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Structural Changes and Sustainability.
A Selected Review of the Empirical Evidence *

Maria Savona[†], Tommaso Ciarli[‡]

Abstract

The paper offers a review of selected topics in the empirical literature on structural change and sustainability. We focus on aspects of structural change that directly affect emissions and energy intensity: changes of the sectoral composition of economies, trade and international fragmentation of production, technological change and innovation, and demand. We identify several empirical facts. First, only a few countries have experienced a decoupling between growth and emissions, due to proportionately faster growth rather than greater energy efficiency. Second, the long-term shift from manufacturing to services has not led, in all cases, to the de-materialisation of economies and a lower environmental burden. Exploitation of energy efficiency increases depends on the ability of the service sectors to incorporate technical changes to reduce energy intensity. Third, global trade and energy and emissions intensity trends support the pollution haven hypothesis, which predicts displacement of the environmental burden from developed to emerging countries. The pursuit by developing countries of a long-term strategy of trading jobs for emissions is likely to exacerbate the asymmetry related to emissions intensities between developed and less developed economies. The review should inform debate on environmental policy within the broader context of innovation and development policies.

Keywords: Structural change; sustainable development; tertiarisation; de-materialisation; pollution haven hypothesis.
JEL: O3, O44; Q55;

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1 Introduction

The processes of economic growth and structural change are intertwined, with structural change occurring at different levels and in different domains, such as production techniques, intermediate and primary inputs, consumption, investment and technological progress. All of these aspects affect the environment in terms of energy and emissions intensity and, more largely, climate change. Ayres and van den Bergh (2005, p. 116) contend that "Economic growth must be accompanied by structural change, which implies continuous introduction of new products and new production technologies, and changes in [energy] efficiency and de-materialisation". It has been argued that we need a theory to link different aspects of economic changes in a comprehensive framework van den Bergh and Gowdy (2000).

Our previous contributions (Ciarli et al., 2010, 2018a; Ciarli and Savona, 2018) provide a theoretical grounding for and derive some empirical regularities related to various aspects of *structural change* and their effect on growth. In this work we draw on the seminal three-sector split model (Fisher, 1939), Lewis's dual sector model (Lewis, 1954; Gollin, 2014) and theories of (unbalanced) economic development (Chenery et al., 1986; Hirschman, 1958; Rosenstein-Rodan, 1943). The aim of this research was to account for numerous aspects that accompany traditional sectoral shifts within national economies, which are related to long-term structural change and growth processes and to both the supply and demand side. Among the supply side aspects considered, structural changes include transformations in the division of labour and trade relations among countries, both of which affect their terms of trade (Prebish, 1950; Singer, 1950); and changes of the organisation of firms and production structures resulting from the diffusion of technical change (Lazonick, 1979; von Tunzelmann, 1995; Mokyr, 2007). Among the demand side aspects examined, structural change implies changes of preferences and the composition of demand for new or cheaper products (Berg, 2002) that affects the societal structure (McCloskey, 2009).

In the present paper and other work (Ciarli and Savona, 2018) included in this Special Issue, we reprise the various aspects of structural change at the macro and meso-levels, that we have shown to be relevant as a result of our previous research. These are the changes of the sectoral composition of economies, which is gaining renewed interest in view of the trends in developing countries (Rodrik, 2016); trade and international fragmentation of production, which affects the new distribution of the environmental burden between developed and developing countries; technological change and innovation, which might open up opportunities to increase energy efficiency; and demand. While much of the literature focuses on subsets of aspects of structural change, as (Barba Navaretti et al., 2014) demonstrate, the aim in this paper is to reveal the linkages among these subsets of aspects and the related evidence from different literatures, including labour economics, trade, environmental economics, the economics of innovation and political ecology. Some of these aspects are quite well established although not free from controversy (i.e., the Environmental Kuznets Curve (EKC)[1] , others have been relatively less

[1]All the acronyms/abbreviations used in this text are listed in Appendix Table 'List of Acronyms'.

explored (i.e., the effect of shifts to services on energy and emissions intensity trends).

The empirical literature uses several variables to investigate the environmental impact of the above mentioned production and consumption changes. The most common include *energy intensity*, which is the ratio of energy inputs to *GDP*, and is inversely related to *energy efficiency*, and *quality of the energy mix*, which is inversely related to the share of fossil fuel sources in the energy inputs mix. A frequently used indicator of environmental sustainability is *level and growth of Greenhouse Gas GHG emissions* resulting from anthropogenic activities (referred to as emissions henceforth). In this paper, unless otherwise specified, we refer mainly to energy intensity and emissions intensity trends.[2]

The present review examines those aspects of structural change that have a direct impact on the patterns of environmental sustainability and implications for climate change more broadly:

1. *sectors*: changes to the sectoral composition of the economy related, mostly, to shifts from manufacturing to services (tertiarisation);

2. *international division of labour*: trade and Global Value Chains (GVCs);

3. *technical change*, which, in our context, includes changes to the energy mix, increased energy efficiency due to technical progress, introduction of new (cleaner) product and services (eco-innovation);

4. *demand*, changes to income levels (*GDP* per capita) which affect consumption patterns and preferences.

Our proposed systematisation of the literature is as comprehensive as possible with respect to the dimensions of structural change mentioned above. The interrelated areas we focus on include:

1. the relation between countries economic growth and environmental performance (in terms of emissions or energy intensity). The EKC being the most common hypothesis on this relation, we look at how this has been quantified and tested, in both seminal as well as the most recent studies;

2. the relation between changes in the sectoral composition of economies, *GHG* emissions, and the energy intensity of production, with a particular emphasis on the tertiarization process;

3. the effect of changing trade patterns on the global map of emissions and changes to energy intensity, with a particular emphasis on the Pollution Haven Hypothesis (*PHH*), and the implications for environmental equity linked to global trade.

[2]While we acknowledge that there is a wealth of indicators of environmental sustainability, such as water pollution, waste, exposure to natural disaster, etc., the endeavor of covering them all here, albeit interesting in the context of structural change, would exponentially inflate the scope of the paper.

The main *contribution* of this empirical review is twofold: first, it identifies a few empirical regularities, which, as argued in a related work (Ciarli and Savona, 2016), serve as an empirical foundation for the modelling effort to understand climate policy complexity, the subject of this Special Issue; second, it identifies areas, among those above, that will require further research and data collection efforts and proposes directions for a research agenda on the topic.

First, by appraising the arguments over the relation between economic growth and environmental sustainability, we find evidence in support of an overall decoupling between economic growth (higher GDP) and energy intensity, which started in the mid 1970s. However, this global average hides substantial cross-country heterogeneity: only a few countries have experienced a real decoupling between growth and energy intensity. The global trend towards decreased energy intensity is attributable to a number of countries growing proportionally faster rather than to a real (global) decrease in energy inputs in GDP.

Second, review of the evidence on the effects of technical and sectoral change on emissions intensity shows that long-term processes of tertiarisation of advanced economies have been accompanied by different degrees of de-materialisation and reduction of emission alongside a decrease of the energy intensity of production. It has been argued that this heterogeneity is due to the relatively poor performance of services in terms of energy efficiency improvements (Marin and Zoboli, 2016). Potential means to reduce energy intensity have been unexploited; also, they depend on whether technical change in services allows improvements in energy efficiency and/or reduced emissions intensity. Sectoral change is shaped by demand (Windrum et al., 2009; Ciarli et al., 2018b), therefore, ultimately, the environmental impact of sectoral shifts depends on consumer preferences.

Third, findings related to global trade and energy and emissions intensity tend to confirm the PHH, which predicts a displacement of the environmental burden from developed to emerging and developing countries, and challenges or, certainly, qualifies - the existence of an EKC at the global level. The displacement of the environmental burden linked to north-south trade and the large differences in environmental regulations dispute claims related to a global level EKC effect. However, we examine the arguments related to the international distribution of income and (global) emissions intensity, which tend to downplay the importance of an actual environmental displacement from north to south. This tends to occur in contexts where policies encourage developing countries to achieve sustainable development by betting on their absolute and comparative advantages in natural resources and related activities. The long-run consequences of a systematic 'game of trading jobs for emissions' in the south are likely to lead to persistent asymmetries and a wider gap between north and south. We argue that this gap could arise for the south as the result of a 'specialisation trap', that is, the failure of developing countries that produce dirty products, to upgrade to lower energy intensive production processes. This phenomenon has been described as an 'environmental Prebisch deterioration' of the terms of trade and resonates with the original Prebisch-Singer hypothesis (Prebish, 1950; Pérez-Rincón, 2006), which predicts that the terms of trade in primary-product-based economies deteriorate vis a vis those of economies specialised in manufactured products. In this context, we pay special attention to the LACs , which are heterogenous and specialised in natural resources based industries. Historically, the policies related to these industries have been aimed at changing the sectoral specialisation towards industry.

In suggesting directions for a research agenda on the topic, we argue that a first fruitful line of research should aim at examining whether and to what extent sectoral structural changes in services imply some degree of de-materialisation and reduced energy and emissions intensity. Simulations on the extent of achievable reductions in energy, emissions and material intensity in the presence of (eco) innovation in services could help grounding evidence on this topic, building on what proposed in (Desmarchelier et al., 2013; Desmarchelier and Gallouj, 2012).

A second research endeavour for scholars interested in the relation between structural changes and environmental sustainability should entail bridging the different disciplines (environmental economists, political ecologists and environmental ecologists) dealing with the prospects of 'trading jobs for emissions' that developing countries currently face, in a context of increasing international fragmentation of production that ideally could facilitate environmental dumping and of premature de-industrialisation in emerging economies (Rodrik, 2016; Di Meglio et al., 2018).

The remainder of the paper is structured as follows. We first examine selected evidence on the macro relations between economic growth and environmental sustainability (Section 2). Second, we review contributions on the sectoral and technical changes in relation to emissions and/or energy intensity trends (Section 3), first by examining the decomposition methods, then the empirical evidence, and focusing particularly on tertiarisation and de-materialisation (Section 3.3). We then examine the literature on international trade, particularly the evidence that seeks empirical support to the pollution haven hypothesis (*PHH*) (Section 4), a topic that deserves review of the arguments on the international distribution of income proposed by environmental economists and political ecologists (Section 5). The conclusions provide a summary of our findings, and discussion of the implications for a research agenda on structural change and sustainability (Section 6).

2 The Origins: Economic development and the Environmental Kuznets Curve

In a recent, comprehensive historical review of the economics of climate change (Stern et al., 2013), Stern argues that the first estimations of anthropogenic emissions affecting climate change [3] were downward biased because they were based on underestimates of fossil fuel resources. The later empirical work on the link between economic growth

[3]The origins of the estimations of trends in Carbon Dioxide *CO2* emissions in relation to economic growth date back to the 1950s and build on John Tyndalls (1859) seminal work. Tyndall was the first to identify heat transmission via gases, i.e. the greenhouse effect (Hulme, 2009) (see also Stern (2007, 2008) for a review).

and climate change (proxied by the increase in energy intensity and the production of emissions, has grown, although the evidence remains somewhat controversial. Comprehensive assessments of the impact of growth on climate change are affected by the high level of uncertainty related to the non-economic impact of climate change and the probability of catastrophic damage (see (Weitzman, 2011)). There is also a large literature on the economic impact of measures aimed at mitigating the effects of climate change, although these, also, are quite controversial. Some of the uncertainty is due to areas that are ignored in relevant analyses: for instance, (Stern et al., 2013) argue that "studies of consumer preferences for adaptation priorities and willingness to pay as an indication of the benefits to be achieved are virtually absent".[4]

There are two main areas of interest in this literature stream: (i) the causal relationship between *GDP* growth and energy intensity or emissions trends and their convergence across countries; and (ii) the decomposition and attribution of sources of emissions to so-called KAYA factors (after (Kaya and Yokobori, eds, 1997)), such as population growth, per capita income and consumption, carbon intensity of energy, energy intensity (see the KAYA decomposition in, among many others, (Raupach et al., 2007)). Here, we focus on the first, the*EKC*, which has triggered a large literature that is reviewed below.

The *EKC* is an inverted U-shaped relation between *GDP* levels and energy intensity and polluting emissions trends, at the country level. One of the first hints of the existence of an inverted U-shaped relationship between economic growth and intensity of energy use and emissions is in Nordhaus (1977). Since then, attempts to quantify the regularities of and exceptions to this relationship have flourished. There are a few extensive reviews covering different time-spans and countries (Dinda, 2004; Millimet et al., 2003; Stern, 2004; Stern and Enflo, 2013). Nevertheless, despite this large literature, countries show heterogeneous evidence on the presence of a *EKC*.

