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International and sectoral variation in energy prices 1995-2011: how does it relate to emissions policy stringency?*

Misato Sato,[†] Gregor Singer,[‡] Damien Dussaux,[§] and Stefania Lovo[¶]

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Abstract

The lack of information on the cost of energy for industry poses a major barrier in assessing the effects of energy prices and taxes on the economic performance and international competitiveness of regulated firms. This paper documents the construction of an energy price index for 12 industrial sectors, covering 48 countries for the period 1995 to 2011. Two distinct indices are constructed: the Variable-Weight Energy Price *Level* (VEPL) which is useful for cross sectional analysis or descriptive statistics and; the Fixed-Weight Energy price *Index* (FEPI) which is designed for use in times series and panel data analysis. We present a descriptive analysis of the major trends in energy prices and taxes, and provide guidelines for the use of our energy price data which is made publicly available for download. The indices reveal, among other things, that industrial energy prices have been on an increasing trend in real terms since 2000 for most countries, and that the gap between the highest and lowest energy prices internationally has widened with the average price in the 10% highest countries being 2.4 times larger than the 10% lowest in 2010. The bulk of variation in industrial energy prices across countries is attributable not to the wholesale price differences but the tax component. We then evaluate to what extent energy prices are a good proxy for emissions policy stringency, and show that it has many attractive qualities and avoids problems common to other proxies which have been used in the literature.

JEL: Q41, Q48, Q58, H23

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[†]Corresponding author. Grantham Research Institute on Climate Change and the Environment, London School of Economics. m.sato1@lse.ac.uk

[‡]Grantham Research Institute on Climate Change and the Environment, London School of Economics. g.a.singer@lse.ac.uk

[§]CERNA, Mines ParisTech, 60 Boulevard St Michel, 75006 Paris, France, damien.dussaux@mines-paristech.fr

[¶]Grantham Research Institute on Climate Change and the Environment, London School of Economics. s.lovo@lse.ac.uk

1 Introduction

Do high industrial energy prices or CO_2 emission reduction policies hold industrial sectors back vis-à-vis their international competitors, or on the contrary, boost energy efficiency and productivity in the long run? The rising price of energy remains a politically sensitive issue particularly in fossil fuel import-dependent regions such as Europe and Japan. Several new trends contribute to this: the slow economic recovery since the 2008 financial crisis, the shale gas boom in the US with the consequent fall in energy prices for US manufacturers, the costly transition from fossil fuel and nuclear to renewable energy sources, notably in Europe, and the increased competition from emerging economies. However, the empirical evidence on the effects of energy prices on industrial competitiveness remain decidedly mixed and one of the major barriers to empirically assessing the effects of energy related costs is the lack of information about relative energy costs across sectors and countries (Dechezleprêtre and Sato, 2014). While energy price for electricity generation and households are readily available, energy prices faced by industrial sectors are harder to obtain for most countries. For most OECD countries, industrial energy prices are published only at the country level (averaged across all industrial sectors) rather than for individuals sectors, and often with considerable missing data points.[1]

This paper contributes to the field in two ways. First, we construct a comprehensive dataset of industrial energy prices indices for 48 countries for the period 1995 to 2011. This is done both at the country level and at the sector level, covering 12 industry sectors.[2] We propose two measures of industrial energy prices: the Variable Weights Energy Price Level (VEPL) and the Fixed Weights Energy Price Index (FEPI). Both measures offer useful advantages and are designed for different purposes as will be explained. The energy price series are made available to researchers without any subscription requirements and can be accessed through the Grantham Research Institute's website[3]. Second, we evaluate to what extent the constructed energy price index is a reasonable proxy for emissions policy stringency. The use of energy prices as a measure of climate or energy policy stringency is not new (see for instance Aldy and Pizer (2014b)). Our contribution is to evaluate to what extent, energy price series are a good proxy for emissions policy stringency. To do so, we build on the work of Brunel and Levinson (2013) and compare VEPL with other existing indicators of policy stringency.

It is understood that a number of factors may account for energy price disparities across countries, such as fossil fuel endowments, energy production costs, transport costs, differences in contractual terms and trade restrictions. Most governments have policies in place to protect industries from rising energy price in one way or another. For example, the UK government has announced a package of cuts for manufacturing businesses chiefly based on lowering green taxes such as by capping the existing carbon price floor.[4] In Germany, the Renewable Energy Act finances fixed feed-in tariffs for renewable energy generation by taxing electricity use, from which many industrial sectors, however, are largely exempt and continue to be so after heavy negotiations with the EU following a "state-aid" case from the European Commission.[5] In fact, competitiveness concerns have shaped policy designs

[1] There are, however, few exceptions. A notable example is the US, where energy prices faced by sectors at the state level can be inferred from fuel expenditure and consumption data from the NBER-CES Manufacturing Industry Database.

[2] We exclude the domestic, commercial and power generation sectors.

[3] http://www.lse.ac.uk/GranthamInstitute/research-theme/energy-technology-and-trade/

[4] See UK 2014 Budget (HM Treasury, 2014). For an informal description, see The Telegraph (2014).

[5] See the European Commission (2013) press release for the state aid case. An agreement has been reached in April 2014 (New Europe, 2014).

for some time. For example the EU Energy Tax Directive (European Council, 2003) has provisions to approve reduction of tax levels "because of the risk of a loss of international competitiveness [...]". Several European countries enforce lower rates of excise duty or give tax exemptions for electricity use by the industrial and business sectors (European Commission, 2014b). Similarly, exemptions from environmental taxation have historically often been made to sectors of the manufacturing industry in many European countries (Ekins and Speck, 1999) and the EU Emissions Trading Scheme also compensates energy in tensive and trade intensive (EITI) sectors with free allowance allocation. Indeed, recent data from the (OECD, 2013b) on sector level energy taxes and exemptions finds that there is substantial differentiated taxation between industrial and non-industrial sectors for certain fuel types.

While such regulatory practices are commonplace, whether there is the need to protect or compensate industries being subject to relatively high energy-related costs is ambiguous and not *a priori* clear. So far, evidence on the relationship between energy costs and economic performance relates to the country level, but less so further down to the sector level. Neuhoff et al. (2014) show that countries with higher energy prices use energy more efficiently. The shares of energy costs per unit of GDP are constant across countries suggesting that high energy prices do not hinder economic performance but in fact foster technological development. At the sector level, Sato et al. (2014) find that energy accounts for a small share of total production costs for the majority of manufacturing sectors hence are unlikely to significantly affect their competitiveness performance. Nonetheless, there are some concerns for energy intensive sectors since persistently high energy cost disparities may affect relative operating margins and returns on investment. Empirically, few studies attempted to isolate and assess the effects of energy price on competitiveness, but the studies have been done in a US context only, and the evidence is mixed. Aldy and Pizer (2011) exploit the variation in energy prices between US states and estimate the effect of electricity prices on industrial supply and demand. They find negative responses in both supply and demand levels, for industries with higher energy intensity, suggesting that high energy costs represents a disadvantage for industrial production. Kahn and Mansur (2013) look at the impact of energy prices on geographical clustering of US manufacturing, but the results are less conclusive. This paper aims to contribute to the empirical literature, by building a new international energy price index which captures energy price differences between countries as well as sectors within countries, which can enable empirical studies on the impact of energy prices on competitiveness in an international context.

Some previous works also constructed weighted energy price indexes. Noailly (2012), for example, calculates an energy price index for the building sector in 7 European countries. The IEA (2013c) construct a weighted industrial energy price index for OECD countries focusing on electricity and gas prices. Linn (2008) and Aldy and Pizer (2014b) construct weighted energy prices index for sectors in the US. Finally, Steinbuks and Neuhoff (2014) construct the average energy price for the manufacturing sector using fuel weights, for 19 OECD countries between 1990 and 2005 for five manufacturing industries. The VEPL and FEPI constructed in this paper have a number of advantages. First, we cover four key types of fuel carriers (electricity, gas, coal and oil) rather than a subset. Second, the VEPL and FEPI provide greater coverage of sectors, countries, including non-OECD countries and years. This was done by supplementing the IEA data with other governmental data where missing, and by developing transparent methods to reduce missing data-points. Third, the VEPL is calculated with both market exchange rates (MER) and purchasing power parity rates (PPP) as, for certain countries, the assumptions on the relevance of nominal exchange rates can have large impacts on the resulting energy price. Fourth, the methodology used is documented, and the data is made widely available. Moreover, the dataset constructed is designed for flexible use e.g. binary variables are created to enable discarding observations that have been imputed using different techniques. On the other hand, the main disadvantage of our approach is that due to the lack of observed sectoral level energy prices, it is difficult to verify the accuracy of our estimated energy price index and the validity of our methodology.

The resulting energy price index reveals a number of insights. Across countries and over 17 years, the energy price gaps have widened in real terms, the highest price being six times bigger than the lowest in 2010. Of the four carriers, prices of electricity vary the most across countries. Taxation differences is a major source of variation in fuel prices across countries. Variation in energy prices are found to be larger between countries than between sectors within the same country. Our analysis also shows that our indices represent a good proxy for emissions reduction policy stringency. We find that our country level industrial energy prices are highly correlated with other measures of emissions reduction policy stringency. This is consistent with the fact that as most emissions pollution arises from energy combustion and electricity production, emission-based policies and energy taxation designed to discourage emissions do ultimately result in higher energy prices. The main advantage of using VEPL and FEPI as a measure of emissions policy stringency is that it is available for many countries and many years as opposed to the majority of existing measures.

This paper is structured as follows. Section 2 describes the methodology, and Section 3 describes the data employed in the construction of the VEPL and FEPI. Section 4 then discusses the strategies used to tackle missing data issues. Section 5 and 6 provide some descriptive analysis at the country level industrial energy price and at the individual sector level respectively. The second part of the paper is covered in section 7 that surveys the literature that uses energy prices as a proxy of emissions policies, and also the broader literature on the measurement of environmental policy stringency. It then compares the VEPL with other measures of emission policy stringency. The last section offers some discussions and suggest gaps for future research.

