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Summary

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Keywords: Energy Intensity, Logarithmic Mean Divisia Index Decomposition, WIOD Database

JEL Classification: Q43, C43

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Energy Intensity Developments in 40 Major Economies: Structural Change or Technology Improvement?☆

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Abstract

This study analyzes energy intensity trends and drivers in 40 major economies using the WIOD database, a novel harmonized and consistent dataset of input-output table time series accompanied by environmental satellite data. We use logarithmic mean Divisia index decomposition to (1) study trends in global energy intensity between 1995 and 2007, (2) attribute efficiency changes to either changes in technology or changes in the structure of the economy, and (3) highlight sectoral and regional differences. We first show that heterogeneity within each sector across countries is high. These general trends within the sectors are dominated by large economies, first and foremost the United States. In most cases, heterogeneity is lower within each country across the different sectors. Regarding changes of energy intensity at the country level, improvements between 1995 and 2007 are largely attributable to technological change while structural change is less important in most countries. Notable exceptions are Japan, the United States, Australia, Taiwan, Mexico and Brazil where a change in the industry mix was the main driver behind the observed energy intensity reduction.

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1. Introduction

Recent environmental, economic and energy trends point at energy issues as a major challenge for the near future. Current and projected trends for population, income and energy demand growth suggest that the pressure on energy and natural resources will increase in the coming decades, especially in emerging and developing economies.[5] This will result in higher levels of anthropogenic emissions unless the world economy switches away from fossil-based energy carriers by facilitating access to more efficient technologies, favoring structural change in the composition of economic activities or increasing the willingness to pay for a clean environment.

Global energy intensity in the past decades has declined despite the notable increase in aggregate gross output and energy use, cf. Allcott and Greenstone (2012, p. 7) and IEA (2012c, pp. 37, 50, 272). This aggregate decline is the

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[5]By 2050, the United Nations projects global population to be almost 9.2 billion. Growth rates are projected to be positive in BRIICS (Brazil, Russia, India, Indonesia, China and South Africa) countries, but they are expected to be particularly high in Africa and South Asia, while population will fall in some European countries, Japan and Korea. Urbanization and average per capita income levels are also expected to increase (OECD, 2012). The increased demographic pressure in less developed countries will have important repercussions for energy demand and use. Energy consumption in OECD and non-OECD countries was almost equal in 2007, but from 2007 to 2035 the US Energy Information Administration forecasts that energy consumption in OECD countries will grow by 14 percent, while energy consumption in non-OECD countries will grow by 84 percent (Wolfram et al., 2012, p. 119).

result of both changes in the structural composition of the world economy and improvements in the technologies used for production worldwide. Economies have shifted toward less energy-intensive sectors, determining an improvement in energy efficiency.[6] At the same time, energy efficiency within all sectors of the world's economies is likely to increase over time as a result of more efficient production technologies and newer vintages of capital equipment.

Different countries and different sectors are very heterogeneous with respect to their energy intensity. Large potential gains still exist, in particular in the industry, building and power sectors and in countries such as China, Brazil and India, whose share in energy consumption will increase in the years to come. For example, China's share in the energy consumption of major economies (European Union, United States, Japan, and BRICS) went from 10% to 20% between 1990 and 2004. By 2050, this share could be as high as 50% in a BaU scenario (IEO, 2010). Energy efficiency could achieve the 31% of the emission reduction necessary to halve emissions by 2050 compared to 2009 levels (IEA, 2012a).

Understanding the drivers behind the national and sectoral dynamics of energy intensity and the interplay of structural changes and sectoral efficiency improvements has therefore important policy implications. Relevant questions in this respect include the following: Is the decline in energy intensity similar in the same sector across different countries? Is the improved efficiency on a global scale driven by changes in some economies and sectors rather than others? Moreover, are efficiency increases caused by shifts in the composition of economies from energy-intensive production toward less energy-intensive production?

Answering these questions helps clarify if the decoupling between output and energy use is attributable to increased sectoral efficiency and better technologies. In this case, policies encouraging technology transfers, economies of scale and learning-by-doing effects can be put in place to replicate improvements in less developed regions which still display higher-than-average energy intensity. These improvements would then come at relatively low costs since efficient technologies are already available. This also has implications for the negotiations of international environmental agreements and optimal policy design. If efficiency improvements can be replicated, the implementation of agreements based on technology transfer might be a better choice in terms of incentive compatibility than the design of new regulatory frameworks to promote the participation of developing countries (Aldy et al., 2010).

Conversely, if energy intensity trends are driven mostly by changes in the structural composition of the economy, perhaps combined with increased imports of energy-intensive goods from less developed countries, it would be more difficult to observe similar developments of energy intensity in those other regions of the world even if specific policies were in place to promote technological development.[7]

This paper makes two major contributions to the literature on energy efficiency. First, we provide an overview of energy intensity improvements with a temporal and geographical focus that is greater than in prior studies. Second, by focusing on sectors and showing their performance across countries, we provide a novel perspective that sheds light on the heterogeneity of sectoral efficiency improvements across countries. We also present a more traditional country-based analysis, in which the sectoral composition of each economy is taken into account. We exploit the international dimension of the newly released WIOD database, which covers the period between 1995 and 2007 and contains data on 34 sectors in 40 major economies, including BRIC (Brazil, Russia, India and China) and other developing countries. The economies included in our analysis represented approximately 85% of the world's GDP in 2009.

We use mean Divisia index decomposition analysis to disentangle the contribution of efficiency improvements (*technology effects*) and structural change (*structural effects*) which accounts for the sectoral composition of the world's economy. We perform this exercise both at the aggregate and at the country level and provide insights on the heterogeneity of the drivers of efficiency improvements in our sample.

We show that heterogeneity among sectors is higher than heterogeneity among countries. Thereby, large economies such as the United States and China often dominate the overall sectoral development of energy intensity. Moreover, the extent to which energy efficiency improvements are driven by the technology or structural components is rather country-specific and does not necessarily depend on the level of economic development nor on the initial energy intensity of a given economy.

[6]In the remainder of this paper, we frequently use the terms *energy efficiency* and *energy intensity* equivalently where energy intensity – the ratio of energy use and gross output – is the reciprocal of energy efficiency.

[7]For a similar argument for the case of the impact of international trade on the pollution in US manufacturing between 1987 and 2001, see Levinson (2009).

The remainder of the paper is organized as follows. In section 2 we present the data used in the analysis and compare our approach to that of previous contributions on energy efficiency. Section 3 describes the improvements of energy efficiency in our sample both from the sectoral and the country perspective. Section 4 introduces the index decomposition framework and section 5 presents the result of this exercise. Section 6 concludes by highlighting the main implications of our findings.

2. Data Description: The WIOD Database

The main data source for our analysis is the newly released World Input-Output Database (WIOD, 2012).[8] The WIOD database is built on national accounts data which was developed within the 7th Framework Programme of the European Commission.[9] The relevant information for the analysis of efficiency improvements is included in the Social Economic Accounts (*SEA*) and the Gross Energy Use information which are accompanying satellite accounts to the WIOD database. Energy use (*EU*) is measured in physical units (TJ) and is aggregated across 26 energy carriers. The measure of sectoral economic activity relevant for our analysis is gross output (*GO*) which is expressed in monetary units in basic 1995 prices and converted to million US$ (1995) using market exchange rates. The WIOD database has two main advantages. First, throughout the data collection effort, harmonization procedures were applied to ensure international comparability of the basic data. This ensures data quality and minimizes the risk of measurement errors which are now rather unlikely to occur. Second, WIOD includes sectoral price deflators whose use allows to retain important information and the heterogeneity of the sectors with respect to price developments. This represents an improvement over the use of aggregate national price deflators. A complete list of 34 sectors which represent one of our units of observation over the period from 1995 to 2007 is presented in Table 1.[10]

The structure of the WIOD database allows us to address the research questions outlined above by focusing on many heterogeneous countries over a fairly long time span. This is an improvement over the previously available literature which was more limited geographically and with respect to the time dimension. A number of available contributions focused on specific countries, most notably the US (among others Sue Wing, 2008, Huntington, 2010), and more recently also emerging economies such as China (Zhang, 2003, Fisher-Vanden et al., 2004, Ma and Stern, 2008, Wu, 2012), India, and South Korea (Sanstad et al., 2006). When a cross-country dimension is present, the study is usually limited to industrialized economies, with a maximum coverage of 19 countries (Mulder and De Groot, 2012). A few papers analyzed convergence of countries in terms of energy intensity, but mostly considering OECD economies (Greening et al., 1998, and more recently Mulder and De Groot, 2012). Alcântara and Duarte (2004) use a structural decomposition analysis to investigate the energy intensities in 14 European countries and 15 sectors but the data is limited to 1995.

More recently, Mulder and De Groot (2012) expand the sectoral analysis to 50 industries, highlighting the differences between manufacturing and service sectors across 19 industrialized countries between 1995 and 2005. Given the sectoral detail of the database and the availability of data for developing and emerging economies, we go further than previous analyses on developing and emerging economies (Markandya et al., 2006, Jakob et al., 2008) by looking into the sectoral specificities of aggregated data.

In the following section we describe the energy efficiency improvements in our sample between the beginning and the end of the sample period. We first show the performance of each sector covered in the database and then move on to the country analysis.

[8]The WIOD database and all satellite accounts are available at http://www.wiod.org. In this paper we use data released in April 2012.

[9]The WIOD project has been funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities. Grant Agreement no: 225 281.

[10]The countries in the database include all EU member states, other OECD member states including all the large developed countries, and the most important emerging economies including the BRIC countries (Brazil, Russia, India, China). All other countries are summarized in an aggregate region "Rest of the World" (RoW) which is used however only to complete the trade data, i.e. no separate accounts for this region are provided. In addition to providing economic time series data for the period from 1995 to 2007, WIOD contains several consistent satellite accounts with the same sectoral classification as the core dataset. The satellite accounts consist of bilateral trade data, socioeconomic data (i.e. skill types of labor, sectoral and total capital stocks) and, most important for our purpose, a rich set of environmental information, including sectoral energy use by several energy carriers (fossil, non-fossil, renewables, etc.).

