TRADE AND THE ENVIRONMENT ANALYZING AGGREGATE, NATIONAL AND SECTORAL ENERGY INTENSITY IN THE EUROPEAN UNION

An Application of the WIOD Database

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Abstract

One of the most promising measures to meet targets set by climate policy is the improvement of energy efficiency, i.e. using scarce and polluting resources less extensively to produce a certain amount of output. In this study we will employ the WIOD database, a harmonized and consistent dataset consisting of timeseries of input-output tables and accompanying environmental satellite and socioeconomic accounts in order to carry out an interesting empirical exercise which consists of two parts: In a first step, we will present a very aggregated picture of EU27 energy intensity and its development between 1995 and 2009. Then, we will dig deeper and introduce sectoral detail in order to see composition differences for the same timeperiod. Subsequently, we will disaggregate the EU27 block into its consisting countries to see regional differences. The final step will be to introduce also a sectoral disaggregation for the individual countries to give a fine-grained picture of the energy-intensity development in Europe. The second part uses the obtained results from the index decomposition by using panel estimations in a similar way like Metcalf (2008) for the United States. By doing so, we want to control for potentially influential factors of the development in the European Union. In particular, we investigate the impact of technological change, structural change, trade, environmental regulation and country specific characteristics.

Keywords: Environmental and Climate Economics, Energy Intensity, Structural Decomposition
JEL-Classification: Q0, Q50

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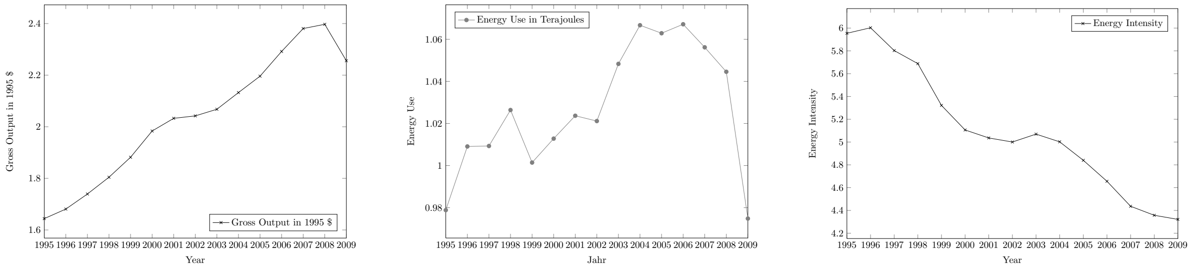
I. INTRODUCTION

THE IMPROVEMENT OF ENERGY EFFICIENCY is one of the most promising measures to meet emission targets set exogenously by climate policy. Beside this effect, it may also help to reduce the dependence on fossil fuels as well as it can foster the competitiveness of industries (Ang et al. , 2010). In this paper, we will introduce and employ the new WIOD Database in order to tell an interesting story about the development of the energy intensity in Europe between 1995 and 2009. As the graphs in this introduction show, the gross output of the aggregate EU 27 has increased by 37.2 % (1a) and the total energy use even decreased by 0.4 % (1b) between 1995 and 2009. In combination this has resulted in a steady decline of energy intensity by 27.4 %[1](1c).



(a) Gross Output (b) Energy Use (c) Resulting Energy Intensity

Figure 1: Gross Output, Energy Use and Energy Intensity in the EU27 1995-2009

While these three figures tell everything, they tell nothing. Is this decline in energy intensity due to a shift in the composition of the aggregated European economy from energy-intensive production towards less energy-intensive production? Or are there more fundamental improvements with respect to energy utilization responsible for the decline? How did individual countries perform in the period? What are the main economic or political drivers? This paper deals with the decomposition of this cleanup and separates the contribution of structural changes (*composition effects*), the effects of efficiency improvements (*technology effects*) and their regional and sectoral patterns (*spatial effects*) by relying on the commonly used approach of index decomposition analysis. The questions asked some lines above are of fundamental importance: If such a cleanup came simply from a changing composition combined with increasing imports of energy-intensive goods from outer-Europe, the development of the energy intensity in Europe would not be replicable in other, less developed regions.[2] But if the decrease in energy-intensity was due to an increased efficiency, this development would be replicable in other regions in the world (maybe even easier due to technology transfers, spillover effects, economies of scale or learning-by-doing). As Wolfram et al. (2012) argue, energy consumption in OECD and non-OECD countries was almost equal in 2007, "but from 2007 to 2035, it [the U.S. En-

[1] The WIOD database takes into account the effects of the financial crisis and its impact on Gross Output and Energy Use: Gross Output declined by 5.9 % and Energy Use by 6.2 % between 2008 and 2009. Energy Use even declined below the level of 1995.

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

ergy 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). To investigate whether the European clean-up is potentially replicable is, against this background, of tremendous importance. To anticipate the major finding of this paper, a substantial fraction of the decrease of energy intensity can be attributed to different facets of technological change and therefore it is replicable in currently less developed countries.

In our analysis we consider Europe for various reasons: First, the European Union regards itself as a leading actor in international climate policy, and as improving energy efficiency is a central pillar of Europe's strategy, we want to investigate the development in this particular region. Second, the data we are using for our analysis allows us to split the sample into three parts. The first part is "before climate policy" between 1995 and 2001, the second part is the "EU ETS Phase 1 + 2" and the third phase is between 2007 and 2009 and makes it possible to investigate the impacts of the financial crisis and the accompanying peak in oil prices in 2008 ($\approx 150\,\mathrm{US}-\$$ per barrel) on technical efficiency in energy use.[3] Finally, and most important, the European integration process is an outstanding example for structural change. While other studies focussed mainly on e.g. the impacts of NAFTA on trade and structural change in the United States, we consider large structural shifts causing enormous opening to international trade. Grossman and Krueger (1991) analyze the impact of the NAFTA free trade agreement on pollution, whereas others look at samples of countries where also structural changes are present but no large differences in the development of e.g. openness across countries have happened (see Antweiler et al. (2001); Cole and Elliott (2003); Cole (2006) or Managi et al. (2009)). Cornillie and Fankhauser (2004) investigated the development of energy intensities for these economies under transition, but their time-frame was 1992 to 1998 and therefore very short. Furthermore, it was the period when the structural break has happened. We also investigate the results of this transition process.

Our analysis consists of two interrelated parts and is organized as follows. In the first part we describe the different data sources we have used and then we present an index decomposition analysis of the energy intensity in Europe between 1995 and 2009. We show measures for the EU 27 aggregate and individual countries with additional sectoral disaggregation. Our analysis reveals the large heterogeneity within Europe. While some countries experienced a clean-up due to structural change, most countries have benefited from technology improvements. However, most studies stop at this point and have a rather descriptive character. One exemption is Metcalf (2008), who investigated the development of U.S. energy intensity on aggregate and state level between 1970 and 2001. He also used an index decomposition framework, but added an econometric analysis to investigate the main economic drivers. In the second part of the paper, we build on Metcalfs work and extend his approach in order to investigate the European economy. By doing so, we can identify causalities that would be unable to be found by an index decomposition framework.

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[3] Additionally, the time-series character of our data allows us to investigate changes. Alcantara and Duarte (2004) for example, use a structural decomposition analysis to investigate the energy intensities in 14 European countries and 15 sectors. However, the authors offer the analysis only for 1995.

We construct several variables which are potential drivers of the different effects, such as an estimate for total factor productivity, trade openness, income per capita, environmental regulation, energy prices and country specific characteristics. Subsequently we present the result of our empirical exercise and discuss the robustness. Finally, we draw some conclusions in section V..

II. DATA ISSUES

A. THE WIOD DATABASE

In the analysis we have employed the World Input-Output Database (WIOD)[4], a consistent and very comprehensive dataset that allows us to compare the development of particular environmental indicators such as energy intensity over the period of time covered by the database (1995 to 2009). The WIOD database has been constructed on the base of national accounts data and harmonization procedures were applied in order to ensure international comparability of the basic data. The dataset covers 40 main countries (27 EU countries and 13 other major countries) which together account for $\approx 80-85\%$ of world's GDP in 2006. The data is disaggregated in 36 industries (agriculture, manufacturing and services). It offers annual data which ranges from 1995 to 2009. Beside the broad country coverage, the sectoral disaggregation and the time period character the dataset has another main important feature: it contains several consistent satellite accounts with the same sectoral classification as the core dataset. The satellite accounts consist of bilateral trade data, socioeconomic data (different skill types of labor, sectoral and total capital stocks, etc.) and, most important for this analysis, it offers a rich set of environmental information. The environmental satellites cover the following data: energy use broke down by several energy carriers (fossil, non-fossil, renewables, etc.), emissions of greenhouse gases $(\mathrm{CO_2}, \mathrm{N_2O}, \mathrm{CH_4})$, air pollutants relevant for acidification $(\mathrm{SO_2}, \mathrm{N_OX}, \mathrm{CH_4})$ and tropospheric ozone information $(\mathrm{N_OX}, \mathrm{NMVOC}, \mathrm{CH_4})$.

B. USED DATA

In this subsection we want to describe the data we have used for both parts of the paper. To perform the index decomposition analysis and the empirical study in a later part of the paper we have used the following information from the WIOD database for all 27 current European Union countries: the Social-Accounts Files (*SEA*) and the Energy Use Files (Gross (*EU*)). The other data sources are the *Penn World Tables* (Mark 7.0), the *CIA World Fact Book* and *the International Energy Agency* and the *Barro and Lee* data on educational attainment. A complete list of the regions and sectors covered by this analysis is given in Appendix A and the summary statistics in Appendix 6. The variable names appear in parentheses.