2 Constructing the energy price database

2.1 Conceptual framework

In this paper, we construct an energy price index for a given sector s in country i , by weighting fuel prices for four carriers (oil, gas, coal and electricity) by the consumption of each fuel type in that sector-country (si). The Variable Weight energy Price Level (VEPL) uses fuel weights which vary over time, whereas the Fixed Weight energy Price Level (FEPI) uses fixed weights. The former is designed to capture the *between*-sector variation in energy prices, thus reflecting the effective energy price level (including tax and other policies) for each sector at a particular point in time. This makes it suitable for cross-sectional analysis and descriptive statistics. The latter instead is an index, which aims to capture the *within*-sector variation, of the change in energy price level over time for a specific country-sector. It is suitable for use in time-series and panel data analysis. The key features of the VEPL and FEPI are summarised in Table 1. We also provide some guidelines about the interpretation and applicability of the two energy price series. All variables included in the database are described in the codebook Table

7, reported in the Appendix C.

In the absence of observed energy price data at the sector level, the construction of sector-level prices using fuel consumption as weights addresses the important issue of heterogenous fuel mix observed across sectors and countries. For example, the steel sector relies heavily on electricity where secondary production is predominant (e.g. Italy and Spain) whereas others rely on coal where there is more primary production (e.g. China and Germany). However, there are many other factors that contribute to the heterogeneity in energy price levels faced by sectors and firms. For example, prices may vary due to network access, compensation fees, long-term energy contracts and other privileges granted to bulk consumers in the energy procurement processes.[6] While understanding how these different factors result in differentiated energy prices for users is important, data constraints limit our choices in the construction of the average energy prices for industrial sectors.

Table 1: Overview of VEPL and FEPI

	VEPL	**FEPI**
Coverage in years	1995-2011	1995-2011
Number of countries	36 (25 OECD countries and 11 non-OECD countries)	48 (32 OECD countries and 16 non-OECD countries)
Number of sectors	12 sectors and one averaged across all sectors (CountryVEPL)	12 sectors and one averaged across all sectors (CountryVEPL)
Number of observa-tions	7098	7225-7647 (depends on year of fixed weight of the versions of FEPI)
Formula	Weighted arithmetic mean	Log of weighted geometric mean
Fuel weights	Variable (time-variant) weight of fuel types	Fixed (time-invariant) weight of fuel types
Purpose	Descriptive statistics, cross-country level comparisons	Time-series or panel data analysis
Price data dummy	*flag_VEPL*: 1 for observed, 2 for imputed with respective fuel price index, 3 for imputed with total energy price index	*flag_FEPI*: 1 for observed, 2 for imputed with respective fuel price index
Biofuel variable	*biofuel_share* indicates the time-variant weight of biofuels.	*biofuel_share* indicates the time-variant weight of biofuels.
Caveats	- Designed for descriptive statistics and not for regression analysis. - The growth in log of the VEPL is not perfectly comparable to the FEPI, as it is the weighted arithmetic mean, with variable weights and a slightly different methodology regarding missing values. - The VEPL is in real terms, i.e. net of economy-wide inflation.	- Only the change in this variable is meaningful, not its level. Therefore, it needs to be taken in first difference in regressions or better, taken in levels and combined with at least country fixed effects. When combined with sector-country fixed effects, a lot of measurement error is controlled for. - As this indicator is already in logs, it should not be transformed into logs again. - The FEPI is in real terms, i.e. net of economy-wide inflation.

[6] See Matthes (2013) for a discussion on these issues which are not taken into account for official industrial electricity prices in Germany.

2.2 Variable-Weight energy Price Level (VEPL)

Our sector-level variable-weight energy price level is calculated for each country i, sector s and year t according to the following equation:

$$VEPL_{ist} = \sum_j \frac{F^j_{ist}}{\sum_j F^j_{ist}} \cdot P^j_{it} = \sum_j w^j_{ist} \cdot P^j_{it} \tag{1}$$

Here, the weights w^j_{ist} applied to the prices vary by country, sector and year. It is by combining country-level fuel prices P^j_{it} by the sector-level fuel weights that we construct the average energy price for each manufacturing sector s in country i in the absence of observed sector level fuel prices. We also construct an index at the country level, and the industrial energy price levels are calculated for each country i and year t according to the following equation :

$$VEPL_{it} = \sum_j \frac{F^j_{it}}{\sum_j F^j_{it}} \cdot P^j_{it} = \sum_j w^j_{it} \cdot P^j_{it} \tag{2}$$

where F^j_{it} is the input quantity of fuel type j in tons of oil equivalent (TOE) for the whole industrial sector in country i at time t and P^j_{it} denotes the average real price per TOE for fuel type j in the industrial and manufacturing sectors including taxes, in country i at time t in constant 2010 USD. Here, the weights w^j_{it} applied to the prices vary on a yearly basis.[7] For the remainder of the paper, this version of the VEPL is termed CountryVEPL.[8]

For oil and coal, average industry prices are available for a range of sub-categories (e.g. light fuel oil, high sulphur oil, coking coal and steam coal). In order to ensure comparability of the prices across countries, a consistent set of sub-fuel types across countries is used. Specifically, high sulphur oil prices are used for oil, and steam coal prices are used for coal, because they represent the most widely used type of coal in industrial production and have fewest missing values. The downside of a consistent price portfolio of sub-fuel types is the measurement error introduced in some sectors that rely on sub-fuel types other than the one chosen. This caveat should be considered for sectors which have portfolios of fuel *sub-types* that diverge significantly from the typical portfolio for this sector.[9] For example, if a particular sector in country A uses primarily high sulphur oil and the same sector in country B primarily low sulphur oil, country B's resulting VEPL tends to be biased downwards because low sulphur oil is generally more expensive per TOE. In order to enable cross-country comparison, VEPL is only constructed for country-years where price series for *all* four fuel types are available, but this

[7] Here, the 12 sectors are weighted equally, hence the industrial composition is not addressed. See Appendix B for how the bias from equally weighting sectors is addressed in the case of another indicator (IAEI).

[8] This represents the industry average energy price level for a specific country, but does not account for energy price levels of non-industrial sectors of that country, such as power generation, retail and households.

[9] Since the sub-types in the fuel use data do not match the sub-types in the price data, it is difficult to isolate out the specific sectors for which this is relevant.

restriction will be relaxed for the FEPI to increase the sample size (see Section 2.3).

The interpretation of the VEPL is straightforward – it represents the effective real energy price level of a particular sector in a particular country and point in time. Because the fuel consumption data used for weighting the fuel prices changes over time, the VEPL reflects any fuel-switching that occurs within a sector over time. For example, the UK experienced a considerable switch away from gas towards coal in the non-metallic minerals sector around 2000. The VEPL is provided in two versions using either the Market Exchange Rate (MER) or the Purchasing Power Parity (PPP) rates, to capture differences in relative costs for industries in different countries.[10] The suitability of one version over the other depends on the degree of international tradability of inputs and outputs for particular sectors in particular countries. The more the inputs and outputs are internationally traded, the less important are specific country price levels which are taken into account by PPP, and the more applicable are MER.[11]

2.3 Fixed-Weight energy Price Index (FEPI)

The fixed-weight price index is constructed for each available country i, sector s and year t, according to the following equation:

$$FEPI_{ist} = \sum_j \frac{F_{is}^j}{\sum_j F_{is}^j} \cdot log(P_{it}^j) = \sum_j w_{is}^j \cdot log(P_{it}^j) \quad (3)$$

where F_{is}^j are the input quantity of fuel type j in tons of oil equivalent (TOE) for sector s in country i and P_{it}^j denotes the real TOE price of fuel type j for total manufacturing in country i at time t in constant 2010 USD. The weights, w_{is}^j, applied to fuel prices are fixed over time. The same methodology is employed in the construction of the country level index. The prices P_{it}^j are transformed into logs before applying the weights so that the log of the individual prices enter linearly in the equation.[12] This is a useful feature for panel data estimations as explained below.

We calculate different versions of the FEPI with different anchor years for the fixed weights, which are taken at 1995, 2000, 2005 and 2010. We also construct a version of the FEPI using average weights over these 4 cross sections. Real prices, P_{it}^j, are based on a different set of sub-fuel types across countries, unlike the VEPL which used a consistent set of sub-fuel types across countries. Considering oil, for example, we might use high sulphur oil prices in one country and low sulphur oil prices in another, depending on which sub-fuel type has the least number of missing values. This flexibility increases the FEPI sample size considerably, but makes it unsuitable for cross-country comparisons. Within any one country-sector, a consistent set of sub-fuel type is used through time. In general, the price changes in sub-fuel types are highly positively correlated in our data. Thus the FEPI is able to capture the relative industrial energy prices over time despite heterogeneous base prices across countries.

The FEPI is intended to capture only energy price changes that come from changes in fuel prices, and not through changes in the mix of fuel inputs. This is an important feature that helps address

[10] Using PPP instead of MER implies a time-constant multiplicative shift in the prices which results in upward scaling of the VEPL for generally "expensive" countries and downward scaling for relatively "cheap" countries.

[11] An example of a study that used PPP in this context is van Soest et al. (2006).

[12] Note that taking the exponential of the FEPI yields the weighted geometric mean of the different fuel prices, so Equation 3 is the log of the weighted geometric mean.

one of the major problems affecting empirical analyses in this field. Even when firm-level energy price data are available they are rarely used in micro-level empirical analysis because of endogeneity concerns. Energy prices often vary with the amount of energy consumed and the choice of fuel types is an endogenous firm decision (Lovo et al. (2014)). Therefore, sector-level prices are commonly used in both micro and sector level empirical analyses. Sector-level energy prices based on variable fuel weights, as provided by our VEPL, however, can be potentially endogenous. For example, technological change, fuel substitution or industry-specific shocks on output demand could potentially affect the distribution of fuel consumption within sectors and, ultimately, the sector-level energy prices (Linn (2008)). The FEPI instead, which is based on fixed weights, is less affected by the above effects.

