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Identifying the Drivers of Demand-based and Production-based GHG Emissions[1]

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Abstract

This paper explores the drivers of emissions intensity improvements for a cross-section of countries over the period 1995-2009. It first documents the pattern of greenhouse gas (GHG) intensity changes across 40 developed and developing countries using the emissions and multiregional Input-output data from World Input-Output Database (WIOD). Since the countries in the dataset consist of both importers as well as exporters of emissions, the paper looks at both production-based intensities as well as demand-based intensities. Demand-based intensities take into account the net emissions from final consumption of domestic and imported goods, as such it excludes emissions from production of exports from domestic emissions and includes those resulted from production of imports. Overall GHG *emission intensities* (tonnes of emissions per US$GDP) are decomposed into *structural* and *technological intensities*.

The paper then regress these intensities against plausible drivers using the cross-section of countries. The plausible drivers include: energy prices; capital and labour inputs; reliance on renewable energy; investment and Research and Development (R&D) rates; overall level of development, population density, urbanization, and trade openness; and policy-relevant variables.

The paper finds that drivers for production-based intensities differ somewhat from demand-based intensities but in plausible ways. Higher electricity prices and greater reliance on renewables reduces emission intensity though only in the 2001-09 period. This change in significance suggest that, once intensities fall, then energy prices and policy relevant drivers become more important in decreasing intensities. Non-GHG directed activities are more important when intensities are higher.

Key Words: Greenhouse gas; Emissions intensity; Technology and Structural change;

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Introduction

While greenhouse gas (GHG) emissions in developed economies have, in general, decreased since the 1990s, a number of studies have shown a concomitant increase from low and middle income countries tied, in part, to increased international trade (e.g., Peters et al. 2011, Weber and Peters 2009, Peters and Hertwich (2008a, 2008b), Raupach et al 2007, Ghosh et al 2014). To account for this shift in the location of emissions, two accounting methods have been developed. The first is *production-based* emissions (PBEs) to account for domestic territorial emissions. This is the standard approach to measuring GHG emissions. The second is consumption-based emissions (DBEs). It tracks emissions embodied in final consumption. This *demand-based* measure takes into account all the net emissions from final consumption of domestic and imported goods. For an overview of demand-based measures of emissions and methodology used to estimate demand-based emissions please see Ghosh et al. (2014).[2] As such, it excludes emissions from the production of exports but includes those related to the production of imports. The intent of the demand-based measure is to allocate the responsibility for emissions to the importing nation rather than the exporting nation as the production-based measure does (Ghosh and Agarwal 2013).

Although GHG emissions at the global level have increased rapidly (essentially due to increased output and population) there has been an overall reduction in *emissions intensity* measured in tonnes of emissions per dollar of GDP (for example, Bruneau and Echevarria, 2009). These reductions in emission intensity arise from three effects. The first, called a *technological effect*, is from changes in the techniques of production related to switching fuel sources, improvements in fuel efficiency, changes in the process of production, and increased abatement activities. The second arises from changes in the relative sizes of sectors in the economy. This *structural effect* arises in the process of development as countries shift production from primary to secondary to services (Polanyi 1944, Schafer 2005, Ghosh and Whalley 2007). It can be altered though investments in physical and human capital, through changes in relative prices, but also through changes in a country's comparative advantages in international production. The third arises from changes in the pattern of trade. This *trade effect* arises from shifts in what, how much, and where products are sourced. These shifts in the pattern of trade have become more important with the rise of China and India, both high intensity GHG emitters, as the location of increased production as well as their place in the global supply chain.

Demand-based emission intensities will differ from production-based intensities for three reasons. First and foremost, demand-based intensities include emissions embodied in imports while excluding emissions embodied in exports. Production-based intensities are the converse. For countries with a small trade profile, this will make little difference. But for most countries, exports and imports, relative to GDP, will be large and so how one accounts for emissions related to imports and exports can matter. Second, the relative size of sectors in an economy will differ from a production basis versus a consumption basis. For instance, natural resource extraction (oil, natural gas, minerals, etc.) is sizable in Canada but a large fraction of it is exported. Hence with a production based approach, the extractive sectors will form a large share of production. But with a demand-based approach, its share of final consumption will be smaller. If natural resource extraction has above average emission intensities, then production-based

[2] Methodology used for estimating the DBEs will be added as an appendix.

measures will tend to show higher intensities. Third, the denominator in each measure is different. The demand-based approach uses final consumption which is essentially a value-added concept. Production-based approaches use gross output which is generally more than twice the magnitude of value-added. Hence, all thing equal, demand-based intensities will be twice the magnitude of production-based intensities. Nonetheless, demand-based intensities are highly correlated with production-based intensities since domestic production still makes up a large part of final domestic demand.

Not only will intensities differ based on the approach taken, the drivers of those intensities will, in principle, be different as will sensitivity to drivers. For instance, capital accumulation could shift production towards heavy manufacturing but will also increase per capita incomes. China is the prime example in which exports is an important driver of production-based emissions. From a production-based approach, GHG intensity could rise. But from a demand-based approach, emission intensity could fall as final demand shifts towards low intensity services.

The objective of this study is to identify the drivers of both the production and demand-based emissions intensity change using detailed input-output level data for a large number of countries for the period 1995-2009. For a deeper understanding of this issue overall emissions intensity of both production-based and demand-based emissions intensity change is decomposed into technological change and structural change. Each of these is then separately analyzed using econometric techniques. This study therefore addresses a number interesting question. First, what had been drivers of emissions intensity and if they are different for production and demand-based measures of emissions. Second, what factors had influenced the technological and structural change in emissions intensities. Finally, what conclusions can be made on the role of trade in influencing the demand-based and production-based emissions intensity?

Results show that most changes in overall intensity are due primarily to changes in technique. The factors that reduce technical intensities for production based measures are similar to those for demand based intensities. By splitting the sample and only looking at 2001-2009 shows that many drivers related to non-GHG activities directly (such as investment rates, R&D, GDP per capita, etc.) become insignificant. However, energy prices then become more important as does the policy relevant factors such as reliance on renewables.

Structural effects are small relative to technical effects. However, results from the later period suggests that, once technical intensities fall to a low level, then structural effects become more sensitive to GHG-relevant policy factors such as the share of renewables.

In what follows, section 1 shows the data and an overview of emission intensities in our sample countries. Section 2 discusses the methodology used to decompose emission intensity changes into technological and structural changes. Section 4 presents the regression model used in this paper. Section 5 discusses the results, provides the summary of findings and concludes.