One of the most comprehensive empirical analyses in terms of time (1971-2010) and country (99 countries) coverage, is provided by Csereklyei et al. (2014). The main findings from this study are as follows.

Growth and energy intensity trends. A heterogeneous process of decoupling.

Firstly, since the mid 1970s, there has been a decoupling between growth and energy intensity at the global level, with energy intensity declining over time, although with an elasticity lower than unity with respect to GDP growth. However, this phenomenon hides a large heterogeneity across countries: decoupling between growth and energy intensity has occurred in only a few developed countries (Csereklyei et al., 2014). As income grows, so it does the ratio of energy input to *GDP*, so that a decoupling occurs only if the rate of growth of energy intensity is slower than the rate of income growth. The global trend towards a decrease in energy intensity is due, mainly, to a number of countries growing proportionally faster rather than to a decrease in the level of energy inputs to *GDP*.

[4] We reprise the issue of demand in Section 3.3 and refer to the few contributions on the role of consumer preferences and demand.

It is interesting that the energy/capital ratio is over time declining proportionally more than energy intensity. Also, those countries that have experienced an increase in their energy intensity have experienced an increase in their energy/capital ratios too. This seems to be in line with the findings for four *LAC*s (Brazil, Chile, Colombia and Mexico) in Altomonte and Correa (2011), who attribute the increase in the energy use coupled with weak productivity growth to the specialisation of these countries in natural resources (see also Barba Navaretti et al. (2014)). Overall, a decoupling effect could hide increases in energy intensity and consumption in absolute terms, so the evidence of alleged achievement of decoupling targets might be misleading.
A recent renewed interest in the trade-off between growth and emissions intensity has sparked new analyses of the impact of population growth. For instance, Casey and Galor (2017) estimate the elasticity of emissions to population and income per capita over the past 60 years and find that it is seven time larger than the elasticity of emissions to income per capita. They conclude that slowing population growth by means of fertility policies could still allow income per capita growth with no increases in emissions.

Convergence of energy intensity and energy/capital ratios.

Secondly, there has been unconditional convergence in terms of energy intensity and the energy/capital ratio since the mid 1970s. Countries with a low initial energy intensity level – with respect to their *GDP* per capita – tend to experience higher increases in both energy intensity and the energy/capital ratio (Csereklyei et al., 2014) [5] It has been argued, also in Stern et al. (2013), that the convergence in energy intensity levels in past decades is unprecedented. In the 20th century, there was much greater variation in energy intensity over time at each given level of income.

Cost share of energy.

Thirdly, although tested for only a small number of countries (Sweden, *US* and *UK*), Csereklyei et al. (2014) find that the cost share of energy in *GDP* has decreased over time. This suggests that the ratio of energy per worker has increased over time (with income), driving the cost share of energy down.

Finally, the 'energy ladder hypothesis' seems to be confirmed by the data: the energy quality mix improves with income growth (Semieniuk, 2018).

The empirical findings mentioned above are confirmed only to some degree in particular macro-areas of emerging countries, for instance in *LAC*s (see Russi et al., 2008; Poudel et al., 2009; Rubio and Folchi, 2012). Poudel et al. (2009) estimate parametric and semi-parametric specifications to test the presence of an *EKC* over the period 1980-2000 in the *LAC*s, based on *CO2* emissions and controlling for forestry area among the usual variables. They find remarkable differences across countries when they con-

[5] Csereklyei et al. (2014) show that all unconditional and conditional convergence tests in their empirical analysis are highly significant, meaning that energy intensity and the energy/capital ratio are increasing in low energy intensive countries.

trol for extension of forestry land: while, with the exception of Brazil, countries with high proportions of forestry land (usually the lowest income countries - Paraguay, Peru, Venezuela, Bolivia and Brazil) are located in the growing segment of the curve, those with a medium presence of forestry (Argentina, Chile, Ecuador, Colombia, Honduras and Nicaragua) tend to show a N-shaped *EKC* curve rather than the traditional U-shape. There seems to be a turning point at the level of about USD 4,800 per capita, beyond which *CO2* emissions intensity starts to rise again. This result is robust to the exclusion from the analysis of Brazil, Colombia and Peru and is found to drive the trend for the whole region. Therefore, it seems that, based on *CO2* emissions, the *EKC* for Latin America is less of a stylised fact than the narrative around the traditional *EKC* might imply.

Overall, the evidence suggests that the *EKC* cannot be considered a 'stylised fact' or empirical regularity for all countries. In fact, much of the evidence reviewed in the rest of this paper deals with empirical issues that qualify the evidence on the EKC. For instance, the cross-country heterogeneity in the occurrence of a growth/energy intensity decoupling is linked strongly to sectoral specialisation, which, in turn, explains the different trends in the energy/capital ratios. The higher risk for those countries that have not yet reached the peak point of the *EKC* or demonstrate an N-shaped *EKC*, is of being caught in a 'specialisation trap', which increases their energy intensity and energy/capital ratio without any productivity gains (Altomonte and Correa, 2011). This chimes with a recent concern expressed by Rodrik (2016) in relation to the 'premature de-industrialisation' in developing countries, while Magnani (2000), for instance, examines the political economy of the EKC by considering the within and between country income distributions. We review the evidence on the sectoral and technical change explaining (at least part of) energy intensity trends in the next section (**??**.

3 Sources of structural changes and energy intensity and emissions trends.

The (implicit) analytical bases of the *EKC* rely, first and foremost, on the structural economic changes occurring at different levels of *GDP*. Economic growth is traditionally associated first to industrialisation and then the progressive tertiarisation (which does not necessarily imply de-industrialisation) of economies. This latter might (or might not, as discussed in Section 3.3) entail some degree of de-materialisation, intended, broadly, as a reduction in energy and natural resources inputs to production **?**. However, technical progress could enable reductions in the energy intensity of production processes, by reducing the energy inputs and improving the energy mix. The empirical literature not only tests for the presence of an *EKC* across countries and time spans and with or without the presence of trade but also decomposes the sources of *GDP* and emissions trends in terms of changes to the sectoral composition of economies and technological change.

This section reviews selected studies to examine the extent to which the increase (decrease) in the energy intensity of production in a given country over a certain time-span can be accounted for by shifts towards sectors with higher(lower)-than-average levels of energy intensity or by within-sector increases (decreases) in energy intensity. In other words, we are interested in the extent to which changes in energy intensity and emissions trends are due to a composition (between-sectors) effect or a technical change (within-sectors) effect. In turn, the technical change effect depends crucially on the extent to which firms have incentives to innovate and use cleaner production processes, and/or introduce new, less energy-intensive products and services, as a result, for instance, of the need to comply with (new) environmental regulations. First, we review the different decomposition methods (3.1) and then discuss the main empirical evidence (3.2). We then review the (comparatively small) literature on tertiarization and de-materialisation (3.3). Finally, we evaluate the seminal and most recent contributions on the effectiveness of environmental regulation on firms eco-innovation (the Porter hypothesis) (Porter and van der Linde, 1995).

3.1 Decomposition methods: A brief inventory

The two most common sets of tools to decompose the sources of energy efficiency between sectoral and technical change are Index Decomposition Analysis (*IDA*) and Structural Decomposition Analysis (*SDA*).[6]

Extending the work of Hoekstra and van den Bergh (2003),[7] Ang et al. (2009, 2010) and Su and Ang (2012) provide comprehensive reviews of the different types and purposes of decomposition techniques. While *IDA* is employed mostly to assess energy use and the drivers of emissions in a specific sector and is used almost exclusively by energy scholars, *SDA* provides a cross-sectoral and, often cross-country (see Section 3.2) decomposition of energy intensity, in an Input Output (I/O) framework. Due to its relevance to this study, we focus on the use of and refinements to *SDA* techniques, as in (Su and Ang, 2012). (Mulder et al., 2014) and (Voigt et al., 2014) also provide useful discussions on the criteria for choosing an appropriate decomposition technique.

Basically, *SDA* techniques allow distinguishing between a structural (cross-sectoral) factor, that is, the aggregate changes in countries energy intensity due to changes in their sectoral composition, holding constant the within-sector energy intensity, and a technical (within-sector) factor, that is, changes in the energy intensity of each sector, holding constant the structure of the economy.

The first use of *SDA* was based on simple, national *I/O* tables, use of arbitrary base years in Laspeyres and Paasche price indices and in general included a residual from the decompostion, which, depending on its dimension, could complicate the interpretation of results, according to Su and Ang (2012). The nature of the successive refinements to these decomposition techniques led to the achievement of important properties such as independence from the unit of analysis and exact decomposition (i.e., with no residual). Currently, the most commonly used *SDA* is the Log-Mean Divisia Index (*LMDI*).

[6]The latter is used, also, to decompose sources of productivity and employment growth.
[7]See also Hoekstra and van den Bergh (2006).

Typically, the energy (energy consumption and emissions) decomposition studies reviewed, use additive rather than multiplicative *LMDI* decomposition techniques. A few decomposition works use the Mean Rate of Change Index (*MRCI*) and parametric Divisia methods. According to Su and Ang (2012), the most recent studies based on these techniques tend to focus on China and Japan, and on emissions rather than energy consumption. Some of the most recent studies reprise the DEL method proposed by Dietzenbacher and Los (1998), which assumes no preference for a particular form (additive or non-parametric) and address the non-arbitrariness issue with respect to the sequence of (decomposition) factors chosen [8].

In the next section, we highlight the empirical evidence based on the use of *SDA* techniques, mainly *LMDI* ones.

3.2 Decomposition evidence: sectoral structure and technical change

One of the most recent and exhaustive additions to the empirical literature that makes use of a *LMDI* decomposition technique, is in (Voigt et al., 2014), who decompose energy savings trends (changes in energy inputs per changes in gross output) between technological change and structural change using World Input Output Data (*WIOD*), matched to Socio Economic Accounts (*SEA*), which provide data on employment, wages and skills and gross energy use, for 40 countries over the period 1995-2007. The novelty of this work is that it also takes account of within-country regional heterogeneity. To our knowledge, this is the most exhaustive decomposition exercise to date.

The authors apply a three-factor (*LMDI*-II) decomposition which looks at: (i) within-sector technical change leading to higher energy efficiency; (ii) the sectoral change effect - split into: (iia) a within-country effect, that is, the shift towards more/less energy intensive sectors at the domestic level, and (iib) a between-country effect which attributes changes in overall energy emissions trends to shifts towards more/less energy intensive countries; and (iii) a global technology effect which looks at global gains in energy efficiency, at the aggregate level, for 34 sectors.

Based on overall trends for different energy sources, Voigt et al. (2014) find that *coke petroleum and nuclear fuel* are the least heterogeneous sectors across countries, in terms of energy intensity improvements. For global sectoral shifts in energy savings, the most energy efficient sectors across countries are *machinery, and electrical and optical equipment*. The evidence shows that in most of the countries included in the study, there is a decoupling between gross output growth and energy use (i.e., energy use grew at a lower rate than gross output - in the *UK* it even declined), with the eastern European countries among the best performers, most likely due to shifts away from energy intensive industries. Overall, sectoral heterogeneity in terms of changes to energy saving (i) emerges as being more pronounced than country heterogeneity (iia).

In relation to convergence patterns, (Voigt et al., 2014) find a strong relationship between initial levels of energy intensity and intensity of energy reduction (Figure 1),

[8] The choice of sequence of factors is not neutral for the results obtained. In general, the *LMDI*, based on index number theory, is preferred for its relative computational (non)complexity and ease of interpretation of results, as they treat zero and negative values in matrices and allow exact decompositions.

so that - not surprisingly - the majority of countries with low initial levels of energy intensity have low energy intensity reductions (most developed countries, and Brazil and Indonesia). Similarly, countries with high initial levels of energy intensity experienced high reductions in energy intensity over the period considered (eastern European countries and China). Despite the structural shift to services, India shows high initial levels of energy intensity and particularly poor performance in terms of reductions in energy intensity rates.

There seems to be an overall trend towards country convergence in energy intensity, which supports the aggregate findings in Section 2. In the structural decomposition analysis, although less pronounced than the cross-sectoral heterogeneity, the specific role of the between-country effect seems to be important: the global energy intensity trend is affected strongly by a global shift in production towards more energy intensive countries. Despite this global shift, world energy intensity shows a decreasing trend, likely driven by an overall positive technology (within-sector) effect.