The FEPI, therefore, captures the within-sector variation in energy prices over time for a particular country, free from fuel substitution effects, and is designed as an energy price index for panel regressions. Panel data analysis using the various versions of the FEPI should always include fixed effects to control for unobserved country-sector characteristics. The use of a log transformation has the advantage of isolating any time-constant but fuel type specific measurement errors in prices as well as any discrepancies in the choice of the sub-type fuel. Both of them can be controlled for by including country-sector fixed effects.[13] Alternatively, regressions that include the VEPL as an explanatory variable could use the FEPI as an instrument as done in Linn (2008). This latter strategy can provide a more precise measurement of cross-year variability in energy prices. Note that the FEPI is expressed in logarithmic and real terms, hence further transformations in this regard are not necessary when used in regression analysis. The FEPI is not provided with PPP prices, as it is designed for regression analysis and including country or country-sector fixed effects would eliminate any difference between PPP and MER versions.[14]

FEPI series are ill-suited for cross country comparisons, due to different underlying fuel types used across countries and sectors as described, and only the *within* country *and* sector group variation over time is meaningful.[15]

3 Data sources

This paper brings together a variety of data sources to construct an energy price index (see Table 2 for sources and Table 3 for coverage). The primary source for energy price data is the IEA Energy End-Use Prices database, and specifically the prices for the industry sector (IEA, 2012). The data points are 12 month averages and available in national currency per tonne of oil equivalent (TOE).

[13] Consider for example measurement error ${x^a}_i$, which leads to $\frac{F^a_{is}}{F_{is}} \times log(P^a_{it} * {x^a}_i) + \frac{F^b_{is}}{F_{is}} \times log(P^b_{it}) = \frac{F^a_{is}}{F_{is}} \times log(P^a_{it}) + \frac{F^b_{is}}{F_{is}} \times log(P^b_{it}) + \frac{F^a_{is}}{F_{is}} \times log({x^a}_i)$, where the last term varies on a sector-country level and is cancelled with accompanied fixed effects due to applying logs at an intermediate stage. This is an advantage of the weighted geometric mean over the weighted arithmetic mean.

[14] The conversion factor from market exchange rates to PPP can be viewed as a constant term across sectors and time which can be controlled for by country of country-sector fixed effects: $WAPI_{ist} = \sum_j \frac{F^j_{is}}{\sum_j F^j_{is}} \times log(P^j_{it} * ConversionPPP_i) = \sum_j (\frac{F^j_{is}}{\sum_j F^j_{is}} \times log(P^j_{it})) + log(ConversionPPP_i)$.

[15] Since the FEPI is the log of the geometric average, the change actually reflects a ratio, consistent with usual index calculations(ILO/IMF/OECD/UNECE/Eurostat/The World Bank, 2004). Therefore, a ratio (for the growth rate) of the FEPI would not be meaningful. For fixed effects panel regression, the FEPI should be included as it is.

We take these data to represent the final industrial energy prices including taxes paid by industry for different fuels, and excluding VAT and recoverable taxes and levies.[16] The raw industrial energy price data are combined with the GDP deflator and exchange rate data (or the PPP conversion factor) to construct the prices in constant 2010 US$. The nominal exchange rate, the PPP conversion factor and the GDP deflator data are taken from World Bank (2013) except for Taiwan, which is from the National Statistics of the Republic of China (2013). The price data are first deflated by the national GDP deflator with a consistent base year 2010 and then converted into constant 2010 USD by applying a fixed ratio between the 2010 deflator and 2010 nominal exchange rate (or PPP conversion factor) to all years. In short (analogous for PPP prices):

$$P^{USD}_{constant} = \frac{P^{LCU}_{nominal}}{Deflator^{LCU}} * \frac{Deflator^{LCU}_{2010}}{ER^{LCU/USD}_{2010}}. \tag{4}$$

For a few countries, inflation was extremely high during some years (e.g. Kazakhstan or Turkey) such that even the deflated prices are meaningless. To this end we included a variable that shows the inflation per country-year in order to facilitate their potential exclusion. Therefore, prices that go into the calculation of the VEPL and FEPI are in real terms and only capture price increases in the fuel basket *relative* to the general economy-wide price inflation.

It has been pointed out that industrial energy price data may not represent the true prices paid by industry, for example, because many countries offer tax exemptions and other subsidies to energy users, including energy intensive industries. Data on these aspects are currently patchy and lack consistency hence these issues are not captured accurately in official data (European Commission (2014a) and OECD (2013b)). These exemptions can be important, for example in Germany, despite the expensive low-carbon energy system transition which is financed by levies, energy intensive industries actually pay a similar amount for electricity as their competitors in the USA (30–40 Euro per MWh) because they enjoy exemptions from grid access fees, renewables support and EU ETS carbon costs (Matthes, 2013). Better availability of harmonised information on such levies and exemptions will lead to improvements in the energy price measures developed in this paper.

The IEA industrial energy price data are supplemented with data from national official data sources. Industrial gas prices for India, for example, are derived from the Ministry of Petroleum and Natural Gas (2012) and Brazilian industrial coal, gas, oil and electricity prices are obtained from Ministério de Minas e Energia (2013).

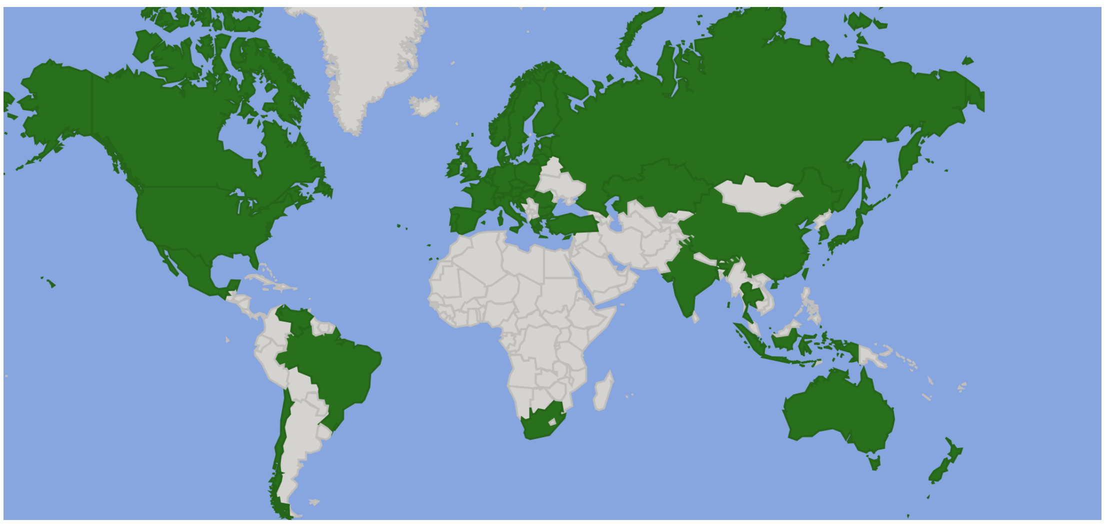
The fuel use data in TOE is derived from the IEA World Energy Balances IEA (2013b) for all countries at the sector level. In order to combine it with the price data, all fuel sub-types are aggregated into four groups (using TOE for better aggregation suitability): oil, gas, coal, electricity. The final amounts of fuel type use per sector serve for the construction of the weights, where a specific weight is calculated as the energy input in TOE of a certain fuel type as share of the total energy input in TOE.

[16] The IEA defines the published industrial energy prices as "the average of amounts paid for the industrial and manufacturing sectors" and "include transport costs to the consumer; are prices actually paid (i.e. net of rebates) and; include taxes which have to be paid by the consumer as part of the transaction and which are not refundable. This excludes value added tax (VAT) paid in many European countries by industry (including electric power stations) and commercial end-users for all goods and services (including energy). In these cases VAT is refunded to the customer, usually in the form of a tax credit. Therefore, it is not included in the prices and taxes columns in the tables." (IEA, 2012).

Table 2: Data sources

Variables	Data source
Industrial energy price	IEA Energy Prices and Taxes (2012), Ministério de Minas e Energia (2013), Ministry of Petroleum and Natural Gas (2012)
Sector fuel use	IEA World Energy Balances (2013b)
Energy price indices	IEA Energy Prices and Taxes (2012)
Exchange rates	World Bank (2013), National Statistics of the Republic of China (Taiwan) (2013)
PPP conversion factor	World Bank (2013)
GDP deflator	World Bank (2013), National Statistics of the Republic of China (Taiwan) (2013)

Table 3: Country and sector coverage



48 Countries			**12 sectors**
Australia	Greece	Poland	Chemical and petrochemical
Austria	Hungary	Portugal	Construction
Belgium	India	Romania	Food and tobacco
Brazil	Indonesia	Russian Federation	Iron and steel
Bulgaria	Ireland	Slovakia	Machinery
Canada	Italy	Slovenia	Mining and quarrying
Chile	Japan	South Africa	Non-ferrous metals
China	Kazakhstan	Spain	Non-metallic minerals
Croatia	Korea, Republic of	Sweden	Paper, pulp and print
Cyprus	Latvia	Switzerland	Textile and leather
Czech Republic	Lithuania	Taiwan	Transport equipment
Denmark	Luxembourg	Thailand	Wood and wood products
Estonia	Mexico	Turkey	Industry average
Finland	Netherlands	United Kingdom	
France	New Zealand	United States of America	
Germany	Norway	Venezuela	

4 Tackling missing data

The IEA energy price data have significant gaps. Where these cannot be filled by other data sources such as data from national statistics offices, we fill data gaps and increase the coverage of the VEPL and FEPI using a simple and transparent approach. Specifically, we look for other observed energy price series which are more complete. In the case of OECD countries, the IEA publishes an industry real price index for each fuel type (oil, gas, coal, electricity) within the same database (IEA, 2012), which tends to have less gaps than the fuel price series themselves. If prices for coal in the UK, for example, are available for some years but missing for others, then we can extract the coal price growth rates over time from the real coal price index for the UK and apply them to the UK coal price data in order to fill the gaps. In this way, our approach relies on observed data rather than statistical imputation methods such as multiple imputation, which is less transparent.[17] If the IEA real price index is also missing for a particular fuel, we then turn to the IEA real general energy price index which is a country level industrial price index averaged across different fuels and apply the growth rates from this index to fill the gaps in the VEPL (but not the FEPI to ensure higher consistency through time by not using potentially different indices per series). For non-OECD countries, the IEA industry real price indices are not available, however, a wholesale price index is available (although with many gaps) for each fuel type, and the growth rate from this is applied, after deflating it appropriately[18]. Applying growth rates from the wholesale energy price to fill gaps in industrial energy price was deemed plausible as they are highly correlated (usually between 75% and 95%) in most countries where both data are available (except for Norway).