1. Data and Methodology

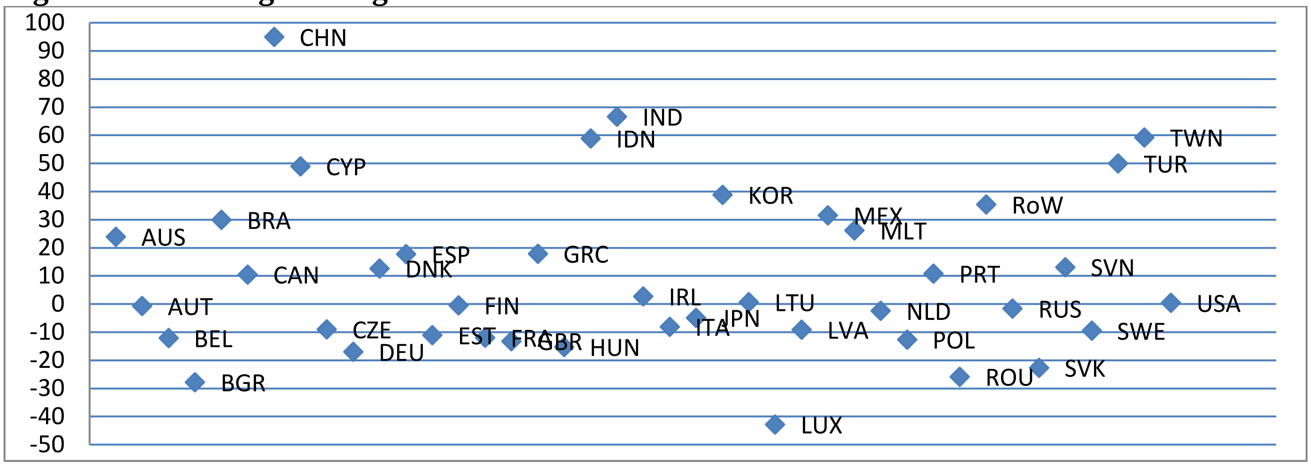
Data

The principal source of data used in this paper is the World Input-Output Database (WIOD) prepared on the basis of officially published input-output tables in conjunction with national accounts and international trade statistics (Timmer (ed.) 2012).[3] It provides multiregional input-output tables representing 35 industrial sectors for 27 EU countries and 13 other major countries in the world for the period from 1995 to 2009. It also provides socio-economic accounts (which contain industry-level data on employment (number of workers and educational attainment), capital stocks, gross output and value added at current and constant prices. The environmental accounts contain data on energy use, CO_2 and other GHG emissions and air pollutants. Data on Gross Domestic product (GDP in $US), population, urbanization, government expenditure, R&D expenditure, population density etc. are taken from World Bank's World Development Indicators (WDI) database. Energy prices come from the International Energy Agency (IEA).

Aggregate GHG Emissions

Global anthropogenic GHG emissions have continued to increase from 1970 to 2010 with larger absolute decadal increases toward the end of this period primarily due to economic growth and population increase. Although emissions have grown, there have been significant emissions intensity improvements. Key drivers of emissions growth (i.e., population and economic growth) have outpaced emission reductions from improvements in energy intensity particularly in the later part of the period. Detailed observation suggests that some developed economies, particularly in Europe, have undergone emissions reductions in absolute terms while the developing economies in general increased their emissions. However, emissions intensities have gone down in all economies albeit at a higher rate in the developing economies of China and India (Figures 1 and 3 below). These suggest that, without additional efforts to reduce GHG emissions beyond those in place today, emissions growth is expected to persist driven by growth in global population and economic activities.

Figure 1: Percentage Change in GHG emissions: 1995-2009



Source: Authors' calculation based on WIOD Database.

[3] This project was funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities.

Emission Intensity

To form the basis for the decomposition the (e_t) production-based emissions intensity can be expressed as:

$$e_t = \frac{E_t}{Y_t} = \sum_{s=1}^{n} \frac{E_t^s}{Y_t^s} \frac{Y_t^s}{Y_t} = \sum_{s=1}^{n} I_t^s S_t^s \qquad (1)$$

Where E_t^s and Y_t^s are the emissions and output in sector *s* in a region at time *t*. Aggregate emission intensity is therefore composed of sectoral emission intensity (I) and the sector shares (S) in the economy. See the appendix for the list of sectors.

In effect, emission intensity is a weighted average intensity across sectors using sectoral shares as weights. Changes in intensities then reflect changes in sectoral intensity and changes in sectoral weights. Sectoral intensities account for direct emissions from production but also the emissions that are embodied in intermediate inputs. The pattern of trade shows up in these sectoral intensities as inputs can be either local or imported. The WIOD database allows us to account for the source of inputs.

There is a growing body of literature suggesting that some developed economies were able to constrain their domestic emissions growth by substituting domestic production via growth in imports. Therefore, if net emissions in trade are accounted for, these economies may no longer claim to have achieved much. At the same time, part of emissions growth in the developing economies is due to increased import demand from developed economies. This consideration resulted in two types of emissions accounting: *production-based* (or territorial emissions) and the *demand-based emissions*. The former accounts for all emissions generated within a country in carrying out economic activities, and is, the basis for national emissions inventory reporting under the UNFCCC.[4] The latter is based on the notion of embodied emissions (or carbon) in final consumption of goods and services or alternatively called the final demand.[5] This therefore includes all direct and indirect emissions irrespective of territorial boundaries in the production of goods and services used for final consumption. The final demand includes final consumption by households, governments and firm's investments. The main difference between the DBEs and the PBEs accounting is the treatment of emissions embodied in trade flows. DBEs which are also called consumption-based emissions (CBEs) accounting excludes emissions embodied in exports, but includes emissions embodied in imports.

DBEs intensity (de_t) takes a commodity approach and so can account for traded goods, both final and intermediate. It is the summation of individual commodity intensities originating from different sources (*r*) and the share of the commodity in the final consumption basket. Hence DBEs account for the source of purchases whether they are local or imported.

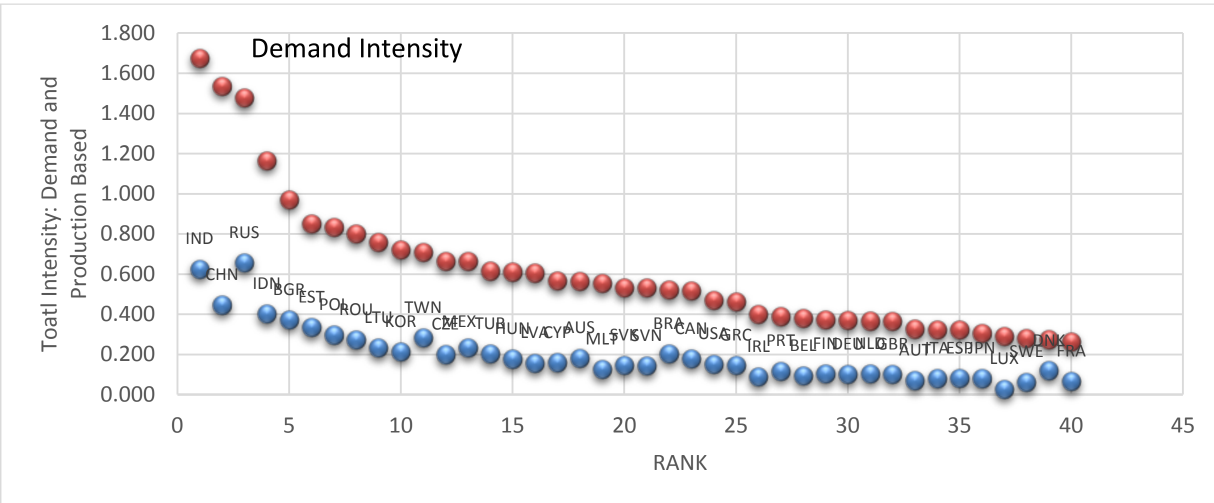
[4] IPCC(2007) defines it as, "national inventories include greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction" (IPCC [2007])

[5] The DBE therefore assign all emission released in the global production of goods and services to the country of final consumption There is a wide body of literature on the demand-based emissions – please see Wiedmann (2009) for a review.

$$de_t = \frac{DE_t}{Y_t} = \sum_{r=1}^{n} \frac{DE_t^r}{FD_t^r} \frac{FD_t^r}{FD_t} = \sum_{r=1}^{n} DI_t^r DS_t^r \qquad \text{where r = originating regions (n=1…40)} \qquad (2)$$

Figure 2 below shows both demand and production-based intensities for 2009 ranked from highest to lowest demand-based intensities. Demand-based intensities are higher though generally follow the same ranking across countries as production-based intensities: countries that are clean are clean on both measures. This arises because domestic production is still a large part of final demand but also because most rich countries' trade is with other rich countries.

