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Sustainable Development and Industrial Development: Manufacturing Environmental Performance, Technology and Consumption/Production Perspectives*

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Abstract

Industrial development has always been seen as the main engine for economic growth due to its large economic multiplier and technological opportunities. However, manufacturing sectors are directly and indirectly responsible for a large share of overall environmental pressures, raising concerns for the environmental sustainability of manufacturing-based development. In this paper we evaluate the drivers and decoupling trends of environmental pressures arising (directly or indirectly) from manufacturing production and consumption for a large selection of developed and developing countries.

As a first step we decompose changes in emission intensity of manufacturing sectors into a series of components by means of a shift-share analysis to identify the main drivers of change. A second step will compare direct environmental pressures generated by manufacturing sectors (production perspective) with the amount of emissions generated (domestically and abroad) by the domestic consumption of manufacturing goods (production perspective). Finally, we evaluate the possible emergence of an EKC dynamics for production and consumption perspective emissions for the world as a whole and for different continents.

Keywords: industrial development, environmental efficiency, shift share analysis, production-consumption perspective, environmental Kuznets curve

JEL: Q55, Q56, O19

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1 Introduction

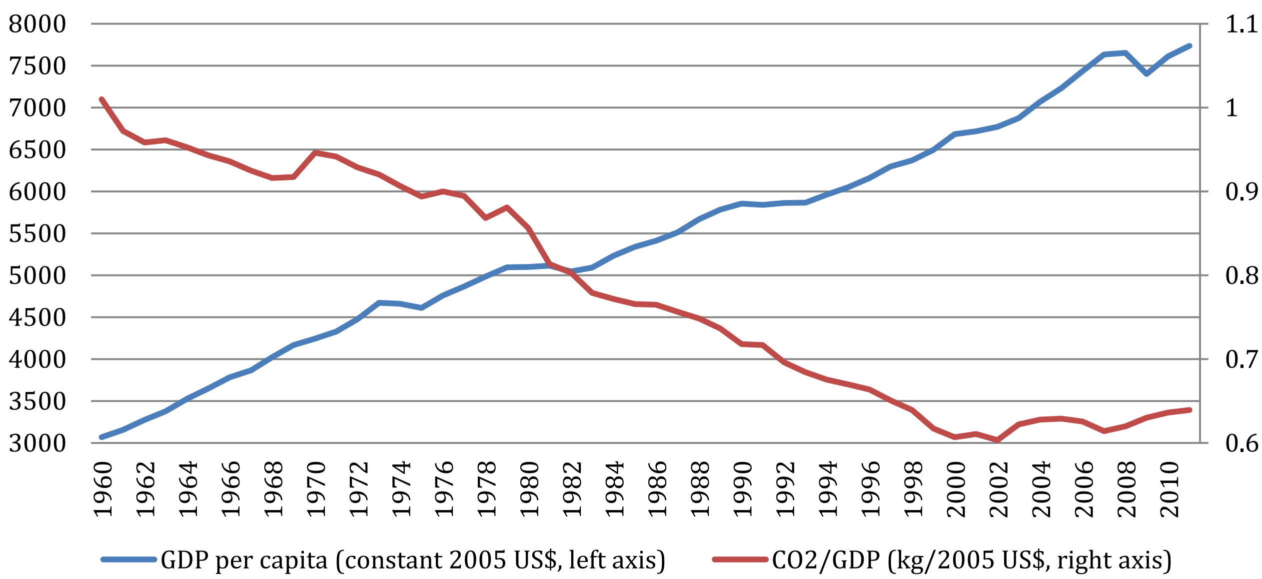
This work aims at analysing the environmental performances of manufacturing sectors and their main drivers, namely economic factors, technology and trade among others. In particular we focus here on the dynamic development of environmental performances, both in absolute terms and in 'productivity' terms, through both decomposition and an econometric analyses. The analysis aims to highlight differences over time, across geographical areas, income categories and by sectorial technological classes. Strong emphasis is assigned to the comparison of consumption and production perspectives[1], while the main framework of reference is based on the Environmental Kuznets curve (EKC) approach. This paradigm allows investigating how environmental performances are (dynamically) affected by population (Martinez-Zarzoso et al. 2007), GDP, technology (Vollebergh & Kemfert 2005), composition effects and trade (see in particular Levinson 2009, for a discussion of the role of trade, composition and technology as drivers of a country environmental performance).