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[4] The WIOD database and all satellite accounts are available at http://www.wiod.org. We use data from February 2012 in this paper.

Energy Use Data

Energy is measured in physical units (TJ) and is aggregated across 26 energy carriers (*EU*). The sectoral classification of energy use is exactly congruent to the socio-economic data we have used from the WIOD database.

Socio-Economic Data

The variables that we need for our index decomposition analysis are defined for time t and measured on an annual basis. (Sectoral) output is expressed in monetary units in basic prices of 1995 and converted to Mio. US-$ (1995) using the supplied exchange rates. One advantage of the WIOD database is the availability of sectoral price deflators such that different price developments can be taken into account, not only on a national, but also on a sectoral level. The measure of sectoral economic activity is gross output (*GO*). We have used hours worked by employees as a measure of labor input (*H_ EMPE*). Data on three types of labor quality is also included (low-skilled (*LAB_ HS*), medium-skilled (*LAB_ MS*) and high-skilled (*LAB HS*). One major advantage of the WIOD database is the capital stock variable. It is generally hard to obtain (physical) capital stock data from official data sources. WIOD offers for physical capital stocks and gross fixed capital formation for each country, sector and year (*K_ GFCF* and *GFCF*). We used this information to construct capital-to-labor ratios (*KL*) and to take capital vintaging into account (*VINTAGING*). We have also used the information on bilateral trade flows to capture the effect of structural change (*OPENESS*).

Other Data

Beside the WIOD database we have also used the *Penn World Tables* (Mark 7.0) to obtain information about real GDP per capita (variable *rgdpch*), the population (*pop*), real openness of a country as defined by the sum of imports and exports divided through GDP (*openk*), real investment (*ki*) and real government consumption (*kg*) as a fraction of GDP (Heston et al. , 2011). The information about the geographical country characteristics, like e.g. the latitude, was obtained from the *CIA World Fact Book*. Information on environmental regulation has been collected from the International Energy Agency and we have constructed an index for the extent and stringency of environmental regulation.[5] Furthermore we have used the Barro and Lee database Barro and Lee (2010) on educational attainment and Psacharopoulos and Patrinos (2004) for estimated social Mincearian returns on education to construct our measure for human capital. Energy prices (*PRICE*) and heating degree days (*HDD*) were collected from Eurostat.

III. INDEX DECOMPOSITION RESULTS

A. INDEX DECOMPOSITION ANALYSIS

In general, there are two broad categories of decomposition methodologies: approaches based on input–output analysis, called structural decomposition analysis (SDA), and dis-

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[5] We thank Enrica de Cian, Elena Verdolini and Sebastian Voigt for providing us with their data on environmental regulation.

aggregation techniques which can be referred to as index decomposition analysis (IDA) and which are related to index number theory in economics.[6]. Ma and Stern (2008) summarizes the main advantages and disadvantages of each approach. The main advantage of the SDA appraoch is the consideration of direct and indirect demand effect through it's methodological structure.[7] However, we use the IDA model and, therefore, energy consumption and the resulting energy intensity refers to direct energy consumption without considering indirect effects. In the following, we will focus on a standard index decomposition approach (IDA) as described e.g. in Ang and Zhang (2000), Boyd and Roop (2004), Ang and Liu (2007) and more recently in Choi and Ang (2012) or Su and Ang (2012) to total, sectoral and national energy intensities. There are several possible ways to decompose indicators. A first possible differentiation of the used methodology is the one between multiplicative and additive decomposition. We will focus on the multiplicative decomposition. Beside the distinction between additive and multiplicative decomposition, it is possible to distinguish between different indicator types (e.g. Paasche-, Laspeyres- or Divisia indices). Following Ang and Zhang (2000) we calculate our decomposition by means of the "Log mean Divisia Index" Ang and Zhang (2000, p. 1157-1160)). It offers very important advantages as it is zero-value robust (Ang and Liu (2007)) and also able to "yield a perfect decomposition" (Ang and Zhang (2000, p. 1169)), which means that there remains no residual term unexplained. Additionally it has the advantage compared to the arithmetic mean Divisia index, that the residual for the arithmetic mean method can be different to zero when the changes in a particular period are substantial, as it is in our case where we use the IDA for cross-country analysis (Ang and Zhang (2000)).

The first step in order to establish a formula for our decomposition analysis is to calculate aggregate energy intensity by summing up the sectoral data:

$$I_t = \sum_i S_{i,t} I_{i,t} \tag{III.1}$$

$$E_t = \sum_i S_{i,t} EI_{i,t} \tag{III.2}$$

The multiplicative decomposition then can be described by the following formula:

$$D_{EI,Tot} = D_{EI,Str} D_{EI,Int} \tag{III.3}$$

$D_{EI,Str}$ is the estimated impacts of *structural change* on the aggregate energy and carbon intensities. $D_{EI,Int}$ is the estimated impacts of changes in the carbon intensity which can partly be explained by a change in the efficiency of the corresponding sector (*technology*

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[6] 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 review of different indices in the context of energy intensity and the index number problem in economics.

[7] For an exemplary application of the SDA approach on Chinese carbon emissions see e.g. Zhang and Qi (2011).

effect). The formulas for the Log mean Divisia index decomposition are then:

$$D_{Str} = \exp \sum_i \frac{L(\omega_{i,T},\omega_{i,0})}{\sum_i L(\omega_{i,T},\omega_{i,0})} \ln\left(\frac{S_{i,T}}{S_{i,0}}\right) \tag{III.4}$$

$$D_{Int} = \exp \sum_i \frac{L(\omega_{i,T},\omega_{i,0})}{\sum_i L(\omega_{i,T},\omega_{i,0})} \ln\left(\frac{I_{i,T}}{I_{i,0}}\right) \tag{III.5}$$

where

$$L(\omega_{i,2006},\omega_{i,2005}) = \frac{\omega_{i,2006} - \omega_{i,2005}}{\ln(\frac{\omega_{i,2005}}{\omega_{i,2006}})} \tag{III.6}$$

stands for the logarithmic mean, e.g. for the years 2006 and 2005.

In the following subsections we will present the decomposition results for the whole EU27 region and how the individual sectoral energy intensity developed between 1995 and 2009. In a next step, we disaggregate the EU27-block into its consisting parts in order to identify regional differences. Most studies of energy intensities stop at this point and have a rather descriptive character. One exception is Metcalf (2008), who has investigated the development of U.S. energy intensity on aggregate and state level between 1970 and 2001. Metcalf added an econometric analysis to investigate the main economic drivers. In the second part of our empirical exercise, we apply and extend his approach to the European economy. By doing so, we can identify empirically causalities that are unable to be found by an index decomposition framework.

B. THE EU27-AGGREGATE: INTRODUCING SECTORS

As we have mentioned in the introduction, the aggregate picture of the European energy intensity tells everything and nothing. What fraction of the 28.9 % decline in aggregate energy intensity is due to *structural effects*, i.e. a shift in the composition of the economy and how much does *technology* account for the aggregate result? To answer this question for the European Union, we have aggregated the economic and environmental data for the individual countries to an "artificial" EU27 block[8], representing the whole European economy consisting of 35 sectors. For the analysis, we have excluded private households, since we are more interested in structural change than in changes in final demand. We emphasize our inclusion of agriculture and services, since we interpret strucutrual change not only within the manufacturing block of an economy, but on a larger scale affecting the whole composition of the economy.

Figure 2 and table **??** summarize the results of the index decomposition for the EU27-aggregate. The index for total energy intensity is declining since 1996 and dropped by 0.24 (24 %) until 2009. The development for the structural effect is very different. While the structure of the aggregated EU27 economy shifted towards less energy-intensive sectors from 1995 to 1999, there was a trend in the opposite direction from 1999 on. The index for the structural effect increased from 0.93 in 1999 to 1.10 in 2009, i.e. the energy-intensive sectors gained weight by 18 %. As the figure indicates, the decline in aggregate energy intensity was mainly due to the technology effect. While the index remain almost constant in the period from 1995 to 1998, it then decreased substantially to a value of 0.69 in 2009.