To summarise, in a ranking of the role of the different sources of energy intensity changes at the global level, the within-sector source (technology) plays the most important role and affects sectoral heterogeneity in energy intensity comparatively more than structural sectoral and country shifts. Among these latter, it seems that the between-country effect is more important than the within-country effect, so that the rise of China, for instance, in the global share of production has affected global energy emissions trends more than national structural changes.

Figures 2 include the group of countries that have performed worst in terms of reducing their energy intensity, that is, they started from low levels of energy intensity and have achieved very low rates of energy intensity reductions. This group includes Brazil, Greece, Indonesia, Italy, Japan and Denmark. For instance, Brazil performed relatively badly in terms of a technology effect, despite the structural shift after year 2000 towards less energy-intensive sectors. However, this has not driven down energy intensity or offset poor technological performance.

[FIGURE 1 HERE]

[FIGURE 2 HERE]

The best performing countries are the UK, Ireland, Sweden, South Korea, Slovenia, Turkey and Cyprus. None presents marked differences in the roles of technology and structural change, both of which have played positive roles in lowering aggregate energy intensity.

While the empirical exercise in Voigt et al. (2014) seems the most exhaustive in its genre, most of the literature that uses *SDA* focuses on a small number of countries or emissions types, and many examine China vis a vis the *US*. For instance, (Mulder and de Groot, 2012) and (Mulder et al., 2014) investigate 18 OECD countries from 1970 to 2005; (Kaivo-oja et al., 2014) studies China (see also (Su and Ang, 2012) and (Tian et al., 2014)) the *US* and the *EU27*; (Poudel et al., 2009), (Russi et al., 2008) and (Jimenez and Mercado, 2014) present evidence on *LAC*s; while (Panayotou et al., 2000) on a number of developing countries. Although the body of evidence based on *SDA* conducted on a large number of countries is smaller that evidence on single macro-regions, we can examine the case of the *LAC*s, which is particularly interesting due to their main specialisation in natural resources.

(Jimenez and Mercado, 2014) provide an interesting methodological extension to *SDA*: after decomposing the trends in energy intensity according to structural and technological change, they conduct a regression analysis to explore the determinants of the decomposition results. They employ a synthetic control method to construct a group of comparison countries and propose some implications of the relative energy performance in the region. This latter (Synth) method uses the characteristics of the average LAC to construct a 'convex combination of non-Latin American Countries with similar characteristics' (Jimenez and Mercado, 2014, p. 164), which represents a set of 'counterfactual' countries. Figs 3 and 4 compare the energy intensity decomposition for *LAC*s and high and middle income countries, distinguishing among intensity (consumption), efficiency (technical change) and types of activity (sectoral change).

[FIGURE 3 HERE]

They find that, overall, energy intensity has decreased over the past 40 years in all the 75 countries included in the study, with marked differences across countries: 54% in high income countries, about 40% in low income countries, while *LAC*s, which, typically, have low initial levels of energy intensity, have slightly under-performed, with only a 20% decrease. According to the decomposition in (Jimenez and Mercado, 2014), the relative contribution of the three factors to the trend of energy intensity varies strongly.

First, in general, technical change is responsible for most of the improvement in energy efficiency.

Second, while in high income countries (typically the OECD group) sectoral change has contributed 10% of the decrease in energy intensity, in the *LAC*s, it accounts for 8% of the increase in energy use (Jimenez and Mercado, 2014, p.165), most likely due to specialisation in extractive natural resources industries[9]. However, this trend is also highly heterogeneous across *LAC*s. This finding is in line with, for instance, Mulder and de Groot (2012), as shown in Fig 4.

[FIGURE 4 HERE]

These results suggest that there is substantial room for improvement in the *LAC*s, based on the technology effect and, also, the structural component of the energy efficiency improvement. In this respect, from the perspective of industrial and political ecologists, it might be useful to increase awareness about the possible implications of macro-economic policies on sectoral change.

Russi et al. (2008) conduct a Material Flow Analysis (*MFA*) over the same period of 40 years for a small group of LACs, that is, Chile, Ecuador, Mexico and Peru, to test

[9] we refer the reader to interesting evidence on the role of natural resource abundance and the natural resource curse are provided in (Barba Navaretti et al., 2014).

the impact of neo-liberal reforms on what industrial ecologists describe as the 'extractive countries'.

MFA is different from *SDA* and is used to assess the impact of structural change promoted by trade, on the Physical Trade Balance (*PTB*) [10] This is the difference between exports and imports in terms of the material-equivalents of flows of goods. (Russi et al., 2008) start from Domestic Material Extraction (*DME*), that is, the amount of raw materials extracted within the countrys borders. They add imports to obtain Direct Material Input (*DMI*), which is material inputs to the national economy, either internal or imported, which feed into further production processes. After subtracting exports from *DMI*, Domestic Material Consumption (*DMC*), which is the total amount of material remaining in the country is obtained. Thus, the countrys trade specialisation is of crucial importance to determine the overall *PTB*.

The use of *MFA* in conjunction with *SDA* techniques is important to assess the relationship between economic growth, and the structural and trade specialisation in countries, such as *LAC*s, where Natural Resources (*NR*) play a large role in the national economy. It is well known that globalisation has changed the relative position of countries in the global market quite radically and has increased the risk of a 'specialisation trap' in the global south. The findings in (Russi et al., 2008) show that increasing trade has not decreased *DMC*. For instance, DMI in mining has increased in Chile and Peru, and in crude oil and construction respectively, DMI has increased in Ecuador and Mexico. The implications of these findings and their policy and political aspects are discussed at more length in sections 4 and 5 respectively.

3.3 Tertiarisation *cum* de-materialisation? Myths and facts

Typical evidence of structural change is a shift from agriculture to industry and then to services in a context of growing GDP (Fisher, 1939). The shift to services or tertiarisation, is associated, intuitively, to some degree of de-materialisation, that is the reduction of the material-intensity of products [11]. However, we have relatively little empirical evidence on the real de-materialisation effect of tertiarisation. The existing evidence suggests a degree of scepticism. We review the findings in the recent context of the call from policy makers for the re-industrialisation of economies [12] .

Is this at odds with enthusiasm for the potential of economic de-materialisation, global emissions abatement and reduced materials intensity of production which are supposed to result from a shift from manufacturing to services? Is there any empirical

[10] We devote a specific section to trade (4, here we consider the relative impact of trade liberalisation on structural change for a set of *LAC*s.

[11] see **?** for a recent examination of material and knowledge contents of industrial products.

[12] See advocates of a 'knowledge driven re-industrialisation' (European Union, 2013) as a strategy for recovery from the recession that has affected EU country labour markets, in what it seems to be a revisiting of the 'Big-Push' strategy in the old Europe. A 'European Industrial Renaissance' (European Union, 2013) would require around a 50% increased demand for manufacturing goods (investment, final consumption and export), accompanied by an associated expected growth of *GDP* and employment of about 10% and an estimated increase in *CO2* emissions of about 13%. The UK Industrial Strategy launched in 2017 proposes a similar plan.

support for the effect of tertiarisation on the de-materialisation of economies?

Kander (2005) provides one of the first descriptive empirical analyses of the association between tertiarisation and de-materialisation, focusing on the Swedish economy from 1970. She argues that the decline in *CO2* emissions in Sweden was linked mainly to changes in the energy carriers mix that is, the fact that the electricity source was nuclear hydropower and biofuels rather than fossil fuel, and more stable energy consumption. She concludes that the effect of the changing sectoral composition of the Swedish economy has had a negligible effect on reducing *CO2* emissions. (Kander, 2005) bases her argument on a re-consideration of the Baumol's cost disease argument put forward in the 1960s by (Baumol, 1967) [13], which suggests that the increase in the services share of economic activities is over-estimated when measured in real (i.e., based on constant prices) rather than nominal terms.

In an updated version of their paper, Henriques and Kander (2010) reprise the argument based upon a more refined SDA. Using a *LMDI* applied to developed and developing countries, they find weak evidence of a *EKC*, especially in late industrialising countries, in line with what the findings in Section 2. For the effect of sectoral change on energy intensity, they measure structural change in sectoral composition in terms of *constant* rather than *current* prices and employment. They estimate that the real sectoral shift is of the order of 10% rather than the 30% measured at current prices. This effect is much less substantial than usually found in empirical studies that examine the same 50 year time span. The results of the *LMDI* decomposition show that sectoral change had only a modest impact on lowering energy intensity and, especially, when accounting for increased use of transport services. In contrast, Henriques and Kander (2010) find that the within-sector effect – that is, the contribution of technical change to lowering energy emissions – has a comparative larger impact.

More recently, It has been suggested that the analogue of Baumol's cost disease – reprised by Kander (2005) and Henriques and Kander (2010) to test the actual effect of tertiarisation of economies on levels of emissions – is responsible for an 'emissions disease' effect for some European countries (Marin and Zoboli, 2014, 2016; **?**). By looking at direct and indirect effects of tertiarisation on the trend of *CO2* emissions intensity using *WIOD* data, (**?**) argue that the sources of Baumol's cost disease - stagnant technological progress and slow productivity growth in most services - translate into similar stagnant performance in terms of energy intensity. They test this conjecture by accounting for the initial levels of direct emissions intensity and the dynamics of direct emissions across a few aggregate manufacturing and service sectors, and indirect emissions intensity generated by domestic and imported final demand for the macro-sectors analysed. Interestingly, they find that the direct emissions intensity of services is lower than the

[13] Baumol's cost disease (Baumol, 1967) argues that, historically, services costs and wages have increased despite a poor services productivity performance. They have been pushed up by manufacturing sector wage increases in line with (higher) productivity gains. There is a major debate over the validity of Baumol's cost disease in relation to services, but this is beyond the scope of this paper. For the purposes of the present review, it is important to acknowledge that the cost disease was attributed to lack of technical progress in services and increased demand for services associated to higher income. For further references, see (Ciarli et al., 2012; Gallouj and Savona, 2008).

emissions intensity of manufacturing macro-sectors, with the exception of transport, although European countries show high heterogeneity in emissions intensity over the period considered. However, it has been argued that a slow improvement in environmental efficiency in the stagnant services sector, combined with a rapid increase in their economic share in real (constant prices) terms, have led to an overall slower improvement in environmental efficiency. The authors describe this as the 'emission disease of services growth'. In addition, the evidence on indirect emissions intensity from domestic and international final demand seems to suggest that the 'environmental disease' of services shows increased dependence on emissions generated abroad (see Section 4 for a review of this crucial topic).

Broadly in line with the results mentioned above, Mulder et al. (2014) (see also Mulder and de Groot (2012) and Florax et al. (2011)) find that, while overall energy intensity levels in several OECD countries during the period 1980-2005 has decreased, this is due, partly, to sectoral change toward services and not improved energy efficiency in these sectors.

Mulder et al. (2014) conducts an interesting exercise to forecast the effect of tertiarisation coupled (or not) with improved energy efficiency in services, in countries where the transition to services is embryonic. They simulate three scenarios for a sample of nine OECD countries: first, they observe that the trend in the aggregate energy intensity levels would have shown significant increase had the share of value added in the service sectors not grown since 1980, confirming that the sectoral effect plays a non-negligible role in lowering overall energy intensity; second, they compare actual and hypothetical energy intensity trends in the case of no improvement in energy efficiency in the service sectors considered. They show that the hypothetical energy intensity saving for the aggregate western economies would have been lower similar to the first scenario – that is, the within-sector effect is comparatively smaller than the sectoral effect. Third, they compare actual and hypothetical trends in energy efficiency improvements in the service sectors and find that the overall hypothesised decrease in energy intensity is more pronounced than the actual decrease. Overall, this confirms that the effect of a shift to services on energy and emissions intensity decreases in the countries analysed is lower that would have been achievable, had technical change allowed improvements to the energy efficiency of services of a similar magnitude to the improvements that have occurred in some manufacturing sectors.

There are two further potential explanations of these trends, beyond the problems related to lack of technical progress, which hamper higher energy efficiency and lower emissions intensity in services. One explanations is the increase in the carbon content of trade and offshoring, and the increased number of sectors and sub-sectors exposed to carbon leakage (Bolscher et al., 2013)[14].