Before delving in more detailed discussions on sectoral performances, it may worth taking a step back to the aggregate environmental-income relationship. Recent studies on the dynamics of CO2 by country outline that high income countries 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 due to the process of deindustrialization/demanufacturing of more advanced countries and to the fact that goods are produced with higher CO_2/value added intensity in emerging countries. Being such demanufacturing a natural evolution of economic systems (Baumol 1967; Rodrik 2013), environmental and innovation policies should favour technological transfers, in addition to the aim of minimising the costs of complying with environmental regulations in the short run, when the two aspects may be in conflict. Finally, technological change is another piece of this complex puzzle, as high technological intensity and high value added specialization allow reducing emissions, then

[1] Following EEA (2014) the production perspective approach considers only direct domestic emissions while final demand consists of total final demand (domestic demand and export) of domestically produced goods. The consumption perspective approach considers also foreign emissions by including in the matrix of inter-industry transactions both domestically produced and imported intermediate inputs, while final demand includes overall demand by resident agents, thus including domestic and imported final consumption but excluding exports.

trade development (e.g. increased net imports of polluting goods) may further contribute to this reduction[2], making necessary to explore both production and consumption perspectives (Marin et al. 2012; EEA 2014a) 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. These empirical facts shortly but coherently narrate pieces of a Kuznets-like dynamics, and Figure 1 shows how the significant increase in CO2/GDP levels was not to sufficient to outweigh the GDP scale effect.

Figure 1 – CO2 emission intensity and GDP trends in the post second world war period



Source: World Bank.

Environmental productivity (EP) is an other relevant factor in this framework, which as in Gilli et al. (2014) we here define as economic value over CO2 emissions (similarly to labour productivity which is defined as VA/L) [3]. Considering this other aspect make the investigation more complex since EP is composed of two latent trends regarding carbon dioxide and economic values. The first one is the elasticity of carbon dioxide to income, when GDP either increases or decreases, which brings us back to the Kuznets discussion. The issue is particularly relevant and regards specifically how to increase the EP performance in medium technology sectors, which are the ones possibly less affected by international trade – to increase value - and international policy pressures

[2] 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.
[3] Value added

to reduce emissions. The second aspect refer again to the role of technological progress, which can be seen as the main element capable of influencing this elasticity, allowing in other terms to sustain a certain level of living standard reducing the impact to the environment. On this point, Vollebergh and Kemfert (2005) observe for instance 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.

Trade issues will be carefully scrutinised in our paper, namely by considering 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 (Keller & Levinson 2002) suggests that more stringent environmental 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 time 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 decomposition analyses, which touch both the production and consumption side of environmental performances. Section two decomposes manufacturing CO_2 emission performances across countries through a shift-share analysis. Section three discusses the so called consumption and production perspective, and introduces the main data used in the analysis. Section four presents empirical exercises aimed at testing for the presence of a non-linear EKC path, accounting for the role of technological change. Finally, Section five lists the main highlights and original outcomes.

2 Decomposition analysis of emissions in the manufacturing sector

In this section, we present a decomposition analysis which relies on the geographical dimension only (shift share analysis), by comparing each country with the world-average and the geographical and income-class average. In doing that we exploited two different data sets. The Real value added in US dollars by manufacturing sectors (ISIC Rev 3.1) comes from the INDSTAT2 database maintained by the UNIDO, while CO2 air emissions from the combustion of fossil fuels are retrieved from the corresponding database maintained by the International Energy Agency (IEA)[4].

Shift share analysis is a common tool in regional and urban economics (e.g., Esteban 2000): its aim is to quantify the role played by different factors in driving 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 differential in the variable of interest 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 (emissions per value added) differentials for the manufacturing sector into three components, called structural (M), differential (P) and allocative (A), which can be interpreted as follows[5]:

1. The differential factor (P), which reflects that part of the difference in emission intensity of a country is due to differences in within-industry 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 sectoral composition is the same.
2. The structural factor (M) reflects a country sectorial mix, and quantifies the contribution of differences in the composition of the manufacturing sector to aggregate differences in emission efficiency. This value assumes positive (negative) value if the region is specialised in more (less) emission-intensive sectors (according to the chosen indicator).
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

[4] See Appendix A for more details on data sources.
[5] In doing so we follow Gilli et al. (2013) to which we refer for further details on this approach. Moreover, Appendix B present a mathematical appendix with the derivations of the M, P and A terms.