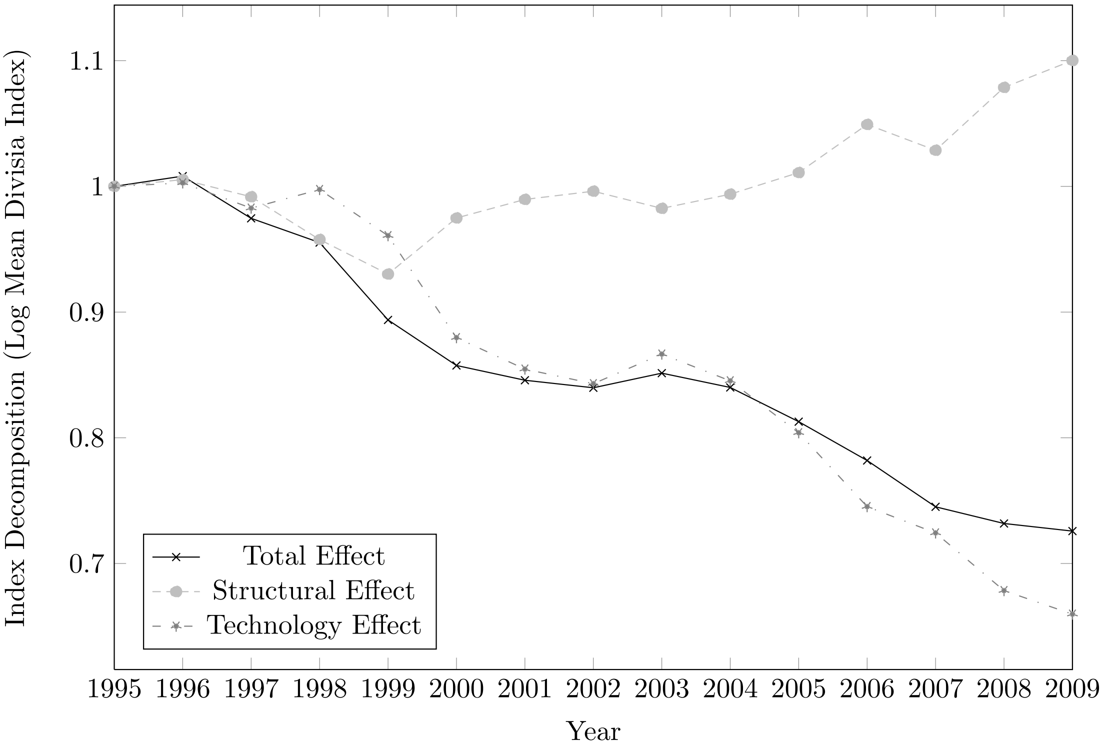

Figure 2: Log Mean Divisia Index Decomposition of Energy Intensity

Figure 9 depicts the different sectoral developments of energy intensity between 1995 and 2009. While some sectors expired a negative development, as e.g. the wood and cork production ("Sector 20"), with an increase in energy intensity by 33 %, the most sectors experienced a decrease. This decrease ranges from moderate -3.8 % in the inland transport sector ("60") to tremendous -56.1 % in the coke, refined petroleum and nuclear fuel sector ("23"), which is a correlate of the energy sector.

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[8] It is "artificial" due to the fact that the former Socialist countries joined EU27 at a later point of time than 1995.

C. DECOMPOSING THE EU27-AGGREGATE: COUNTRIES AND SECTORS

As we could show in the previous section, the inclusion of sectors added a lot of explanatory power to the analysis. In this section, we disaggregate the EU27 into its consisting countries.

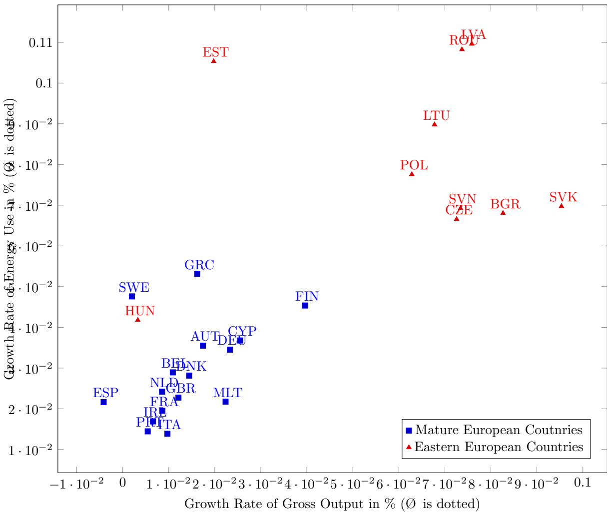


Figure 3: GO- and EU-Growth

Figure 3 illustrates two stylized facts. It presents the development of Gross Output and the change in Energy Use (both in %). We have performed the index decomposition analysis for all countries and present the results by different regional country groups as e.g. Cornillie and Fankhauser (2004). We keep ourselves brief, since most graphs tell their own tale. However, we address peculiarities in several countries and refer the interested reader to the work of other authors, dealing with that perticualar country in more detail. Our regional classification is the following:

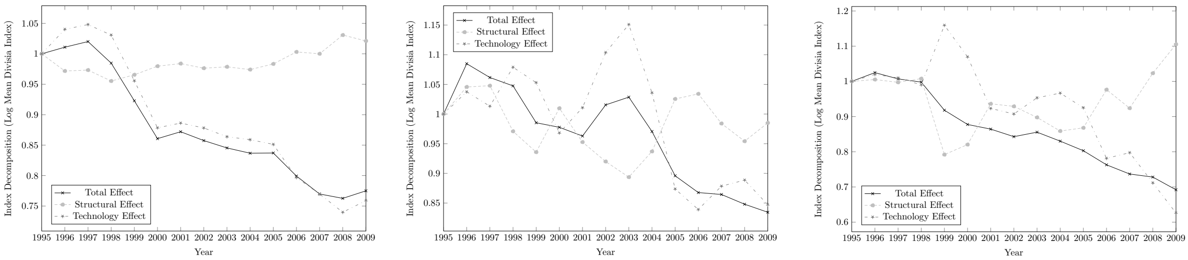
- Central Europe: Austria, Belgium, France, Germany, Luxembourg, Netherlands
- Northern Europe: Denmark, Finland, Ireland, United Kingdom, Sweden
- Southern Europe: Cyprus, Greece, Italy, Malta, Portugal, Spain
- Eastern Europe: Bulgaria, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Slovakia, Slovenia

Central Europe

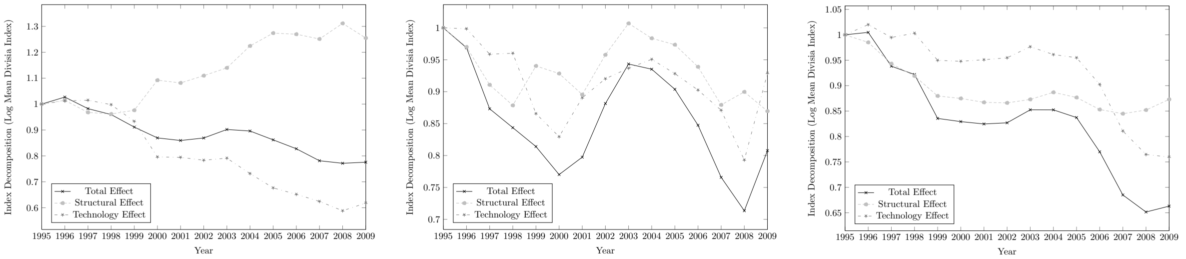
The central European block consists of Austria, Belgium, France, Germany, Luxembourg and the Netherlands. All countries are characterized by a high level of income per capita. France and the Netherlands show a continuous decline in overall energy intensity but while the economy in France shifted towards a more energy-intensive production, the composition in the Netherlands remained almost unaltered. Also the German economy changed towards more energy-intensive production, with an increase of the structural change index of + 25.5 %. However, this effect is dominated by the clean-up in the industries, represented by a decline of the technology index by almost 40 %.

Northern Europe

Northern Europe consists of Denmark, Finland, Ireland, the United Kingdom and Sweden. Although energy intensity is characterized by decreasing patterns in all countries, the decrease is rather moderate. Especially the Scandinavian countries show only a very modest decline of the technology index, which is due to their mature status as an economy.

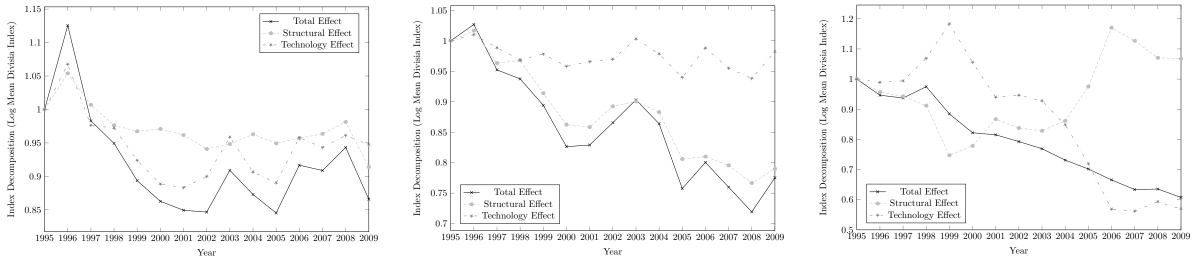


(a) Austria (b) Belgium (c) France

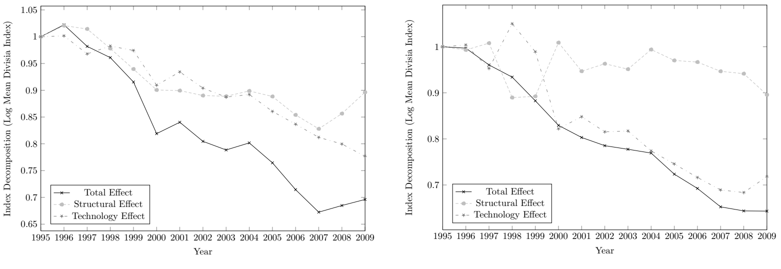


(d) Germany (e) Luxembourg (f) Netherlands

Figure 4: IDA for the Central European Block



(a) Denmark (b) Finland (c) Ireland

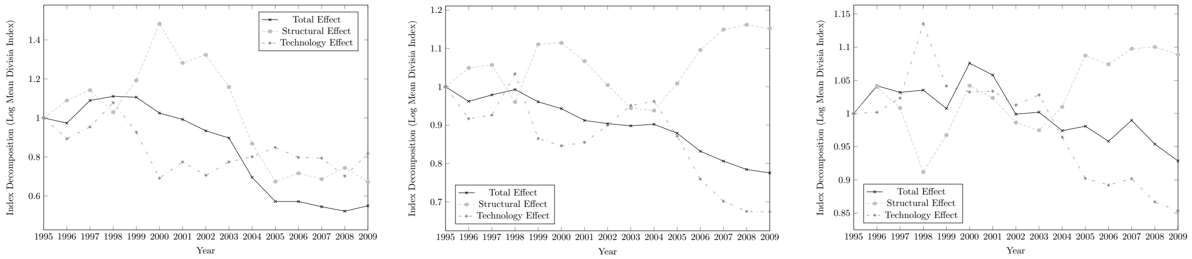


(d) Sweden (e) United Kingdom

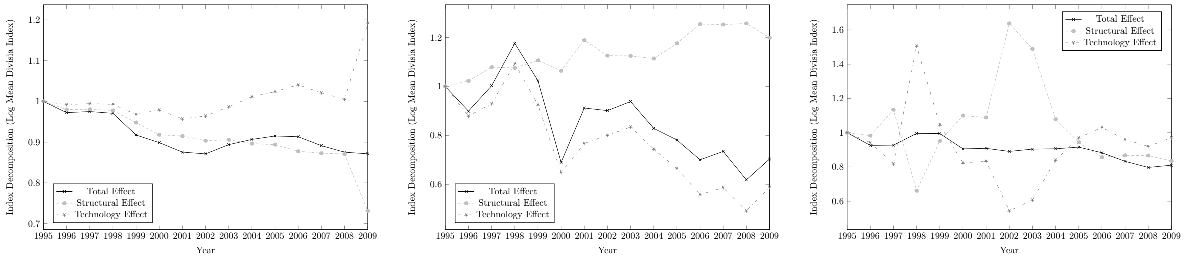
Figure 5: IDA for the Northern European Block