For some countries, we used data from the electricity generating sector from the IEA Energy End-Use Prices database to impute some data points. In particular, this refers to the coal price for Mexico, the growth rate in natural gas price for Indonesia and the growth rate in the coal price for Taiwan. In these instances, the levels and correlation of the prices with the industrial sectors are generally very high. For Taiwan, the growth rate in the industry low sulphur oil price is applied to the industry high sulphur oil price, both also being generally highly correlated. [19]

To identify data points that have been imputed using the above methods, a number of variables are created. For the VEPL, *flag_VEPL* takes the value 1 for all observed values (27%), 2 for values imputed with the respective fuel price indexes (19%), 3 for values imputed with the total energy price index (20%) and 0 for missing (33%) (where imputation was not possible). For the FEPI, a variable called *flag_FEPI* takes the value 1 if the data is observed (32%), 2 for index-imputed values with the respective index (15%) and 0 for missing (52%). These identifiers enable users to exclude imputed data points or conduct sensitivity tests.

In some cases, it is not possible to construct a price index because prices are missing for a particular fuel type for all years, hence no growth rates from other dataset can be applied. If the fuel type with

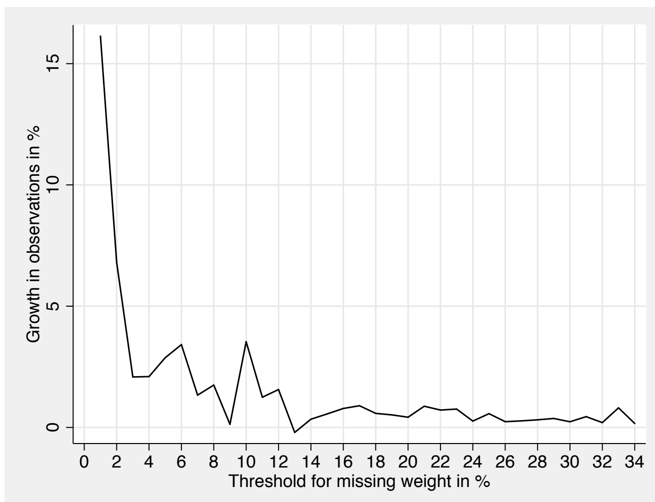
[17] If $IN^j_{i,t}$ is the real price index of fuel j. Then, if $P^j_{i,t}$ is missing, we impute it by $P^j_{i,t} = P^j_{i,t-1} \times (1 + \frac{IN^j_{i,t} - IN^j_{i,t-1}}{IN^j_{i,t-1}})$.

[18] The only small irregularity is the gas price for China, which is imputed through the average growth rate in the wholesale indices of oil, coal and electricity from 1998 until 2004 for the VEPL (but not the FEPI).

[19] The added data points described in this paragraph represent less than 6% of the sample. In order to easily identify the observations where missing values have been filled using these alternative data sources, the variable *price_source* is constructed in the database. It takes the value 1 if one of the price data points comes from the above additions and zero otherwise.

missing prices accounts for a small share of a sector's fuel consumption, then we consider it reasonable to construct the FEPI using the three remaining fuel types. Thus, the FEPI is allowed to be based on less than four fuel types, if the excluded fuel type represents less than 12% of the sectors' total fuel consumption. The 12% threshold was chosen by comparing the number of additional observations gained against the threshold level (Figure 1). As shown, thresholds beyond 12% do not significantly increase the number of observations recovered. The gain in observations numbers is substantial compared to the version which requires all 4 fuel types – non-missing values increase from 47% to 72% (in the FEPI_fw2010 version). If the ignored missing values are random and not systematically biased there is limited harm in statistical inference and even if they are not random, a potential bias introduced is small due to the low weight. Our database contains also a version of the FEPI, where we do not allow this potential exclusion of fuels, which is called *FEPI_allfuels.*

Figure 1: Trade-off between observations gained and accuracy for the FEPI_fw2010.



Notes: Shows the growth in observations by increasing the threshold (on the horizontal axis) for the FEPI_fw2010. After 12%, the additional growth in observations is less than 1% for each percentage point increase in the threshold level.

To deal with missing values in the sectoral fuel consumption data, we used linear interpolation for *TOE* input gaps in the sector-fuel specific series. For missing values that are before or after the first or last available value respectively, we expanded the first available *TOE* value backward in time, and the last available value forward in time, respectively. For entirely missing series, we took the average *weight* across sectors within a country for a particular fuel type (i.e. country average weight) as opposed to the average weight within a sector across countries (i.e. sector average weight). This is because the coefficient of variation (CV) in the average weights is lower and less dispersed within a country, compared to weights within a sector across countries. This also suggests a more fundamental point. On average, the variation in the fuel portfolio of sectors is greater across countries within a particular sector than across sectors in a given country. Fuel portfolios seem to be more driven by country, rather than sector characteristics.

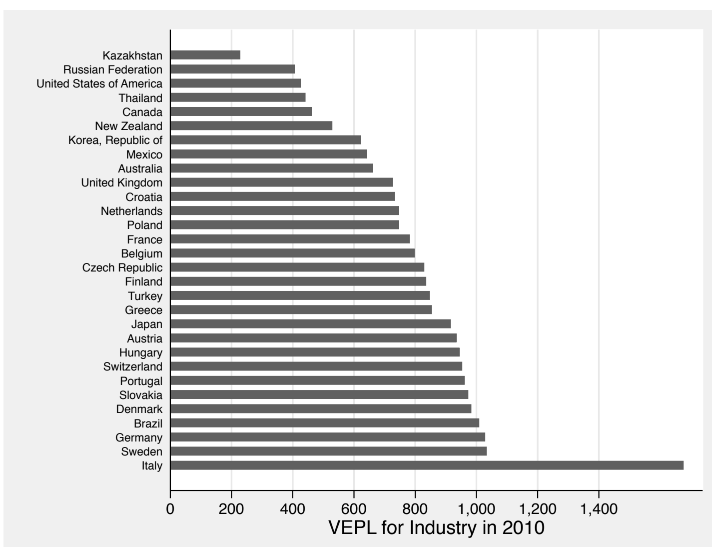
Finally, the IEA price and fuel data do not match exactly regarding their fuel sub-types. As explained above, we took representative prices for both indices, for the VEPL these are consistent across countries to allow for descriptive cross-country comparisons. For this reason, the biofuels and waste category was excluded from calculating the the VEPL as there is no clear association that can be established between the fuel price data and the weights. For example, the wood and wood products sector may use some of its residue as fuel and declare it as biofuels and waste. Biofuels is a significant fuel only in sectors “Paper, Pulp and Print”, “Wood and Wood Products” and “Food and Tobacco” in certain countries and may thus be problematic for the analysis of these sectors. A variable called *biofuel_share* indicates the time-variant share of biofuels in the sector’s total energy consumption to enable to identify country-sectors of particular concern.

5 Country level industrial energy prices: descriptive evidence

5.1 Variation in industrial energy prices across countries

Average industrial energy prices vary substantially across countries. In 2010, the top 10% average energy price was 2.4 times larger than the bottom 10%[20]. The bar chart of Figure 2 shows the variation in the country level average industrial energy prices (CountryVEPL) in 2010 (in 2010$). In general, European countries tend to have higher industrial energy prices, compared with countries in north and central America and Asia. Among OECD countries, lowest energy prices are observed in the USA (426 USD/toe) and in Canada (461 USD/toe). Industrial energy prices are at least twice as large in many other heavily industrialised countries such as Germany, France or Japan. Between the outliers Kazakhstan (230 USD/toe) and Italy (1675 USD/toe) there is a price gap of a factor of six. The patterns are similar when using PPP conversions instead of MER.[21]

Figure 2: CountryVEPL in 2010



Notes: The country level industrial energy price VEPL (in 2010$) is depicted for 2010 using MER.