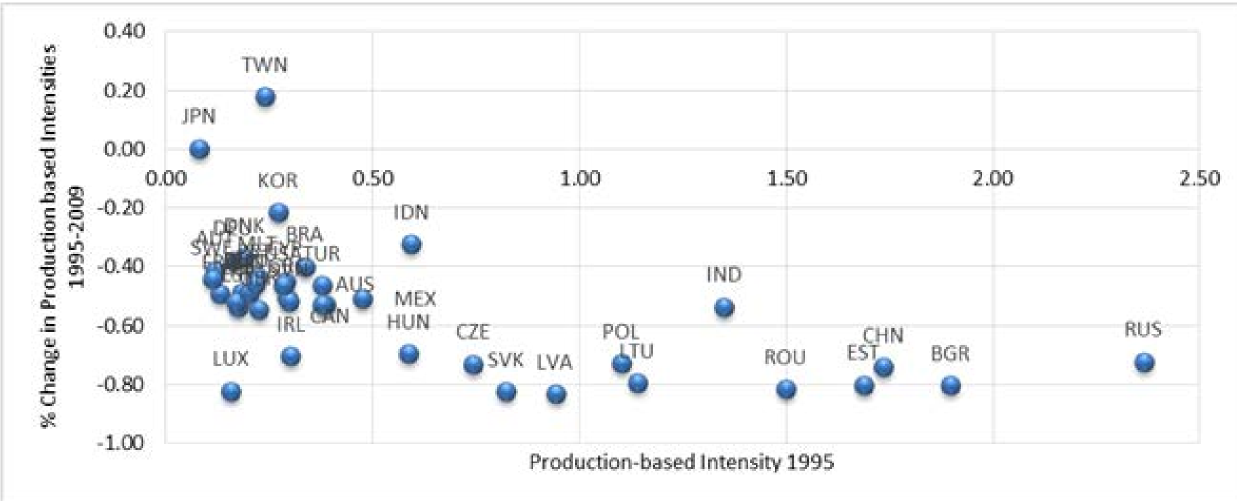
Figure 2: Demand and Production-based GHG intensities: 2009



Source: Authors' calculation based on WIOD Database.

The WIOD data shows that emissions intensities have gone down for all but one country (TWN). See Figure 2 below. In this figure, countries are sorted from left to right based on their initial intensities in 1995 with the initial "cleanest" countries to the left. Note that the higher the initial intensity, the larger to decrease in intensities over time. A similar pattern emerges for Demand-based intensities (available upon request).

Figure 3: Percentage Change in Production-Based GHG intensities: 1995-2009



Source: Authors' calculation based on WIOD Database.

Figure 3 suggests convergence in average GHG intensities. This in fact occurred. The standard deviation in production based intensities was 0.58 in 1995 and fell to 0.14 in 2009. It fell from 1.38 to 0.34 for demand based intensities.

2. Decomposition of Emissions Intensity

Following Bruneau and Renzetti (2009) and Cole, Elliott, and Shimamoto (2005) changes in emissions intensity between two periods can be written as:

$$\frac{E_{t+1}}{E_t}-1=\frac{1}{e_t}\sum_{s=1}^{n}\frac{L(I^s_{t+1}S^s_{t+1}, \mathrm{I}^s_t\, S^s_t)}{L(\mathrm{I}^s_{t+1}\, I^s_t)}(I^s_{t+1}-I^s_t)+\frac{1}{e_t}\sum_{s=1}^{n}\frac{L(I^s_{t+1}S^s_{t+1}, \mathrm{I}^s_t\, S^s_t)}{L(\mathrm{S}^s_{t+1}\, S^s_t)}(\mathrm{S}^s_{t+1}-S^s_t) \qquad (3)$$

where L is the log-mean function.

The left hand side of Equation (3) gives the relative changes in emission intensities between time t+1 and t.

Aggregate emissions intensity can therefore be expressed by the changes of its two components: changes within sector emissions intensities and changes in the relative weights of sectors.

The first term on the right hand side provides the estimates of technical changes in production processes in different sectors (commodities in the case of demand intensities) of the economy. Technological change covers a broad range of elements including energy efficiency improvements, process changes, mitigation, and changes in energy mix resulting in declining emissions per unit of output. This therefore can further be decomposed into changes in energy mix and efficiency improvement. However, given that there is not much detail available in this database we do not undertake this exercise in this paper, rather the regressions analysis address this issue.

The second term on the right hand side shows the contribution of structural shifts across industrial sectors (or final consumption in case of demand-based intensities). These structural changes arise in the process of development and from changes in relative prices. Structural changes can be slow and so are not expected to have large effects except for some fast growing, lower income countries.

Following the log mean divisia index methodology as in equation (3) DBEs intensity in this case can be written as:

$$\frac{DBE_{t+1}}{DBE_t} - 1 = \frac{1}{de_t}\sum_{r=1}^{n}\frac{L(\mathrm{DI}_{t+1}^r\, DS_{t+1}^r, \mathrm{DI}_t^r\, DS_t^r)}{L(\mathrm{DI}_{t+1}^r\, DI_t^r)}(\mathrm{DI}_{t+1}^r - DI_t^r)$$
$$+\frac{1}{de_t}\sum_{r=1}^{n}\frac{L(\mathrm{DI}_{t+1}^r\, DS_{t+1}^r, \mathrm{DI}_t^r\, DS_t^r)}{L(\mathrm{DS}_{t+1}^r\, DS_t^r)}(\mathrm{DS}_{t+1}^r - DS_t^r) \tag{4}$$

The first term on the right hand side captures the changes resulting from changing emission intensities within commodity groups which includes emissions from imported goods. The second term captures changes in the sources of consumption.

Technique Effects

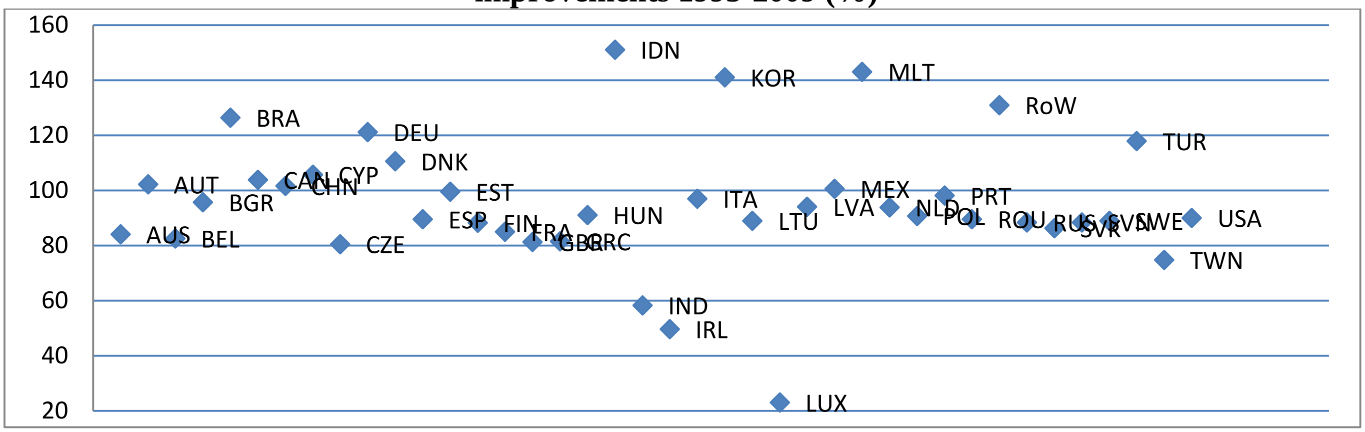
The technique effect holds the relative size of the sectoral (commodity) components constant and reflects the weighted average change in sectoral (commodity) intensities. GHG emissions and energy intensity are highly correlated due to predominance of fossil fuel in total energy.

From above, energy intensity improvements will lead to emissions intensity improvements. The literature on energy intensity is quite large (see for example Metcalf (2008), Rose & Chen (1991), Schipper et al. (1990), Sue Wing (2008)). In the US context, the literature suggests that that rising per capita income and higher energy prices have played an important part in lowering energy intensity at the State level. Results reveal that price and income predominantly influence intensity through changes in energy efficiency rather than through changes in economic activity (Metcalf 2008). Other studies also show that efficiency gains are the primary driver in the energy intensity decrease between 1970s and 1990s (Rose & Chen (1991), Schipper et al. (1990)).