Southern Europe

The Southern European Block consists of Cyprus, Spain, Greece, Italy, Malta and Portugal. Those are countries with a moderate or low level of per-capita income. 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 the energy intensity reached the highest level in 2004 for Spain. Thereafter, it declined, mainly due to the technology effect which sharply dropped. We can also confirm the findings of Mendiluce et al. (2010) for the other southern European countries: energy intensity remained almost unaltered, with the exception of Cyprus.



(a) Cyprus (b) Spain (c) Greece

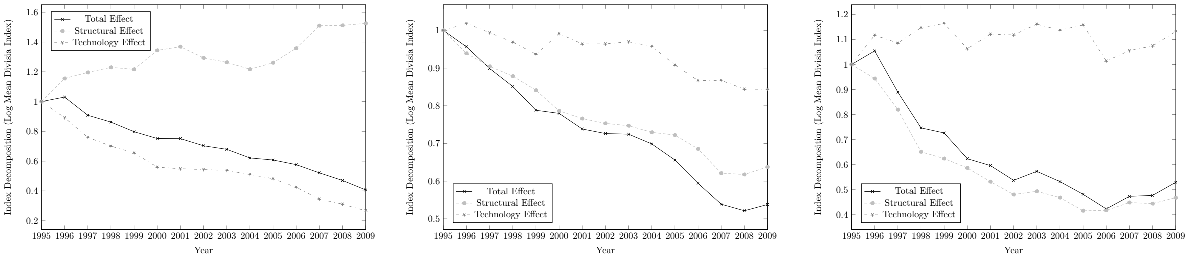


(d) Italy (e) Malta (f) Portugal

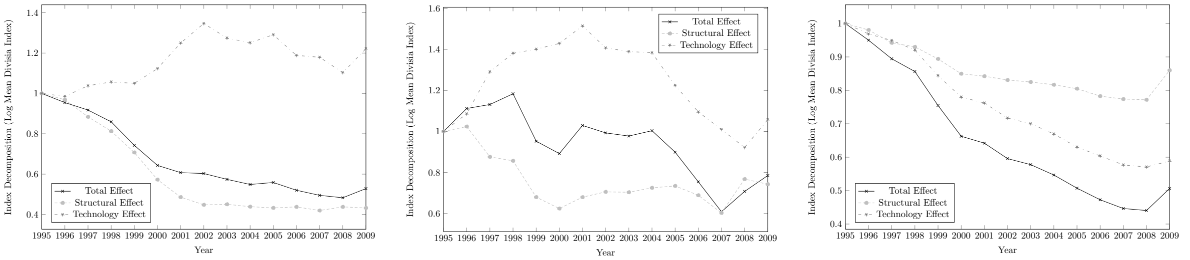
Figure 6: IDA for the Southern European Block

Eastern Europe

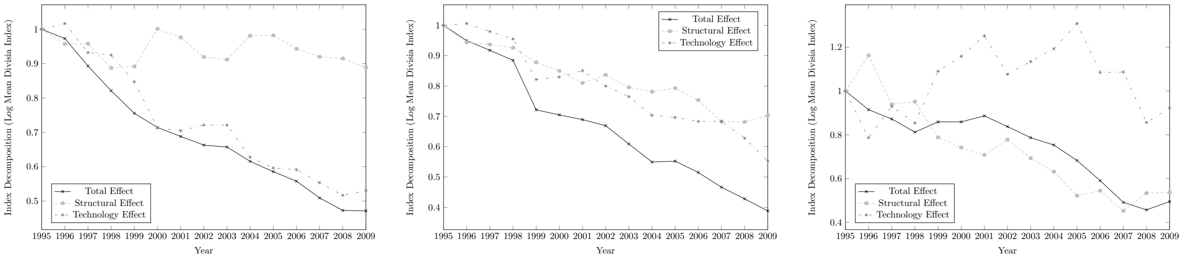
The Eastern European countries are Bulgaria, the Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Slovakia and Slovenia. This is the most interesting group of countries, since it experienced the largest structural change in our sample. Cornillie and Fankhauser (2004) found a decoupling 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. But while Latvia's improvement in terms of energy intensity was due to an improved technology, the clean up in Estonia was driven by a changing structure towards 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 example for a positive development is Poland. As Gurgul and Lach (2012) note, the recent decade the economic growth of Poland was linked by changes of electricity utilization and that the Polish industry has adopted new, more energy-efficient technologies in order to face a number of international environmental requirements. Romania and Bulgaria have 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).



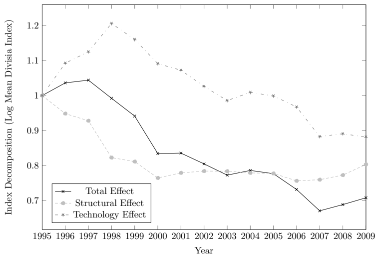
(a) Bulgaria (b) Czech Republic (c) Estonia



(d) Hungary (e) Lithuania (f) Latvia



(g) Poland (h) Romania (i) Slovakia



(j) Slovenia

Figure 7: IDA for the Eastern European Block

D. SUMMARY

To summarize the first part of the paper, we have employed the WIOD database in order to depict the development of an aggregate European energy intensity between 1995 and 2009. Therefore, we have constructed an "artificial" EU27 aggregate. Subsequently, we have introduced sectoral detail and employed an index decomposition analysis in order to quantify the contribution of structural change and technological improvements to the decline of the European energy intensity by 27.4 %. Then we have disaggregated the artificial EU27 to the individual countries and applied the index decomposition framework to the 27 individual economies. Although being very illustrative until now, the analysis is more descriptive. To analyze possible explanatory factors, we set up an empirical analysis in the following second part of the paper. We use the obtained values for the three indices and create a panel-data set for all 27 countries and 15 years in order to carry out an empirical investigation of the observed energy intensity trends.

IV. EMPIRICAL INVESTIGATION

A. MODEL AND VARIABLES

First, we estimate three similar panel models j with the type of the index as the dependent variables ($j \in (D_{Tot}, D_{Str}, D_{Int})$). As our indices measure the real decline in energy intensity, the fraction which is due to structural change and the contribution of technology, we want to control for potentially influential factors. Our estimation model is characterized by the following equation:

$$\begin{aligned}\text{Index}_{jit} = {} & \beta_0 + \\ & + \beta_1 \cdot \text{TFP}_{it} + \beta_2 \cdot \text{OPEN}_{it} + \beta_3 \cdot \text{K/L}_{it} + \beta_4 \cdot \text{INCOME}_{it} + \beta_5 \cdot \text{INCOMESQR}_{it} + \\ & + \beta_6 \cdot \text{LATITUDE}_{it} + \beta_7 \cdot \text{COMMUNIST}_{it} + \beta_9 \cdot \text{ENERGYPRICE}_{it} + \\ & + \beta_{10} \cdot \text{REGUL}_{it} + \beta_{11} \cdot \text{AREA}_{it} + \beta_{12} \cdot \text{HDD}_{it} + \beta_{13} \cdot \text{TREND} + \\ & + \gamma_i \\ & \text{with } j \in (D_{Tot}, D_{Str}, D_{Int})\end{aligned} \tag{IV.7}$$

The variables are:

- TFP = Estimated Total Factor Productivity
- OPEN = Instrumented Trade Share (Frankel and Romer (1999))
- K/L = Capital to Labor Ratio (**?**)
- INCOME = Instrumented Income per Capita (Frankel and Rose (2005))
- INCOMESQR = Income per Capita Squared
- LATITUDE = Latitude of the Country
- HDD = Heating Degree Days

- COMMUNIST = Dummy = 1 if country was former communist
- ENERGYPRICE = Price of Energy
- REGUL =
- TREND = Control variable for time trend

Before we will present our results, we will discuss and justify the variables. Our model consists of 10 variables (and a control for a time trend) which can be attributed to the different effects.