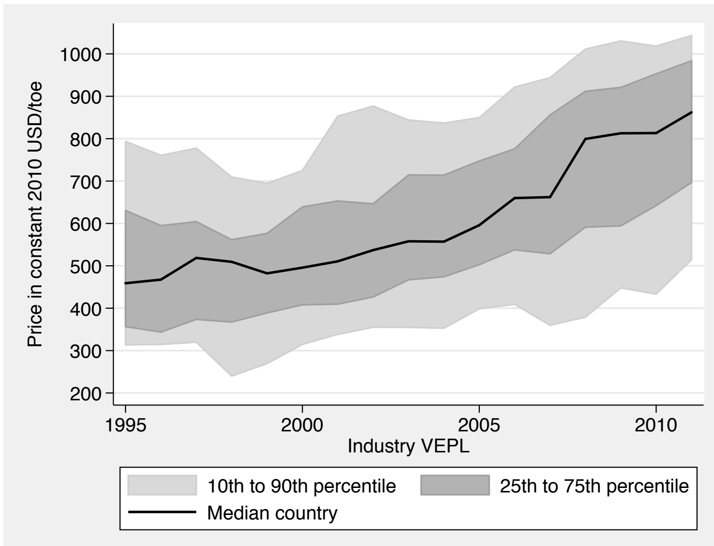
[20] The 5% and 95% percentiles have a similar factor of 2.5.

[21] In PPP terms, in many eastern or southern European countries, such as Poland or Greece, prices are inflated to at least double the US price. The VEPL PPP version can be accessed through the online database.

5.2 Industrial energy prices over time

We find that country-averaged industrial energy prices generally increased over the covered time period, as plotted by the solid line in Figure 3 which represents the median country at a time. There is a clear upward trend from around 2000, which is disturbed temporarily around the financial crisis in 2008/2009. Between 2000 to 2011, energy prices increased by around 70% in real terms for most countries. The dispersion of the CountryVEPL across countries has been stable over time, as shown by the roughly even percentile band widths over time, which show the distribution of countries around the median.[22]

Figure 3: CountryVEPL over time



Notes: The solid line represents the median of the CountryVEPL across countries (MER), and the shaded areas the interquartile range and the 10th and 90th percentile of the distribution of countries at a time.

5.3 The EU-US energy price gap

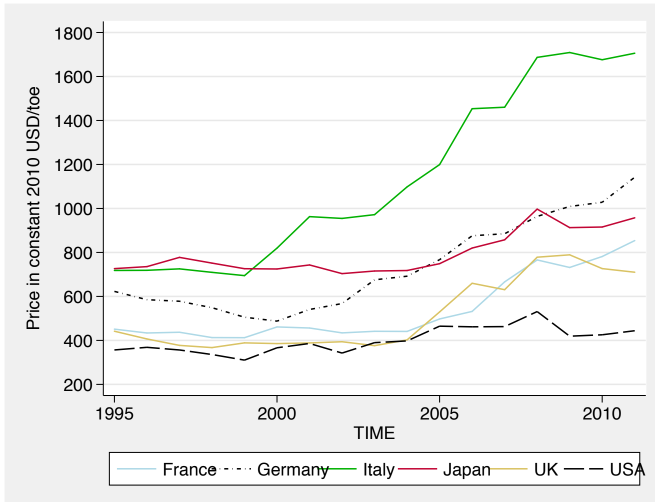
The cost of energy is becoming an increasingly important dimension of industrial competitiveness for European industries, particularly after the shale gas boom in the USA. Analysis of the energy price gap between EU and the USA has been conducted by the European Commission (2014a) using data from the World Input Output Database. Below we replicate their analysis with the key advantage that our energy prices include taxes that are key drivers of cross-country cost differences.

Figure 4 shows the evolution of the CountryVEPL for six major OECD countries. The trend is similar to the evolution of real energy prices in the manufacturing sector reported in European Commission (2014a). However, instead of aggregating the EU27, we show that the energy price gap between the USA and the EU crucially differs depending which EU country is compared. Before 2005, the gap between the US and some EU countries like France or the UK has been close to zero, while it was already large for Italy and Germany. By 2010, the gaps in average industrial energy price with the USA had grown considerably as most countries saw a rapid rise in prices while US prices remained

[22] The coefficient of variation is nearly constant over time. Similar patterns were found in a sub sample of only OECD countries. Using PPP shows a slight divergence over time.

mostly stable. The CountryVEPL for the UK, for instance, is 70% higher than in the US, whereas Germany is 140% and Italy 395% higher in real terms.

Figure 4: CountryVEPL for the six largest OECD economies

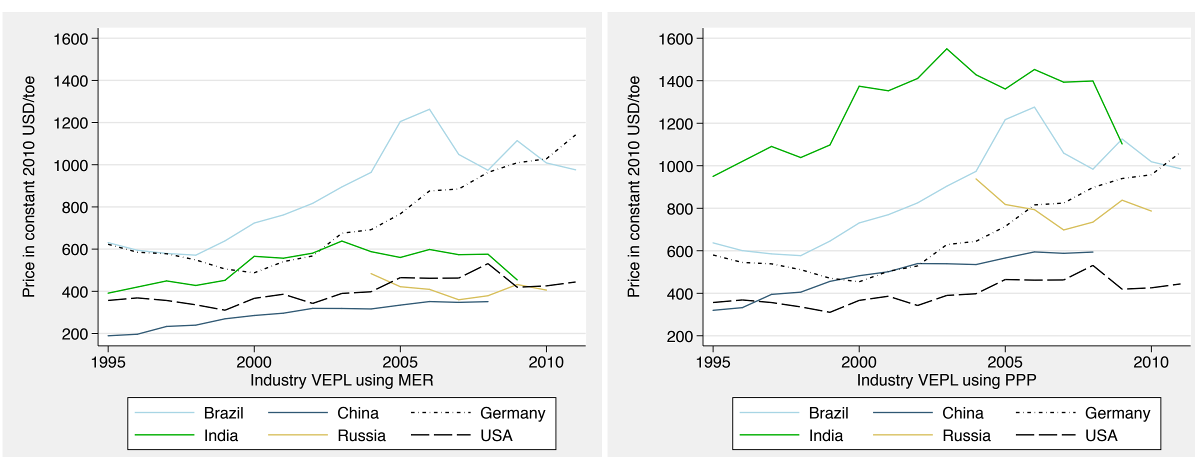


Notes: The panels show the country level VEPL (in 2010$) for selected OECD economies over time, based on MER.

5.4 Industrial energy prices in emerging economies

Figure 5 plots the CountryVEPL for Brazil, China, India, Russia, Germany and the USA for comparison. The left panel uses MER as conversion basis, while the right panel uses PPP rates. We find that energy prices in emerging economies have also been rising during the sample period, but at varying speeds. A comparison of the two graphs reveals the importance of the choice of the underline exchange rates for these countries (particularly for India and Russia).

Figure 5: CountryVEPL for emerging economies



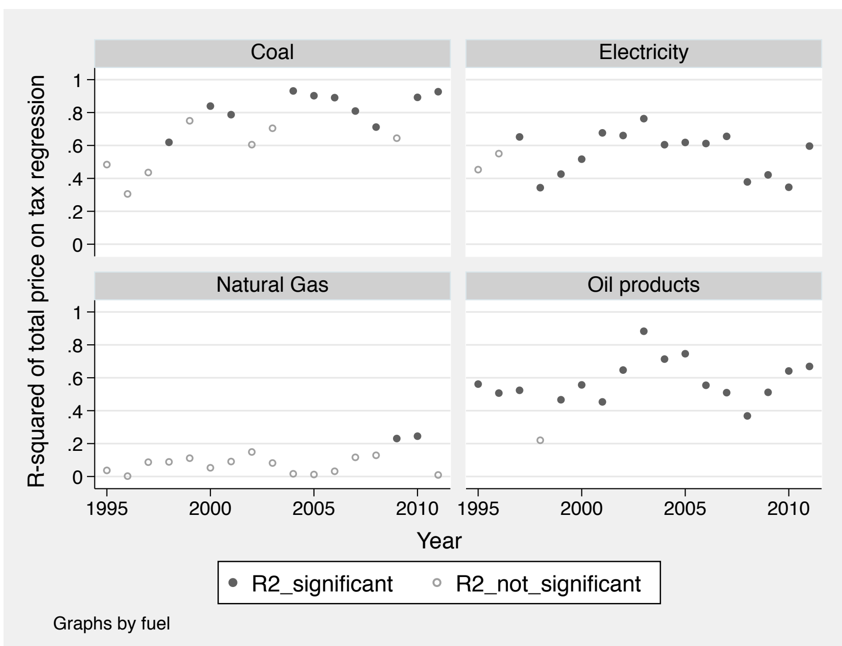
Notes: The panels show the CountryVEPL (in 2010$) for selected emerging economies and two OECD economies over time. The left panel is based on MER and the right on PPP rates.

It highlights the difficulty of comparing energy prices (or any prices for that matter) across countries with varying levels of economic development. For example, China's industrial energy prices are lower than that of the USA in terms of MER but higher in terms of PPP. Among these countries, industrial energy prices in Brazil stayed consistently high both in MER and PPP terms, exceeding price levels of Germany until recent years. Energy prices based on MER and PPP can be viewed as an upper and lower bound, in the sense of how heavily and efficiently the inputs and outputs of the industry are traded on international markets, which rely on MER rather than PPP rates.

5.5 Energy taxation

Energy prices paid by firms reflect various elements that are influenced by both markets and government policy. The energy element consisting of the wholesale energy price (including fuel purchase, production, transport, processing and the constructing, operation and decommissioning of power plants) and the retail price, which is the sale of energy to the consumer. The network element of the price includes the cost of transmission and distribution infrastructure including maintenance and expansion of grids, system services and network losses. On top of these is the tax component, which may also include levies and exemptions. These may include general taxation (the IEA data excludes VAT), or energy specific levies, for example to finance energy and climate policies such as the promotion of energy efficiency or renewable technologies.

Figure 6: Percentage of CountryVEPL variation explained by taxes



Notes: The four panels plot R-squared against time for the associated fuel types. The R-squared are calculated from regressions of the net industry fuel price on a constant and the tax component (based on MER) for a particular year. Solid dots represent R-squared from a significant association at the 5% level for a particular year.