The WIOD database can account for changes in the pattern of trade. There are two reasons to include these in the technological effect. First, changes in production techniques include changes in energy inputs and their embodied emissions. For example, a shift from coal to natural gas will lower sectoral emissions and, by extension, overall emission intensity. However, a firm switching energy sources, which is an intermediate input to production, is not fundamentally different from switching the location of those purchases. Both are firm-level decisions that reflect, among other things, changes in relative prices across intermediate inputs and across countries. Second, the data shows that the pattern of technical intensities with trade effects is almost identical to those without trade effects (a correlation of 0.97) so from a regression perspective, may not matter.

Figure 4 shows the contribution to overall intensity decreases from 1995-2009 due to technical changes. The figure plots changes in overall intensity and intensity holding the structure of the economy constant. As can be seen, improvements in emissions intensity between 1995 and 2009 were primarily obtained through improvements in technical efficiency. For instance, In Australia, about 84% of the decline in overall intensity is due to improvements in technology, i.e., how is it produced including fuel switching. The remaining 16% is due to structural changes. For Brazil, the contribution is about 130%. This implies that structural changes have increased intensity and so technological changes more than offset the structural effects and have led to a net decrease in intensity.

Figure 4: Contribution of technical change in overall Production-based intensity improvements 1995-2009 (%)



Source: Authors' calculation based on WIOD Database.

Demand-based intensities show a similar pattern in that the technique effects dominate. However, technique effects tend to be relatively stronger contributor to overall emission intensity since structural effects, outlined below, tend to shift most economies toward more GHG intensive sectors.

Results presented in this paper are consistent with other research. For example, there had been a number of studies on energy intensity improvements in Chin. Technological change has been the single most important factor responsible for overall energy intensity improvements in China (see Ang & Zhang (2000) as well as Ma and Stern (2008)). Ma and Stern (2008), in fact, find that structural change at the industry and sector level has in fact increased the energy intensity during 1980-2003, although the structural change at the industry level was very different in the 1980s and in the post-1990 period. While structural change involving shifts of production between sub-sectors decreased overall energy intensity, the increase in energy intensity since 2000 is explained by negative technological progress and inter-fuel substitution is found to contribute little to the changes in energy intensity. As far as emissions intensity is concerned, Zhang (2009) finds that of the 76% energy related CO_2 intensity improvement from 1992-2006, 70% was due to efficiency gains.

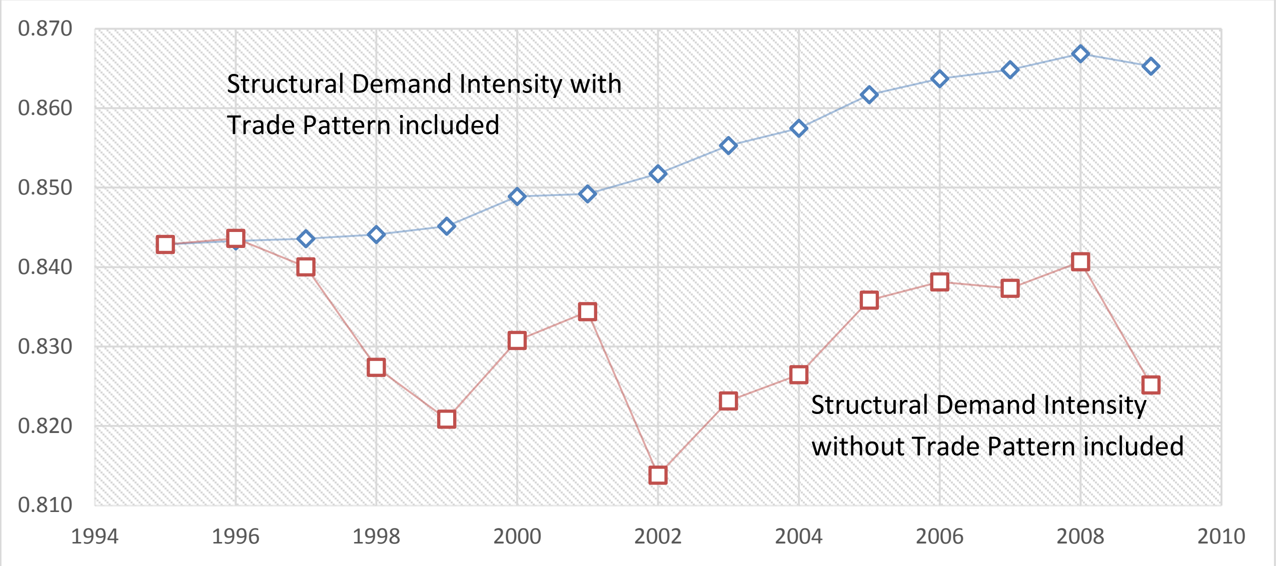
Structural Effects

Structural effects hold sectoral (commodity) technological intensities constant and reflect changes in the sectoral (commodity) weights (i.e., contribution to GDP) due to changes in the structure of the economy. These structural changes arise in the process of development and from changes in relative prices. Figure 4 implies that, relative to technique effects, structural effects are generally weak. In fact, structural shifts have offset emissions intensity improvements in a number of countries. These include Indonesia, Brazil, Korea, Turkey, Germany and China. Structural shifts in both production and consumption activities have contributed relatively more in overall emissions intensity improvements in India, Luxemburg and Ireland.

Sue Wing and Eckaus (2004) decomposed the trend in US energy-GDP ratio into the contributions of structural change and shifts in the intensity of energy use within individual sectors. Their econometric estimation results indicate that, while intra-sectoral reductions in intensity were driven by the substitution of variable inputs and the embodied energy-saving technology within accumulating stocks of capital, the overall influence of disembodied technological progress was small and energy-using in its overall character.

As with technique effects above, changes in the pattern of trade can be included or excluded. This is not relevant in the production-based approach since net imports are not accounted for. But it matters for demand-based approaches. As an example, Figure 5 shows the US from 1995-2009. The figure compares structural effects including or excluding trade effects. The top line includes changes in the source of net imports. It suggests that, all things equal, the US is shifting final demand towards more GHG intensive commodities. The bottom line excludes changes in the source of net imports. Now the data suggests a small shift towards less GHG intensive commodities. The difference is due to a shift in net imports from lower intensity jurisdictions towards higher intensity jurisdictions. Similar effects arise in most of our sample countries.

Figure 5: United States Structural Effects for Demand-Based Intensity 1995-2009



Source: Authors' calculation based on WIOD Database.

Though suggestive, Figure 5 is not evidence that the US is off-shoring GHG emissions since the analysis does not distinguish between a shift from domestic to foreign supply and a shift from one foreign supplier to another. Both are included in the trade pattern. Offshoring implies shifting suppliers to offshore locations. Although the WIOD allows us to make that distinction, we leave this discussion for future analysis.

These results here are consistent with other research. hen taking into account of trade, changes in the sources of imports have worked against overall emissions intensity improvements, particularly in the developed economies of Canada, European Union (EU 27) and United States where imports from relatively emissions intensive sources are increasing (Ghosh et al 2014).

However, a recent study finds that between 2002 and 2009, China experienced a 3% increase in carbon intensity, though trends differed greatly among its 30 provinces essentially driven by structural shifts towards more carbon intensive sectors (Guan et al 2014). Although Ghosh et al find that overall production-based emissions intensity in developing countries such as China and India is higher than those in developed economies, Douglas and Nishioka (2012) using data on emissions from 41 industrial sectors in 39 countries find no evidence that developing countries specialize in emissions-intensive sectors; instead, their results suggests that emissions intensities differ systematically across countries because of differences in production techniques. Their results also reveal that while international differences in emissions intensity are substantial, they do not play a significant factor in determining patterns of trade.

3. Regression Analysis

A primary objective of this paper is to examine the patterns and drivers of both production-based and demand-based emissions intensity in the 40 economies/regions using detailed data put together by Timmers et al. (2012) under a European Commission project.