Total Factor Productivity

The first variable is the estimated *total factor productivity* (TFP). Syverson (2011) reports in his survey, that even within the United States (and there within four-digit SIC industries), the (average) difference in logarithmic multi-factor productivity between an industry's 90^{th} and 10^{th} percentile plants is $.651$ what results in a TFP ratio of $e^{.651} = 1.92$. That means, that even within a single four-digit SIC industry in one country the 90^{th} percentile of the productivity distribution produces almost twice as much output with the same inputs as the 10^{th} percentile plant. Comin et al. (2006) investigate direct measures of technology adoption for more than 75 different technologies and demonstrate that the cross-country differences in technology are roughly four times larger than cross-country differences in income per capita and that technology is positively correlated to income per capita. Thus, cross-country variation in TFP is, almost solely, determined by the cross-country variation in physical technology. As the European Union is a much more heterogenous economic environment than the United States, we argue that differences in multi factor productivity growth are (a) substantial for itself and (b) have a substantial impact for energy utilization. We rely on a standard measure for gross output based TFP as presented in Hsieh and Klenow (2010).[9] Level accounting can be interpreted as the cousin of the traditional growth accounting as introduced by Solow (1957). Comparison studies of e.g. labor productivity often used the United States as the technology leader and compared the distance of other countries to this world technology frontier. As we are interested in the technological development of energy use, we use the country with the second-lowest aggregate energy intensity in 1995 as the reference country (we have decided to choose Austria instead of Luxembourg, the selection is, however, arbitrary). To estimate the multi factor productivity we use information on Gross Output and Capital-to-Output ratio from WIOD. We assume a share of capital of 0.3. To control for human capital, we combine these data with the updated Barro and Lee dataset on educational attainment and information on Mincerian returns on eduction provided by Psacharopoulos and Patrinos (2004).[10]. Our

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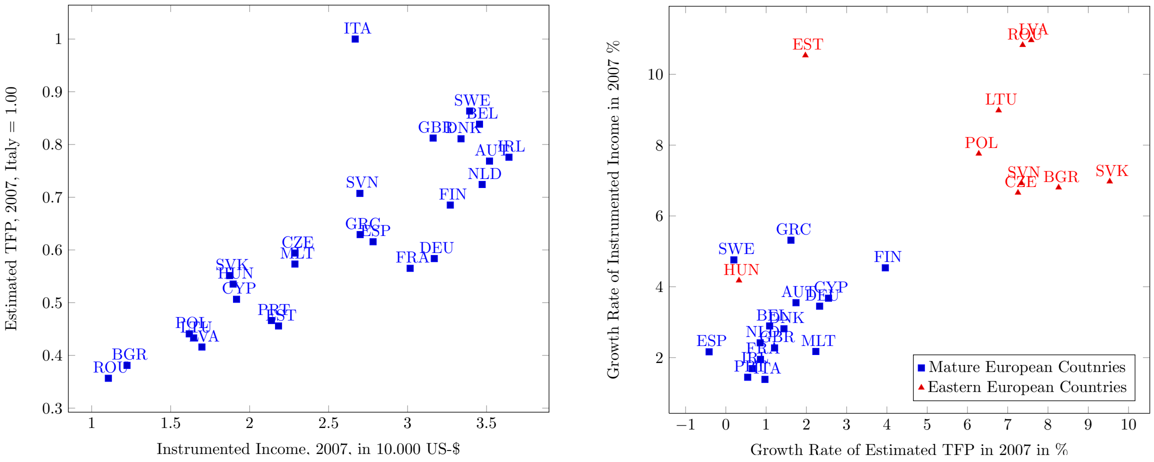
[9] Citing Hsieh and Klenow (2010) is, of course, very selective and neglects many other important contributions dealing with multi-factor productivity issues. We refer the interested reader to the surveys by Caselli (2005) and Syverson (2011).

[10] Psacharopoulos and Patrinos (2004) provides detailed information on Mincerian returns for 16 of our 27 countries. We assume for the remaining 11 countries the same returns as for comparable countries in terms of economic and political structure. To provide an example, we use the 6.4 % p.a. given for Belgium and apply them also to the Netherlands.

estimation equation for TFP builds on Hall and Jones (1999); Alcalá and Ciccone (2004) and Hsieh and Klenow (2010) and takes the form:

$$\mathrm{TFP}_{it} = \frac{\mathrm{rgdpwok}}{(\frac{\mathrm{K}}{\mathrm{GO}} \cdot \mathrm{rgdpwok})^{\alpha} \cdot \exp(\Theta \cdot \mathrm{SchoolingYears}))^{1-\alpha}} \tag{IV.8}$$

We combine variuous data sources to obtain our estimate for TFP. First, we use the real gdp per worker from the Penn World Tables 7.0. K over GO is the relation of physical capital stock to gross output, taken from WIOD. α is the share of capital compensation and is assumed to be 0.3, which is in line with common assumptions. Θ are the Mincerian returns on eduction, again taken from Psacharopoulos and Patrinos (2004). We combine this information with our interpolated version of the Barro and Lee data and correct the TFP measure therefore for human capital formation. To see how our measure for total factor performs, we have calculated growth rates of TFP and instrumented income per capita and plotted them. The result is presented in :



(a) TFP vs. Income

(b) TFP-Growth vs. Income-Growth

Figure 8: TFP vs. Instrumented Income and TFP-Growth vs. Income-Growth

Our expectation is, that the coefficient will be negative in the case of D_{Tot} and D_{Int}, implying a lower index value for higher rates of total factor productivity. The effect on the economic structure is unknown ex ante.

Income

The variables INCOME and INCOMESQR refer also to the technology and their foundation is the Environmental Kuznets Curve (EKC) literature (see Copeland and Taylor (2004) for an excellent theoretical foundation and discussion). The EKC states, that there is an inverted U-shaped relationship between e.g. income and pollution. A rising income is accompanied with higher levels of pollution until a certain point. Then the relationship turns around and pollution begins to decline. The reasons can be found on the supply side of the economy, as higher levels of income enable better, i.e. more efficient technologies and on the demand side, since higher levels of income may induce a shift in preferences for environmental protection. In order to avoid potential endogeneity issues, we rely on instrumental variables for income borrowed from the growth literature (Frankel and Rose (2005)).

The estimation equation for the instrument of income is based on (Frankel and Rose , 2005; Managi et al. , 2009), the estimation results can be found in appendix G:

$$\begin{aligned}
\ln\left(\frac{Real\_GDP}{Pop}\right)_{it} &= \alpha_0 + \alpha_1 \ln\left(\frac{Real\_GDP}{Pop}\right)_{it-1} + \alpha_2 \ln\left(\frac{Real\_I}{GDP}\right)_{it} \\
&\quad + \alpha_3 \ln(n+g+\delta)_{it} + \alpha_4 \ln LABHS_{it} + \alpha_4 \ln K_{it}^{H_c} \\
&\quad + \alpha_4 \ln\left(\frac{K}{L}\right) + \alpha_4 \ln RealOpenness_{it} + \varepsilon_{it} \qquad \text{(IV.9)}
\end{aligned}$$

Equation G17 includes all influences forcing income to grow from the level in $t-1$ to its level in t we want to condition and which are standard in the literature on economic growth. Such influence factors are for instance factor accumulation as modeled in the Solow Model. In the present approach, human capital is modeled twofold. First, we follow Hall and Jones (1999) and Alcalá and Ciccone (2004) and construct average human capital stocks $K_{it}^{H_c}$. Hall and Jones (1999) and Alcalá and Ciccone (2004) used old estimates of returns to schooling and old data on average schooling years. We rely on updated measures of returns to schooling provided by Psacharopoulos and Patrinos (2004) and on the newest version of the Barro and Lee educational attainment data (Barro and Lee , 2010). As Barro and Lee (2010) provider their data in 5-year intervals we have interpolated the values between the intervals. The average human capital stock $K_{it}^{H_c}$ in country i is then defined as: $K_{it}^{H_c} = \exp(\phi(S_c))$, where S_c is average schooling and $\phi(\cdot)$ a piecewise linear function capturing estimated social Mincerian returns (we rely on measures for Mincerian returns provided for Europe by Psacharopoulos and Patrinos (2004) with yearly rates of return of 15.6 % for primary education, 9.7 % for secondary and 9.9 % for tertiary education.One problem which may arise out of using this human capital measure is that high-skilled labor employment is an investment into human capital or new technology, respectively. To process of generating new technologies and innovations is uncertain and so is the investment. To cope with this problem, we use the share of high-skilled worker compensation in total worker compensation ($LABHS$) offered in the WIOD socio-economic accounts. First of all, investment clearly is the change of the capital stock over time from period t to $t+1$. Since the identity of savings and investment has to be considered, we can measure (net) investments (the change of capital stock over time) as the fraction of real GDP which has been saved. The Penn World Tables 7.0 offer this data. Hereafter we define real investments as I/GDP. Furthermore, the growth of per capita income depends not only on investment into physical capital but also on its depreciation (δ) and the rate of growth of labor productivity (g). As usual, we assume these values of being 0.05. Another which negatively affect capital accumulation is the rate of growth of the population (n). We calculate n using the Penn World Tables 7.0. Together ($n+g+\delta$) and are expected to have a negative impact on income per capita. Following Managi et al. (2009) we also control for the (logarithmic) capital to labor ratio $\frac{K}{L}$ and (logarithmic) real openness $RealOpenness$.

We expect, that the coefficient for INCOME will be positive and for INCOMESQR negative in the case of D_{Tot} and D_{Int}, implying higher index values for higher incomes until the peak of the EKC will be reached and then a lower index value for higher rates of income.