NACE	**WIOD industries**
AtB	Agriculture, hunting, forestry and fishing
C	Mining and quarrying
15t16	Food , beverages and tobacco
17t18	Textiles and textile products
19	Leather, leather products and footwear
20	Wood and products of wood and cork
21t22	Pulp, paper, paper products, printing and publishing
23	Coke, refined petroleum and nuclear fuel
24	Chemicals and chemical products
25	Rubber and plastics
26	Other non-metallic mineral products
27t28	Basic metals and fabricated metal products
29	Machinery nec
30t33	Electrical and optical equipment
34t35	Transport equipment
36t37	Manufacturing nec, recycling
E	Electricity, gas and water supply
F	Construction
50	Sale, maintenance and repair of motor vehicles
51	Wholesale trade and commission trade
52	Retail trade, except of motor vehicles and motorcycles
H	Hotels and restaurants
60	Inland transport
61	Water transport
62	Air transport
63	Supporting and auxiliary transport activities
64	Post and telecommunications
J	Financial intermediation
70	Real estate activities
71t74	Renting of machinery and equipment and other business activities
L	Public administration and defence,social security
M	Education
N	Health and social work
O	Other community, social and personal services

Table 1: WIOD industries and definition by NACE

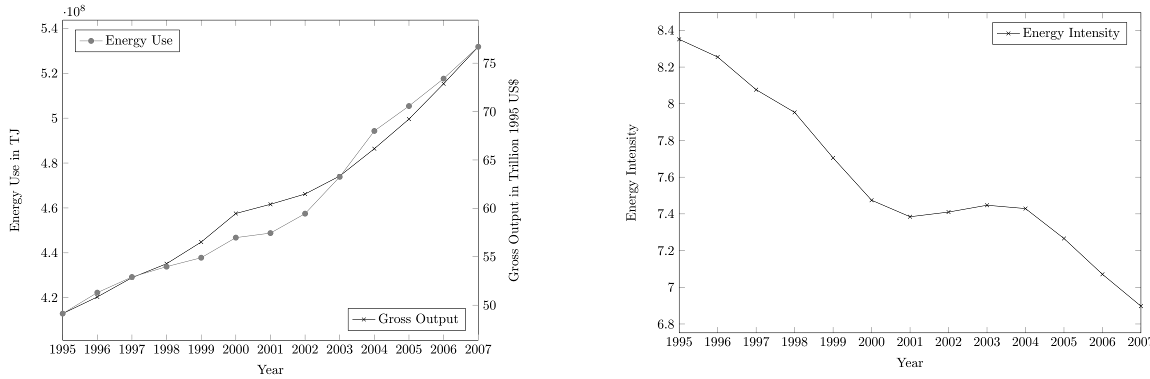
3. Energy Intensity Developments between 1995 and 2007

3.1. Aggregate Sectoral Developments

From 1995 to 2007, gross output and energy use of the 40 economies included in our sample increased by 53.2% and 27.0%, respectively (Figure 1a). Accordingly, energy intensity – computed by dividing energy use by gross output – declined by 18% (Figure 1b). Over the time period considered, we can identify two time intervals characterized by a similar reduction in energy intensity: 1995 to 2000 when energy intensity declined by 11 percentage points, and 2004 to 2007 when energy intensity declined by 7 percentage points after a relatively stable period between 2001 and 2003.

This aggregate decrease in energy intensity is the result of very heterogeneous sectoral dynamics. Figure 2 provides an overview in this respect. We calculate the energy intensity changes between the beginning and the end of the sample period for each sector in each country. Each bar in Figure 2 shows the heterogeneity of these sectoral changes across countries. The lower bound represents the 10th percentile in energy intensity changes, the upper bar represents the 90th percentile.[11] The median is marked with an empty circle while the filled square represents the energy intensity

[11]Given that our analysis covers 40 countries, the bar includes information on the 32 countries which are between the 10th and 90th percentiles.



(a) Energy Use – Gross Output

(b) Energy Intensity

Figure 1: Energy Use vs. Global Gross Output — Global Energy Intensity

change of the sector aggregated over the 40 countries in the sample.[12] Sectors are ranked in descending order based on their average energy intensity levels over the time span from 1995 to 2007. The numbers in parentheses indicate the average share of that sector in worldwide gross output and energy use over the sample period, respectively. The top two sectors – coke, refined petroleum and nuclear fuel (23) and electricity, gas and water supply (E) – lead the field by a wide margin in terms of both energy intensity and energy use.

In all sectors, the median value of efficiency change is negative, meaning that more than half of the countries experienced reductions in energy intensity over the sample period. In all but four sectors, highlighted in black in the figure, also the weighted average intensity change is below zero, ranging from a moderate -5.2% in the pulp, paper, printing and publishing (21t22) to a tremendous -62.8% in the electrical and optical equipment sector (30t33).The only sectors which saw a modest increase in average energy intensity are mining and quarrying (C), supporting and auxiliary transport activities, activities of travel agencies (63), education (M), and electricity, gas and water supply (E).

Comparing the median and the weighted average value, we can gain general insights on the country distribution with respect to energy intensity development. If the mean growth rate is above the median, this indicates that countries with a high share of gross output within the specific sector performed worse than the majority of other countries. For instance, in sectors E, 63 and M the United States accounts for the largest share of gross output as well as energy use. In all three cases, energy intensity in the US grew at a higher rate than the weighted mean, indicating a rather poor performance. Also the energy intensity of Japan, with high output and energy use shares in all three sectors, increased.

A number of sectors saw reductions in energy intensity in nearly all countries considered, as both the 10th and 90th percentiles lie below or only slightly above 0%. These include transport equipment (34t35), basic metals and fabricated metal (27t28), post and telecommunications (64), machinery (29), electrical and optical equipment (30t33), financial intermediation (J), construction (F), and chemicals and chemical products (24).

Two sectors show a particularly high heterogeneity of energy intensity improvements across countries. In wood and products of wood and cork (20) and the real estate activities (70) energy intensity decreased on average, but some outlier countries display significant declines in energy efficiency, e.g. Taiwan and Indonesia. The impact of these sectoral developments on aggregate trends shown in Figure 1 is very different. On the one hand, the wood sector bears only a small share on the aggregate output of all countries and hence has a small impact on the aggregate trends. Conversely, the real estate sector has one of the largest shares in total gross output. Furthermore, with the exception of the electricity sector (E), all industries with an energy use share higher than 5% exhibit a decline in energy intensity which might be the most important driver of the decrease in total energy intensity.

The sectors with the smallest heterogeneity across countries include post and telecommunication (64), financial intermediation (J), agriculture, hunting, forestry and fishing (AtB) and basic metals and metal products (27t28). In particular, the basic metals and metal products sector has high gross output and energy use shares. As a result, its

[12] The aggregated energy intensity change of a respective sector is calculated by adding up energy use of sector i for all countries j and dividing it by the sum over the sector's gross output in each country j, $EI_i = \sum_j EU_{ij}/GO_{ij}$. Based on this we can compute the aggregate change of energy intensity. It is hence equivalent to the mean intensity change weighted by gross output.

impact on the development of aggregate energy intensity is high. The same is true in terms of gross output for the sectors AtB and J.

Figure 3 shows 1995 and 2007 levels of energy intensity of four sectors, the two with the largest initial share of energy use (upper panel) and the two with the largest initial share of gross output (lower panel). The countries included in the figures are the top 15 countries in terms of aggregate gross output in 1995 and are presented in this order.

Looking at the performance of the electricity sector in these countries, it is obvious that the increase of aggregate energy intensity in this sector as depicted in Figure 2 is driven by the increase in the United States, as shown in Figure 3a. The intensity decline in most countries does not reflect on the weighted mean because energy intensity in the production of electricity increased by 21.5% in the United States.

In terms of contributions to both energy use and gross output of electricity production worldwide, the US has by far the highest values in the sample, representing 30% and 25% for energy use in 1995 and in 2007 and 20% and 15% of gross output in 1995 and in 2007, respectively. The second most important electricity sector is that of China for which comparable statistics in energy use are 11% in 1995 and 23% in 2007 and for gross output 3% in 1995 and 12% in 2007. While the Chinese electricity sector is still significantly smaller than the US electricity sector in 2007, its energy use share doubled over the sample period and its gross output share quadrupled, thus almost reaching the US levels by 2007. The electricity sectors of all other countries lag far behind those of the US and China in terms of their energy use shares. Large economies such as India, Japan, Germany, France and the United Kingdom have relatively stable energy use shares between 4 and 6%. One exception is the Russian electricity sector whose share declined moderately from 13% to 9% in the sample period while its gross output share remained stable at approximately 2.5%.