The second concerns directly to the role of demand and consumer preferences in relation to basic goods, and luxury goods and services, and their respective environmental

[14] The relocation of manufacturing to less environmentally stringent countries, for instance, might be a source of de-industrialisation, but not necessarily of lower (global) emissions since this phenomenon hides carbon intensive offshoring. We tackle this briefly in Section 4.

quality (i.e., levels of energy and emissions intensity). Consumer preferences and income distribution are fundamental determinants of the shift to (less energy intensive and potentially more environmentally friendly) services or products. Both the seminal (von Hippel, 1988) and more recent (García-Quevedo et al., 2016) innovation literatures link (incentives for) innovation efforts to the presence of a critical mass of demand. For instance, (García-Quevedo et al., 2016), among other innovation scholars, show empirically that incentives for firm investment in R&D reduce significantly if firms expect stagnancy or lack of demand. More importantly, (von Hippel, 1988)'s contribution identifies the pioneer consumer as promoting initial innovation investments and the introduction of more energy efficient products or new services. This is based on pioneer consumers preferences for higher (environmental) quality products and their ability to pay higher prices. Once a critical diffusion is achieved, prices reduce and pull wider diffusion of new products and services among lower income consumers. However, it has been shown Magnani (2000); Vona and Patriarca (2011) that the role of the pioneer consumer in the initial diffusion of new, less energy intensive products and services (eco-innovations) has been undermined by high income inequality and that preferences for environmentally friendly products and services are highly non-linear. (Vona and Patriarca, 2011), in particular, show that in a context of high income inequality, excessive income distance between the pioneer consumer and low income consumers hampers the diffusion of new products and services. The only aggregate effect - for instance, of the introduction of eco-innovation - is a consumption polarisation, which does not lead to significant positive environmental externalities[15]. These findings provide important insights for understanding the potential for technical change, higher energy efficiency and reduced emissions intensity linked to a shift to services.

Overall, the empirical literature indicates that the decrease in energy intensity levels linked to tertiarisation is less than the potential decrease, had services ensured within-sector improvement in energy efficiency. However, the technological progress that would make services less 'stagnant' (referring to Baumols cost disease (Baumol, 1967)) inevitably is linked to increased use of Information and Communication Technologies (*ICT*), which are heavy energy users. The findings show that services have experienced a modest energy intensity reduction while their energy consumption share has increased in absolute terms over time. An exception to this pattern is Japan, which has seen an increase in both energy consumption share and energy intensity in services (Mulder et al., 2014). Although the number of contributions that focus specifically on the impact of tertiarisation on national and global emission and energy intensity trends is appreciably smaller than the numbers of studies reviewed in the previous sections, the de-materialisation of economies has been emphasised as contributing crucially to energy efficiency improvements based on tertiarisation. This is slightly at odds with the fact that the OECD countries seem to have reached a ceiling in relation to the real and nominal shift to services. However, for developing and transition countries, the exploitation of this sectoral shift remains a challenge and, perhaps, an opportunity and a potential source of greater benefits in terms of reducing energy and emissions. This is feeding

[15] We reprise briefly in Section 3.4 examination of firm incentives to introduce eco-innovation.

debate beyond environmental sustainability Rodrik (2016); McMillan et al. (2014); Di Meglio et al. (2018) and represents a promising direction for research that would inform green industrial policy (Rodrik, 2014).

3.4 Technical change, environmental regulation and firm eco-innovation

Technical change to increase energy efficiency and lower emissions intensity results to a large extent from firm incentives and financial efforts to introduce eco-innovations. These are supposed to reduce the environmental impact of production processes and/or the introduction of new, cleaner products and services to achieve a critical level of diffusion among consumers [16].

The seminal contribution on the relationship between the introduction of environmental regulations and firm incentives to eco–innovate is the known Porter hypothesis Porter and van der Linde (1995). In a nutshell, the Porter hypothesis is based on the assumptions that incentives to spend on R&D and innovation are part of a profit maximising strategy; that R&D spending is linearly and positively associated to the introduction of product/service and process innovations, and that these increase sales and profits or result from the need to comply to environmental regulations. The Porter hypothesis supposes that well-designed environmental regulations can create incentives for firms to innovate and increase competitiveness while achieving positive environmental externalities. Or, alternatively, that in the absence of such regulations, firms will be neither able to identify or exploit technological and market opportunities to innovate to reduce their environmental impact. In the context of the above literature, we need to assess whether (within-sector) technical change is the result of an automatic market mechanism based on perfect rationality, symmetric information and profit-maximising behaviour or is the result of a carefully designed policy action based on the introduction of environmental regulations, in the absence of which firms would not have any incentive to reduce the environmental impacts of production processes.

The debate centred on the Porter hypothesis is grounded in the large literature emerged since and a vast body of work over the last 20 or so years (for recent reviews see (Wagner et al., 2004; Ambec et al., 2013)). Despite such remarkable research effort, the empirical evidence does not reach a consensus on the Porter hypothesis, although, on balance, it finds a positive relationship between environmental regulations and firms (eco) innovation performance (measured as R&D expenditures or patent counts) (Jaffe and Palmer, 1997; Ambec et al., 2013).[17]. What emerges from critiques of the Porter hypothesis is that environmental regulation, ultimately, could harm economic growth through the introduction of uncertain (in terms of their environmental impact) technological innovations. Supporters of the Porter hypothesis, point, instead, to the capacity of public regulators to identify technological opportunities that would otherwise be missed

[16] We have briefly mentioned the role of the demand side and issues related to consumer preferences and income distribution in the section on de-materialisation (3.3). We will reprise these from the international perspective in Section 4. Here we focus on the (supply side) incentives that facilitate technical change

[17] Some empirical works that test the Porter hypothesis look at the effect of environmental regulation in a PHH context (see Section 4)

by a myopic, not fully informed and not optimising private sector. Popp et al. (2010) offer a balanced review of the theoretical and empirical work on the induced innovation from environmental regulation, highlighting, among other things, the barriers to firm adoption of environmental regulations and the different effects on innovation and productivity performance.

Nesta et al. (2014) and Nesta et al. (2018) offer recent and robust empirical evidence on the effects of different types of environmental regulations - distinguishing between market based (taxes, cap-and-trade systems, feed-in tariffs) and command-and-control regulations which simply set emissions limits. They look at the effects of regulations on both static and dynamic efficiency, where the latter measures the precise effect of the regulations on firms incentives to eco-innovate, in countries at different stages of development. Within the context of this review, (Nesta et al., 2018) offer original comparative evidence of the effects of the introduction of different types of environmental regulations, as well as policy mix of lowering entry barriers in conjunction with environmental regulations, in countries at different stages of development. They find that in national contexts with initial high levels of energy intensity and low levels of technological capabilities to eco-innovate - such as emerging countries - stringent command-and-control regulatory policies are more effective for creating incentives, whereas in (mostly developed) countries with initial low levels of energy intensity and long-term cumulated technological capabilities, market-based environmental regulations might be more effective for creating incentives to achieve the technology frontier. Therefore, environmental policies have large non-linear effects and the initial level of development and stock of technological capabilities have a substantial role in directing technical change towards higher energy efficiency and lower emissions intensity.

As argued also in Ambec et al. (2013), empirical tests of the Porter hypothesis might push governments to design effective environmental regulations, for instance, in the US where climate change denial has recently surged. Further work on the Porter hypothesis would benefit from continuous research, more data collection, longitudinal analyses and a better understanding of innovation in economic academic circles.

4 Global structural change, trade and the pollution haven hypothesis

Trade, Foreign Direct Investments (*FDIs*), and increasing international fragmentation of production leading to GVCs require consideration of the concept of structural change and sustainable economic development from a global, cross-country perspective. Environmental economists have investigated the effect of trade in relation to the PHH).

The *PHH* states that cross-country differences in environmental regulations could lead developed countries to shifting the location of polluting industries to developing countries and increasing imports of 'dirty' goods produced in developing countries. This results in trade flows shaping specialisation patterns, such that developing countries could achieve comparative advantage in the production of *GHG* intensive goods. Proponents of the *PHH* claim that this process contributes to explaining the inverted U shaped relation between growth and polluting emissions in developed countries (discussed in section 2), which can afford to clean their domestic production and to import dirty products from developing countries. If the PHH could be confirmed empirically, this would substantially weaken arguments in support of a national *EKC*: although an individual country might manage to achieve a certain level of decoupling, this would not necessarily translate into a global emissions reduction since different countries hold different positions in the global effort towards mitigating climate change. One of the consequences of the *PHH* is that a global EKC trend would be unlikely; more likely would be a redistribution of emissions across countries.

The *PHH* has a numerous contributions, some in support, others offering counter-arguments (including among others, (Cole, 2004; Panayotou et al., 2000; Kander and Lindmark, 2006; Wiedmann, 2009)). For instance, according to (Cole, 2004), first, different international environmental regulations are not enough to increase environmental compliance costs, which could be large in absolute terms, but as a percentage of the firm's total costs, might be negligible. Second, these cost differences are not sufficient to determine the re-location of firms to developing countries. Third, the relocation of firms would be deterred by other aspects such as poor infrastructure, corruption, institutional instability and potential reputation losses if Multinational Corporations (*MNC*) are perceived by the media and the public as contributing to 'trading jobs for emissions' (Arto et al., 2014).

PHH scepticism revolves around how the different flows of net exports are interpreted. Specifically, an increase in dirty net exports from developing countries might be due to an increase in their overall consumption shares (and, therefore, production) of dirty products. Similarly, a decrease in net dirty exports in developed countries might be due to a smaller domestic share of dirty consumption rather than this demand being met by imports from developing countries. This latter argument is among several that explain national *EKCs*. That is, *GDP* and income growth are associated to changes in consumption preferences, which become more price inelastic and move towards cleaner, although more expensive products [18].

Several scholars have tried to test the PHH. For instance, (Cole, 2004) estimate a *EKC* equation that takes account of different types of polluting emissions, income, sectoral change and trade, for developed and developing countries. In the context of emissions trends (specific to air and water pollution), their findings support an inverted U shaped relation to income, with a turning point of about $43K in 1973. Sectoral changes are partly responsible for the decline in emissions since the manufacturing share of *GDP* is correlated positively to the environmental quality of most of the indicators considered in their work. In the context of trade, the *PHH* is partly proven for some pollutants and some periods of time. This supports the view that the occurrence of a redistribution of emissions in line with the *PHH* being responsible, in part, for the national *EKC* and, therefore, that a global '*EKC* effect' does not hold. The turning points are at lower levels of income than if the *PHH* effect is held constant. Cole and colleagues

[18] We link the main caveat to this evidence, to the presence of non-homothetic preferences (Magnani, 2000; Vona and Patriarca, 2011)

find that air pollution emissions, in particular, seem to have a negative relationship to the share of pollution-intensive imports from developing countries. More recently, Aichele and Felbermayr (2015) empirically assessed the post-Kyoto protocol effects in terms of emissions trading and found that the binding commitments under Kyoto have increased committed countries' embodied carbon imports from non-committed countries, by around 8% and increased the emissions intensity of their imports by about 3%.

(Cherniwchan et al., 2017) provides a recent review of the methods, findings and policy implications for trade and the environment, which points to the importance of micro-level analyses for empirical assessment of the *PHH*. The authors combine reviews of traditional decomposition analyses with a partial equilibrium model of firms (and plants) strategic decisions. Production strategies at the micro level and their impact on emissions complete the picture of the impact of trade on emissions at the global level. From our perspective, and in line with (Cherniwchan et al., 2017), the *pollution offshoring hypothesis* is particularly interesting. Although similar to the PHH, according to (Cherniwchan et al., 2017) [p. 4] it 'explicitly links firm level decisions to offshore dirty intermediate inputs to trade liberalization'. The decision to off-shore dirty segments of production to less strictly regulated countries *competes* with abatement decisions. Trade liberalisation and environmental regulation might reduce the incentive to invest in emissions abatement technologies since these would be more costly than offshoring dirtier production. Investigating firms (heterogeneous) off-shoring decisions should be part of the PHH empirical research agenda.