Trade

The next variable is OPEN, defined as the sum of export and imports divided through the real Gross Output in 1995 US-$:

$$Openess_{ijt} = \frac{X_{ijt} + M_{ijt}}{GO_{it}REAL_{i,1995}}; \qquad i \neq j \tag{IV.10}$$

The gravity equation estimated to obtain the geography-based bilateral trade share of two countries i and j is based on Frankel and Romer (1999); Frankel and Rose (2005):

$$\begin{aligned} \ln Openess_{ijt} \;=\;& \gamma_0 + \gamma_1 \ln Distance_{ijt} + \gamma_2 \ln Pop_{it} + \gamma_3 \ln Pop_{jt} \\ & + \gamma_4 \ln Area_{it} + \gamma_5 \ln(Area_{jt} + \gamma_6(LL_{it} + LL_{jt}) + \gamma_7 CB_{ijt} \\ & + \gamma_8 CB_{ijt} \ln Distance_{ijt} + \gamma_9 CB_{ijt} \ln Popit + \gamma_{10} CB_{ijt} \ln Popjt \\ & + \gamma_{11} CB_{ijt} \ln Areait + \gamma_{12} CB_{ijt} \ln Areajt + \gamma_{13} CB_{ijt}(LL_{it} + LL_{jt}) + \varepsilon_{ijt} \end{aligned} \tag{IV.11}$$

The regressor D_{ijt} represents the geographic distance between the capitals of the two trade partners i and j. Pop_{it} and Pop_{jt} is a measure of population (and not a measure of the economically active population as in Frankel and Romer (1999) due to missing data for 2009 in the Penn World Tables for some countries) of country i and j, respectively. In addition to this, $(Area_{it}$ and $Area_{jt})$ are controls for the size of two countries, whereas LL_{it} and LL_{jt} are dummies measuring whether the countries are land locked. $(LL_{it} + LL_{jt}$ is the common landlocked dummy. This means that the dummies representing the countries' land locked status are summed up. The variable CB_{ijt} represents a dummy taking the value of one if trade partners share a common border. The common border dummy is also interacted with other explanatory variables to capture trade between neighboring countries more accurately. The equation is estimated using least squares, using the bilateral trade data for all countries included in WIOD. The economically active population is defined as in Frankel and Romer (1999) by using the Penn World Tables (Mark 7.0) and the geographical information were obtained from the CIA World Fact Book. After having estimated the (first stage) regression to construct the instrument for trade openness, the fitted values have to be aggregated across all bilateral trade partners. This is because the second stage regression of the reference model (see equation **??**) uses only trade openess for every country but no bilateral trade flows. The aggregation yields trade openess for a respective country adjusted by output-based PPP's. The aggregation method used is presented in equation F16:

$$\hat{Openess}_{it} \;=\; \sum_{i \neq j} e^{\hat{\gamma}' \boldsymbol{X}_{ijt}} \tag{IV.12}$$

The vector γ represents the coefficients in equation F15 whereas the vector $\boldsymbol{X}_{ijt}$ stands for the right-hand side variables in equation F15. From the first stage regression, fitted values where used to predict trade openness.

As Antweiler et al. (2001) have demonstrated in their seminal paper, trade can have a significant and positive impact on the environment through its effects on the income and especially the composition of the economy. When this is the case, we expect that trade can have also a significant indirect effect on the energy intensity in an economy. Our expectation for the coefficient of OPEN is, that it will be negative for all three indicators.

Capital-to-Labor Ratio

The capital to labor ratio K/L is also relevant for the structure of the economy under investigation. We adopt the assumption of Antweiler et al. (2001) that more capital-intensity is complementary to pollution and energy use. The WIOD database has sectoral estimates for physical capital stocks included for all countries and periods of time such that we can test the hypotheses, that an increasing capital to labor ratio as in indirect measure of structural change is resulting in an increasing energy-intensity.

Variables	Capital Intensity	Energy Use
Capital Intensity	1	
Energy Use	0.44***	1
(* p<0.10, ** p<0.05, *** p<0.01)		

Table 2: Correlation Capital-Intensity and Energy Use

Table 2 shows the correlation between total energy use and capital-intensity (measured in physical capital stock per working hour) which is 0.44 and statistically significant on the 1 % level for our 27 country sample.We expect a negative coefficient for the K/L variable for D_{Str}.

Country Fixed Effects

The variables LATITUDE and COMMUNIST are fixed country effects that we want to capture. The rational behind the latitude variable is, that geography might be an important driver of energy intensity that one should account for. Southern European countries as e.g. Italy or Spain have a bigger demand for power plant cooling and energy for air conditioning (not in the private, but e.g. the service sectors) as the central European countries. On the other hand Northern European countries as e.g. Finland or Sweden may have a larger demand for heating an electricity for light generation. By including the LATITUDE of a country we control for these effects. Metcalf (2008) used the heating demand days and cooling demand days as a control for climate factors, but we think that the geographical latitude is as meaningful. The COMMUNIST variable is a dummy variable equal to one if a country was part of the former Soviet block. The intuition behind this variable is the following: suppose that the fall of the iron curtain was a tremendous structural break and the old capital stock in these countries was almost worthless. Then the vintage capital structure may be a different one than in the "old" European countries. Another possibility were the cheap abatement possibilities and "low-hanging fruits" in terms of energy efficiency in the former Soviet countries. Our COMMUNIST dummy captures these effects.

Regulation and Prices

The last three variables are prices and regulatory measures. Therefore we have used the annual average energy prices and carbon prices as a measure for price induced changes in the technology or structure of the economies. Additionally, we have collected data on environmental regulation in the European Union for the whole time period under consideration. tba...

B. RESULTS AND INTERPRETATION

- Work heavily in Progress!

V. CONCLUSION

The purpose of this paper is to explain the forces driving improvements in energy intensity in the European Union between 1995 and 2009, i.e. in a time without and with climate policy and economic turbulence. It contributes to the large literature in energy decomposition analysis in three ways. First, it is the only analysis of changes in energy intensity at the country and sectoral level using a perfect decomposition methodology. Second, this study uses econometric methods to identify the drivers of changes in efficiency and economic activity indexes. And finally, it demonstrates the scientific usefulness of the new WIOD database.

DEPENDENT VARIABLE:	**TOTAL EFFECT**		**STRUCTURAL EFFECT**		**TECHNOLOGY EFFECT**	
INDEX VALUE	**Coef.**	**z**	**Coef.**	**z**	**Coef.**	**z**
Instrumented Per Capita Income (logarithmic)	-2.236*	-2.43	3.997*	2.14	-4.323*	-2.51
	(0.921)		(1.870)		(1.722)	
Instrumented Per Capita Income Squared (logarithmic)	0.098*	2.08	-0.213*	-2.22	0.209*	2 > .36
	(0.047)		(0.096)		(0.088)	
Instrumented Trade Openness	0.000	0.40	-0.001	-0.91	0.001	0.90
	(0.000)		(0.001)		(0.001)	
Capital to Labor Ratio (logarithmic)	0.394*	2.34	-1.217**	-3.06	1.176**	3.19
	(0.169)		(0.397)		(0.368)	
Capital to Labor Ratio Squared (logarithmic) -0.025	-1.43	0.151***	3.54	-0.124**	-3.13	
	(0.018)		(0.043)		(0.040)	
D.Estimated Total Factor Productivity (logarithmic)	-0.280	-1.66	-0.274	-0.89	-0.105	-0. > 37
	(0.169)		(0.309)		(0.283)	
Capital Vintaging (logarithmic)	0.032	0.85	0.027	0.35	0.043	0.62
	(0.038)		(0.075)		(0.069)	
REGUL	-0.006	-0.63	-0.015	-0.89	0.021	1.39
	(0.009)		(0.017)		(0.015)	
EU15	0.159***	3.44	0.135	1.17	0.040	0.37
	(0.046)		(0.116)		(0.108)	
Geographical Latitude	-0.005***	-6.49	-0.000	-0.22	-0.005**	-2.67
	(0.001)		(0.002)		(0.002)	
Area in km2 (logarithmic)	-0.029	-1.85	-0.042	-1.08	-0.004	-0.12
	(0.016)		(0.039)		(0.037)	
Population Growth	0.071	1.23	-0.072	-0.69	0.147	1.53
	(0.058)		(0.105)		(0.096)	
Heating Degree Days (logarithmic)	0.042	1.21	-0.106	-1.30	0.163*	2.17
	(0.035)		(0.081)		(0.075)	
Energy Price (logarithmic)	-0.052*	-2.05	-0.153**	-3.19	0.106*	2.41
	(0.025)		(0.048)		(0.044)	
MODEL SUMMARY:						
Time Fixed Effects	Yes		Yes		Yes	
N	312		312		312	
R^2(overall)	0.788		0.331		0.433	
R^2(between)	0.789		0.390		0.478	
R^2(within)	0.781		0.243		0.363	

* p<0.10, ** p<0.05, *** p<0.01; robust standard errors appear in parentheses; a constant is included in all regressions

Table 3: Random Effects Panel Regressions for the different indicices

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A COUNTRIES AND SECTORS IN THE WIOD-DATABASE

Countrycode	Country	Countrycode	Country
AUS	Australia	JPN	Japan
AUT	Austria	KOR	Korea
BEL	Belgium	LVA	Latvia
BRA	Brazil	LTU	Lithuania
BGR	Bulgaria	LUX	Luxembourg
CAN	Canada	MLT	Malta
CHN	China	MEX	Mexico
CYP	Cyprus	NLD	Netherlands
CZE	Czech Republic	POL	Poland
DNK	Denmark	PRT	Portugal
EST	Estonia	ROM	Romania
FIN	Finland	RUS	Russia
FRA	France	SVK	Slovakia
GER	Germany	SVN	Slovenia
GRC	Greece	ESP	Spain
HUN	Hungary	SWE	Sweden
IND	India	TWN	Taiwan
IDN	Indonesia	TUR	Turkey
IRL	Ireland	GBR	United Kingdom
ITA	Italy	USA	United States