There is a dearth of econometric literature directly focusing on the drivers of lowering carbon intensity. Andersson and Karpestam (2013) analyze the short-term and the long-term determinants of energy intensity, carbon intensity and scale effects for eight developed economies and two emerging economies from 1973 to 2007. They find differences between the short-term and the long-term response and suggest that climate policy is more likely to affect emissions over the long-term than over the short-term. Their results also suggest that climate policies should be aimed at a time horizon of at least 8 years. Intuitively, they find capital accumulation is the main driver of emissions in the long-run. While productivity growth reduces energy intensity, increase in oil price reduces both the energy intensity and the carbon intensity. Interestingly, although the real oil price effect suggests that a global carbon tax is an important policy tool to reduce emissions, a carbon tax is likely to be insufficient to decouple emission from economic growth. Such a decoupling in their view is likely to require a structural transformation of the economy and therefore the challenge is thus to build new economic structures where investments in green technologies are more profitable.[6]

Regression model

The regression analysis attempts to identify underlying factors that influence GHG emission intensity in our sample countries. Fixed-effects OLS Panel regression is used with emission intensity as the dependent variable. The baseline regression equation is given by

$$\ln \mathrm{E}_{i,t} = a_0 + a_i C + a_t T + a_1 \ln \mathrm{X}_{i,t} \qquad (5)$$

[6] Moshiri, Saeed (2012, 2013) yet to be reviewed.

where Eit are emission intensity of country i in period t. Xit are time-varying factors that would plausibly alter intensities (detailed below). C is a vector of country dummies that capture non-time-varying factors specific (and unobserved) to each country. This fixed effect captures unobserved heterogeneity across countries. T is a vector of year dummies that capture time-varying factors that are not specific to individual countries such as changes in the world price of oil. The use of natural log means the coefficients are interpreted as elasticities. Quadratic terms can be used to allow for non-constant elasticities.

All three measures of intensity are analyzed: overall intensity, technological intensity (emission intensity after removing changes in structural composition), and structural intensity (after removing the effect of technological intensity changes). It is expected that the drivers of technical change could be different than the drivers of structural change (e.g., see Antweiler et al 2001). For example, electricity suppliers may alter their energy mix away from carbon sources and toward renewables under carbon pricing schemes. This would tend to reduce overall emission intensities as well as technical intensities. However, as long as energy prices are not affected, there is no particular reason to expect the structural composition of an economy to change simply because the energy input mix has changed.

Both production-based and demand-based intensities are considered for the regression analyses under the presumption that drivers may be different or, at least, sensitivity could be different. For instance, industry may be more sensitive to energy prices whereas households are not. Hence the coefficient for demand based intensities could be smaller than for production-based intensities. This is an empirical matter.[7]

The drivers of emissions intensities are put into different categories: energy prices; regulatory factors; investments and R&D; relative wage-capital costs; and general economic development. These are discussed in detailed below.

Energy prices

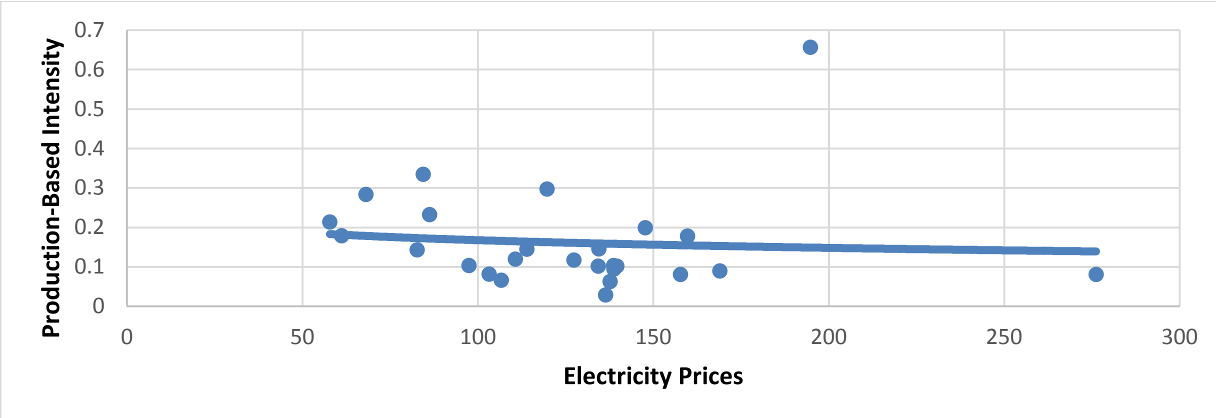
To under the inter-relationship between emissions intensity and energy prices, both average annual electricity prices and natural gas prices are used as explanatory variables. Prices are obtained from the IEA and are in US dollars per MWh (where energy embodied in natural gas is converted to an equivalent MWh basis). The IEA reports both industrial prices as well as household prices. We report regressions with industrial prices. Results with household prices are available on request. Unfortunately, data for all countries are not available for all the years. Data covers about 20-27 countries depending on the year.

Theoretically it is expected that technological efficiency of energy use to improve with higher energy prices. Natural gas and electricity are used in different ways by the users and are not fully substitutable. Hence to allow for the response to electricity prices to differ with the natural gas prices both are used simultaneously in regression. It is also expected that higher energy prices will alter the relative size of sectors and so reduce structural intensities as well.

[7] A possible explanatory variable is net export ratio, which may have significant effect on demand-based index but may not on production-based index. We plan to explore it later.

Figure 6 below shows a cross-section of countries for which there is data in 2009. The plot shows that increasing energy prices leads to lower overall GHG intensity though the effect is not strong.

Figure 6: Electricity Prices and overall Production-Based GHG intensity 2009



Source: IEA and WIOD database

Regulatory or other policy factors

Countries differ in terms of current, past, and future policies to mitigate GHG emissions. For instance, market-based policies such as carbon taxes are already in place in a number of European countries (Denmark, Finland, France, Iceland, Ireland, Norway, Sweden, and in some provinces of Spain), in Chile, in Canada's British Columbia, and are scheduled for introduction in South Africa. Other countries are members of the European GHG Permit Trading program or have regional trading programs (i.e., California and Quebec). Though many of these policies are implemented after 2009, firms may have anticipated them and started to change their behavior earlier. For instance households may have installed photovoltach in anticipation of higher future energy prices.

However, countries can also alter energy use even without explicit GHG goals. For instance, they can subsidize home insulation improvements or solar electrical production, mandate more fuel efficient auto fleets, or provide investment incentives for new technologies. All can reduce GHG intensities. Alternately, or at the same time, governments can implicitly subsidize coal, gas, and oil production though tax codes leading to higher GHG intensities.

We do not have access to cross country data sufficient to deal with the issues above separately although some will be captured by country fixed effects three proxies of regulatory stringencies are implemented as described below.

To account for all the different ways in which countries may have altered GHG emissions, the share of renewable energy out of total energy is used as a proxy for GHG-altering policies. To note, air pollution standards implemented by many economies, may also have resulted in fuel-switching (from coal to natural gas or another low carbon-fuel or renewables) and consequent decline in GHG emissions. Using the WIOD data, two measures of renewable energy are undertaken. The first is broadly defined as the share of total energy use deriving from non-carbon sources. This includes hydro, solar, wind, biomass, and geothermal. The second excludes hydro power generation and includes only those that have had government support in some way. We choose to use this more restrictive definition.

Since energy prices (electricity and natural gas) are already being accounted for, it is not expected that the reliance on renewable energy will affect the composition of an economy and therefore, renewables, per se, should not affect intensities related to structural composition only. However, all thing equal, increases in the share of renewable energy should be reflected in lower emissions intensities, holding composition constant. That is, techniques should be cleaner even if the composition of economic activity is not.