Overall, the evidence related to the PHH is uncertain in terms of whether developing countries will experience similar *EKC* patterns. If the income elasticity of 'dirty' manufacturing products remains the same, then domestic sectoral change in developed countries towards less polluting sectors will be merely hiding a pollution haven effect.[19]

The PHH debate is particularly relevant to the *developmental and employment potential* of economic growth. A multifaceted notion of sustainable development, which includes economic and social aspects as well as environmental sustainability, would need to account for countries' different preferences related to full employment and/or greener growth. Some scholars, for instance (Arto et al., 2014)), argue that when considering the occurrence of a *PHH* and suggesting a feasible global climate change policy, it is important to 'discount' the detrimental effects of the environmental burden displaced on the global south by the developed countries against the net employment gains that accrue to the developing countries via increased exports. In other words, some countries are 'trading emissions for jobs'.

To investigate this empirically, Arto et al. (2014) examine emissions and employment in the world economy, under the assumption that some developing countries might agree to bearing the environmental costs of more energy intensive exports in exchange for net employment gains. They use multi-regional I/O data on emissions and employment trade balances. They define a country A as in 'emissions surplus' if the emissions generated

[19]Those interested in the broad topic of trade and emissions, and trade liberalisation and the PHH could refer to (Taylor, 2005) and (Barba Navaretti et al., 2014) for extensive theoretical and empirical reviews.

by that countrys exports are greater than the emissions generated by its trade partner country B to produce the goods imported by country A. Similarly, they define a country as in an employment trade balance surplus if the employment generated by its export activity is greater than the employment loss due to importing. Based on these definitions, they find that countries that are in net emission surplus are those that gain the most in terms of employment generation.

Their findings show that the key players in the 'trading emissions for jobs' game are China, the *US* and the *EU27*.[20] In this context, it should be noted that the debate on the *PHH* is being affected by a radically changed perspective on emissions responsibility: the *producer responsibility principle* has shifted to a *consumer responsibility principle*, which is supposed to correct for the potentially perverse effect of an emissions trade (see also (Peters, 2008) and (Wiedmann et al., 2011)) for some relevant policy implications of the emissions responsibilities generated by international trade.)

In the context of this review, policy makers need to be aware of the trade-off between emissions reductions and job creation, which is sector specific, as highlighted in Section 3. For example, energy, gas and water supplies are the most emissions-intensive and the least employment-friendly sectors compared to electrical and optical equipment manufacturing where an emissions-reduction policy that limited exports would result in comparatively higher job losses (see Figures 5 and 6).

[FIGURE 5 HERE]

[FIGURE 6 HERE]

Another contributor to the debate on the *PHH*, from the perspective of natural resources extraction and use, is (Wiedmann et al., 2013) (see also (Wiedmann, 2009) and (Wiedmann et al., 2011) for prior methodological contributions). (Wiedmann et al., 2013) identify national Material Footprints (MFs), using a consumption-based indicator of resources use, which is equivalent to raw materials use, for the international trade of 186 countries over the period 1990-2011. [21] Their empirical exercise shows that, at higher levels of income, countries tend to reduce their domestic materials extraction through international trade, but overall materials consumption increases.

More in-depth empirical analyses of the trade-offs from environmental sustainability in terms of sectoral level employment gains (see Figure 7), would provide a clearer indication of the sectoral change that would reduce environmental impacts and increase employment.

[FIGURE 7 HERE]

[20] Although China is a top emissions exporter, with an estimated 37.5% of employment creation through international trade, and the *US* and the *EU27* are its main export destinations, it is the *EU27* that emerges as the top importer of embodied emissions.

[21] The authors use the global MRIO (Multi-Region I/O) database, EORA, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Global Material Flow Database.

5 The political economy debate around the pollution haven hypothesis

The political economy debate over international trade and displacement of the environmental burden from developed to developing countries hosts different perspectives. The potential emergence of persistent ecological distributional conflicts is considered differently by environmental economists, ecological economists (Muradian and Martínez-Alier, 2001; Muradian et al., 2002; Pérez-Rincón, 2006; Russi et al., 2008; Munoz et al., 2011) and political ecologists (Martínez-Alier, 1995; Martínez-Alier et al., 2010). These strands of work are of interest here, as national structural change policies need to take account of employment friendly shifts that minimise emissions and energy intensity increases, in a global context that is experiencing increased inequality in the distribution of the environmental burden generated by trade specialisation.

Muradian and Martínez-Alier (2001) and Muradian et al. (2002) review some of these perspectives. Generally, environmental economists see trade barriers as illegitimate policy tools even in the context of international differences in environmental standards, which are the origins of the *PHH* evidence. Any outcome that is based on free trade is supposed to be better from an environmental perspective since, in the long run, the high rate of growth ensured by free trade will shift consumers environmental preferences towards cleaner products and ensure better environmental outcomes (see, for instance, (Werner Antweiler and Taylor, 2001)). Also, although some countries have less strict standards in line with their particular environmental and/or growth priorities, these are not tenable in the long run. For example, *MNCs* will avoid investments in developing countries with weak environmental regulation, because poor quality institutions and infrastructure will make them less attractive.

Ecological economists tend to be critical of the benefits of free trade (see, e.g.: (Pérez-Rincón, 2006; Russi et al., 2008; Munoz et al., 2011)). They reject the assumptions made by environmental economists that free trade leads naturally to higher growth rates. They argue that economic growth is a limited indicator of welfare since it ignores environmental externalities and the depletion of natural capital. Further, it cannot be taken for granted that higher growth rates will ensure a long run (how long?) shift in consumers environmental preferences towards greener products and reduce environmental exploitation, especially in contexts of high between-country inequality (Vona and Patriarca, 2011). The idea of ensuring growth and being able, later, to account for environmental damage is unsustainable in the long run. First, the long run consequences of environmental degradation are largely unknown and the negative effects of loss of biodiversity are virtually infinite and, therefore, not discountable. Second, the *EKC* predicts generally higher *GDP* turning points than the world median *GDP* per capita. An inverted U shaped relation between income and environmental conditions could lead to irreversibility of the ecological threshold before the economic threshold is achieved. Ecological economists highlight that the most likely scenario, based on international differences in environmental regulations, is a permanent divide between the developed and the developing countries, with cost-internalising systems resulting in a systematic race to the bottom. The World Trade Organization (*WTO*) should prevent ecological dumping and encourage standardisation of environmental regulation so that demand for green products from the north will lead, eventually, to changed production processes in the south.

(Muradian and Martínez-Alier, 2001) calls for a synthesis of the ecological economists and political ecologists views, and a 'Southern approach' to resolve eco-dumping. It has in fact been suggested that the perspective of ecological economists, summarised above, is representative of a 'northern perspective'. In our view, a 'northern ecological perspective' is likely to minimise the real environmental displacement to the south in a context where the south is being encouraged to be more sustainable in relation to its natural resources use and specialisation in primary products. Encouraging increased exports of natural resources and primary products from the south, to preserve the local environment in the north, is likely to widen the north-south gap and become a 'specialisation trap' for the south. Ultimately, policies supporting export and specialisation in primary and natural resources sectors in general, might produce short-run improved growth rates in the south, but more pervasive asymmetries and unsustainable development in the long-run.

It is argued (see also (Pérez-Rincón, 2006; Russi et al., 2008; Munoz et al., 2011)) that a finer-grained policy perspective should take account of the different national centres of power to formulate an institutional approach to environmental issues, aimed at correcting the intrinsic asymmetries that are exacerbated by *MNC* world trade related to primary products and extractive activities. For instance, the idea that developing countries could benefit from upgrading their specialisation to the immediate upstream phases of raw materials use, is misleading. It would exacerbate the environmental cost to the south of *both* extraction and processing of raw materials. It is predicted that the world will witness an increasing unequal ecological exchange, with a new wave of 'environmental Prebisch deterioration' in the terms of trade.

Environmental Terms of Trade (*ETT*) and the Balance of Embodied Emissions in Trade (*BEET*) are used to test the hypothesis of an 'environmental Prebisch deterioration' in the terms of trade [22]. Contributions along these lines are intended to represent a counter-argument to the evidence provided by the World Bank, based on what Muradian et al. (2002) call 'weak sustainability indicators', which measure the monetary value of the natural capital depletion associated to imports of natural resources. Strong sustainability indicators include both the monetary value of natural capital depletion and trace countries ecological footprints, including, among other things, environmental space, material flows, the pollution embodied in trade-flows, assessed in physical units of measurement (see also (Wiedmann et al., 2013)).

In the absence of a decisive political choice, persistent unequal ecological exchanges will imply increasing peripheralisation of environmental intensive activities to the south, leading to a specialisation trap (see also Martínez-Alier (1995) and Martínez-Alier et

[22] *ETT* and *BEET* allow quantification of the ecological exchange and occurrence of a Prebisch deterioration in the environmental terms of trade: a country A causes a deterioration in the *ETT* of a country B if the environmental burden of A's import from B is systematically larger than the burden of B's imports from A. A falling *ETT*s mean that A is displacing its consumption environmental burden to B, which is reflected in their respective *BEET*s.

al. (2010)). This, in turn, will erase the idea of a national *EKC* and a decoupling between economic growth and environmental degradation in which embodied pollution is systematically higher than the reduction in *GHG* emissions achieved locally over time.

6 Concluding remarks

6.1 Summary of the empirical evidence

We reviewed the empirical evidence on selected aspects of structural change and environmental sustainability, within three broad areas of investigation, which cut across the contributions from a variety of disciplines including environmental and ecological economics, development, economics of innovation, trade. The three areas are: (i) the origins and development of the *EKC*, since its original formulation to the latest empirical analysis conducted in developed and developing countries; (ii) the relationship between changes to the sectoral composition of economies, technical change and their impact on the emissions and energy intensity of production, with a particular emphasis on the processes of tertiarisation; (iii) the effect of the globalisation of structural change and changes to trade patterns on the global map of emissions intensity, with a particular emphasis on the *PHH* and north-south equity linked to global trade.

We summarise below the (relatively) uncontroversial evidence that emerges, while in the next section we highlight areas that would require further research efforts.

(i) On the *EKC*: Since the mid 1970s, an overall decoupling between growth and energy intensity has occurred. However, this global average hides a large degree of cross-country heterogeneity: only a few countries have experienced a real decoupling between growth and energy intensity. In most cases, the global decreasing trend in energy intensity is attributable to a share of countries growing proportionally faster, rather than to an actual decrease of the level of energy inputs into *GDP*.

The energy/capital ratio has been declining over time proportionally more than energy intensity. Conversely, those countries that have experienced an increase in their energy intensity levels have seen their energy/capital ratios increasing, for instance, African and Latin American countries.

The cost share of energy in *GDP* has decreased over time, suggesting an increase in effective energy per effective worker over time (with income), which has driven down the energy cost share .

Finally the energy quality mix has improved with income growth. For instance, evidence for the *LAC*s shows remarkable differences across countries, depending on their *natural resources* specialisation and forestry land area: the majority of LACs show an N-shaped *EKC* curve, which drives the trend for the whole region and does not support the occurrence of a global *EKC* (see also point iii) below).

(ii) On whether structural change in general and particularly that consisting of shifts towards services implies de-materialisation of economies and reduced energy intensity. Focusing on the OECD countries, the literature shows that, overall energy intensity levels since the mid 1980s, have decreased mainly due to within-sector technical change that have led to improved energy efficiency and reduced emissions trends. The between-sectors effect has also brought about improvements in energy intensity trends, due, partly, to sectoral change toward services. However, current energy intensity improvements seem to be substantially lower than if services had achieved greater energy efficiency improvements via technical change. There is unexploited potential for energy intensity reductions, which is dependent on catching up in services to ensure within-sector energy efficiency improvements. The technological progress needed is however linked to increased use of *ICTs*, which are energy-intensive and could offset the (material-intensity) gains of a structural shift to services. An important related issue is the extent to which demand is able to support a shift to services that ensures a degree of de-materialisation. This is linked to the role of consumption preferences and, importantly, within and across country income inequality.

(iii) On the presence of a *PHH*: The displacement of the environmental burden linked to north-south trade, and large differences in environmental regulations, support the *PHH* and the view that a global level '*EKC* effect' has not occurred. There is some uncertainty about whether developing countries will experience the same *EKC* patterns that have characterised the developed countries. If the income elasticity of manufacturing 'dirty' products does not fall, this will lead to domestic sectoral change in the developed countries toward less polluting sectors which will entail a PHH effect. For instance, *LACs* are net exporters of material-intensive goods as well as being the potential destination for relocated 'dirty products'.