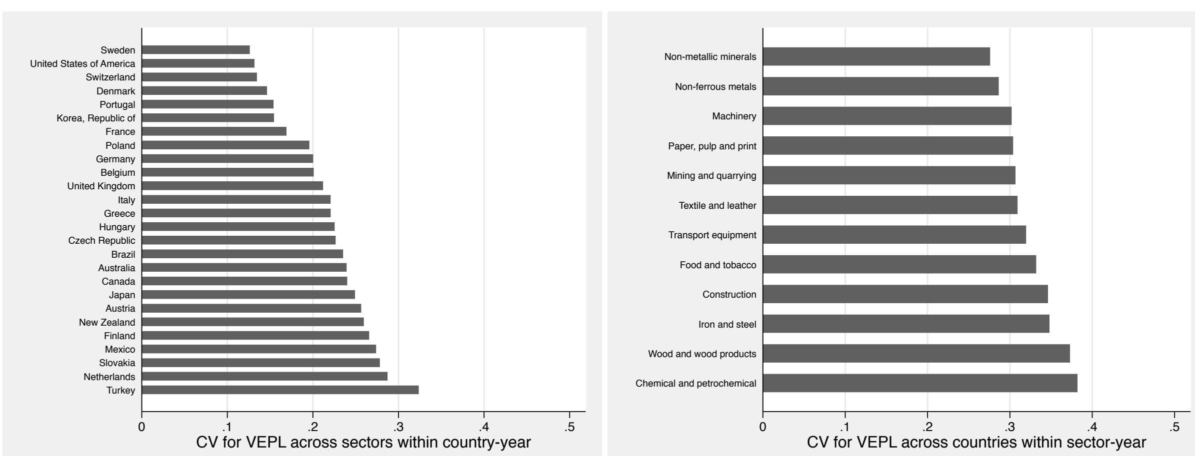
We find that the cross-country variation in the tax component contributes significantly to the variation in the final industrial fuel prices. For a subset of countries and year, mostly OECD countries, the IEA reports also average industrial fuel prices *excluding* taxes. We use this information to calculate implicit taxes. For each year, we regress the after-tax fuel price on the tax component and a constant term. Figure 6 reports the R-squared of each regression.[23] We find that the tax component is able to explain 80% to 90% of the variation in coal prices across countries. For electricity, this is around 60% and for oil, 50% to 80%. The explanatory power of taxes for the variation in gas price is somewhat lower at 20%, as gas prices are strongly conditioned on the geography of transport infrastructure.

6 Sector-level energy prices: descriptive evidence

6.1 Variation in energy prices across sectors

Turning now to the sector level energy prices, we observe that energy prices vary across sectors within a particular country and year. The degree of variation across sectors differs by country, as shown in the left-hand side of Figure 7 that reports the coefficients of variation. Cross-sectoral energy price gaps are more pronounced in Turkey, the Netherlands and Slovakia but less in Sweden, the US and Switzerland. Recalling that variations in prices across sectors are derived from differences in fuel portfolios, the greater heterogeneity observed in Turkey can be related to its high electricity price and the fact that the machinery sector, for example, is highly electricity intensive compared to the construction sector that uses mainly coal. Sweden, on the other hand, has more equal energy prices as its industrial sectors are more similar to each other in their energy portfolio compared to Turkey. Comparing across industrial sectors, there is more variation in energy prices across countries in the chemicals and petrochemicals, wood, iron and steel and construction sectors, but less variation in the non-metallic minerals, non-ferrous metals and machinery sectors (right-hand side of Figure 7). Comparing the two charts in Figure 7, energy prices vary more across countries for the same sector, than they do across sectors within the same country.

Figure 7: CV for the VEPL across countries in 2010

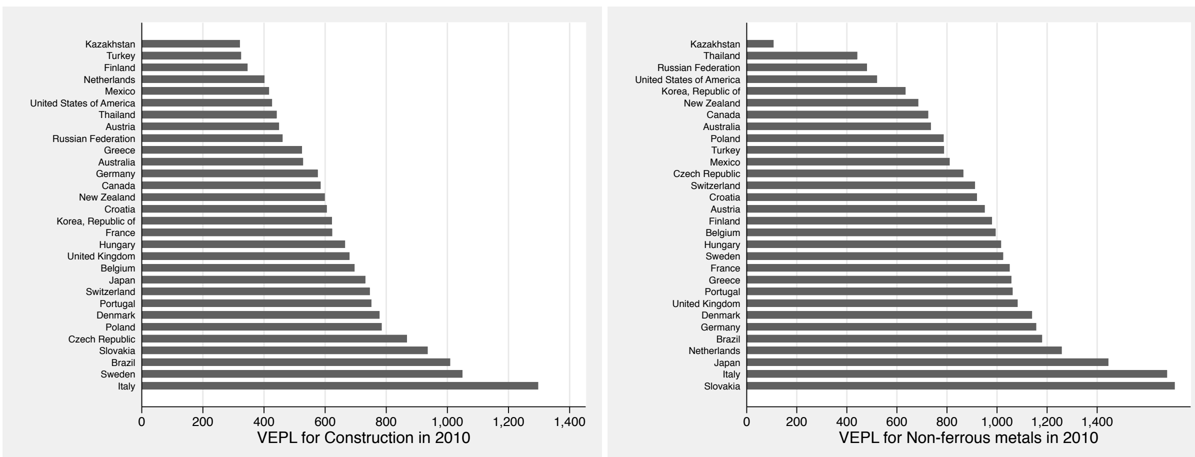


Notes: The coefficient of variation (CV) is shown, based on the VEPL in MER.

[23] The R-squared is used as it is straightforward to interpret the percentage of the variation, but it should be noted that it is the correlation that is of interest here and not causality. The number of observations (countries) is typically around 15-20, except for coal, where the number of observations are lower (6-8).

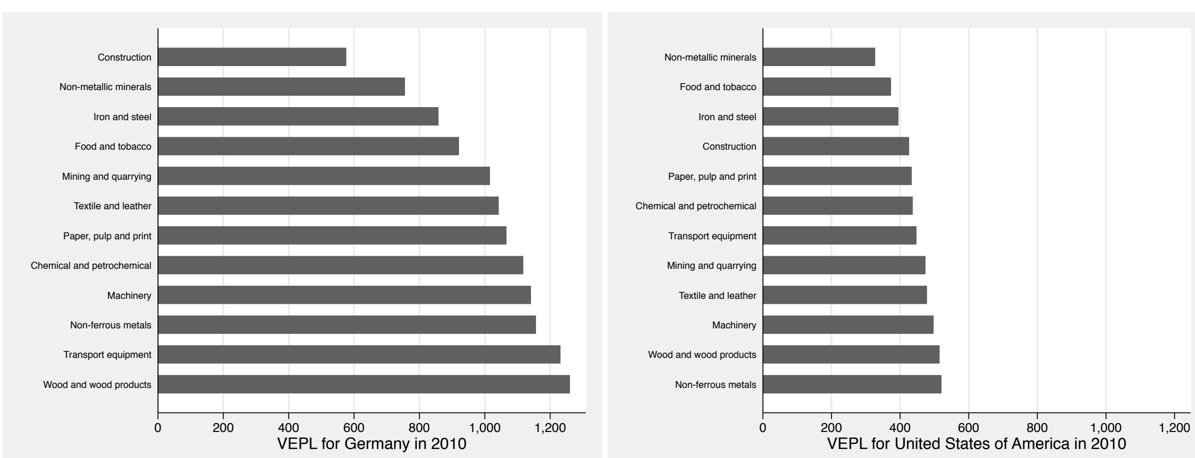
Figure 8 shows the variation in energy prices for two particular sectors – construction (left), non-ferrous metals (right) – across countries in 2010. Taking the price gap between Germany and the US as an example, the average energy price in Germany is 35% higher in construction and 120% higher in the non-ferrous metals sector that is electricity intensive. Figure 9 shows how energy prices vary across sectors in Germany much more than they do in the US for the same year. Interestingly, the ordering of sectors in terms of the level of energy price is similar, which is often the case in other countries as well. Non-metallic minerals, construction and iron and steel tend to have low energy prices whereas the non-ferrous metals, wood and wood products and machinery sectors are relatively more exposed due to underlying fuel mix.

Figure 8: Construction and non-ferrous metals VEPL (MER) in 2010



Notes: VEPL (in 2010$) for the construction sector (left) and the non-ferrous metals sector (right) in 2010. All panels are based on MER.

Figure 9: VEPL (MER) for different sectors in Germany and the USA in 2010

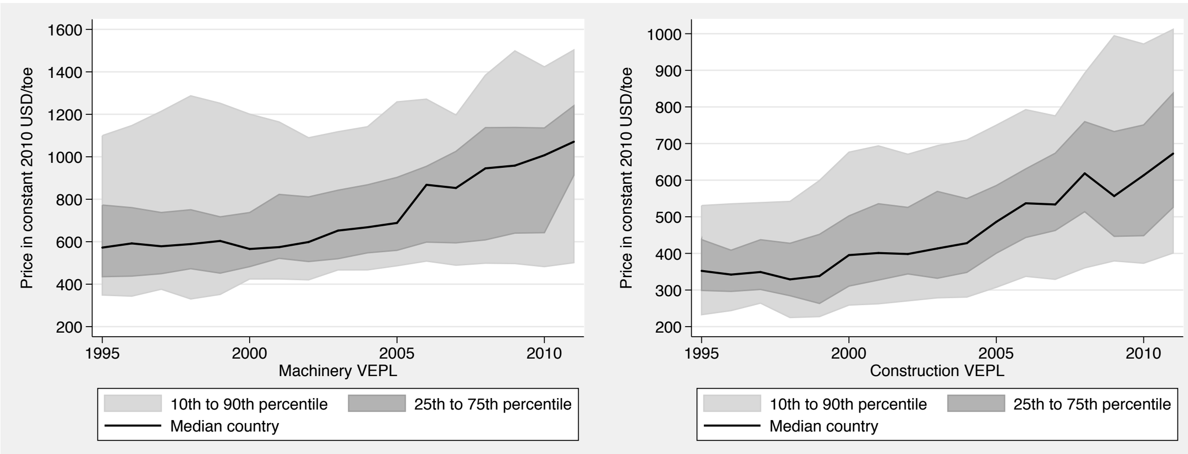


Notes: VEPL (in 2010$) for all different sectors in Germany (left) and the USA (right) in 2010. All panels are based on MER.