Table 4: Country coverage of the WIOD database

WIOD industries	NACE
AGRICULTURE, HUNTING, FORESTRY AND FISHING	AtB
MINING AND QUARRYING	C
FOOD , BEVERAGES AND TOBACCO	15t16
Textiles and textile	17t18
Leather, leather and footwear	19
WOOD AND OF WOOD AND CORK	20
PULP, PAPER, PAPER , PRINTING AND PUBLISHING	21t22
Coke, refined petroleum and nuclear fuel	23
Chemicals and chemical products	24
Rubber and plastics	25
OTHER NON-METALLIC MINERAL	26
BASIC METALS AND FABRICATED METAL	27t28
MACHINERY, NEC	29
ELECTRICAL AND OPTICAL EQUIPMENT	30t33
TRANSPORT EQUIPMENT	34t35
"MANUFACTURING NEC; RECYCLING"	36t37
ELECTRICITY, GAS AND WATER SUPPLY	E
CONSTRUCTION	F
"Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel"	50
Wholesale trade and commission trade, except of motor vehicles and motorcycles	51
"Retail trade, except of motor vehicles and motorcycles; repair of household goods"	52
HOTELS AND RESTAURANTS	H
Inland transport	60
Water transport	61
Air transport	62
"Supporting and auxiliary transport activities; activities of travel agencies"	63
POST AND TELECOMMUNICATIONS	64
FINANCIAL INTERMEDIATION	J
Real estate activities	70
Renting of m & eq and other business activities	71t74
"PUBLIC ADMIN AND DEFENCE; COMPULSORY SOCIAL SECURITY"	L
EDUCATION	M
HEALTH AND SOCIAL WORK	N
OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES	O

Table 5: WIOD industries and definition by NACE

B DESCRIPTIVE STATISTICS

Variable	**Mean**	**SD**	**Min**	**Max**
Population Growth Rate	0.0093168	0.0848748	-0.2109411	0.8882784
Geographical Latitude	45.3173	14.92279	0	64
Instrumented Trade Openness	121.0975	40.24236	56.84722	223.2632
Instrumented Per Capita Income (logarithmic)	9.880905	0.4339857	8.756545	10.50283
Instrumented Per Capita Income Squared (logarithmic)	97.8201	8.427514	76.67708	110.3095
Regulation Index	0.5333333	0.4995285	0	1
Capital to Labor Ratio (logarithmic)	4.491655	0.9144116	2.581031	5.797801
Capital to Labor Ratio Squared (logarithmic)	21.00879	7.897984	6.661723	33.6145
Estimated Total Factor Productivity (logarithmic)	5.571875	0.3758685	4.652076	6.227804
Heating Degree Days (logarithmic)	7.8538	0.5619603	5.725557	8.698567
Energy Price (logarithmic)	-2.832061	0.3805766	-4.006409	-1.893128
Capital Vintaging (logarithmic)	-2.597142	0.2897146	-3.845229	-1.918876
Area in km2 (logarithmic)	11.35354	1.522951	5.755742	13.21225

Table 6: Descriptive Statistics of used Variables

Year	**Mean**	**Std. Dev.**	**Min**	**Max**
Total Effect				
1995	1	0	1	1
1996	0.998	0.057	0.899	1.125
1997	0.966	0.068	0.872	1.131
1998	0.950	0.105	0.747	1.184
1999	0.885	0.099	0.722	1.106
2000	0.828	0.111	0.624	1.076
2001	0.831	0.118	0.596	1.058
2002	0.816	0.123	0.537	1.015
2003	0.816	0.134	0.573	1.029
2004	0.786	0.143	0.532	1.004
2005	0.751	0.144	0.481	0.981
2006	0.713	0.149	0.423	0.958
2007	0.676	0.154	0.446	0.99
2008	0.659	0.157	0.428	0.954
2009	0.672	0.151	0.388	0.929
Structural Effect				
1995	1	0	1	1
1996	1.008	0.058	0.939	1.162
1997	0.984	0.085	0.820	1.196
1998	0.925	0.113	0.651	1.23
1999	0.91	0.142	0.624	1.217
2000	0.928	0.205	0.573	1.483
2001	0.917	0.198	0.486	1.369
2002	0.929	0.238	0.448	1.638
2003	0.91	0.214	0.45	1.489
2004	0.887	0.186	0.439	1.224
2005	0.882	0.214	0.416	1.274
2006	0.892	0.234	0.417	1.358
2007	0.876	0.258	0.42	1.51
2008	0.894	0.251	0.438	1.512
2009	0.887	0.246	0.432	1.525
Technology Effect				
1995	1	0	1	1
1996	0.992	0.071	0.787	1.117
1997	0.987	0.094	0.76	1.291
1998	1.039	0.153	0.701	1.506
1999	0.989	0.146	0.656	1.401
2000	0.922	0.181	0.560	1.429
2001	0.937	0.191	0.549	1.514
2002	0.916	0.198	0.544	1.407
2003	0.929	0.192	0.538	1.389
2004	0.914	0.193	0.511	1.384
2005	0.887	0.203	0.482	1.308
2006	0.835	0.191	0.425	1.188
2007	0.812	0.193	0.345	1.179
2008	0.772	0.188	0.311	1.103
2009	0.801	0.223	0.267	1.222

Table 7: Summary Statistics for the Country-Specific IDA (1995 = 1.00)

C Country IDA: Summary

	2000			2005			2009		
Country	D_{Tot}	D_{Str}	D_{Int}	D_{Tot}	D_{Str}	D_{Int}	D_{Tot}	D_{Str}	D_{Int}
AUT	0.861	0.980	0.879	0.837	0.983	0.851	0.801	1.030	0.778
BEL	0.994	1.005	0.989	0.962	1.046	0.920	0.804	1.004	0.800
BGR	0.752	1.344	0.559	0.608	1.262	0.482	0.404	1.521	0.265
CYP	1.040	1.481	0.702	0.532	0.627	0.848	0.499	0.655	0.763
CZE	0.779	0.785	0.992	0.656	0.721	0.909	0.538	0.637	0.844
DEU	0.836	1.089	0.768	0.818	1.270	0.644	0.754	1.251	0.602
DNK	0.863	0.971	0.889	0.845	0.949	0.890	0.624	0.859	0.727
ESP	0.957	1.112	0.861	0.904	1.012	0.894	0.761	1.147	0.663
EST	0.622	0.586	1.062	0.483	0.416	1.161	0.516	0.464	1.113
FIN	0.819	0.863	0.949	0.756	0.806	0.938	0.757	0.789	0.959
FRA	0.878	0.820	1.071	0.803	0.868	0.925	0.689	1.106	0.623
GBR	0.826	1.008	0.820	0.719	0.969	0.742	0.630	0.893	0.706
GRC	1.068	1.071	0.996	0.892	1.101	0.811	0.822	1.127	0.729
HUN	0.644	0.573	1.124	0.558	0.432	1.292	0.528	0.431	1.224
IRL	0.823	0.778	1.057	0.738	0.973	0.758	0.595	1.058	0.562
ITA	0.896	0.917	0.977	0.912	0.894	1.020	0.863	0.729	1.184
LTU	0.885	0.624	1.417	0.895	0.735	1.217	0.776	0.762	1.019
LUX	0.762	0.908	0.839	0.903	0.943	0.958	0.794	0.844	0.941
LVA	0.656	0.849	0.773	0.501	0.801	0.625	0.489	0.851	0.574
MLT	0.733	1.082	0.677	3.610	1.055	3.421	1.023	1.090	0.939
NLD	0.857	0.876	0.978	0.871	0.877	0.993			
POL	0.717	1.004	0.714	0.588	0.985	0.597	0.472	0.891	0.530
PRT	0.893	1.094	0.816	0.917	0.951	0.964	0.778	0.847	0.919
ROU	0.705	0.850	0.830	0.553	0.793	0.697	0.388	0.704	0.551
SVK	0.859	0.742	1.158	0.682	0.521	1.309	0.496	0.537	0.925
SVN	0.835	0.764	1.093	0.777	0.777	1.000	0.706	0.801	0.882
SWE	0.802	0.903	0.888	0.747	0.891	0.839	0.667	0.899	0.742
EU27	0.853	0.975	0.875	0.811	1.012	0.801	0.667	1.101	0.606