(iv) On the link between trade and environmental equity. Policy makers in the global south should be warned about a 'northern ecological perspective' that aims to minimise environmental displacement from north to south. The long-run consequences of systematic 'trading jobs for emissions' in the south is likely to produce a larger north south gap and a 'specialisation trap' for the south. Further, the hypothesis of an 'environmental Prebisch deterioration' in the terms of trade should be seen as a possible alternative to the World Bank trade scenario. This is based on weak rather than strong sustainability indicators, which discount the long-run natural capital depletion that a specialisation trap might lead to.

6.2 A research agenda on structural changes and environmental sustainability

The empirical evidence reviewed in this work is not always conclusive about the effects of structural changes on environmental sustainability, due, not least, to the intrinsic uncertainty linked to future technical change aimed at reducing energy intensity across different sectors. However, the areas selected here and the related findings provide useful background to inform debates on the political economy of environmental policies.

Some of the topics do not offer conclusive evidence, and this opens gaps in the literature that would need to be addressed through further research effort.

The most important, in our view, is the ' trading jobs for emissions game, which characterises the strategies of many developing countries. In this respect, this empirical review puts into perspective many of the positions that have emerged post-Kyoto and post-Paris protocols (Aichele and Felbermayr, 2015), and encourages more fine-grained empirical analyses of the resulting changing shape of trade. In parallel, more refined data, especially EEA data, should be a priority world-wide.

All the aspects of structural changes covered in this review represent areas of policy intervention. These are:

- sectoral upgrading, ideally towards sectors that are less energy and emission intensive, but with high employment elasticity;
- technological upgrading in sectors that present higher technological opportunities to improve their energy mix, among which firm incentives to eco-innovation as a result of appropriate environmental regulations;
- continuous effort to maintain and increase the stock of technological capabilities to lower energy and emission intensity of production;
- bold interventions to reduce within- and between-country inequality, which emerges to be the *condition sine qua non* for policies that create incentives to move to green consumption to be effective.

Particularly in developing countries, there is a policy *conundrum* linked to the 'trading jobs for emissions', and, more generally, to improve the environmental sustainability of their growth patterns. To appropriately inform the policy choices illustrated above, more research is needed.

A first fruitful line of research should aim at examining whether and to what extent tertiarisation implies degrees of de-materialisation and reduced energy and emissions intensity. A few studies, beyond those reviewed in this paper, have attempted to understand the degree of achievable reductions in energy, emissions and material intensity in the presence of (eco) innovation in services (Desmarchelier et al., 2013; Desmarchelier and Gallouj, 2012). Particularly in this domain, it would be important to grounding concerted actions in the domains of industrial and environmental policies, most especially in developing countries. Indeed, in a context of premature de-industrialisation in emerging economies (Rodrik, 2016; Di Meglio et al., 2018) it is important to identify suitable directions of structural change.

A second research endeavour worth pursuing is to achieve a higher degree of multidisciplinariety in tackling societal challenges linked to the environment, particularly to address those related to the 'trade jobs for emissions' game illustrated above. Environmental economists, political ecologists and environmental ecologists should join forces and offer an integrated view of how to tackle the opportunities and challenges that developing (and developed) countries face. One such challenges is to determine the benefits, side-effects and conditions for developing countries to participate to global value chains. In a context of increasing international fragmentation of production, eco-dumping might be more likely to occur, and the enforcement of global environmental standards such as those proposed by the latest Paris Agreements become even more crucial.

Thirdly, our review highlighted the need to devote more research effort to the effects of environmental regulations on demand, particularly accounting for consumer preferences and income inequality. This view is supported in a recent contribution that has the ambition of setting a new research agenda for the emerging field of "Envirodevonomics" to tackle climate change (Greenstone and Jack, 2015). According to (Greenstone and Jack, 2015), Envirodevonomics should devise a new political economy framework to address environmental sustainability in developing countries, one that shapes the relationship between economic development, changing patterns of consumption and allows a global governance of environmental quality. Indeed, one of the nodal issues at the intersection of these areas is the need to increase the Marginal Willingness To Pay (MWTP) for higher environmental quality in developing countries: a low income level is identified as the main impediment for individuals to value improvements in environmental quality higher than a marginal increase in income, not surprisingly. Addressing within and between countries income inequality is a must for both international development and global environmental sustainability, and our auspice is that more empirical efforts helps grounding actions in this domain.

References

Aichele, Rahel and Gabriel Felbermayr, "Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade," *Review of Economics and Statistics*, 2015, *97* (1), 104–115.

Altomonte, Hugo and Nelson Correa, "La dinámica del consumo energético industrial en América Latina," *Revista CEPAL*, 2011, *105*, 7–37.

Ambec, S., M. A. Cohen, S. Elgie, and P. Lanoie, "The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness?," *Review of Environmental Economics and Policy*, jan 2013, *7* (1), 2–22.

Ang, B.W., A.R. Mu, and P. Zhou, "Accounting frameworks for tracking energy efficiency trends," *Energy Economics*, sep 2010, *32* (5), 1209–1219.

_ , H.C. Huang, and A.R. Mu, "Properties and linkages of some index decomposition analysis methods," *Energy Policy*, nov 2009, *37* (11), 4624–4632.

Arto, Inaki, José M. Rueda-Cantuche, Valeria Andreoni, I. Mongelli, and A. Genty, "The game of trading jobs for emissions," *Energy Policy*, mar 2014, *66*, 517–525.

Ayres, Robert U. and Jeroen C.J.M. van den Bergh, "A theory of economic growth with material/energy resources and dematerialization: Interaction of three growth mechanisms," *Ecological Economics*, oct 2005, *55* (1), 96–118.

Barba Navaretti, Giorgio, Giovanni Facchini, Tommaso Frattini, Marzio Galeotti, Gianmarco Ottaviano, Giovanni Pica, Francesco Vona, and Silvia Cerisola, "How Do Value Added, Migration, and Energy Interact? Initial evidence and open issues," Technical Report, Centro Studi Luca D'Agliano, Milano 2014.

Baumol, William J, "Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis," *The American Economic Review*, 1967, *57* (3), 415–426.

Berg, Maxine, "From imitation to invention: creating commodities in eighteenth-century Britain," *Economic History Review*, 2002, *55* (1), 1–30.

Bolscher, Hans, Verena Graichen, Graham Hay, Sean Healy, Jip Lenstra, Lars Meindert, David Regeczi, Marie Theres von Schickfus, Katja Schumacher, and Floor Timmons-Smakman, "Carbon Leakage Evidence Project - Factsheets for selected sectors," Technical Report 2013.

Casey, Gregory and Oded Galor, "Is faster economic growth compatible with reductions in carbon emissions? The role of diminished population growth," *Environmental Research Letters*, 2017, *12* (1), 014003.

Chenery, Hollis Burnley, Sherman Robinson, and Moises Syrquin, *Industrialisation and Growth: A Comparative Study*, New York: Oxford University Press, 1986.

Cherniwchan, Jevan, Brian R. Copeland, and M. Scott Taylor, "Trade and the Environment: New Methods, Measurements, and Results," *Annual Review of Economics*, aug 2017, *9* (1), 59–85.

Ciarli, Tommaso and María Savona, "De los cambios cuadráticos a los cambios exponenciales: relación entre estructura económica y sostenibilidad," 2016.

_ and Maria Savona, "Modelling the Evolution of Economic Structures and Climate Changes: A Review," 2018.

_ , André Lorentz, Marco Valente, and Maria Savona, "Structural Changes and Growth Regimes," *Journal of Evolutionary Economics*, 2018.

_ , _ , _ , and _ , "Structural changes and growth regimes," *Journal of Evolutionary Economics*, may 2018, pp. 1–58.

_ , _ , Maria Savona, and Marco Valente, "The effect of consumption and production structure on growth and distribution. A micro to macro model," *Metroeconomica*, 2010, *61* (1), 180–218.

_ , Valentina Meliciani, and Maria Savona, "KNOWLEDGE DYNAMICS, STRUCTURAL CHANGE AND THE GEOGRAPHY OF BUSINESS SERVICES," *Journal of Economic Surveys*, jul 2012, *26* (3), 445–467.

Cole, Matthew A, "Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages," *Ecological Economics*, jan 2004, *48* (1), 71–81.

Csereklyei, Zsuzsanna, Maria del Mar Rubio Varas, and David Ian Stern, "Energy and Economic Growth: The Stylized Facts," Technical Report nov 2014.

Desmarchelier, Benoît and Faïz Gallouj, "Endogenous growth and environmental policy: are the processes of growth and tertiarization in developed economies reversible?," *Journal of Evolutionary Economics*, aug 2012, *23* (4), 831–860.

_ , Faridah Djellal, and Faïz Gallouj, "Environmental policies and eco-innovations by service firms: An agent-based model," *Technological Forecasting and Social Change*, sep 2013, *80* (7), 1395–1408.

Di Meglio, Gisela, Jorge Gallego, Andres Maroto, and Maria Savona, "Services in developing economies: The de-industrialization debate in perspective.," *Development and Change.*, 2018, *Forthcomin.*

Dietzenbacher, Erik and Bart Los, "Structural Decomposition Techniques: Sense and Sensitivity," *Economic Systems Research*, dec 1998, *10* (4), 307–324.

Dinda, Soumyananda, "Environmental Kuznets Curve Hypothesis: A Survey," *Ecological Economics*, aug 2004, *49* (4), 431–455.

European Union, "Towards Knowledge Driven Reindustrialisation," Technical Report, European Union, Brussels 2013.

Fisher, Allan G B, "Production, primary, secondary and tertiary," *Economic Record*, 1939, *15* (1), 24–38.

Florax, R J G M, Henri L F De Groot, and Peter Mulder, *Improving Energy Efficiency Through Technology: Trends, Investment Behaviour and Policy Design*, Edward Elgar Publishing, 2011.

Gallouj, Faïz and Maria Savona, "Innovation in services: a review of the debate and a research agenda," *Journal of Evolutionary Economics*, sep 2008, *19* (2), 149–172.

García-Quevedo, José, Gabriele Pellegrino, and Maria Savona, "Reviving demand-pull perspectives: The effect of demand uncertainty and stagnancy on R&D strategy," *Cambridge Journal of Economics*, sep 2016, *41* (4), bew042.

Gollin, Douglas, "The Lewis Model: A 60-Year Retrospective," *Journal of Economic Perspectives*, 2014, *28* (3).

Greenstone, Michael and B. Kelsey Jack, "Envirodevonomics: A Research Agenda for an Emerging Field," *Journal of Economic Literature*, mar 2015, *53* (1), 5–42.

Henriques, Sofia Teives and Astrid Kander, "The modest environmental relief resulting from the transition to a service economy," *Ecological Economics*, dec 2010, *70* (2), 271–282.

Hirschman, Albert O, *The Strategy of Economic Development*, New Haven: Yale University Press, 1958.

Hoekstra, Rutger and Jeroen C.J.M. van den Bergh, "Comparing structural decomposition analysis and index," *Energy Economics*, jan 2003, *25* (1), 39–64.

_ and _ , "The Impact of Structural Change on Physical Flows in the Economy: Forecasting and Backcasting Using Structural Decomposition Analysis," *Land Economics*, nov 2006, *82* (4), 582–601.

Hulme, Mike, "On the origin of the greenhouse effect': John Tyndall's 1859 interrogation of nature," *Weather*, may 2009, *64* (5), 121–123.

Jaffe, Adam B. and Karen Palmer, "Environmental Regulation and Innovation: A Panel Data Study," *Review of Economics and Statistics*, nov 1997, *79* (4), 610–619.

Jimenez, Raul and Jorge Mercado, "Energy intensity: A decomposition and counterfactual exercise for Latin American countries," *Energy Economics*, mar 2014, *42*, 161–171.

Kaivo-oja, J., J. Luukkanen, J. Panula-Ontto, J. Vehmas, Y. Chen, S. Mikkonen, and B. Auffermann, "Are structural change and modernisation leading to convergence in the CO2 economy? Decomposition analysis of China, EU and USA," *Energy*, aug 2014, *72*, 115–125.

Kander, Astrid, "Baumol's disease and dematerialization of the economy," *Ecological Economics*, oct 2005, *55* (1), 119–130.

_ **and Magnus Lindmark**, "Foreign trade and declining pollution in Sweden: a decomposition analysis of long-term structural and technological effects," *Energy Policy*, sep 2006, *34* (13), 1590–1599.

Kaya, Yoichi and Keiichi Yokobori, eds, *Environment, Energy, and Economy: strategies for sustainability*, Tokyo: United Nations University Press, 1997.