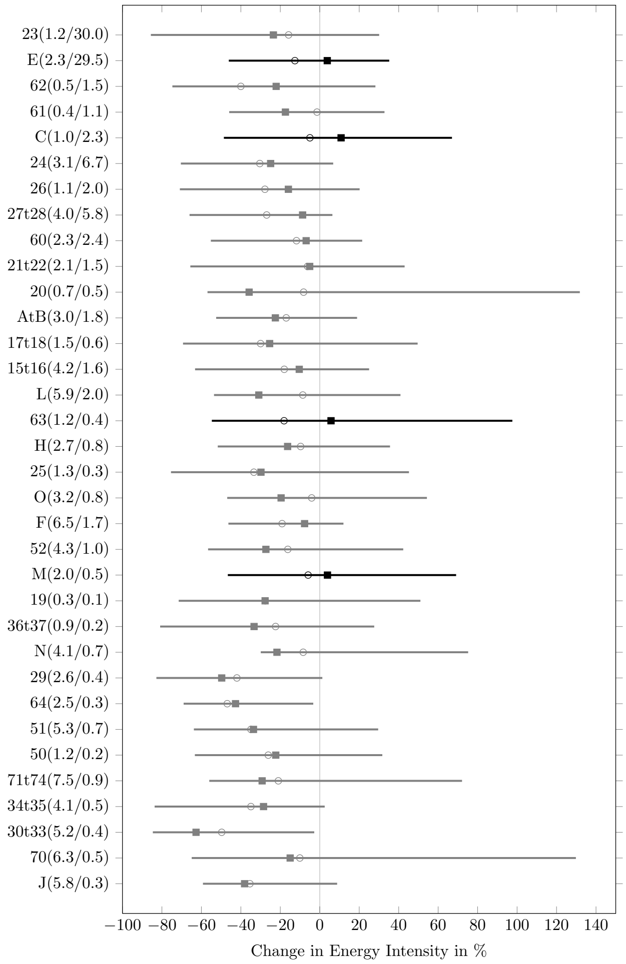
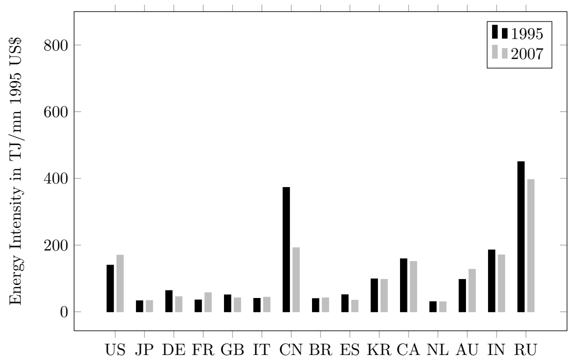
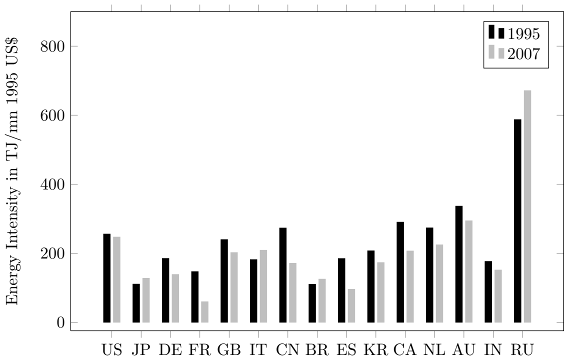


Figure 2: Sectoral development of energy intensity. For the sector definition, see Table 1. In parentheses: average share of sector in global gross output and global energy use, respectively. Empty circles represent median changes and filled squares depict output weighted mean changes in energy intensity.

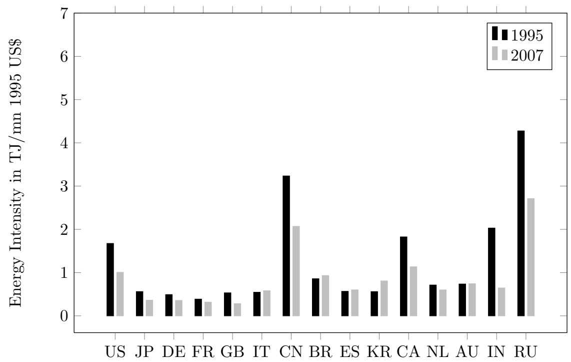
Among the top 15 countries, the least energy efficient electricity sectors both at the beginning and at the end of the sample period are those of Russia, China, the US, Canada and India. The energy intensity levels of power production in the US and Canada are far above those of comparable other developed countries such as Japan, Germany, France and the UK. By the end of the period, energy intensity in the electricity sector declined in most top countries, with the exception of the US, France and Australia. The improvements were very pronounced in China though, whose energy intensity decreased by almost 50%. Russia performs worst throughout the sample period, having by far the highest energy intensity in the production of electricity in 1995 as well as in 2007. However, its electricity sector is comparatively small and thus has a less significant impact on the "global" performance. The future development of energy efficiency in electricity at the aggregate level will be influenced to a great extent by the performance of specific countries such as Russia, China and the United States which have a high share of energy use and gross output in the sector, but are also comparatively inefficient in using energy inputs.



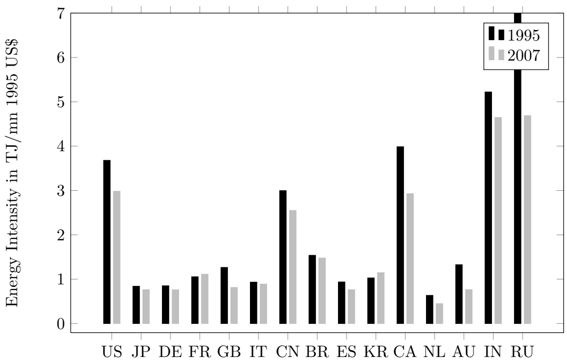
(a) Sector E – Electricity, gas and water supply



(b) Sector 23 – Coke, refined petroleum and nuclear fuel



(c) Sector 71t74 – Renting of machinery and equipment and other business activities



(d) Sector F – Construction

Figure 3: Energy intensity in 1995 and 2007 for sectors with highest energy use and gross output.[13]

The coke, refined petroleum and nuclear fuel sector (Figure 3b) shows less heterogeneity across countries than the electricity sector. Russia emerges as an outlier, with very high energy intensity levels which increase between 1995 and 2007. Both in terms of energy use and gross output, the dominance of the United States is even more pronounced in this sector than it is in the electricity sector. In 1995 the US energy use share within coke, refined petroleum and nuclear fuel was approximately 30% and remained almost constant during the period while the gross output share decreased from 25% in 1995 to 19% in 2007. With respect to both these indicators, China rose to second in rank by 2007, although still far behind the United States (13% for energy use and 12% for gross output in 2007). Furthermore, countries like Japan, India, Russia, Germany, France, the United Kingdom, South Korea, Canada and Brazil display almost equal shares of energy use and gross output (between 3 and 7% for either indicator). Most of these countries were able to improve their energy efficiency over the sample period, with the notable exceptions of Japan, Italy, Brazil and Russia. Therefore, the energy intensity decline experienced by the coke sector in most countries, in particular in the two dominant economies of China and the US, outweighed the increases in the other countries. This resulted in an overall average decrease in energy intensity.

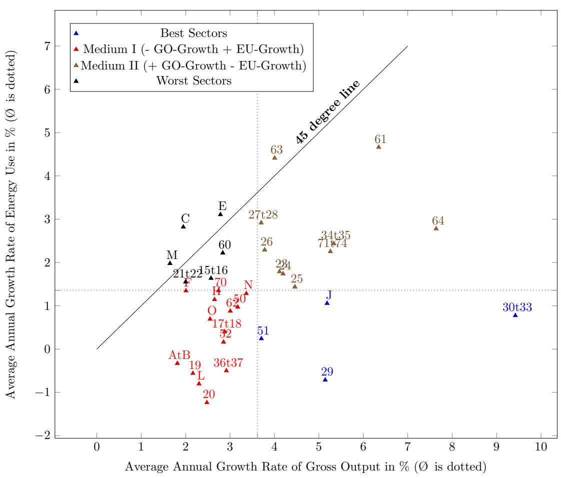
In the two sectors with the largest gross output shares – renting of machinery and equipment (Figure 3c) and construction (Figure 3d) – energy intensity levels are much lower than in the sectors E and 23. There is a certain degree of heterogeneity across countries in these sectors, with Russia, China, India, Canada and the US being significantly above the other countries' intensity levels. In both sectors, improvements took place in most countries, suggesting that energy efficiency levels are converging. In particular the renting of machinery sector exhibits relatively large energy intensity declines, especially in the US whose dominance in this sector is striking. Its gross output share is 35% while

[13] We adjusted the scale of the ordinate in Figure 3d for comparability reasons. The 1995 energy intensity level of Russia is 21.16 TJ/mn 1995 US$.

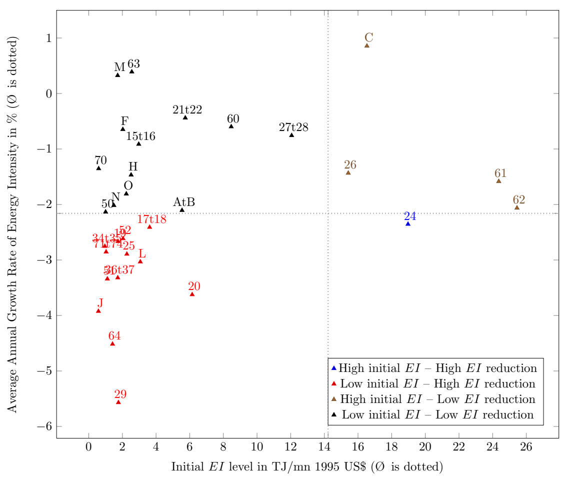
its energy use share is above 50%, both remaining almost constant over the sample period. Thus, the high energy intensity reduction rates in the US (almost 40% between 1995 and 2007) determine the quite strong performance of this sector. Also the countries ranking next in terms of gross output and energy use, i.e. Japan, France, the UK and Germany, show high energy intensity reduction rates (between 20 and 40%). Conversely, efficiency improvements are less pronounced in the construction sector. The dominating countries in this sector are the US, Japan and China whose reduction rates are lower (between 10 and 20%) than those of the dominating countries in sector 71t74. A notable exception is Russia in which intensity levels in 2007 are 78% smaller than at the beginning of the period. Concerning the energy intensity levels of different countries, the sectors with largest gross output shares perform in a similar way to those with a high energy use share. Russia, China and India show high energy intensity, but developed economies such as Canada and the United States are fairly comparable to China and India in this respect.

The aggregate sectoral analysis has shown that heterogeneity within each sector across countries is high. This suggests that there might be benefit from supporting the diffusion of efficient technologies from more frontier countries to the laggards. Technology diffusion and transfer could improve the overall performance, in particular if directed toward the biggest economies in terms of gross output and energy use shares such as China, Russia and India. However, unless advanced economies also commit to improving their energy efficiency, improvements in the overall indicators will be hard to achieve.

Figure 4a presents the relationship between the average annual growth rates of gross output and energy use for the "global" sectors. The 45 degree line identifies the sectors with equal energy use and gross output growth rates, i.e. on this line energy intensity remained constant over the time period considered. As pointed out in the analysis of Figure 2, four sectors (M, C, F, 63) exhibit growing energy intensity levels. While gross output growth rates are positive in each sector, some sectors even show a decrease in energy use – agriculture, hunting, forestry and fishing (AtB), manufacturing nec, recycling (36t37), leather products (19), machinery (29), public administration and defence (L), and wood and wood products (20). Out of these sectors, machinery is particularly worth mentioning since declining energy use is accompanied by high gross output growth rates. Furthermore, also the result for the electrical and optimal equipment sector (30t33) – very high output growth and only low energy use growth – confirms our findings from Figure 2.



