X	X	X	X	X	X
	KEN	Kenya			X	X	X	X				
	TZA	United Republic of Tanzania					X	X	X	X		
Medium-low income	BOL	Bolivia			X	X	X	X	X			
	CIV	Côte d'Ivoire					X	X	X			
	EGY	Egypt		X	X	X	X	X	X	X	X	X
	GHA	Ghana		X	X	X	X					
	GTM	Guatemala		X	X	X	X					
	HND	Honduras				X	X	X	X			
	IDN	Indonesia			X	X	X	X	X	X	X	X
	IND	India		X	X	X	X	X	X	X	X	X
	KGZ	Kyrgyzstan								X	X	X
	LKA	Sri Lanka		X	X	X	X	X	X	X	X	X
	MAR	Morocco			X	X	X	X	X	X	X	X

Income group	ISO	Country	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
	MNG	Mongolia									X	X
	NGA	Nigeria		X	X	X	X					
	NIC	Nicaragua		X	X	X	X					
	PAK	Pakistan		X	X	X	X	X	X	X		
	PHL	Philippines		X	X	X	X	X	X	X	X	X
	PRY	Paraguay		X	X	X						
	SEN	Senegal								X	X	
	SLV	El Salvador		X	X	X	X	X	X			
	VNM	Vietnam								X	X	
	ZMB	Zambia			X	X		X	X			
Medium-high income	ARG	Argentina					X	X	X	X	X	X
	AZE	Azerbaijan								X	X	X
	BGR	Bulgaria							X	X	X	
	BIH	Bosnia and Herzegovina						X				
	BRA	Brazil						X	X	X	X	
	CHN	People's Republic of China				X	X	X	X	X	X	X
	COL	Colombia		X	X	X	X	X	X	X	X	X
	CRI	Costa Rica						X	X	X	X	X
	DOM	Dominican Republic			X	X	X					
	DZA	Algeria		X	X	X						
	ECU	Ecuador		X	X	X	X	X	X	X	X	X
	GAB	Gabon			X	X						
	HUN	Hungary	X	X	X	X	X	X	X	X	X	X
	IRN	Islamic Republic of Iran		X	X	X	X	X	X	X	X	X
	IRQ	Iraq			X	X	X	X				
	JOR	Jordan						X				
	MEX	Mexico					X	X	X	X	X	X
	MKD	FYR of Macedonia						X	X	X	X	X
	MYS	Malaysia		X	X	X	X	X	X	X	X	X
	PAN	Panama		X	X	X	X	X				
	PER	Peru					X	X	X	X	X	
	ROU	Romania						X	X	X	X	
	THA	Thailand			X	X	X	X	X	X	X	X
	TUN	Tunisia				X		X	X	X		
	TUR	Turkey	X	X	X	X	X	X	X	X	X	X
	VEN	Venezuela		X	X	X	X	X	X			
	ZAF	South Africa		X	X	X	X	X	X	X	X	X
High income	AUS	Australia	X	X	X	X	X	X	X	X	X	X
	AUT	Austria	X	X	X	X	X	X	X	X	X	X
	BEL	Belgium	X	X	X	X	X	X	X	X	X	X
	CAN	Canada	X	X	X	X	X	X	X	X	X	
	CHL	Chile		X	X	X	X	X	X			
	CZE	Czech Republic							X	X	X	
	DEU	Germany								X	X	X
	DNK	Denmark	X	X	X	X	X	X	X	X	X	X
	ESP	Spain	X	X	X	X	X	X	X	X	X	X
	FIN	Finland	X	X	X	X	X	X	X	X	X	X
	FRA	France	X	X	X	X	X	X	X	X	X	X
	GBR	United Kingdom		X	X	X	X	X	X	X	X	X
	GRC	Greece	X	X	X	X	X	X	X	X	X	X
	HKG	Hong Kong, China			X	X	X	X	X	X	X	
	HRV	Croatia						X				

Income group	ISO	Country	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
	IRL	Ireland	X	X	X	X	X	X	X	X	X	X
	ISR	Israel		X	X	X	X	X	X	X	X	X
	ITA	Italy		X	X	X	X	X	X	X	X	X
	JPN	Japan					X	X	X	X	X	X
	KOR	Korea		X	X	X	X	X	X	X	X	X
	LTU	Lithuania								X	X	
	MLT	Malta								X		
	NLD	Netherlands	X	X	X	X	X	X	X	X	X	X
	NOR	Norway	X	X	X	X	X	X	X	X	X	
	NZL	New Zealand	X	X	X	X	X					
	POL	Poland	X	X	X	X	X	X	X	X	X	
	PRT	Portugal	X	X	X	X	X	X	X	X	X	X
	RUS	Russian Federation							X			
	SAU	Saudi Arabia					X	X	X	X	X	X
	SGP	Singapore		X	X	X	X	X	X	X	X	
	SVK	Slovak Republic							X	X	X	
	SVN	Slovenia						X	X	X	X	
	SWE	Sweden	X	X	X	X	X	X	X	X	X	X
	TWN	Chinese Taipei			X	X	X	X	X	X	X	
	URY	Uruguay		X	X	X	X	X	X	X	X	X
	USA	United States	X	X	X	X	X	X	X	X	X	X

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