Reliance on renewables can be thought of a ‘supply side’ response: the energy mix responds to policy initiatives and so GHG intensity of energy also responds. However, on the ‘demand side’, factors that influence the incentive to reduce GHG emissions can also be considered. Here two likely factors are included. First is population density. Most energy production emits both GHG emissions and air pollutants such as NOx, SO2, PM10, and ozone. The greater the population density, the more likely we will see higher concentrations of air pollutants, and the greater the demand for a government response to clean up the air. Hence higher population density should reduce intensities. Data comes from the World Development Indicators (WDI) with population per square kilometer.

A second demand side factor is the degree of urbanization. Here the presumption is that greater urbanization allows individuals to form more cohesive political groupings and so place greater pressure on governments to respond to local demands for improved air quality. The measure of urbanization is the share of population in urban centers taken from the World Development Indicators’ database.

Investment and R&D expenditure

Most GHG emissions arise from energy use and the carbon dioxide emissions from burning fossil fuels is the largest source of GHG emissions (Global Carbon Project 2014). New investments tend to incorporate newer technologies, many of which are more energy efficient. This is expected to reduce technological intensities. Hence, the rate of investment, as measured by the share of GDP, should be negatively correlated with technological intensity.

However, depending on where investments take place, the composition of the economy may be GHG increasing or decreasing. For instance, for poorer countries, more investment tends to raise primary and secondary activity and so can be expected to raise GHG intensity. Rich countries undergoing de-industrialization will expect to see a decrease in GHG intensity as tertiary industries grow. This suggests that the elasticity of intensity with respect to investments could be positive at low incomes but negative at high incomes. For the regression analysis, investment rates on a per capita basis are used. Data is from the WDI database.

Also important are R&D expenditures. Though not all research and development is focused on energy savings or GHG abatement, some would be. Hence it is expected to have a negative correlation between the intensity of R&D and technical intensities. However, R&D may or may not drive the composition of activities towards less GHG intensity. That is, the structure of an economy may not change with R&D intensity as R&D, as a percent of GDP, tends to be quite small (from 0 to 4%) so any effects are possibly too small to identify. Data is from the WDI database.

Relative wage-capital cost

Based on standard economic theory, it is expected that capital abundant countries, measured by their K/L ratio will have an economic composition shifted towards capital intensive sectors. Typically one expects that this would entail greater energy and GHG intensity as countries take on more manufacturing. However, to the extent that many of the OECD countries are undergoing de-industrialization, a greater K/L ratio is also consistent with a shift into capital-intensive but not energy–intensive production (e.g., high tech rather than steel). Further, more capital tends to be 'deepening' suggesting an economy of scale effect that would lead to less energy use per unit of output. Together, this suggests that a higher K/L ratio would be consistent with lower intensities for both structural and technique intensities. The aggregate capital-labour ratio is measured as real fixed capital stock (1995 US$) divided by total hours worked by persons engaged (millions of hours) using data from the WIOD database.

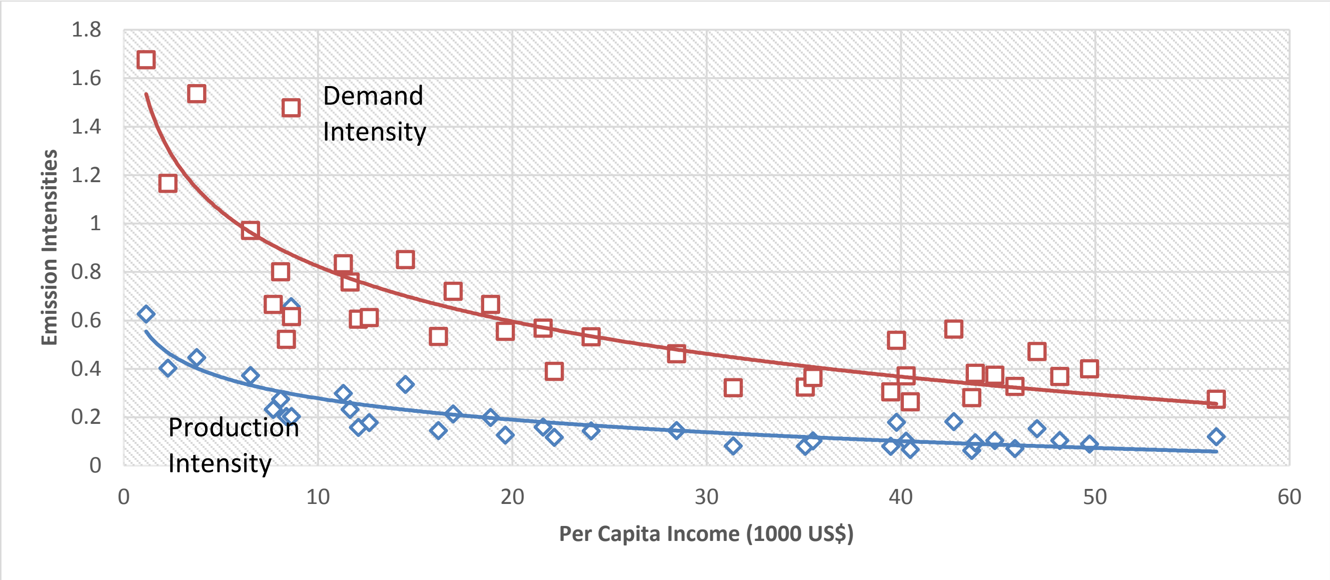
Standard economic theory also tells us that the greater cost of capital, the more inclined firms will be to substitute toward labour. This in turn suggests that energy use, and hence GHG emissions, would also fall as capital becomes more expensive. Furthermore, the composition of the economy should shift towards less capital intensive production. Hence it is expected that both the technical intensity and the composition intensity to be declining as capital becomes more expensive. To identify the relative cost of capital, total compensation to capital divided by total compensation to labour is included in regression. Data is from the WIOD database.

General economic development

To capture other aspects of the economic development process, other plausible GHG drivers are also included. First is *per capita GDP*. There is ample evidence (Bruneau and Echevarria, 2009) that a clean environment is a normal good: people are willing to pay for a cleaner environment as they become richer. They can do this by choice of vehicle and house characteristics or though other individual behavior. Second, this desire for a cleaner environment can manifest through public goods such as safe and efficient infrastructure and transportation. It can also manifest though regulatory stringency as they push local governments to enact and enforce tighter air quality measures. Together then, it is expected richer countries will have cleaner economies with lower GHG intensities. As the model already accounts for regulatory factors, government expenditures; and energy prices, the coefficient on per capita GDP then captures all the private activities that alter intensities. This could very well be positive if travel and house size are normal goods.

Table 7 shows the relationship between per capita income and overall GHG intensities. Intensities, on average, fall with higher per capita income for both demand and production based intensities. Note that the figure does not account for other covariates. If other covariates are correlated with income, then there may be no direct effect of income on intensities. This is an empirical matter.

Figure 7: Per capita income, Demand and Production-Based GHG intensity, 2009



Also important is the ability of countries to adopt new technologies and new ideas from other countries. The better the access to other countries, the lower would be the GHG intensity. To account for this an *openness index* (export to GDP ratio) is used. However, since the intensity measures account for the input mix, some of which comes from abroad, one might expect that more open countries could have higher GHG intensities. That is, if a country is more open, they are more likely to have 'off-shored' dirty GHG production to mainly poorer countries. Hence the average intensity of production and consumption could be higher than countries that rely less on traded goods to meet local needs. Which effect dominates is an empirical matter.

A third component is the share of Government expenditure in total GDP. The idea here is that the greater the share of total expenditures from government the greater the expenditure on infrastructure. This will tend to increase fuel use for private consumption purposes and would also be complementary to manufacturing production. In both cases, it is expected to see higher GHG technical intensities as also well as higher structural intensities.

4. Regression Results and Summary of Findings

The regression results are presented in the following tables. All regressions have year and country fixed effects with robust standard errors.