(a) Correlation between growth rates of gross output and energy use



(b) Correlation between initial energy intensity levels and growth rates of energy intensity

Figure 4: Correlation between central indicators by sector

The sectors can be divided into four groups according to whether they are above or below the mean growth of gross output and energy use. The best performing sectors are found in the lower right where high gross output growth is coupled with low or negative energy use growth. The financial intermediation (J) and the wholesale trade (51) sectors also belong to this group, albeit with a lower performance than the other two sectors. Among the worst performing sectors in the upper left, where low output growth is accompanied by high energy use growth, we find energy-intensive sectors such as inland transport (60) and pulp and paper (21t22) in addition to those sectors with increasing energy intensity levels. The biggest groups are however those with a mixed performance – either low output growth and low energy use growth or vice versa.

Figure 4b shows the correlation between initial energy intensity levels (1995) and average energy intensity growth rates (between 1995 and 2007).[14] Based on several studies which examine convergence in energy intensity at the country level (e.g. Greening et al., 1998, Mulder and De Groot, 2012), we investigate whether a similar behavior can be detected for the sectoral perspective. As a matter of course, we do not expect energy-intensive sectors to approach the same intensity levels as service sectors. Nevertheless, sectors with high initial intensity levels are supposed to improve energy efficiency at a higher pace for reasons such as stronger cost saving efforts and increased regulatory measures. Although we cannot identify a clear relationship between both indicators and the hypothesis can hence not be confirmed, this graph shows two important things. First, a huge cluster of sectors is located at initial energy intensity levels below 6 TJ/mn US$ without a clearly identifiable pattern of energy intensity development. Second, two of the sectors belonging to the best performing group in Figure 4a – machinery and electrical and optical equipment – show high energy intensity reduction rates despite low initial levels. These are hence two of the best performing sectors in our sample from a global perspective. Such conclusion is interesting, especially for electrical and optical equipment which has a relatively large share in total gross output and therefore a high influence on aggregate indicators.

The analysis presented so far shows that energy efficiency improvements were achieved in most of the sample sectors. There are only a few exceptions in which energy intensity increased over time, and these include two among the most energy-intensive sectors, such as electricity (E) and mining and quarrying (C). Industries with high initial energy intensities did not improve energy efficiency at a higher pace than sectors with lower initial levels of energy intensity. Moreover, heterogeneity can be detected in many sectors with respect to the performance of different countries.

In the following subsection we present a similar descriptive analysis focusing on the country level. We then move to the decomposition analysis.

3.2. Country Level Developments

We now explore the heterogeneity of energy efficiency improvements across countries. Figure 5 shows the distribution of energy efficiency improvements for all sectors within a given country. The bars are constructed in a manner analogous to those shown in Figure 2.[15] Countries are ranked in descending order based on their average energy intensity levels between 1995 and 2007 and the numbers in parentheses indicate the average share of each country in global gross output and global energy use, respectively. Also in this case, if the weighted mean growth rate (filled square) is above the median (empty circle), this indicates that sectors with a high share of gross output within the specific country performed worse than the majority of other sectors.[16]

Similar to the sectoral analysis, we observe energy intensity reductions in most countries of our sample. The only exception in this regard is Brazil. The extent of the reductions covers a broad span, from 0.7% in Greece to almost 55% in Latvia. The picture is heterogeneous also for the economies with the highest average gross output and energy use shares, such as the US, Japan, China and Russia. Japan shows the lowest reduction rates among these countries (11.5%) whereas the emerging economies of Russia and China exhibit larger reduction rates of 39 and 48%, respectively.

As apparent from Figure 5, in general, countries with higher mean intensity are those where efficiency improvements were more significant, in line with the hypothesis that highly inefficient systems can benefit from low hanging fruits when pursuing a better use of energy inputs. Conversely, in countries which are located at the bottom of Figure 5 having a higher level of efficiency, improvements in the use of energy are smaller.

With respect to the spread of energy intensity reduction across the sectors in each country, we observe large differences. Many countries – namely Bulgaria, India, China, Latvia, Canada, Malta, and Denmark – have 90th percentiles below or slightly above zero, i.e. almost the totality of the sectors actually reduced their energy intensity

[14] We excluded the sectors electricity, gas and water supply (E) and coke, refined petroleum and nuclear fuel (23) from the figure due to their very high initial energy intensity levels. Sectors E and 23 have initial energy intensity levels of 96.7 and 208.8 TJ/mn 1995 US$ and average energy intensity growth rates of 0.31% and -2.23%, respectively.

[15] Since for each country we have information on 34 sectors, the bars effectively include information on 28 sectors.

[16] For reasons of better comparability, we cut the results for Indonesia and Luxembourg. Their 90th percentile is 415.0% and 200.6%, respectively.

levels. In various other countries the distribution across sectors is clearly dominated by negative changes in energy intensity. This observation is confirmed when looking at the median which is also negative for most economies.

Also in this case, we can compare the median with the weighted average and conclude that in countries such as Russia and India, sectors with a higher share of gross output in the whole economy performed better or worse, respectively, than the majority of other sectors.

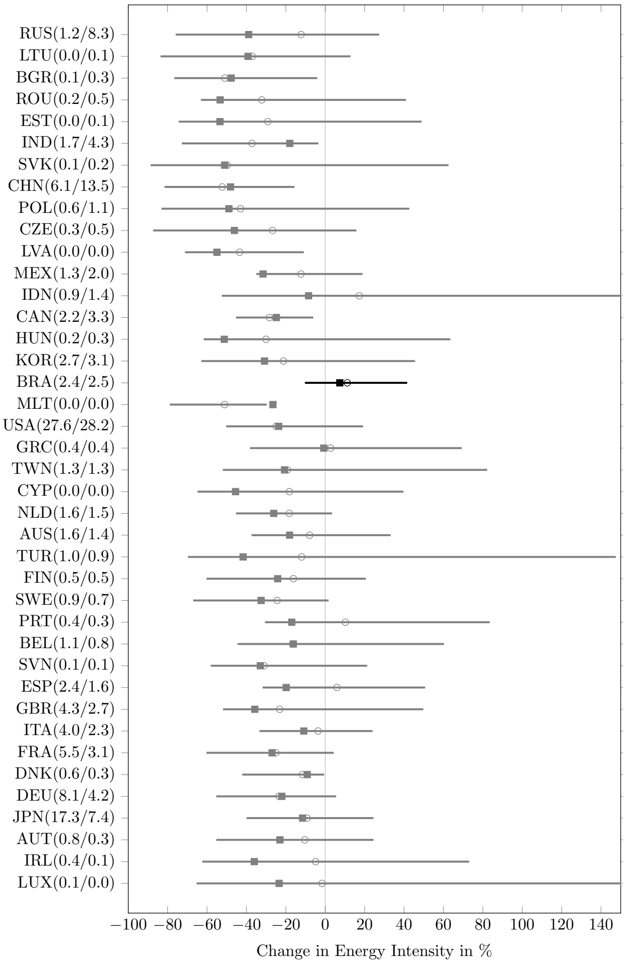


Figure 5: Country development of energy intensity. In parentheses: average share of country in global gross output and global energy use, respectively. Empty circles represent median changes and filled squares depict output weighted mean changes in energy intensity.

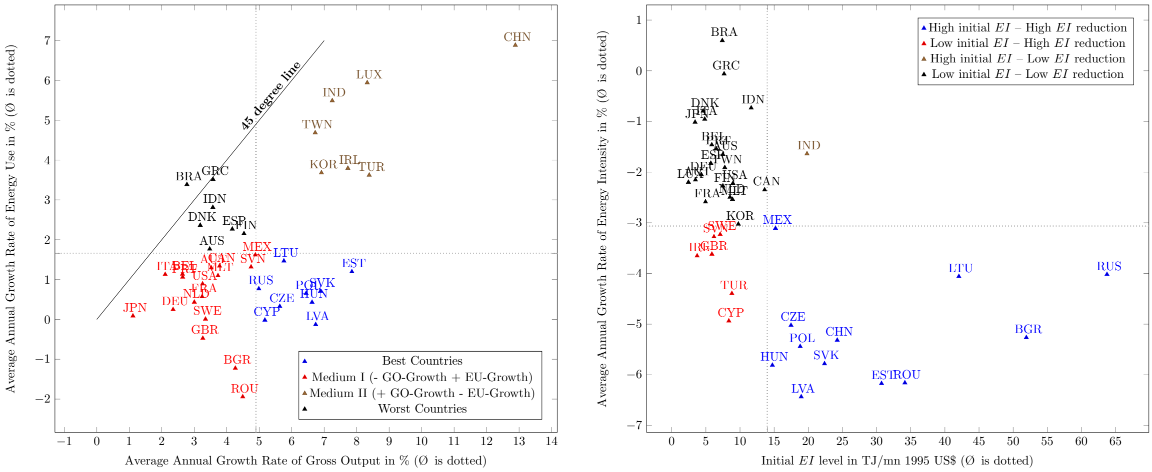
In comparison to the sectoral analysis presented in Figure 2, heterogeneity in energy intensity change is less pronounced within countries than within sectors, with the exception of Indonesia, Turkey and Luxembourg. The average difference between the 90th and the 10th percentile is 85.8 for countries (excluding the three countries mentioned) while it is 101.4 for the sectoral perspective. This indicates that conditions in a given country have a stronger influence on the development of energy efficiency than conditions in a given sector. The overall environment, be it with respect to the structural or innovative situation, seems to be an important aspect resulting in a general pattern of energy efficiency improvements in the majority of sectors of a specific country.