6.2 Divergence and convergence of energy prices within sectors

We find that energy prices are converging internationally in some industrial sectors but diverging in others. For example, in the machinery sector (Figure 10 left) energy prices are generally rising while their dispersion is, if anything, decreasing over time suggesting convergence in energy prices. In other sectors such as the construction sector, dispersion of the energy price across countries are increasing over time (Figure 10 right).

Figure 10: Dispersion of the VEPL across countries within selected sectors.



Notes: The solid line represents the median of the industry VEPL across countries, and the shaded areas the interquartile range and the 10th and 90th percentile of the distribution of countries at a time for the specified sectors. VEPL is based on MER

6.3 Electricity price and share of fuel consumption

We find that cross-sectoral differences in fuel mix accounts for part of the difference in energy prices. Specifically, differences in the share of electricity in the total fuel consumption is a major source of variation, not only because electricity is the most expensive carrier but also because it is the most important carrier for all sectors, accounting for more than 50% in all sectors except the construction and non-metallic minerals sector (see Table 4 which reports a measure that captures the importance of a fuel component in the VEPL).[24]

[24] We do this by multipling the price and the weight of a particular fuel and divide it by the VEPL, that is: $\frac{F_{ist}^{fuel}}{F_{ist}^{total}} \cdot P_{it}^{fuel}/VEPL_{ist}$. An alternative by country representation conveys the same message of very high electricity shares.

Table 4: The importance of the components of the VEPL

	Oil	**Gas**	**Coal**	**Electricity**
Chemical and petrochemical	14%	19%	3%	64%
Construction	38%	12%	5%	45%
Food and tobacco	15%	20%	4%	62%
Iron and steel	7%	16%	14%	63%
Machinery	9%	14%	2%	76%
Mining and quarrying	20%	11%	3%	66%
Non-ferrous metals	9%	12%	3%	77%
Non-metallic minerals	18%	22%	14%	46%
Paper, pulp and print	11%	13%	3%	73%
Textile and leather	13%	16%	2%	69%
Transport equipment	10%	15%	3%	71%
Wood and wood products	11%	9%	4%	75%
Total	**15%**	**15%**	**5%**	**65%**

Notes: The percentages shown are calculated as the price times weight for the associated fuel divided by the VEPL. The reported numbers are averages for all countries and years.

6.4 Fuel switching

Sectors' fuel portfolios can vary over time as a response to changes in energy prices but also due to changes in factors of production, technological advances and other industry-specific shocks. Fuel switching varies notably across sectors and countries. In the face of energy price shocks, for example, the ability to switch fuel type is closely linked to the flexibility and adaptability of the production process, capital turnover rates and the rate of technological change that characterise a particular sector or country. Considering the chemical and petrochemical sector (Figure 11), for example, we observe stable consumption shares over time in Japan and Russia (from 2000). On the other hand, in Italy the chemical and petrochemical sector has experienced a notable switch from gas to electricity since 2003, partly due to a process of outsourcing the electricity generation process to energy companies, while in Sweden, around the same period, the substitution occurred from oil to electricity.

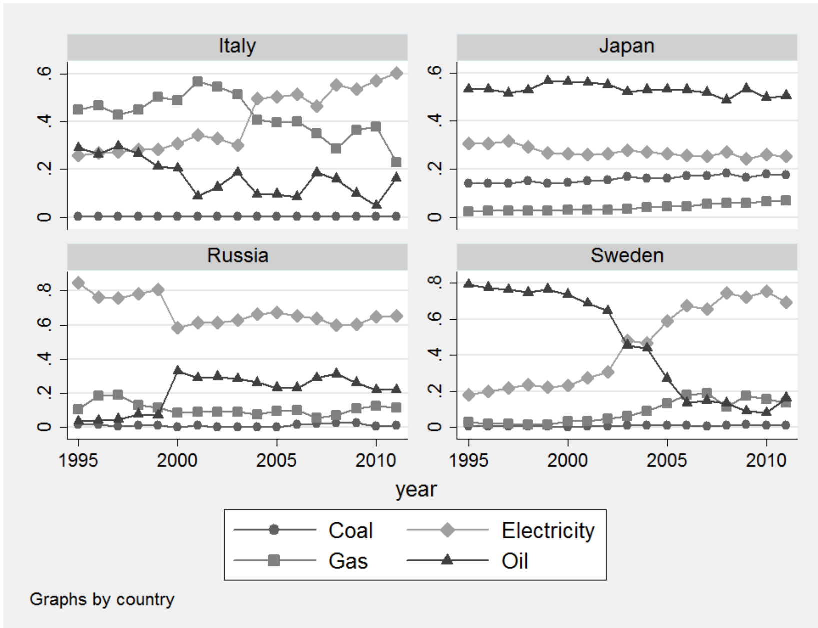
While there is a large degree of heterogeneity across sectors and countries, in general we observe gradual changes in fuel shares over time in most sectors. This has important implications for the use of our VEPL in empirical analyses that assume the exogeneity of a sector's fuel mix. We, therefore, recommend the use of the FEPI, either directly or as instrument, for estimations in a panel data setting.

6.5 Energy taxation

To what extent do tax levels vary across sectors within a country? Because sector-level variations in the VEPL are entirely driven by consumption weights, in order to explore this question we use a new database collected by the OECD (2013b) on effective tax rates on different fuels at the sector level in OECD countries[25]. First, we calculate the coefficient of variation (CV) of the tax rates across sectors for each country and fuel (oil, coal, gas, electricity). We find that the energy tax rates vary across sectors for coal and oil, whereas very similar tax rates tend to be applied across sectors for electricity

[25]The date of the tax rates is 1st April 2012, however, as fuel weights are only available until 2011 at the moment of this paper, we take these tax rates as proxy for 2011 tax rates and treat them as such.

Figure 11: Fuel consumption shares in the chemical and petrochemical sector



Notes: Missing data points in fuel consumption shares are calculated as described in Section 4.

and natural gas (dark bars in Figure 12). These variations across sectors within a country are much smaller compared with the variation in tax across countries for the same sector (light bars).

The *observed* variation in energy taxation across industrial sectors in OECD (2013b) can be contrasted with that obtained using the VEPL, which *proxy* price variation across sectors. To do so, we use the OECD energy tax data to construct a "VEPL_tax" indicator, in which sector variation in energy prices are introduced using observed variations in energy tax levels.[26] Contrasting VEPL_tax and the original VEPL, we find very similar levels of dispersion, both in terms of variation across sectors within countries, and across countries within sectors. The correlation between VEPL and VEPL_tax is very high (around 0.99) but this is not surprising because the within variation in both VEPL indicators are driven mostly by sector-specific fuel weights. Thus, while there are large variations in taxes across countries, we observe limited variation in taxes across sectors within a country. That energy taxes vary little across sectors within a country suggests the VEPL can be considered a reasonable measure of a sector's exposure to energy price regulations.

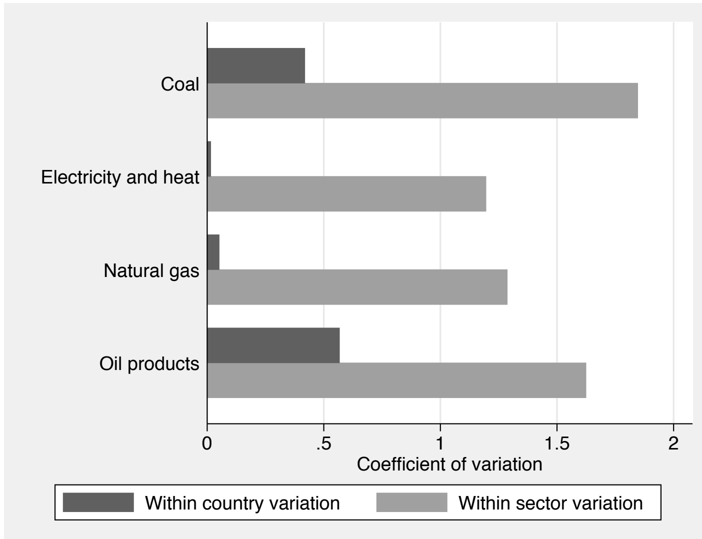
7 Energy prices and climate policy stringency

7.1 Rationale

Governments have two non exclusive solutions to introduce incentives to cut GHG emissions generated by the economy. First, they can introduce policy instruments directly addressing GHG emissions, either

[26] Some countries in the average industry price data from IEA (2012) may have weighted the taxes across industrial sectors by fuel usage to arrive at the industry average price including taxes. However, the accompanying manual is not clear about this and seems like there is no harmonised methodology across all countries.

Figure 12: Comparing sector-level tax variation within countries across sectors (dark) with across countries within sectors (light)



Notes: The dark grey bars are the mean of the coefficients of variation in taxes for each country, across its industrial sectors. The light grey bars are the mean of the coefficients of variation in taxes for each industrial sector, across all countries. The year of the data is 2012 and is from the OECD (2013b).

"command and control" instruments such as New Source Performance Standards in the U.S. or economic instruments such as carbon tax and cap-and-trade mechanism that generate explicit carbon prices. Second, governments can tax GHG-intensive fuels to give companies incentives to consume less energy and to switch to cleaner fuels. Both solutions increase the energy price faced by manufacturing firms.