Lazonick, William H., "Industrial Relations and Technical Change: The Case of the Self-Acting Mule," *Cambridge Journal of Economics*, sep 1979, *3* (3), 231–262.

Lewis, Arthur W, "Economic Development with Unlimited Supplies of Labour," *Manchester School of Economic and Social Studies*, 1954, *22*, 139–191.

Magnani, Elisabetta, "The Environmental Kuznets Curve, environmental protection policy and income distribution," *Ecological Economics*, 2000, *32*, 431–443.

Marin, Giovanni and Roberto Zoboli, "The 'emission disease' in services," in "IAERE Conference" 2014.

_ **and** _ , "The integrated economic and environmental footprint of the EU: domestic and global effects of a transition to services," 2016.

Martínez-Alier, Joan, "The environment as a luxury good or too poor to be green?," *Ecological Economics*, apr 1995, *13* (1), 1–10.

_ **, Giorgos Kallis, Sandra Veuthey, Mariana Walter, and Leah Temper**, "Social Metabolism, Ecological Distribution Conflicts, and Valuation Languages," *Ecological Economics*, dec 2010, *70* (2), 153–158.

McCloskey, Deirdre Nansen, "Science, Bourgeois Dignity, and the Industrial Revolution," MPRA Paper 22308 jul 2009.

McMillan, Margaret, Dani Rodrik, and Íñigo Verduzco-Gallo, "Globalization, Structural Change, and Productivity Growth, with an Update on Africa," *World Development*, nov 2014, *63*, 11–32.

Millimet, Daniel L., John A. List, and Thanasis Stengos, "The Environmental Kuznets Curve: Real Progress or Misspecified Models?," *Review of Economics and Statistics*, nov 2003, *85* (4), 1038–1047.

Mokyr, Joel, "Knowledge, Enlightenment, and the Industrial Revolution: Reflections on The Gifts of Athena," *History of Science*, jun 2007, *45*, 185–196.

Mulder, Peter and Henri L.F. de Groot, "Structural change and convergence of energy intensity across OECD countries, 19702005," *Energy Economics*, nov 2012, *34* (6), 1910–1921.

_ , _ , and Birte Pfeiffer, "Dynamics and determinants of energy intensity in the service sector: A cross-country analysis, 19802005," *Ecological Economics*, apr 2014, *100*, 1–15.

Munoz, Pablo, Rita Strohmaier, and Jordi Roca, "On the NorthSouth trade in the Americas and its ecological asymmetries," *Ecological Economics*, sep 2011, *70* (11), 1981–1990.

Muradian, Roldan and Joan Martínez-Alier, "Trade and the environment: from a Southern' perspective," *Ecological Economics*, feb 2001, *36* (2), 281–297.

_ , Martin O'Connor, and Joan Martínez-Alier, "Embodied pollution in trade: estimating the environmental load displacement' of industrialised countries," *Ecological Economics*, apr 2002, *41* (1), 51–67.

Nesta, Lionel, Elena Verdolini, and Francesco Vona, "Threshold Policy Effects and Directed Technical Change in Energy Innovation — isigrowth," 2018.

_ , Francesco Vona, and Francesco Nicolli, "Environmental policies, competition and innovation in renewable energy," *Journal of Environmental Economics and Management*, may 2014, *67* (3), 396–411.

Nordhaus, William D., "Economic Growth and Climate: The Carbon Dioxide Problem," *American Economic Review*, 1977, *67* (1), 341–346.

Panayotou, Theodore, Alix Peterson, and Jeffrey D. Sachs, "Is the Environmental Kuznets Curve Driven by Structural Change? What Extended Time Series May Imply for Developing Countries," 2000.

Pérez-Rincón, Mario Alejandro, "Colombian international trade from a physical perspective: Towards an ecological Prebisch thesis," *Ecological Economics*, oct 2006, *59* (4), 519–529.

Peters, Glen P., "From production-based to consumption-based national emission inventories," *Ecological Economics*, mar 2008, *65* (1), 13–23.

Popp, David, Richard G. Newell, and Adam B. Jaffe, "Energy, the Environment, and Technological Change," in "Handbook of the Economics of Innovation," Vol. 2 of *Handbook of the Economics of Innovation*, Elsevier, 2010, chapter 21, pp. 873–937.

Porter, Michael E and Claas van der Linde, "Toward a New Conception of the Environment-Competitiveness Relationship," *Journal of Economic Perspectives*, nov 1995, *9* (4), 97–118.

Poudel, Biswo N., Krishna P. Paudel, and Keshav Bhattarai, "Searching for an Environmental Kuznets Curve in Carbon Dioxide Pollutant in Latin American Countries," *Journal of Agricultural and Applied Economics*, 2009, *41* (01), 13–27.

Prebish, Raul, *The Economic Development of Latin America and its Principal Problems*, United Nations Department of Economics Affairs, Lake Success, N.Y.: United Nations Publications, 1950.

Raupach, Michael R, Gregg Marland, Philippe Ciais, Corinne Le Quéré, Josep G Canadell, Gernot Klepper, and Christopher B Field, "Global and regional drivers of accelerating CO2 emissions.," *Proceedings of the National Academy of Sciences of the United States of America*, jun 2007, *104* (24), 10288–93.

Rodrik, Dani, "Green Industrial Policy," *Oxford Review of Economic Policy*, 2014, *30* (3), 469–491.

_ , "Premature deindustrialization," *Journal of Economic Growth*, mar 2016, *21* (1), 1–33.

Rosenstein-Rodan, P N, "Problems of Industrialisation of Eastern and South–Easthern Europe," *The Economic Journal*, 1943, *53* (210/211), 202–211.

Rubio, M.d.Mar and Mauricio Folchi, "Will small energy consumers be faster in transition? Evidence from the early shift from coal to oil in Latin America," *Energy Policy*, nov 2012, *50*, 50–61.

Russi, Daniela, Ana C. Gonzalez-Martinez, José Carlos Silva-Macher, Stefan Giljum, Joan Martínez-Alier, and Maria Cristina Vallejo, "Material Flows in Latin America," *Journal of Industrial Ecology*, oct 2008, *12* (5-6), 704–720.

Semieniuk, Gregor, "Energy in Economic Growth: Is Faster Growth Greener?," 2018.

Singer, H K, "The Distribution of Gains Between Investing and Borrowing Countries," *American Economic Review*, 1950, *40*, 473–485.

Stern, David Ian, "The Rise and Fall of the Environmental Kuznets Curve," *World Development*, 2004, *32* (8), 1419–1439.

_ **and Kerstin Enflo**, "Causality between energy and output in the long-run," *Energy Economics*, 2013, *39* (C), 135–146.

_ **, Frank Jotzo, and Leo Dobes**, "The Economics of Global Climate Change: A Historical Literature Review," Technical Report nov 2013.

Stern, Nicholas, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, 2007.

_ , "The Economics of Climate Change," *American Economic Review*, apr 2008, *98* (2), 1–37.

Su, Bin and B.W. Ang, "Structural decomposition analysis applied to energy and emissions: Some methodological developments," *Energy Economics*, jan 2012, *34* (1), 177–188.

Taylor, M. Scott, "Unbundling the Pollution Haven Hypothesis," *The B.E. Journal of Economic Analysis & Policy*, 2005, *4* (2).

Tian, Xin, Miao Chang, Feng Shi, and Hiroki Tanikawa, "How does industrial structure change impact carbon dioxide emissions? A comparative analysis focusing on nine provincial regions in China," *Environmental Science & Policy*, mar 2014, *37*, 243–254.

van den Bergh, Jeroen C.J.M. and John M. Gowdy, "Evolutionary Theories in Environmental and Resource Economics: Approaches and Applications," *Environmental and Resource Economics*, 2000, *17* (1), 37–57.

Voigt, Sebastian, Enrica De Cian, Michael Schymura, and Elena Verdolini, "Energy intensity developments in 40 major economies: Structural change or technology improvement?," *Energy Economics*, jan 2014, *41*, 47–62.

von Hippel, Eric A., *Sources of Innovation*, New York: Oxford University Press, nov 1988.

von Tunzelmann, G Nick, *Technology and Industrial Progress: The Foundations of Economic Growth*, Aldershot: Edward Elgar, 1995.

Vona, Francesco and Fabrizio Patriarca, "Income inequality and the development of environmental technologies," *Ecological Economics*, sep 2011, *70* (11), 2201–2213.

Wagner, Marcus, Wagner, and Marcus, "The Porter Hypothesis Revisited: A Literature Review of Theoretical Models and Empirical Tests," jul 2004.

Weitzman, Martin L., "Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change," *Review of Environmental Economics and Policy*, aug 2011, *5* (2), 275–292.

Werner Antweiler, Brian R. Copeland and M. Scott Taylor, "Is Free Trade Good for the Environment?," *American Economic Review*, 2001, *91* (4), 877–908.

Wiedmann, Thomas, "A review of recent multi-region inputoutput models used for consumption-based emission and resource accounting," *Ecological Economics*, dec 2009, *69* (2), 211–222.

__ , **Harry C. Wilting, Manfred Lenzen, Stephan Lutter, and Viveka Palm**, "Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region inputoutput analysis," *Ecological Economics*, sep 2011, *70* (11), 1937–1945.

__ , **Heinz Schandl, Manfred Lenzen, Daniel Moran, Sangwon Suh, James West, and Keiichiro Kanemoto**, "The material footprint of nations.," *Proceedings of the National Academy of Sciences of the United States of America*, sep 2013, pp. 1220362110–.

Windrum, Paul, Tommaso Ciarli, and Chris Birchenhall, "Consumer heterogeneity and the development of environmentally friendly technologies," *Technological Forecasting and Social Change*, 2009, *76* (4), 533–551.

7 Appendix

7.1 List of Acronyms

- BEET: Balance of Embodied Emissions in Trade
- CAAA: Clean Air Act Amendment
- DMC: Domestic Material Consumption
- DME: Domestic Material Extraction
- DMI: Direct Material Input
- EEA: European Environmental Agency
- EKC: Environmental Kuznet Curve
- ER: Environmental Regulations
- ETT: Environmetal Terms of Trade
- FDI: Foreign Direct Investments
- GHG: Greenhouse Gas (emissions)
- GDP: Gross Domestic Product
- GVC: Global Value Chains
- ICT: Information and Communication Technology
- IDA: Index Decomposition Analysis
- LACs: Latin American Countries
- LMDI: Log-Mean Divisia Index
- MFA: Material Flow Analysis
- MNC: Multinational Corporations
- MRCI: Mean Rate of Change Index
- NRI: Natural Resource Industries
- OECD: Organisation for Economic Cooperation and Development
- PHH: Pollution Haven Hypothesis
- PTB: Physical Trade Balance
- R&D: Research and Development
- SDA: Structural Decomposition Analysis
- SEA: Socio Economic Account (in WIOD)
- SEEA: System of Environmental-Economic Accounting
- WIOD: World Input Output Data
- WTO: World Trade Organisation

7.2 Non-exhaustive list of data sources

IEA data: http://www.iea.org/statistics/

EEA data: http://www.eea.europa.eu/data-and-maps

Penn World Tables: http://www.rug.nl/research/ggdc/data/pwt/

International Comparison Programme: http://icp.worldbank.org/

Maddison Project Data: http://www.ggdc.net/maddison/maddison-project/home.htm

Total Economy Database: http://www.conference-board.org/data/economydatabase/

University of Queensland International Comparison Database: http://uqicd.economics.uq.edu.au/

Centre for International Price Research: http://www.vanderbilt.edu/econ/cipr/index.html

OECD Environmental Data Compendium: http://www.oecd.org/env/indicators-modelling-outlooks/oecdenvironmentaldatacompendium.htm

OECD Environmental Data and Indicators: http://www.oecd.org/env/indicators-modelling-outlooks/data-and-indicators.htm

Database of Social, Economic and Environmental Indicators for Latin America and the Caribbean: http://www.cepal.org/cgi-bin/getProd.asp?xml=/prensa/noticias/comunicados/5/26665/P26665.xml&xsl=/prensa/tpl-i/p6f.xsl&base=/prensa/tpl-i/top-bottom.xsl

UN Environment Programme, Division of Early Warning and Assessment: http://www.unep.org/dewa/africa/

For an overview of National sites with official Environmental Data: http://unstats.un.org/unsd/environment/clinks.htm