The correlation between the average annual growth rates of gross output and energy use is illustrated in Figure 6a. The 45 degree line identifies the countries where output and energy use grew at the same rate. The relationship is clearly positive with a correlation coefficient of 0.57, and the figure yields two interesting insights. First, in almost each country energy use grew at a lower rate than gross output resulting in significant energy intensity reductions throughout our sample as already pointed out by Figure 5. During the sample period, Brazil is the only country showing an increase in energy intensity while Greece's energy intensity remained almost constant.

Second, for some countries we even observe reductions in total energy use. This applies in particular to countries which were part of the Eastern Bloc, but also to the United Kingdom. In the former countries, this is most likely due to the economic collapse after the political changes in 1989/1990 and structural changes away from energy-intensive industries.[17] The United Kingdom, conversely, displays not only a reduction in energy use, but also relatively high growth rates of gross output. This suggests that in this country a real decoupling of economic growth from energy consumption occurred.

The countries can be grouped in three main clusters based on Figure 6a. The best performing cluster is located in the bottom right part of the chart where high output growth rates are coupled with relatively low increases in energy use. It consists mainly of Eastern European countries. A second cluster, consisting mostly of developed countries, shows low growth rates of gross output. Within this cluster, most countries also exhibit low energy use growth rates (or even declines), e.g. the United Kingdom, the Netherlands and Sweden. However, the energy use growth rate of some countries in this cluster, such as Brazil, Greece and Indonesia, is clearly above average. The third group can be found in the upper right part of the graph and includes important emerging economies, such as China, India, Taiwan and South Korea, where both output and energy use growth rates were high.

[17]Note that our observation period starts in 1995, i.e. many of these countries had already overcome the most severe period of the economic collapse.



(a) Correlation between growth rates of gross output and energy use

(b) Correlation between initial energy intensity levels and growth rates of energy intensity

Figure 6: Correlation between central indicators by country

The energy intensity performance of countries is also related to their initial efficiency levels. Convergence in energy intensity between countries has already been highlighted by previous studies, such as Greening et al. (1998) and Mulder and De Groot (2012) for OECD countries and Markandya et al. (2006) and Jakob et al. (2008) who also considered developing countries. Figure 6b shows the relationship between initial energy intensity levels and average annual growth rates of energy intensity over the period between 1995 and 2007. A negative relationship can be detected which is confirmed by a correlation coefficient of -0.54. This indicates that countries with higher initial energy intensity levels show higher reduction rates, i.e. convergence of energy intensity occurred in the considered period.[18]

More precisely, countries can be grouped by their performance relative to the average over countries along two dimensions: initial energy intensity (high/low) and energy intensity reduction (high/low). The largest groups are those with low initial energy intensity and low energy intensity reduction and high initial energy intensity and high energy intensity reduction, indicating once more a strong relationship between initial energy intensity and energy intensity reduction.

In the low/low group we mostly find developed countries with the exception of Brazil and Indonesia. In the high/high group, on the other hand, we find mostly Eastern European countries and emerging economies, such as China. India is the only member of the group with high initial energy intensity and low energy intensity reduction rates and shows surprisingly low improvements in energy intensity compared to all other countries with high initial energy intensity. Countries with low initial energy intensity (below the mean value of approximately 15 TJ/mn 1995 US$) can be further divided in those with very low energy intensity reduction or even growth (Brazil, Greece, Indonesia, Denmark, Japan, Italy), countries with medium energy efficiency improvement (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Luxembourg, Malta, Netherlands, Portugal, Spain, Taiwan, United States), and countries with a high reduction in energy intensity above the overall mean reduction rate (Cyprus, Ireland, Slovenia, South Korea, Sweden, Turkey, United Kingdom).[19]

The descriptive analysis presented in this subsection shows that in most countries energy efficiency increased over the sample period in the majority of sectors, with more inefficient countries being able to reap the low hanging fruits. This supports the theory of convergence across countries. This notwithstanding, the spread of change across domestic

[18] A complete overview of total growth between 1995 and 2007 of gross output, energy use and energy intensity as well as initial energy intensity levels for all sample countries can be found in Table A.3 in Appendix A.

[19] In a strict sense, South Korea's reduction rates are slightly below average. Due to its proximity to the latter group, we assign South Korea to these countries.

sectors is very heterogeneous. In the next sections, we describe the applied decomposition approach and decompose both the aggregate and the country energy intensity developments to show to what extent they have been due to shifts in the sectoral composition of global and country production or to the improvements of the technological component.

4. The Mean Divisia Index Decomposition of Energy Intensity

While the descriptive analysis presented so far is illustrative of the efficiency development across sectors and countries, it does not inform about the drivers behind the changes which have occurred. In this section, we use a decomposition analysis of energy intensity to shed light on these issues, both at the aggregate and the country level.

The development of energy intensity in the economy can be attributed to two different but equally relevant changes. On the one hand, energy intensity can increase or decline as a result of changes in the industrial activity composition (*structural effect*). On the other hand, overall energy intensity changes may also result from sectoral energy efficiency improvements or deteriorations (*technology effect*). The main purpose of this paper is to study the trends in energy intensity in 40 economies and disentangle in detail the contributions from structural changes in the economy, i.e. a shift to economic sectors which feature higher or lower energy intensities, respectively, as well as the effects of improvements in energy efficiency. Such a research question can be addressed using two broad categories of decomposition methodologies: approaches based on input-output analysis, called structural decomposition analysis (SDA), and disaggregation techniques which can be referred to as index decomposition analysis (IDA) and which are related to index number theory in economics.[20]

We use an index decomposition approach (IDA) as described by Ang and Zhang (2000), Ang and Liu (2001), Boyd and Roop (2004), Ang and Liu (2007) and more recently by Choi and Ang (2012) or Su and Ang (2012) for total, sectoral and national energy intensities. We focus on the structural changes that affect the supply side of the economy (productive sectors) and thus exclude the private households.

Following Ang and Zhang (2000), we rely on multiplicative decomposition and use the "logarithmic mean Divisia index" (LMDI) approach (Ang and Choi, 1997). This methodology offers very important advantages: (1) it is zero-value robust (Ang et al., 1998, p. 491) and (2) it "yields perfect decomposition" (Ang et al., 1998, p. 495), i.e. no unexplained residual exists. The latter is a considerable advantage with respect to the arithmetic mean Divisia index where the residual can be different from zero "when changes in the variables [...] are substantial", as in the case where the methodology is used in cross-country analyses (Ang and Zhang, 2000, p. 1165).[21]

Our variable of interest is total energy intensity of the economy at time t either for the global aggregate (subsection 5.1) or for the 40 countries in our sample (subsection 5.2). It is defined as a weighted average of sectoral energy intensities,

$$I_t = \sum_i \frac{GO_{i,t}}{GO_t}\frac{EU_{i,t}}{GO_{i,t}} = \sum_i S_{i,t} I_{i,t}, \tag{1}$$

with the following notation:

- period: $t \in (1995, 2007)$,
- sectors: $i = 1, \ldots, 35$,

[20] The roots of index numbers can be traced back to the French Dutot in 1738 and the Italian Carli in 1764 (Chance, 1966, Diewert, 1993). See also Diewert (1993) for a technical summary of index number theory. Boyd and Roop (2004) offer a more comprehensive review of different indices in the context of energy intensity and the index number problem in economics. The SDA and IDA are not the only approaches for analyzing energy intensity trends. Kim and Kim (2012), for instance, employ Data Envelopment Analysis (DEA) to compare international energy intensity trends. The DEA approach allows to find the countries lying on a technological frontier and to calculate the distances of other countries to this frontier. Ma and Stern (2008) summarize the main advantages and disadvantages of each approach.

[21] An alternative approach is additive decomposition. In addition, one could choose between alternative indicators, such as Paasche or Laspeyres indices. However, due to unexplained residuals during the decomposition procedure which also arise for those types of indices, we prefer the logarithmic mean Divisia index.

- energy use of the economy in period t: EU_t,
- sectoral energy use of sector i in period t: $EU_{i,t}$,
- gross output as a measure of economic activity in period t: GO_t,
- sectoral gross output of sector i in period t: $GO_{i,t}$,
- share of sector i in total gross output in period t: $S_{i,t} = \frac{GO_{i,t}}{GO_t}$,
- total energy intensity in period t: $I_t = \frac{EU_t}{GO_t}$, and
- sectoral energy intensity of sector i in period t: $I_{i,t} = \frac{EU_{i,t}}{GO_{i,t}}$.

The multiplicative decomposition of change in total energy intensity between the periods $t = 0$ and $t = T$ is then described by[22]

$$D_{Tot,T} = \frac{I_T}{I_0} = D_{Str,T} D_{Int,T}. \tag{2}$$

$D_{Str,T}$ is the estimated impact of *structural change* on total energy intensity in period T. $D_{Int,T}$ is the estimated impact of changes in the sectoral energy intensity levels in period T which can be explained by a change in the efficiency of the corresponding sector (*technology effect*). The formulae for the log mean Divisia index decomposition are

$$D_{Str,T} = \exp \sum_i \frac{L(\omega_{i,T}, \omega_{i,0})}{\sum_i L(\omega_{i,T}, \omega_{i,0})} \ln\left(\frac{S_{i,T}}{S_{i,0}}\right), \tag{3}$$

$$D_{Int,T} = \exp \sum_i \frac{L(\omega_{i,T}, \omega_{i,0})}{\sum_i L(\omega_{i,T}, \omega_{i,0})} \ln\left(\frac{I_{i,T}}{I_{i,0}}\right), \tag{4}$$

where

$$L(\omega_{i,T}, \omega_{i,0}) = \frac{\omega_{i,T} - \omega_{i,0}}{\ln(\frac{\omega_{i,0}}{\omega_{i,T}})} \tag{5}$$

is defined as the logarithmic mean, e.g. for the periods 0 and T, and serves as a weighting scheme in the index decomposition framework (Ang and Zhang, 2000) and $\omega_{i,t}$ is the country share of energy consumption, $\omega_{i,t} = \frac{EU_{i,t}}{EU_t}$.

The rest of this paper compares the development of the structural change component $D_{Str,t}$ and the technology effect $D_{Int,t}$ over time across sectors and countries. By looking at these two variables, we assess their relative weights on energy efficiency improvements. Following the analysis of the global trends, we compare those to specific country trends to highlight region and sector specific dynamics.