As a robustness check, the sample is split into 1995-2000 and 2001-2009 with regressions run for the later period. First, the idea of splitting the sample is that countries are converging to the lowest intensities over time (see figure 3). The convergence of intensities suggests that those that have made the most gains early in the period may have less room for future improvements. Hence the drivers of intensities in the earlier period may lose their impact. Second, our data predates much of the regulatory initiatives so may not be picking up newer regulations within the larger sample. Third, actual GHG regulations at the start of the sample may have been too weak to alter intensities in any significant way. Hence early data may fail to pick up any systematic effects. Even if GHG policies have been relatively strong, there may have been policies that offset these gains (e.g., tax breaks to large GHG emitters). Time fixed-effects will only change the intercept terms, not changes in the slope coefficients of interest.

Results are reported in the tables below. Columns 1 and 2 of each table show regression results for Production-based intensities for the entire sample period and for only 2001-2009. Columns 3 and 4 show the same for Demand-based intensities.

Overall Production-Based and Demand-Based Intensity Drivers:

In general, the drivers of intensity are the same regardless of the accounting framework. What drives production intensities also drives demand-based intensities. Their coefficients may differ but the overall picture is the same. As noted above, this arises since most final demand is made up from local production.

As expected, energy prices, to some extent, matter. Overall intensities decrease with electricity prices though the sensitivity to electricity prices falls in the later period. Though the sensitivity to electricity prices falls in the later period, they are still statistically significant. This may reflect the fact that, as intensities fall, it becomes harder to reduce them further with only energy pricing. Surprisingly, natural gas prices do are not correlated with average intensity across countries. This may be capturing a reverse causality; countries with large natural gas demands (say due to industrial structure) will tend to have high prices. More comments below on this.

Regulatory or other factors (i.e., % renewables, urbanization, population density) have mixed results. The share of renewables has a negative impact on both intensities but only in the later period. This may reflect the low level of renewables use in the earlier period. But for the later period, the more the use of renewables, the greater is the reduction in GHG intensities.

Higher urbanization rates and population density are correlated with increased intensity though these effects disappear in the later period. Note that this pattern emerges even though country fixed effects are included. Results below show that the technique and composition effects tend to work in opposite directions with the technique effect dominating.

Investment rates are shown to be significant in driving intensities downward for both demand and production intensities. However, in the later period, the sign reverses so that higher investment rates raise intensities though the effect is very small. Again, this may be picking up the big decreases in the early period when small investments could make big differences. R&D investments have little effect and none in the later period.

Higher K/L ratios are consistent with lower GHG intensities though these effects disappear in the later period. Include relative compensation provides an additional negative effect on intensities though again they disappear in the later period. One way to think of this is in terms of ‘effective capital’. The idea is that the same stock of capital may yield higher returns in one country than another and so would be reflected in higher relative capital compensation. One plausible reason is that capital in one country may be less energy intensive and so, for a given menu of labour wages, leaves more profit for capital owners. Hence if capital is more effective, it uses less energy and so emits less GHG.

As for the development indicators concerned, the results suggest that per capita income raises intensities for the overall sample but reduces it in the later period. As noted, since other drivers of GHG emissions are already accounted for, this variable captures private activities that alter GHG emissions. Since energy use is generally a normal good (people drive more and have larger houses) it is not surprising to see a positive coefficient. However, in the later period, higher incomes lead to less GHG emissions so this cannot be the only story.

The openness index shows that more open countries, all thing equal, have higher intensities. This suggests that the learning from other countries is likely not a big driver above what high investment rates would deliver. Rather, it appears that being more open leads to higher GHG technical intensities and could reflect competitive pressures. This warrants more investigation.

The share of government expenditures in GDP seems to have a small negative effect on technical intensities but a small positive effect on structural intensities. Overall, the effects cancel. These effects disappear in the later period.

Technical Intensity Drivers:

Table 2 shows results for regressions using technical intensities (e.g., holding structural composition constant). In general, the pattern of drivers for technical intensities is the same as for overall intensities primarily because overall intensities strongly reflect technical intensities.

The signs of the regressors are more or less as expected. As above, electricity prices reduce intensity though natural gas prices do not. The percent of renewables in energy matters quite strongly but only in the later period. This could arise since the use of renewables was still developing in the earlier period.

Higher investment rates reduce technical intensities with research and development playing a role but only for demand intensities. Similarly, higher compensation for capital and higher capital-labour ratios reduce intensity though these effects disappear in the later period. Higher GDP per capita lowers intensity but, again, only in the later period.

Structural Intensity Drivers:

Table 3 shows results for regressions using structural intensities (e.g., holding technical intensities constant as well as trade composition). A priori, the drivers of technical intensities may not be strong enough to alter structural intensities. First, the economies in our sample are generally richer OECD countries; there are not big differences in structural intensities. Nor have they changed much over the period. Further, differences in structures would reflect underlying idiosyncratic features of each economy. Hence, incentives that influence firm and household behavior may not be sufficient to alter the overall structure of the economy.

Results bear this out as there are only a few statistically significant drivers of structural intensities for the later period. For production based intensities, energy prices either do not matter or are of the ‘wrong sign’. That is, higher electricity prices are correlated with a structure shifted towards higher GHG sectors. As above, this suggests a reverse causality: countries with big demands for energy will tend to have higher prices.

For demand based intensities, the only notable repressors are the policy regressors. Other factors are insignificant. For instance, the share of renewables matters, at least in the later period. The greater the share, the more final demand is shifted to lower GHG sectors. Recall that energy prices are accounted for so this shift is not driven by any induced rise in energy prices. Rather, it suggests that countries that have lower reliance on energy have chosen to pursue more non-renewables.

Interestingly, higher urbanization and higher population density are significant and important drivers in the later period, primarily for demand based intensities. If these are proxies for stricter GHG regulation (or air pollution in general) then this suggests that policy is a major driver but only in the later period. In the early part of the data series, regulation may have been too weak to show up relative to background noise. But once GHG intensities have fallen with the taking of the 'low hanging fruit' of technical change, then policy induced changes do have important structural impacts.

TABLE 1: Overall Production and Demand Intensity Drivers

Total Intensity		1	2	3	4
		Production Based		Demand Based	
		1995-2009	2001-2009	1995-2009	2001-2009
Dependent variable: ln of Average Intensity	**N=**	**215**	**129**	**215**	**129**
Electricity price	**lnEL**	-0.368***	-0.103***	-0.308***	-0.082**
		0.058	0.034	0.046	0.037
Gas Prices	**lnGAS**	0.018	-0.015	0.029	0.015
		0.040	0.022	0.031	0.021
ratio of renewable energy production to total	**lnRNsh2**	0.116	-0.341**	0.106	-0.308**
		0.143	0.131	0.122	0.127
urban/pop ratio	**lnURB**	1.120**	0.339	1.159***	0.665*
		0.448	0.343	0.391	0.362
pop/land ratio	**lnDEN**	1.895***	-0.161	1.577***	0.467
		0.453	0.384	0.350	0.387
Investments per capita in $US	**lnINV**	-0.377***	0.021	-0.269***	-0.143
		0.068	0.114	0.056	0.115
Square of (**Investments per capita in $US)**	lnINV2	-0.033***	0.026***	-0.029***	0.007
		0.004	0.006	0.003	0.007
R&D as share of GDP	**lnRAD**	-0.032	0.028	-0.084*	-0.006
		0.056	0.042	0.049	0.039
	lnRAD2	0.143**	0.017	0.143***	0.059
		0.058	0.041	0.047	0.039
compensation K/L	**lnKL2**	-1.425***	0.162	-1.329***	-0.218
		0.255	0.192	0.220	0.238
	lnKL22	0.113***	-0.031	0.113***	-0.014
		0.033	0.022	0.028	0.025
stock K/L_hr	**lnKL1**	-0.204***	0.064	-0.212***	-0.036
		0.060	0.063	0.057	0.071
	lnKL12	-0.035***	0.083	-0.034***	-0.113
		0.012	0.095	0.012	0.093
per capita income in US$	**lnGDP**	0.139***	-0.297***	0.123***	-0.216***
		0.052	0.052	0.044	0.054
	lnGDP2	0.023***	-0.001	0.025***	0.005**
		0.004	0.002	0.003	0.002
openness index	**lnOPEN**	0.428***	-0.038	0.368***	-0.060
		0.082	0.085	0.069	0.086
govt expenditures as share of GDP	**lnGOVT**	0.014	-0.003	0.002	-0.002
		0.016	0.009	0.013	0.009
	lnGOVT2	0.000	-0.003	0.000	0.000
		0.005	0.002	0.004	0.002