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 important 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 interpretation of coefficients reported in the following tables is straightforward: a negative sign always indicates a better than average performance, and a positive sign a worse than average performance.

Table 1 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 that they are specialised in sectors in which they are more environmental efficient than average. This is an interesting result, which underlines that despite the fact that these countries tend to be, on average, less environmental efficient than the world level, they 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 2, 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.

Table 1 – Shift share analysis (CO2/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 2 – Shift share analysis (CO2/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						
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

Country	1970			1990			2010		
	A	M	P	A	M	P	A	M	P
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 Consumption vs production perspective

The analysis in Table 1 and Table 2, are conducted using data on direct emissions from manufacturing sectors i.e. environmental pressures directly exerted for 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 only) 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 when adopting this last approach is that consumption footprints data need to be estimated. In our analysis, we rely on environmentally extended input-output (EEIO) modelling starting from the EORA multi-regional input-output database (Lenzen et al., 2013)[11]. We compare, for the four income groups first and then for a selection of countries, the consumption and the production perspective of manufacturing production/consumption. In particular, in Table 3, the first five columns represent the ratio of emissions induced worldwide by domestic consumption of manufacturing goods (‘consumption perspective’) that occurs in any sector (e.g. electricity generation in the utilities sector purchased by the manufacturing sector) 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, an 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.[12]

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 means that they induce relatively more emissions worldwide with respect to the two other income groups. This is obviously only a relative result, given by the comparison of the coefficients across the groups. This evidence does not consider the size of emission of the two income groups. If we look at the right five columns of table 3 in fact, we can easily note that despite their (relatively) 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

[11] More details about data and methods for this section are reported in Appendix C.
[12] The world-level weighted average of this indicator is not necessarily equal to one as the consumption perspective of manufacturing goods on the one hand does not consider those manufacturing goods that serve to generate final products and services in non-manufacturing industries and on the other hand it does account for emissions occurring to non-manufacturing sectors that serve as suppliers of intermediate goods and services to the manufacturing sector.

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 emerge. The most relevant one is the fact that we observe opposite trends of this indicator in high income countries and the three other groups. High income countries increased 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 experienced opposite trends. The driving forces behind this evidence are manifold. Firstly, an increase in domestic emission efficiency decreased the production footprint for a given level of industrial production, increasing the level of the indicator. Secondly, also offshoring and delocalisation are two factors which might have decreased the production footprint, explaining again the result for high income country. Thirdly, the increasing process of industrialisation experienced by the other three income groups, as suggested by the increasing trend in their contribution to global direct emissions, is probably the main driver behind their performances. Moving to Table 4, 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 3 – Consumption vs production perspective of manufacturing consumption/production by income group (own elaboration on EORA)

	Consumption perspective / production perspective					**Share of global direct CO2 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 4 – Consumption vs production perspective of manufacturing for selected countries (average production perspective CO2 emissions > 1% of world total – own elaboration on EORA)

	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**
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%

	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**
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%
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%**

4 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 (Marin & Mazzanti 2010).

We analyse EKC dynamics by using an unbalanced panel dataset which runs over 8 periods (5-years length) 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 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:

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

Where CO_2 is the amount of CO2 emissions from manufacturing sectors (from the EORA database, refer to Appendix C for further details). We will scrutinise both production, namely direct emissions produced by economic activities, and consumption perspectives (refer to Appendix C 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 2014a). POP is population, GDP the income factor. Technological elements (TECH) are proxied by the flow and stock of national patents (PATc, PATs) and spillovers (SPILL), built 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. We 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 C.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[13].

[13] 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.

4.1 Whole sample[14]

The aggregate evidence for production perspective CO_2 emissions of manufacturing sectors (Table 5) does not reject the hypothesis of a Kuznets like inverted U shape relationship, with a turning point in terms of GDP per capita that lies in between the average and the maximum GDP per capita observed in the sample[15].