5. Decomposition of Energy Intensity: Aggregate and Country Level Results

5.1. Aggregate Energy Intensity Decomposition

Figure 7 summarizes the results of the global index decomposition which highlights the contribution of the technology and the structural effect on aggregate energy intensity changes. The results are presented such that the 1995 levels of total energy intensity and its components are normalized to 1, according to equations (2) to (4). The figure thus shows the corresponding levels of the components relative to the respective 1995 value. A decrease in the structural component testifies a shift of the economy toward less energy-intensive sectors and vice versa. On the other hand, a decrease in the technology component indicates a declining energy intensity within the sectors of the economy. While both effects result in lower energy intensity at the aggregate level, a reduction in the technology component is, from a long term perspective, more desirable than changes in the structure of the economy toward less energy-intensive sectors. Improvements in technologies, which determine decreases in the technology component, are much less easily reversible than structural changes. Moreover, it is replicable also in other economies and sectors through, for instance, better use of production inputs or the diffusion of more advanced production technologies.

[22] In our case, $t = 0$ serves as the starting period, i.e. the year 1995.

The overall decline in aggregate energy intensity observed between 1995 and 2007 is the result of the interplay of technological change and structural composition of the world economy. However, the decomposition highlights that the decline in aggregate energy intensity over the complete time horizon considered is mainly attributable to the technology effect. While the decrease of the structural component between 1995 and 1999 shows a shift toward less energy-intensive sectors, since then this indicator has remained rather stable around the same values. The index for the structural effect was in fact approximately the same in 1999 and 2007. Conversely, the technological component went from 1 in 1995 to 0.86 in 2007. The most rapid decline in the technology effect has been observed between 2003 and 2007 (an annual reduction rate of 2.3% as opposed to 1.5% between 1995 and 2001).

In more detail, we observe four phases with respect to total energy intensity decline. In the first phase, between 1995 and 1999, the decrease in aggregate energy intensity is basically composed of a shift toward less energy-intensive sectors and an improvement in energy intensities although both effects are relatively small in absolute terms. In the second phase, between 1999 and 2001, both effects move into opposite directions showing a slight switch to energy-intensive industries but an even stronger decrease of the technology effect. The technology index declines fast enough to ensure a further drop in aggregate energy intensity. In the third subperiod from 2001 to 2003, both components reverse their previous directions, i.e. the structural effect declines to a value lower than in 1999 whereas the technology index increases relatively strongly. As a result, aggregate energy intensity rises slightly. The year 2003 is noticeable for two reasons. First, the structural effect rose again as it did after a period of decline starting from 1997. With current data availability, it is however impossible to judge if the structural component will fluctuate back to the same values, basically mirroring the changes in the period between 1999 and 2003 or whether it will increase significantly. Second, after 2003 the technology effect decreased sharply compensating the increase in energy intensity due to the structural effect so that aggregate energy intensity dropped substantially to a value of 0.82 in 2007.

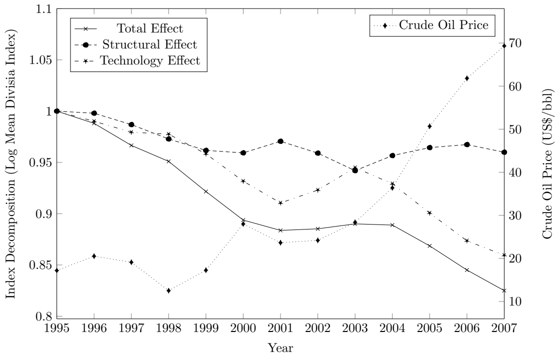


Figure 7: LMDI decomposition of global energy intensity and crude oil price

The dotted black line in Figure 7 shows the development of the crude oil price during the considered period. Before 1998, the oil price was rather stable. Since 1998, we see two major increases: the first from 1998 up to 2000, after which the oil price dropped again slightly. Conversely, the period between 2002 and 2007 was characterized by a steady increase in the oil price. In light of the oil price dynamics, the results of the decomposition suggest that increases in energy prices were accompanied by the adoption of better technologies. Also the structure of the economy initially responded to these dynamics, shifting away from energy-intensive sectors. However, as previously noticed, the structural component was rather stable after 1999, while the technology component continued to decrease.

5.2. Country Level Decomposition

The aggregate decomposition of the world economy provided in the previous subsection highlights how the structural component of the economy has been rather stable since 2000. In contrast, the technology component kept decreasing in our sample. In the following, the decomposition exercise will be carried out at the country level. The comparison of the aggregate and country level analysis is useful because GHG emissions are an issue that needs to be tackled at the aggregate level. Understanding the aggregate effects of the energy use and energy efficiency shifts occurring in major economies is helpful to provide a global picture of where the world is headed in terms of structural composition and aggregate efficiency. However, decisions regarding energy use, efficiency and climate challenges rest within each country. The aggregate trends presented in the previous subsection are likely the result of very heterogenous country performances in terms of structural and technology component. The country-level decomposition presented below allows to compare the aggregate trends to each single country's performance.

Table 2 reports descriptive statistics for the total, the structural and technology effects emerging from the country level decomposition. While the mean of the total effect is below 1.00 during the entire period, the mean for the structural effect decreased only slightly by 11% in contrast to a 17% mean decline in the technology effect. The indicators thus suggest that the contribution from the technology effect was in general higher, in particular toward

Year	Mean	Std. Dev.	Min	Max
Total Effect				
1995	1.00	0.00	1.00	1.00
1996	0.99	0.05	0.90	1.13
1997	0.97	0.07	0.86	1.13
1998	0.96	0.10	0.74	1.18
1999	0.91	0.11	0.72	1.19
2000	0.86	0.12	0.62	1.13
2001	0.86	0.13	0.59	1.15
2002	0.84	0.13	0.54	1.13
2003	0.84	0.14	0.57	1.12
2004	0.81	0.14	0.53	1.12
2005	0.78	0.14	0.48	1.10
2006	0.74	0.15	0.42	1.09
2007	0.70	0.15	0.45	1.07
Structural Effect				
1995	1.00	0.00	1.00	1.00
1996	1.01	0.05	0.94	1.16
1997	0.99	0.08	0.81	1.20
1998	0.95	0.11	0.65	1.23
1999	0.94	0.14	0.64	1.28
2000	0.95	0.18	0.57	1.48
2001	0.94	0.18	0.49	1.37
2002	0.94	0.21	0.45	1.63
2003	0.92	0.20	0.45	1.48
2004	0.91	0.19	0.44	1.58
2005	0.91	0.22	0.43	1.70
2006	0.91	0.25	0.43	1.94
2007	0.89	0.26	0.42	1.87
Technology Effect				
1995	1.00	0.00	1.00	1.00
1996	0.99	0.06	0.79	1.12
1997	0.99	0.08	0.76	1.29
1998	1.02	0.13	0.70	1.50
1999	0.97	0.12	0.66	1.40
2000	0.92	0.15	0.56	1.43
2001	0.93	0.16	0.55	1.51
2002	0.92	0.16	0.55	1.41
2003	0.93	0.16	0.54	1.39
2004	0.91	0.17	0.51	1.38
2005	0.89	0.18	0.48	1.30
2006	0.85	0.18	0.43	1.17
2007	0.83	0.19	0.35	1.16

Table 2: Descriptive results for the country-specific IDA

the end of the considered period. The standard deviations for the structural effect are, especially in the later years, much higher than the standard deviations of the total effect and the technology effect, depicting a large heterogeneity in terms of individual structural change effects. The span between the maximum and minimum in 2007 is 0.62 for the total effect, 0.81 for the technology effect and 1.45 for the structural effect, also indicating the large heterogeneity in terms of patterns of structural change.

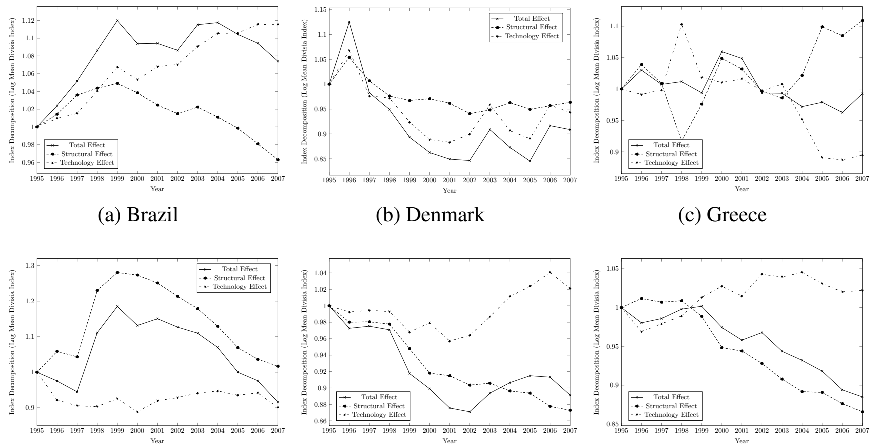
The remainder of this section analyzes the country level dynamics in terms of structural and technology effect. Countries are presented along the categories highlighted by Figure 6b.

5.2.1. IDA for Countries with Low Initial Energy Intensity and Very Low Energy Intensity Reduction

Although Brazil, Greece, Indonesia, Denmark, Japan and Italy share similar initial characteristics, these countries are very heterogeneous (see Figure 8) and the reasons behind the similar trends in energy intensity can also be expected to be quite different. In Brazil, a worsening in the technology effect drove up the general trend for energy intensity. After 2000, Brazil behaved similarly to Italy and Japan. Despite the structural adjustment toward less energy-intensive industries, the technology effect increased constantly. In Indonesia the structural effect has shaped the overall trend of energy intensity, which peaked between 1999 and 2000 and declined thereafter. The development of the total effect is almost congruent to the structural effect whereby the technology effect decreased only slightly. In Denmark both effects went in the direction of decreasing energy intensity, but at a moderate pace. Greece does not show a clear trend until 2003 when the technology effect dropped and the structural effect rose, compensating one another.