TABLE 2: Technical Production and Demand Intensity Drivers

TECHNICAL Intensity		1	2	3	4
		Production Based		Demand Based	
		1995-2009	2001-2009	1995-2009	2001-2009
Dependent variable: ln of Average Intensity	**N=**	**215**	**129**	**215**	**129**
Electricity price	**lnEL**	-0.290***	-0.181*	-0.296***	-0.142***
		0.043	0.065	0.046	0.049
Gas Prices	**lnGAS**	-0.091***	-0.059**	0.017	0.002
		0.031	0.032	0.032	0.026
ratio of renewable energy production to total	**lnRNsh2**	-0.053	-0.434***	0.068	-0.017
		0.104	0.161	0.122	0.213
urban/pop ratio	**lnURB**	0.331	-0.921*	1.033***	1.483***
		0.380	0.546	0.367	0.424
pop/land ratio	**lnDEN**	1.664***	0.758	1.466***	1.775***
		0.319	0.538	0.348	0.468
Investments per capita in $US	**lnINV**	-0.198***	-0.405**	-0.245***	-0.307**
		0.053	0.178	0.053	0.140
Square of (**Investments per capita in $US)**	lnINV2	-0.017***	0.004	-0.027***	-0.003
		0.003	0.010	0.003	0.008
R&D as share of GDP	**lnRAD**	-0.105***	0.061	-0.069	-0.022
		0.037	0.069	0.048	0.050
	lnRAD2	0.074*	-0.001	0.129***	0.080
		0.042	0.072	0.049	0.053
compensation K/L	**lnKL2**	-1.278***	-0.279	-1.247***	-0.510*
		0.207	0.268	0.219	0.289
	lnKL22	0.112***	-0.008	0.104***	-0.010
		0.026	0.033	0.027	0.027
stock K/L_hr	**lnKL1**	-0.205***	-0.077	-0.173***	-0.002
		0.051	0.093	0.056	0.070
	lnKL12	-0.031***	0.023	-0.027**	-0.210*
		0.010	0.156	0.012	0.125
per capita income in US$	**lnGDP**	0.074*	-0.105	0.092**	-0.145**
		0.043	0.094	0.042	0.066
	lnGDP2	0.011***	-0.006	0.022***	0.002
		0.003	0.005	0.003	0.003
openness index	**lnOPEN**	0.396***	-0.039	0.334***	-0.101
		0.070	0.132	0.067	0.113
govt expenditures as share of GDP	**lnGOVT**	-0.023***	-0.015	0.001	-0.007
		0.007	0.013	0.012	0.015
	lnGOVT2	0.002	0.002	0.000	0.002
		0.002	0.003	0.004	0.003

TABLE 3: Structural Production and Demand Intensity Drivers

Structural Intensity		1	2	3	4
		Production Based		Demand Based	
		1995-2009	2001-2009	1995-2009	2001-2009
Dependent variable: ln of Average Intensity	**N=**	**215**	**129**	**215**	**129**
Electricity price	**lnEL**	0.016	0.085**	-0.004	0.001
		0.025	0.034	0.013	0.021
Gas Prices	**lnGAS**	0.086***	0.036**	0.019**	0.021
		0.023	0.017	0.009	0.013
ratio of renewable energy production to total	**lnRNsh2**	0.049	-0.094	-0.026	-0.260**
		0.063	0.072	0.041	0.102
urban/pop ratio	**lnURB**	0.361*	0.306	-0.144	-0.475*
		0.206	0.314	0.119	0.263
pop/land ratio	**lnDEN**	-0.181	-0.964***	-0.183	-0.601*
		0.211	0.311	0.114	0.309
Investments per capita in $US	**lnINV**	-0.081**	0.125	-0.025	0.152*
		0.031	0.091	0.016	0.081
Square of (**Investments per capita in $US)**	lnINV2	-0.007***	0.007	-0.001	0.011**
		0.002	0.005	0.001	0.004
R&D as share of GDP	**lnRAD**	0.045*	0.040	-0.008	0.026
		0.024	0.038	0.010	0.028
	lnRAD2	0.075***	0.083**	-0.006	-0.002
		0.026	0.041	0.013	0.027
compensation K/L	**lnKL2**	0.007	0.151	0.072	0.138
		0.099	0.124	0.056	0.146
	lnKL22	-0.005	-0.003	-0.006	0.005
		0.014	0.018	0.007	0.017
stock K/L_hr	**lnKL1**	-0.057**	0.008	-0.003	-0.035
		0.031	0.054	0.016	0.050
	lnKL12	-0.015*	0.056	0.000	0.137**
		0.007	0.073	0.003	0.066
per capita income in US$	**lnGDP**	0.024	-0.039	0.029**	0.028
		0.023	0.054	0.013	0.046
	lnGDP2	0.005**	0.004	0.002**	0.005**
		0.002	0.002	0.001	0.002
openness index	**lnOPEN**	0.051	0.029	0.021	0.113
		0.036	0.065	0.020	0.071
govt expenditures as share of GDP	**lnGOVT**	0.024***	0.006	0.016***	0.020**
		0.007	0.006	0.003	0.009
	lnGOVT2	0.002	0.000	-0.002***	-0.003*
		0.002	0.001	0.001	0.002

5. Summary of Findings

Emissions intensity improvement is the key to controlling total GHG emissions. This paper explores the drivers of emissions intensity improvements over the period 1995-2009 using a large multi-regional input-output database for 40 regional economies, each having 35 industrial sectors. Both production-based and demand-based are computed and then decomposed into technological and structural intensities.

The first main result is that production and demand intensities, though of different magnitudes, generate more or less the same relative ranking across countries. Hence the argument that accounting for final demand is critical to understanding the pattern of GHG emission does not hold for this set of countries. Countries that are low GHG intensive under a production-based accounting are low under a demand-based approach.

The second result is almost all countries have seen a marked decrease in GHG intensity. Only one country, Taiwan, in our sample had no change in intensity though it started from a low intensity already. The most GHG intensive countries in 1995 tended to have the largest decreases. Hence, for these sample countries, average GHG intensity fell about 30% from 1995-2009 with a compressing of the variation (i.e., convergence) across countries.

The third result is that most of the decreases in overall intensity are driven by reductions in sectoral (i.e., technical) intensities rather than structural changes. Structural changes tend to be small and can either reinforce or offset the technical improvements in process and fuel use. This suggests that, though offshoring of production is likely to have occurred, the magnitude of these changes was small relative to technological changes.

The fourth result is that accounting for trade patterns matters to the interpretation of demand-based structural effects. The WIOD database can control for the pattern of trade in the decomposition exercise. Structural effects, with trade effects included, tend to show developed countries shifting toward more GHG intensive sectors under both demand and production-based approaches. But once the pattern of trade is held constant, the shift is slightly away from GHG intensive sectors. This applies to most countries suggesting that overall growth is biased towards lower GHG intensive sectors.

Fifth, most drivers of overall intensity changes act through the technique effect. Energy prices, investments, research and development, capital-labour ratios, and capital compensation tend to decrease technological intensities. There were fewer drivers of structural change. This could be because the sample size was too small or too short in time to accurately identify effects given that structural effects are small to start with.

Sixth, the drivers of intensity change seem to be changing over time. Statistical significance changes depending on the sample period. Most drivers lose their statistical significance in the later period. For the period 2001-2009, higher energy prices and greater reliance on renewables matter in reducing intensities with renewables very important. This suggests that policy drivers may become more important than other, non-GHG directed activities, once intensities fall to a low level. More research is warranted to explore this more.

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