While technological variables are not significant[16], both TRADE and Inequality appear to impact negatively on emissions. The role of trade openness may reflect the fact that smaller open economies 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 the role played by technology deserves a comment. First, in the EKC relevant literature, the inclusion of specific technological variables is not common. Technological variables are often captured by fixed effects in different econometric contexts (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 & Becchetti (2006) and Auci & Trovato (2011): the former 'adjusts' the EKC through the inclusion of variables that account for the energy supply infrastructure and the industry mix. Though technology is explicitly considered, its empirical inclusion finds proxies in the two mentioned factors. The latter 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*'.

Another issue is that we can only include total patents, not green ones. Total patents capture the overall innovation capacity, both in brown and green economy. It would be nevertheless un-correct

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[14] 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.

[15] We note that cubic effects are not significant here and for subsamples of countries.

[16] 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.

to include green patents even if they were available, since green patents are defined only for green sectors and thus are more a proxy of the "greeness" of the sector than of the abating technology; indeed, several emission reducing innovation are not patented in green sectors[17].

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. 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.

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. 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 higher income countries offshore polluting productions with little shift to the consumption of goods characterised by a small footprint. If, on the one hand, higher income countries prefer a clean environment at home because environmental quality is considered as a normal good, on the other hand, progressing along the income curve increases the demand for goods that are increasingly produced abroad. Inequality turns out to be positively related with consumption perspective emissions per capita while the relationship was negative for production perspective emissions.

Table 5 – EKC for production perspective (all countries)

Variable	A	B	C	D	E	F
lnGDP	1.370***	1.625***	1.373***	1.331***	1.398***	1.035*
$\ln GDP^2$	-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.

[17] Green patent here is referred to the OECD ENV-TECH classification.

Table 6 – EKC for 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.

4.2 Europe

The turning point of the EKC for the European sub sample is within the range of observed GDP levels as well. Temporal effects seem to capture a large part of emission reduction since the mid-80s (Table 7).

Regarding the other potential drivers of emission reduction, only TRADE maintains significance – and a negative sign of the coefficient - when temporal dummies 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 absolute decoupling in terms of overall footprint of consumed manufacturing goods for European countries.

Table 7 – EKC for production perspective (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 8 – EKC for 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.

4.3 Asia

The evidence for Asian countries presents a robust EKC. We note that both TRADE and the intensity of patents flow (PATc) are significant (Table 9). Both coefficients show a negative sign: in Asian countries, trade openness and technological intensity have both reduced emissions. 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.

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. There are also countries (Japan, Malaysia, etc) whose exports is less dependent on carbon intense inputs. Further analyses could look at even more specific levels, up to the country level. 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 (Table 10) 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); PATc (Positive), PATs (positive) and GINI (positive).

Table 9 – EKC for production perspective (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 10 – EKC for 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.

4.4 Africa

As it was expected, African countries do not present EKC dynamics. The CO2-GDP elasticity is around 0.147, thus indicating a relative decoupling. The coefficient is not large in magnitude, but an actual 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 11). In addition to that, while the TRADE element is not significant, 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[18].

[18] These results are not reported for a matter of space but are available upon request.

Table 11 - EKC for production perspective (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.

4.5 America

The area presents a within-range turning point for the EKC curve (Table 12), where nevertheless temporal effects are positive over 90s and in the post 2000 decade. 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 points of view[19].

Table 12 – 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.

5 Concluding remarks

Our paper provides diverse and complementary insights on the relationships between environmental performances and the correlated drivers, taking a new original manufacturing sector perspective. The shift share analysis 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

[19] These results are not reported for a matter of space but are available upon request.

greener sectors, a result which is in line with 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. The econometric exercise 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 not relevant besides Asian economies. The results for technology are not unexpected and do not contradict previous evidence: 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. Interestingly, 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. 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 spillover effects, though this 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 perspective 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: IEA and INDSTAT databases – Online Supplementary Material

The empirical analysis reported in shift share analysis of the current article 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 D.1. 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 D.2. 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
	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			

Income group	ISO	Country	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
	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				
	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

Income group	ISO	Country	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
	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

Appendix B: Shift-share analysis – Online Supplementary Material

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 C: Consumption perspective and the EORA database – Online Supplementary Material

Information on CO_2 emissions used in analysis of section 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 CO_2 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.

Table C.1. Descriptive Statistics - Econometric analysis

Variable	Description	Observations	Mean	Std. Dev.
CO_2	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 neighboring 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

Appendix D: Definition of sector by technology group - Online Supplementary Material

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

Sector code (Nace rev 1.1)	**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