5.2.2. IDA for Countries with Low Initial Energy Intensity and Low Energy Intensity Reduction

Countries with low initial energy intensity and low energy intensity reduction are shown in Figure 9. They include mainly Western European countries as well as the North American economies and Australia. Although energy intensity is characterized by decreasing patterns, the reduction is moderate. This could be due to their mature status as an



(a) Brazil (b) Denmark (c) Greece

(d) Indonesia (e) Italy (f) Japan

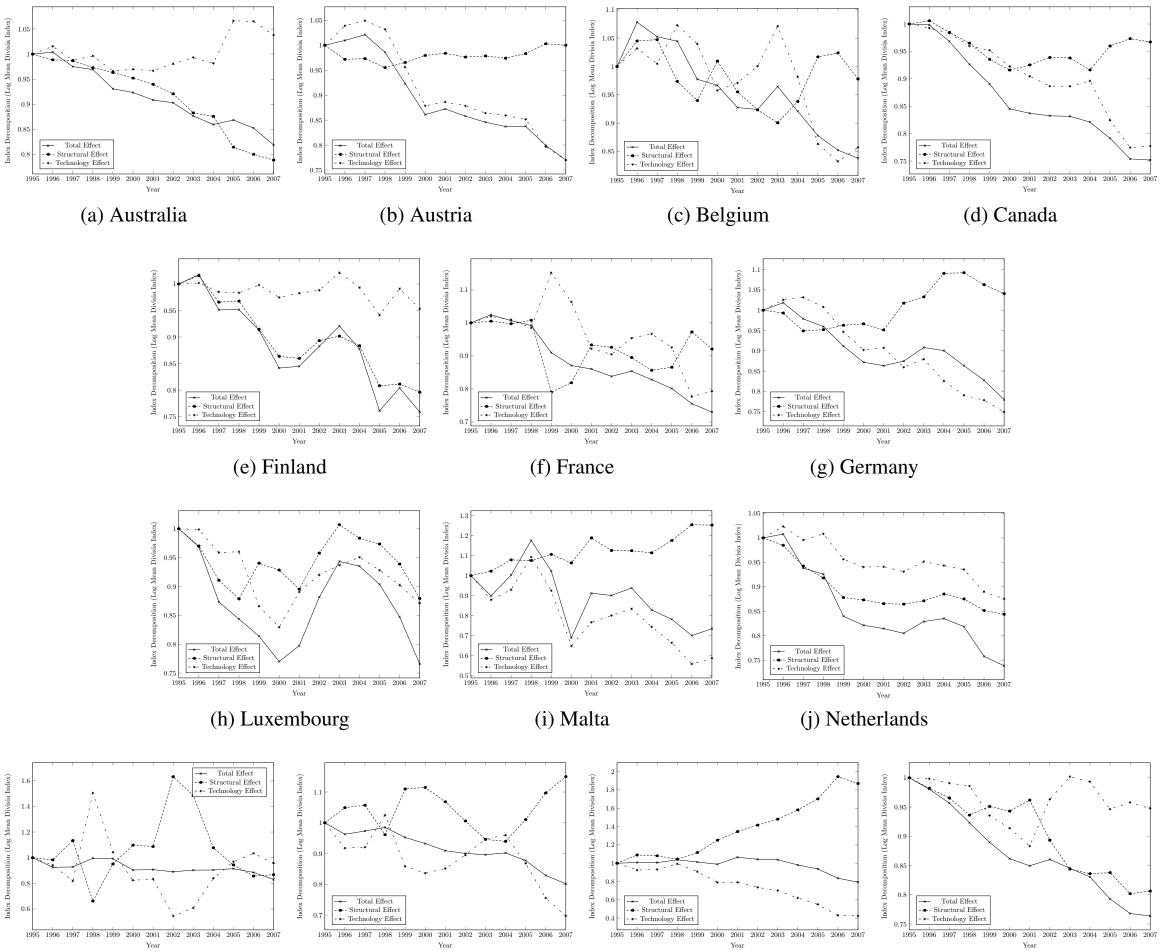
Figure 8: IDA for countries with low initial energy intensity and very low energy intensity reduction (less than 1% annually)

economy which is reflected in lower output growth rates and lower initial levels of energy intensity. However, even within this group heterogeneity is high and a common pattern does not emerge. For example, Finland, Australia and the United States reduced energy intensity mostly through structural adjustment while technology improvements were very mild. The structural effect declined by approximately 20% in all three countries, while the technology effect fell by only 5% in Finland and the US and even increased by 4% in Australia throughout the sample period. In contrast, Canada, Austria, Germany, Spain and Taiwan shifted their economies toward a more energy-intensive production, especially after 2000, but this process was accompanied by a cleaning-up in those industries, represented by the decline of the technology index. Mendiluce et al. (2010) compared the evolution of energy intensity of Spain with 15 other European countries (including Portugal, Italy and Greece). We can confirm their finding that Spain's energy intensity had its last peak in 2004. Thereafter, it declined, mainly due to the technology effect which sharply dropped. We can also confirm the findings of Mendiluce et al. (2010) for Portugal, Italy and Greece (the latter two belonging to the group with very low energy intensity reduction outlined in subsection 5.2.1): energy intensity remained almost unaltered. In (relative) comparison to other regions, particularly in Europe, Southern European countries performed worse between 1995 and 2007.

The United States exhibits a reduction by approximately 20 to 25% over the 13 years considered. This corresponds to annual reduction rates between 1.74% and 3.84%. The result is in line with other studies for the United States. For example, Huntington (2010) estimated an annual reduction of 2.3% between 1972 and 2006. Metcalf (2008) obtained a decline of 27% over 19 years between 1985 and 2004. The structural decomposition shows that this decline rests on different pillars. Overall, the largest fraction of the energy intensity decline in the United States is based on structural change while the technology effect shows only a slight decrease compared to the structural effect. In particular, between 1999 and 2001, reductions in the total effect can be attributed to decreases in the technology effect whereas in the periods before 1999 and after 2001, total energy efficiency improvements are mainly due to the shift toward less energy-intensive industries. After 2001, the technology effect showed a sharp increase from which it hardly recovered until 2007. This result for the US confirms what previous studies found. Greening et al. (1998) and more recently Sue Wing (2008) highlighted the role of changes in the industry mix. Sue Wing (2008) also suggested that the structural effect tends to follow the trend of oil prices. Our results confirm this finding for both the structural effect and overall energy intensity when looking at the crude oil price development as depicted in Figure 7.

5.2.3. IDA for Countries with Low Initial Energy Intensity and High Energy Intensity Reduction

The results for the respective countries are presented in Figure 10. High reduction rates in energy intensity are driven by both efficiency improvements as well as structural changes toward less dirty industries. This pattern is –



(a) Australia (b) Austria (c) Belgium (d) Canada

(e) Finland (f) France (g) Germany

(h) Luxembourg (i) Malta (j) Netherlands

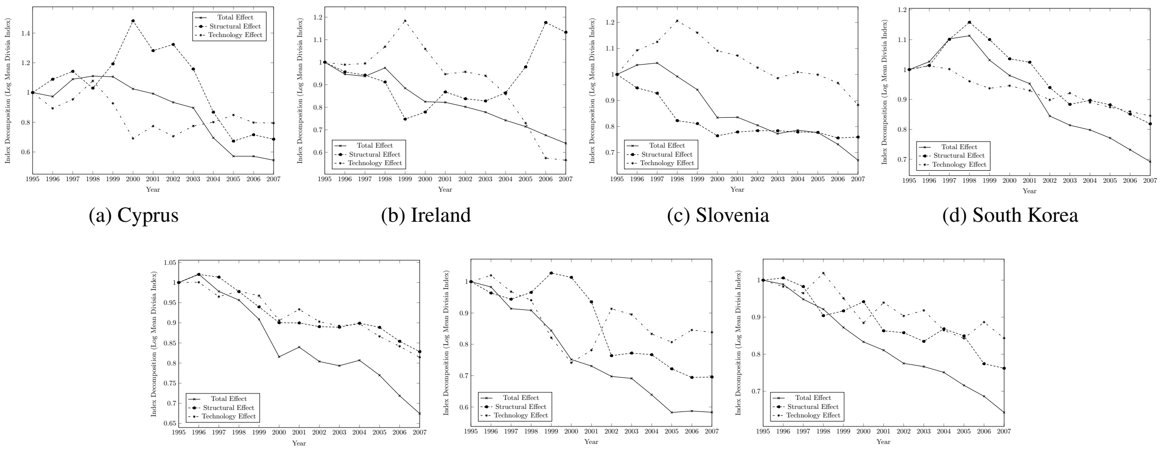
(k) Portugal (l) Spain (m) Taiwan (n) United States

Figure 9: IDA for countries with low initial energy intensity and low energy intensity reduction (between 1% and 3% annually)

to different degrees – common to all countries in this group, at least after 1999/2000. Only Ireland shows some sort of structural break in 2005. Since that date the economy moved toward energy-intensive sectors but the very rapid decline in the technology effect succeeded to bring down the overall energy intensity by about 30%.