Table 8: IDA Results

D SECTORAL DEVELOPMENT: RELATIVE CHANGES TO PREVIOUS YEAR

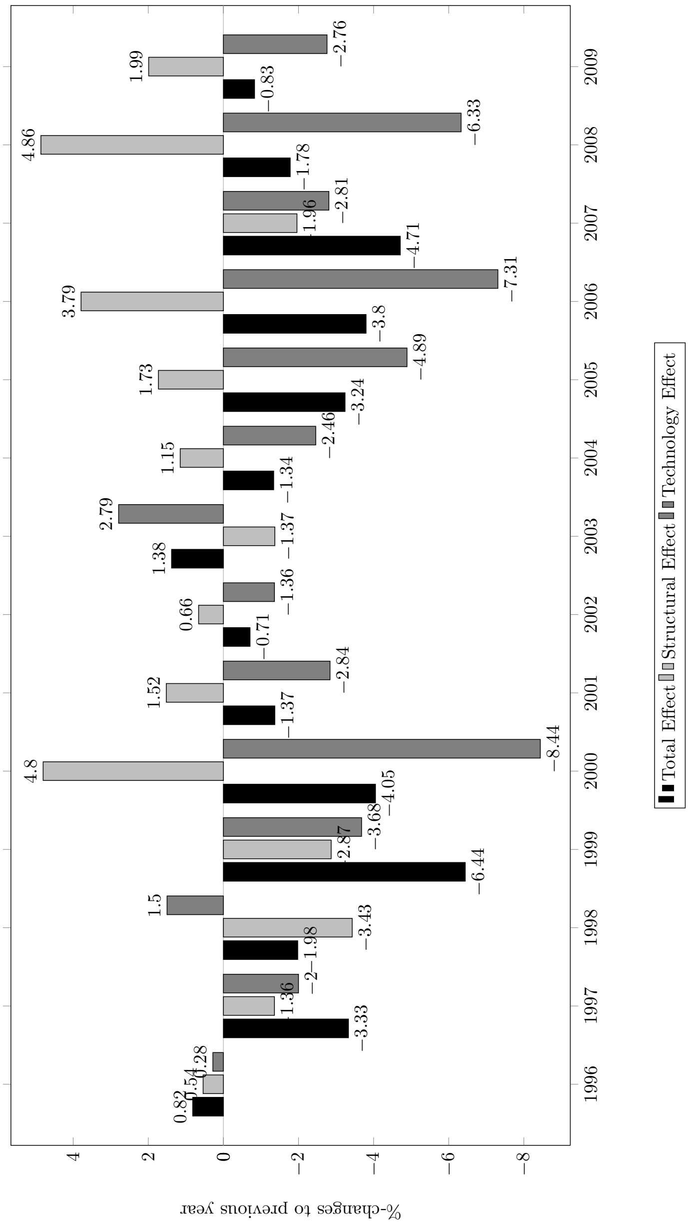

Figure 9: Sectoral Development of the EU27 Energy Intensity

E TOTAL FACTOR PRODUCTIVITY

Our estimation equation for TFP builds on Hall and Jones (1999); Alcalá and Ciccone (2004) and Hsieh and Klenow (2010) and takes the form:

$$MFP_{it} = \frac{rgdpwok}{(\frac{K}{Y} \cdot rgdpwok)^{\alpha} \cdot \exp(return\_alternative \cdot yr\_sch))^{1-\alpha}} \tag{E13}$$

F The Trade Instrument

We define real openness between country i and country j as:

$$Openess_{ijt} = \frac{X_{ijt} + M_{ijt}}{GO_{it} REAL_{i,1995}}; \qquad i \neq j \tag{F14}$$

The gravity equation estimated to obtain the geography-based bilateral trade share of two countries i and j is (Frankel and Romer , 1999):

$$\begin{aligned} \ln Openess_{ijt} \quad = \quad & \gamma_0 + \gamma_1 \ln Distance_{ijt} + \gamma_2 \ln Pop_{it} + \gamma_3 \ln Pop_{jt} \\ & + \gamma_4 \ln Area_{it} + \gamma_5 \ln(Area_{jt} + \gamma_6(LL_{it} + LL_{jt}) + \gamma_7 CB_{ijt} \\ & + \gamma_8 CB_{ijt} \ln Distance_{ijt} + \gamma_9 CB_{ijt} \ln Popit + \gamma_{10} CB_{ijt} \ln Popjt \\ & + \gamma_{11} CB_{ijt} \ln Areait + \gamma_{12} CB_{ijt} \ln Areajt + \gamma_{13} CB_{ijt}(LL_{it} + LL_{jt}) + \varepsilon_{ijt} \end{aligned} \tag{F15}$$

Our constructed trade share is then defined as:

$$\hat{Openess_{it}} \quad = \quad \sum_{i \neq j} e^{\hat{\gamma}' \boldsymbol{X}_{ijt}} \tag{F16}$$

The vector γ represents the coefficients in equation F15 whereas the vector $\boldsymbol{X}_{ijt}$ stands for the right-hand side variables in equation F15. From the first stage regression, fitted values where used to predict trade openness.

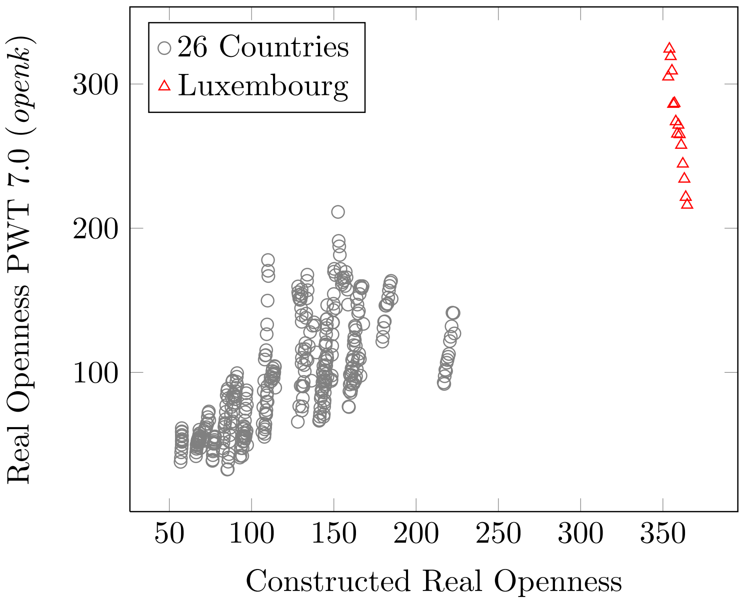

Figure 10: Constructed vs. Actual Trade Share

Dependent Variable:	**OLS Estimates**	
log Openness	**Coefficients**	**t-Statistic**
log_ Distance	-1.031***	-43.37
	(0.02)	
log_ Pop_ i	-0.149***	-6.35
	(0.02)	
log_Area_ i	-0.041*	-1.94
	(0.02)	
log_ Pop_ j	0.648***	35.76
	(0.02)	
log_Area_ j	0.009	0.67
	(0.01)	
CommonLandlocked	-0.279***	-6.83
	(0.04)	
CB	1.938**	2.22
	(0.87)	
CB_ Dist	0.070	0.30
	(0.23)	
CB_ Pop_ i	-0.283**	-2.51
	(0.11)	
CB_ Area_ i	0.123	0.93
	(0.13)	
CB_ Pop_ j	-0.054	-0.55
	(0.10)	
CB_ Area_ j	0.008	0.08
	(0.10)	
CB_ LL	0.083	0.83
	(0.10)	
constant	3.659***	16.73
	(0.22)	
Model Summary:		
Observations	15653	
F-Statistic	392.963	
Adj. R^2	0.242	
Root-MSE	2.187	

* p<0.10, ** p<0.05, *** p<0.01, robust standard errors appear in parentheses

Table 9: Estimation Results for Gravity Model

G THE INCOME INSTRUMENT

The estimation equation for the instrument of income is:

$$\begin{aligned}\ln\left(\frac{Real\_GDP}{Pop}\right)_{it} &= \alpha_0 + \alpha_1 \ln\left(\frac{Real\_GDP}{Pop}\right)_{it-1} + \alpha_2 \ln\left(\frac{Real\_I}{GDP}\right)_{it} \\ &+ \alpha_3 \ln(n+g+\delta)_{it} + \alpha_4 \ln LABHS_{it} + \alpha_4 \ln K_{it}^{H_c} \\ &+ \alpha_4 \ln\left(\frac{K}{L}\right) + \alpha_4 \ln RealOpenness_{it} + \varepsilon_{it} \qquad \text{(G17)}\end{aligned}$$

DEPENDENT VARIABLE:	**FIXED EFFECTS ESTIMATES**	
LOG REAL GDP PER CAPITA	**Coefficients**	**t-Statistic**
$\ln\left(\frac{Real\_GDP}{Pop}\right)_{it-1}$	0.859***	44.62
	(0.02)	
$\ln\left(\frac{Real\_I}{GDP}\right)_{it}$	0.125***	7.28
	(0.02)	
$\ln(n+g+\delta)_{it}$	-0.122***	-3.35
	(0.04)	
$\ln LABHS_{it}$	0.017	1.12
	(0.01)	
$\ln K_{it}^{H_c}$	0.010	1.46
	(0.01)	1.46
$\ln\left(\frac{K}{L}\right)$	-0.024	-1.47
	(0.02)	
$\ln RealOpenness_{it}$	0.059***	2.95
	(0.02)	
constant	0.413**	2.46
	(0.17)	
MODEL SUMMARY:		
Observations	375	
F-Statistic	1247.58	
Adj. R^2	0.9875	
* p<0.10, ** p<0.05, *** p<0.01, robust standard errors appear in parentheses		

Table 10: Estimation Results for Income Instrument

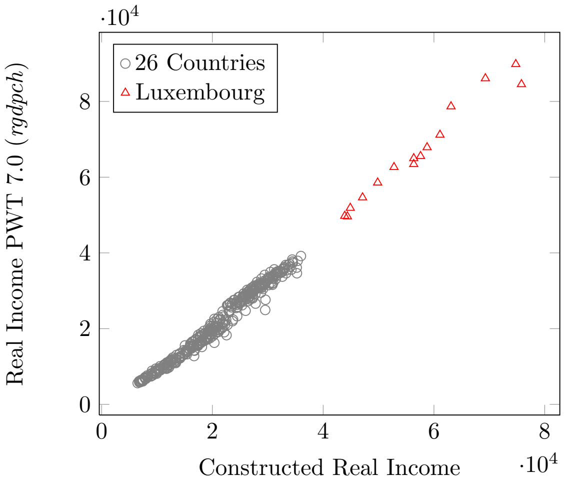

Figure 11: Constructed vs. Actual Real Income per Capita