7.3 Figures

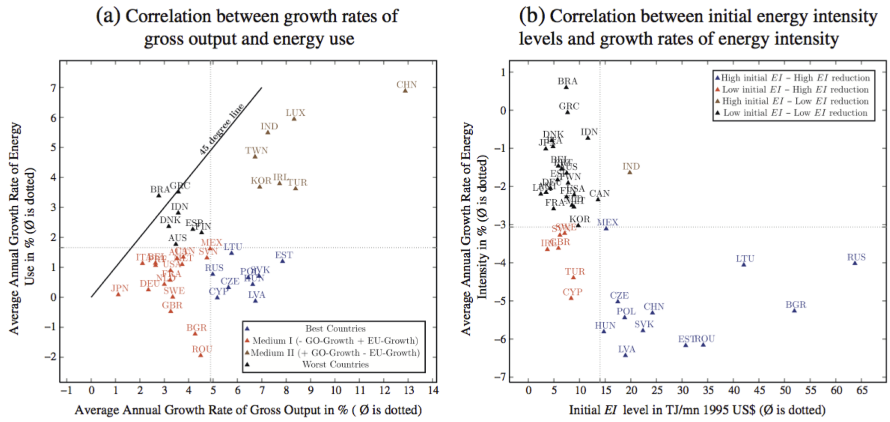

Figure 1: ***Correlation between Growth rate of gross output and energy use (a); Correlation between initial levels and growth rates of energy intensity (b).*** *Source: Voigt et al. (2014)*

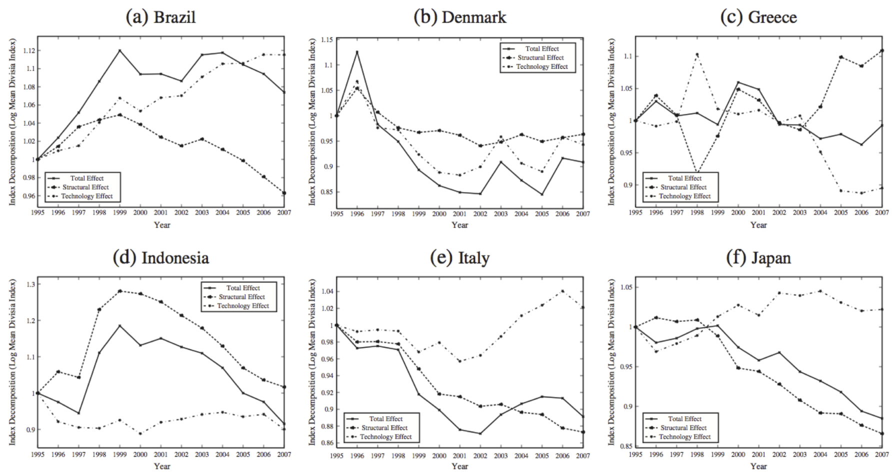

Figure 2: ***Index Decomposition Analysis for countries with low initial energy intensity and very low energy intensity reduction*** *(less than 1% annually). Source: Voigt et al. (2014)*

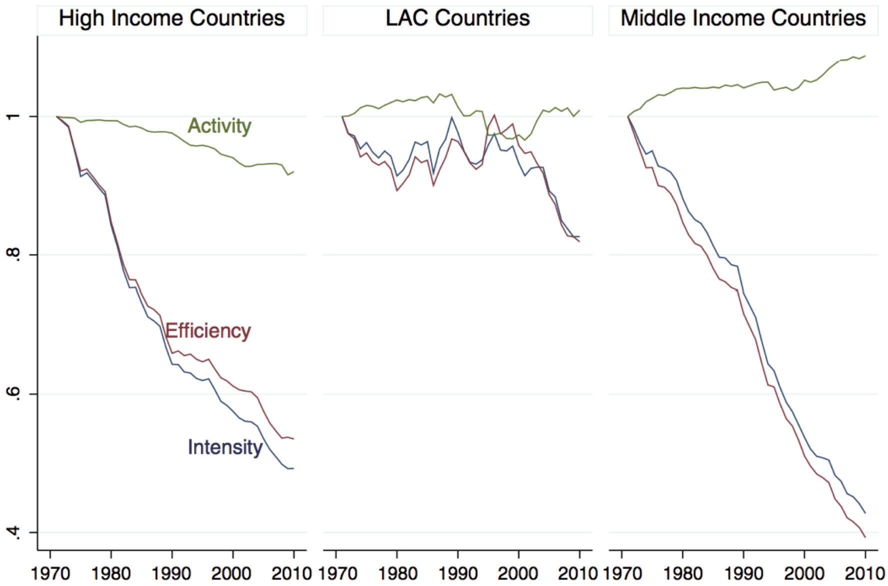

Figure 3: ***Comparative energy intensity decompostion in LACs***. *Source: Jimenez and Mercado (2014)*

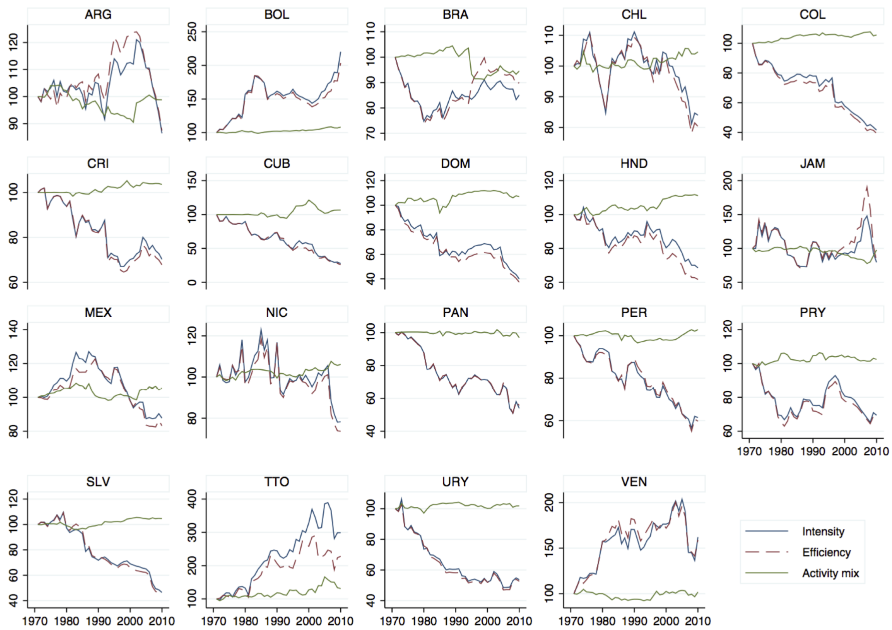

Figure 4: ***Comparative energy intensity decomposition in LACs***. *Source: Jimenez and Mercado (2014)*

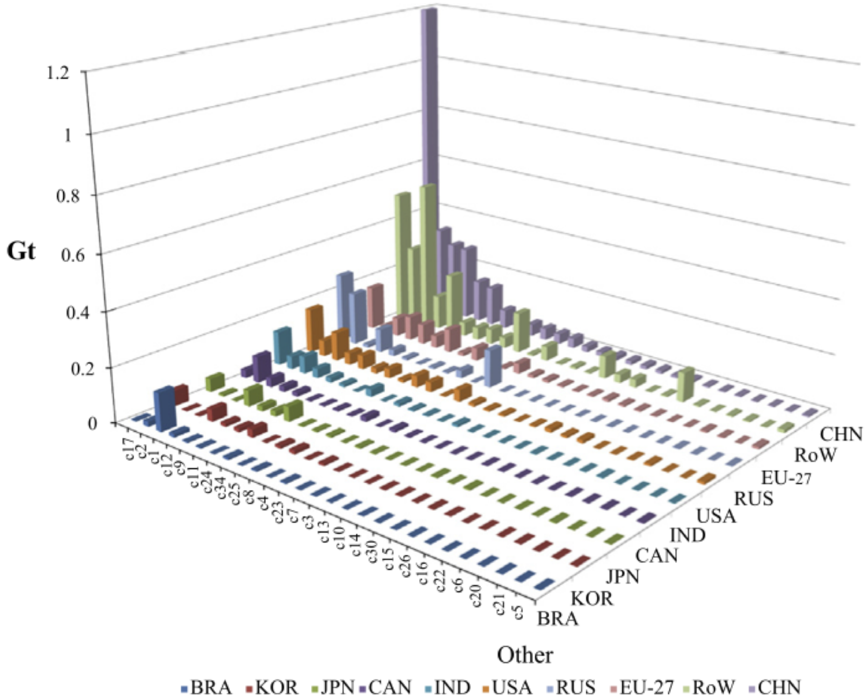

Figure 5: ***Global GHG emissions embodied in exports by sector in selected countries.*** *2008 Note: See Appendix. Source: Arto et al. (2014)*

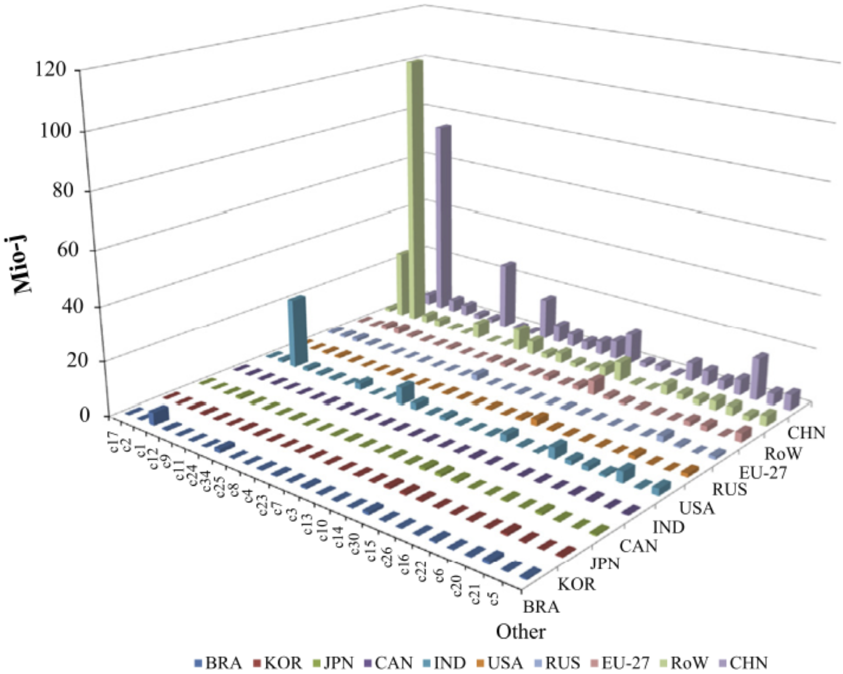

Figure 6: ***Global employment embodied in exports by sector in selected countries,*** *2008.(Million jobs). Note: See Appendix. Source: Arto et al. (2014)*

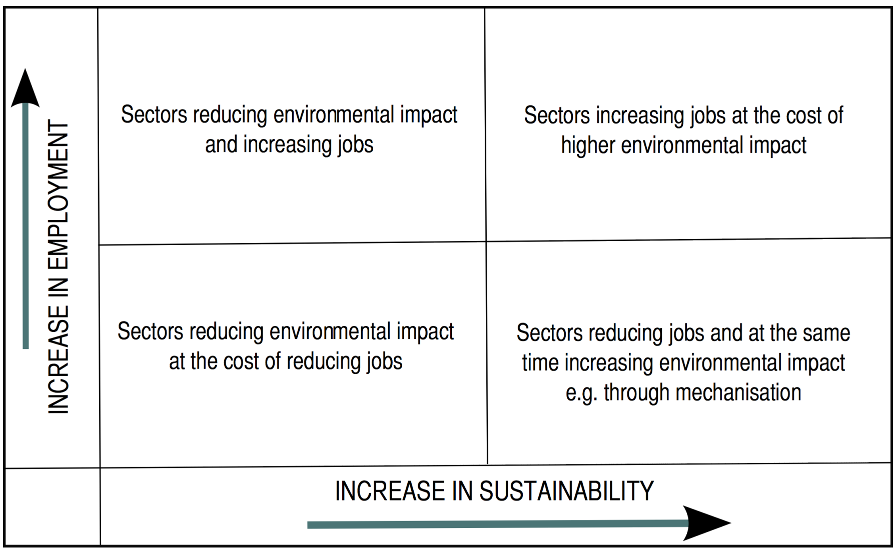

Figure 7: ***Trading jobs for emissions.*** *Source: Own elaboration based on Altomonte and Correa (2011)*

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