5.2.4. IDA for Countries with High Initial Energy Intensity

Since only one country, namely India, belongs to the group with high initial energy intensity and low energy intensity reduction, we merge both groups with high initial energy intensity levels. The results are shown in Figure 11. A tremendous share of this group consists of Eastern European countries (Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, and Slovakia). These economies experienced the largest structural change as also shown by other recent studies (Mulder and De Groot, 2012). Cornillie and Fankhauser (2004) found a decoupling of energy use and economic activity in the Baltic states (Estonia, Latvia and Lithuania) between 1992 and 1998. We can confirm this trend for Latvia and Estonia, although not for Lithuania (notable declines in Lithuania's energy intensity occur mainly after 2003). But while Latvia's improvement in terms of energy intensity was mostly due to an improved technology, the clean-up in Estonia was driven by a changing structure toward less energy-intensive production. Our results are in line with Balezentisa et al. (2011) who offer a detailed discussion of the policy measures that affected the positive development in Lithuania, notably the investments in the modernization of buildings. Another



(a) Cyprus (b) Ireland (c) Slovenia (d) South Korea

(e) Sweden (f) Turkey (g) United Kingdom

Figure 10: IDA for countries with low initial energy intensity and high energy intensity reduction (more than 3% annually)

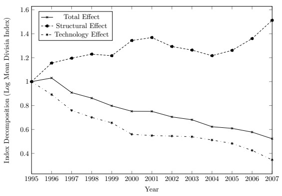
example for a positive development is Poland. As Gurgul and Lach (2012) note, in the recent decade the economic growth of Poland was linked to changes of electricity utilization and the Polish industry has adopted new, more energy-efficient technologies in order to face a number of international environmental requirements. Romania and especially Bulgaria also experienced a dramatic improvement in terms of energy efficiency. Popovici (2011) summarized the development, noting that "[t]he Romanian economy was in 1990 one of the most energy-intensive in the region – only Bulgaria's economy was more energy-intensive – due to the obsolete technologies [...] that were energy-intensive and had to import an increasing part of their raw materials. Due to the closure, technology upgrading and restructuring in the heavy industries, Romania is nowadays much less energy intensive" (Popovici, 2011, p. 1845). In China, the decline can be attributed almost entirely to the technology effect which is nearly congruent with the total effect while the structural change remains more or less constant, as found also in Fisher-Vanden et al. (2004). The result for China confirms what most studies found (Wu, 2012, Ma and Stern, 2008, Fisher-Vanden et al., 2004, Zhang, 2003). Previous studies highlighted the dramatic decline observed until 2000 while afterwards energy intensity has remained constant or slightly increased. Our results confirm this slowdown of the reduction between 2000 and 2004. Since then, energy intensity begun to decline again, driven by the technology effect. This is in contrast to an increasing energy intensity between 1998 and 2006 that was found by Zhao et al. (2010). A pattern similar to that of China applies to India, albeit to a smaller extent and lagged by several years, i.e. sharp declines occur after 2000.

In Russia, on the other hand, while both effects decrease over the period, the main driver of this decline is structural change. Nevertheless, we observe a relative reduction in energy intensity which is nearly as high as that of China. Also Mexico shows a relatively strong decline in total energy intensity which is – as in the case of the United States – principally driven by a reduction in the structural effect.

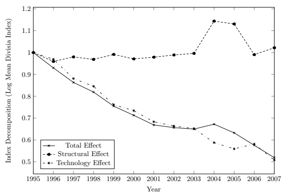
6. Conclusion

This paper analyzed energy intensity trends for 40 major economies between 1995 and 2007. It contributes to the large literature in energy index decomposition analysis in several ways. First, it employs a novel socio-economic database consistently accompanied by environmental satellite accounts to construct measures of energy intensity for 34 sectors. Based on this harmonized dataset, a comprehensive compendium of energy intensity time series has been computed.

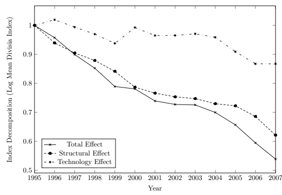
Second, we were able to show that heterogeneity in each sector across countries is high. This trend is dominated by large economies, mainly the United States and China. On the other hand, all but one country experienced overall energy efficiency improvements which is driven by intensity declines in the large sectors of the specific economies.



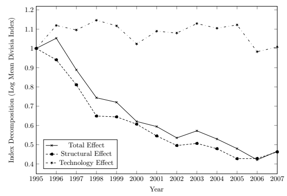
(a) Bulgaria



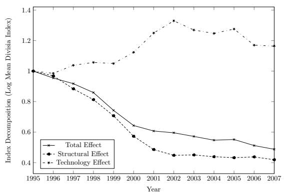
(b) China



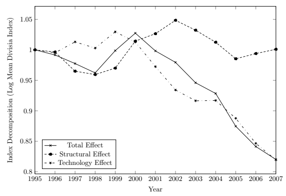
(c) Czech Republic



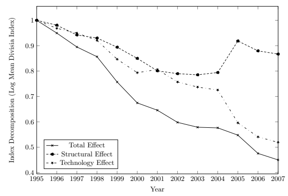
(d) Estonia



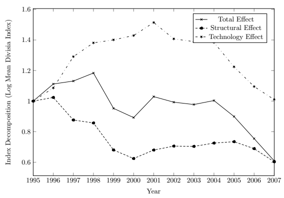
(e) Hungary



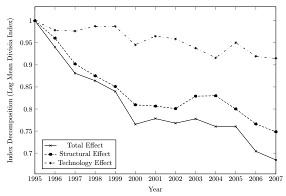
(f) India



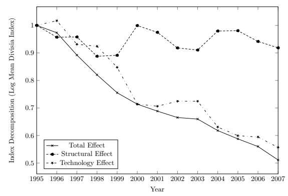
(g) Latvia



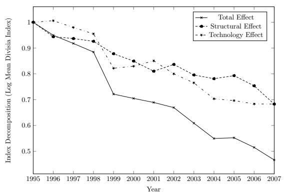
(h) Lithuania



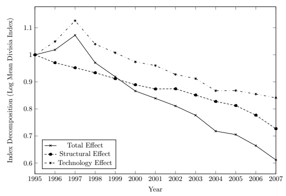
(i) Mexico



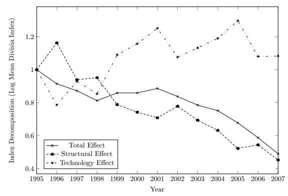
(j) Poland



(k) Romania



(l) Russia



(m) Slovakia

Figure 11: IDA for countries with high initial energy intensity

Third, it decomposes energy intensities into structural and technology effects in order to examine what share of temporal variation is due to actual changes in energy efficiency and is thus replicable, and what share is based merely on structural changes of the economy. We find that countries can be grouped in four main clusters and that initial levels of energy intensity correlate with country grouping in terms of energy intensity performance. Countries that in 1995 had a high energy intensity of the economy are characterized by relatively high energy intensity reduction rates. Despite the regional variations, the general result is that in these countries both the technology and structural indexes improved over the time horizon considered. Countries that in 1995 had a low energy intensity of the economy took different pathways. A group of countries have reduced energy intensity by less than 10% between 1995 and 2007, mostly because of a stagnation in the technology effect. Most countries however have shown medium reduction rates, between 10 and 30%. In this case, the drivers are country-specific and it is more difficult to identify a general tendency. Finally, a few countries improved energy efficiency significantly, further below the already low initial levels in 1995. In this case, both the structural and technology effects work in the direction of a less energy-intensive economy.

The aggregate and country-level decompositions of energy intensity we presented in this paper suggest very different conclusions. At the global level, a high portion of energy intensity declines is driven by the technology effect, suggesting a general move towards more efficient means of production. Conversely, our country-level analysis shows that the heterogeneity across countries is high and that a common pattern cannot be easily singled out. Countries' performances in terms of the structural and technology component differ independently of the economy's level of development or initial level of energy efficiency. Among the different economies in our sample, some large countries where the role of the technology component was high include, among others, Canada, Germany, France, Spain, China, India and Poland. Arguably, efficiency improvements in these countries will be long lasting, as these economies rely on more efficient production methods. Energy efficiency improvements of countries such as the US, Japan and Italy are on the contrary due to a shift towards less intensive production sectors, and might be reversed in the future more easily.

Our analysis suggests some interesting directions for future research. A first step would be to explore the determinants of the country's heterogeneity in performance, in order to isolate those factors that can promote technological change and thus bring about long lasting improvements in energy efficiency. Finally, a case study analysis of those countries where the impact of the technology effect was significant is clearly worthwhile.

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Appendix A. Descriptive Statistics

Country	*GO* Growth '95-'07	*EU* Growth '95-'07	*EI* Growth '95-'07	'95 *EI* Level
Australia	50.7	23.4	-18.1	7.5
Austria	51.5	16.7	-23.0	3.5
Belgium	36.7	14.6	-16.2	5.9
Brazil	38.9	49.1	7.4	7.4
Bulgaria	65.1	-13.7	-47.7	51.9
Canada	56.1	17.3	-24.8	13.6
China	328.1	122.3	-48.1	24.2
Cyprus	83.2	-0.2	-45.5	8.4
Czech Republic	93.0	4.0	-46.1	17.5
Denmark	45.7	32.4	-9.1	4.6
Estonia	147.7	15.4	-53.4	30.7
Finland	70.2	29.1	-24.1	7.5
France	46.7	7.1	-27.0	4.9
Germany	32.1	3.0	-22.0	4.4
Greece	52.5	51.4	-0.7	7.7
Hungary	116.0	5.3	-51.2	14.7
India	131.6	89.9	-18.0	19.8
Indonesia	52.4	39.5	-8.5	11.6
Ireland	144.4	56.4	-36.0	3.7
Italy	28.4	14.4	-10.9	4.8
Japan	14.2	1.1	-11.5	3.4
Latvia	118.7	-1.5	-55.0	19.0
Lithuania	95.8	19.1	-39.2	42.0
Luxembourg	161.0	99.9	-23.4	2.4
Malta	55.2	14.0	-26.5	8.9
Mexico	77.1	21.3	-31.5	15.2
Netherlands	42.6	5.3	-26.1	8.5
Poland	111.6	8.1	-48.9	18.8
Portugal	36.8	13.5	-17.0	6.5
Romania	69.5	-21.0	-53.4	34.1
Russia	79.3	9.6	-38.9	63.7
Slovakia	122.3	8.8	-51.1	22.4
Slovenia	74.5	17.0	-32.9	6.2
South Korea	123.1	54.3	-30.8	9.8
Spain	63.3	30.9	-19.8	5.7
Sweden	48.4	0.1	-32.6	7.1
Taiwan	118.3	73.2	-20.7	7.8
Turkey	162.8	53.3	-41.7	8.8
United Kingdom	47.0	-5.5	-35.7	5.9
United States	46.9	12.2	-23.6	9.0

Note: *GO* - gross output. *EU* - energy use. *EI* - energy intensity. Growth values in %. Energy intensity levels in TJ/mn 1995 US$.

Table A.3: Growth rates and levels of central indicators

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