Policy instruments directly addressing GHG emissions raise the cost of producing electricity in the power sector. This reduces electricity supply and increases the equilibrium price of electricity. Ultimately, industrial energy prices increase as electricity constitutes a large share of industrial energy consumption. Second, governments support energy production and consumption in a number of ways. The OECD (2013a) inventory of estimated budgetary support and tax expenditures for fossil fuels reports over 500 measures in all 34 OECD countries. The IEA (2011) estimated fossil-fuel subsidies in 37 developing economies to have totalled 409 billion USD in 2010. Because fuel subsidies lower the price of energy, they are at odds with strict climate policies even if they are implemented for various policy reasons that are indirectly related to climate policy[27]. A country that heavily supports fossil fuel consumption through low energy price can, therefore, be reasonably considered to have a lax climate policy other things being equal[28]. Ultimately, industrial energy prices can be viewed as a proxy for climate policy stringency because they can be both an instrument for environmental policy and/or the result of climate policy or energy taxation.

[27]Energy subsidies are implemented to protect industries from international competition while energy taxation aims to generate revenue for government.

[28]As an illustration, IEA and OECD modelling suggest that phasing-out fossil-fuel consumption subsidies could cut GHG emissions significantly (IEA et al., 2011).

7.2 Other proxies of climate policy stringency

Various proxies have been proposed in the literature to measure environmental policy stringency but few are specific to climate policy. van Soest et al. (2006) pioneered this field by measuring the stringency of energy policy for two industries in nine European countries. They calculate stringency as the difference between the shadow price of energy and what they call the undistorted market purchase energy price. The shadow price is defined as the benefit of using one additional unit of energy input that cannot be captured because of the policy constraints such as fuel economy standards. It is estimated by the minimisation of a generalised Leontief cost function. Sauter (2014), uses an extensive database of CO_2 emissions to construct a CO_2 policy input index and a CO_2 performance index. Aldy and Pizer (2014a) evaluate several metrics of GHG mitigation effort. They compare several measures including changes in emissions, emissions intensities, emission abatement, carbon prices, energy prices and taxes, and mitigation costs.

To advance this literature, Brunel and Levinson (2013) compare and evaluate several measures of environmental policy stringency and find very low levels of correlation between several measures. They identify four main obstacles to measuring stringency – multi-dimensionality, simultaneity, industrial composition and capital vintage – and suggest a new proxy, an industry-adjusted emission intensity, that tackles most of these barriers. In Section 7.4, we evaluate how the Variable-Weight Energy Price *Level* (VEPL) performs as a proxy for regulatory stringency.

7.3 Advantages and limits of using energy price as a proxy for climate policy

The first obstacle identified by Brunel and Levinson (2013) is multi-dimensionality of environmental regulations. Governments regulate pollutants released in different processes, targeting different economic agents, and using different regulatory strategies e.g. setting emission standards, using economic instruments or by mandating firms to use specific technologies. The multiplicity of dimensions makes it difficult to summarise country regulatory stringency into a single measure that is comparable across countries. Moreover, subsidies supporting fossil-fuel consumption are not only prevalent and numerous but also difficult to identify and measure, so as to compare across countries. Section 7.1 argued that the industrial energy prices are the direct and/or indirect result of climate policy and energy taxation. Observed industrial energy prices, therefore, can partly summarise the multiplicity of policy mechanisms into one single measure. An alternative and frequently used approach to addressing multidimensionality is to build a composite index.[29] These, however, are artificial measures and differences between countries do not usually have a meaningful economic interpretation. In that respect, the cardinal nature of energy prices present a clear advantage. Yet as pointed out by Aldy and Pizer (2014a), energy prices capture the effect of some regulatory instruments but not all. For instance, they do not capture efficiency standards that aim to reduce energy consumption in the industry.

The second obstacle identified is simultaneity. Regulatory stringency, chosen by policy makers, likely depends on a country's pollution levels, posing a major challenge for researchers that aim at identifying

[29] See Smarzynska and Shang-Jin (2003), Cole and Elliott (2003), Kellenberg (2009), Kalamova and Johnstone (2011), and Fredriksson and Millimet (2004).

the impact of climate policy on pollution outcomes. We argue that this bias is less pronounced with energy prices because they are not likely to be driven by emission levels.

The third obstacle to the measuring of climate policy stringency is industrial composition. Consider two countries that have identical fuel prices before taxation. The two countries can apply the same regulatory stringency i.e. identical sector-level fuel taxes but exhibiting different country-level fuel prices due to different sector composition – a sector where taxation is high may be a more or less significant part of a country's economy. The extent to which industrial energy prices suffer from this measurement error depends on how they are constructed. Our index weights fuel prices by their consumption shares. In doing so it might suffer from a composition effect because overall fuel consumption reflects the composition of a country's industry. On the other hand, using a simple average of fuel prices would not necessarily improve the way the index captures stringency because a country's fuel composition does matter. For example, a very high energy price for a sector that represents a negligible share of the economy should not necessarily be interpreted as a sign of strict climate policy when compared to a country with similar prices but where the same sector represents a very large share of the economy.

The last obstacle identified by Brunel and Levinson (2013) is capital vintage. Some regulations are 'grandfathered' meaning that they apply only to new or significantly modified production plants. Considering for example the power generation sector, in the short run, energy prices can only proxy for regulations that are not grandfathered, e.g. a carbon tax. However, because in the long run grandfathered regulations also constrain the rise of power generation capacity, they reduce energy supply with consequent effects on energy prices. As a result, industrial energy prices are less affected by capital vintage bias.

Energy price as a proxy for climate has two other advantages in contrast to other measures. First, it does not capture green behaviour motivated by factors other than regulation. When using PACE data, the applied researchers must assume that the abatement costs are incurred in reaction to regulation only. But firms incurs PACE for other reasons such as signalling to consumers their green production process or simply reducing input cost through the introduction of integrated technologies that reduce input use per unit of output. Second, energy price is a result of 'enforced' regulations. Measures based on climate laws count capture publicised stringency and fail to capture actual stringency faced by firms.

Perhaps one of the major drawbacks of using energy prices as a measure of climate policy stringency is that they also capture price distortion resulting from factors other than environmental regulations such as a country's endowment of mineral fuels, the quality of power infrastructure, the state of technology related to the production of mineral fuels and electricity, and the structure of the energy market. In empirical investigations, time invariant determinants of energy prices, such as mineral fuel endowments, can be captured by country fixed effects in a panel data setting. Unfortunately, no immediate solution is available to deal with time-varying confounding factors. However, if one assumes that these factors vary less rapidly over time than regulatory factors, then energy price variations should capture changes in regulatory stringency. Aldy and Pizer (2014a) conclude that mitigation effort cannot be summarised into one single measure. Relying on several measures is preferable, but this is complex to implement in empirical analysis. This paper shows that despite some drawbacks, energy prices are a sound and practical measure of climate policy stringency for industrial sectors in light of the methodological obstacles faced by previous measures.

7.4 Correlations between energy prices and alternative measures of climate stringency

Brunel and Levinson (2013) estimate the correlation between four measures of stringency. They find very small correlation coefficients which suggests that overall, previous measures poorly captured the same aspects of environmental stringency.[30] This analysis differs in several ways. First, we focus specifically on emissions reduction policies rather than considering environmental policy broadly. Second, our comparison is more comprehensive and includes eight stringency measures to cover the full spectrum of approaches developed so far in the literature. Among these different approaches we select only those measures pertaining to energy and climate policy. In addition, we also implement the new methodology proposed by Brunel and Levinson (2013), that uses an industry-adjusted emission-intensity measure to proxy environmental policy, and include this in our comparison. The construction of these measures are detailed in Appendix B. The sources for all measures of stringency are detailed in Table 5.

The first group of measures we consider are "naïve" in that they suffer importantly from at least one of the obstacles described above. These naïve measures are country energy intensity, CO_2 emission intensity, and country stock of climate law. Energy intensity is calculated as the ratio between a country's total energy use and its GDP. Similarly, emission intensity equals the ratio between a country's total CO_2 emission and its GDP. We expect that, at a given level of GDP, a country with stricter regulation uses less energy and emits less emissions. Energy intensity and emission intensity are naïve measures of stringency because they do not take into account a country industrial composition. The third naïve measure belongs to the regulation-based approach. It is the cumulated stock of climate laws adopted at the national level. We discount the stock by an annual depreciation rate of 15% to reflect the fact that new laws weight more or may replace older laws. The stock of climate laws is naïve for three mains reasons. First, different laws might have not the same level of stringency but they have equal weight in the stock calculated. Second, even if laws are comparable over time within countries, it is likely that they are not comparable between countries. Lastly, laws are stringent only if properly enforced.

The second group of measures considered belongs to the general composite indexes approach. The World Economic Forum (WEF) environmental stringency measure is based on executives survey. It is an ordinal measure computed from scores given by executives to the question: "How would you assess the stringency of your country's environmental regulations?". Scores vary from 1 = "very lax" to 7 = "world's most stringent". Another general composite index is the 2014 Environmental Performance Index (EPI) is constructed through the calculation and aggregation of 20 indicators reflecting national-level environmental data[31]. These indicators are combined into nine categories: health impacts, air quality, water and sanitation, water resources, agriculture, forests, fisheries, biodiversity and habitat, climate and energy. We select the component of the 2014 EPI dedicated to climate change and energy. This element weights 25% in the 2014 EPI and is computed based on country trend in CO_2 emissions per KWh, change of trend in carbon intensity, and trend in carbon intensity.

[30] High coefficients of correlation between the measures would suggest that they capture the same underlying variation. Note that this is a necessary but not sufficient condition for these measure to capture climate and energy policy stringency.

[31] For robustness, we also calculate the correlation with the 2012 EPI. Both indices are available for 2010.

Table 5: Data Sources for measures of climate regulatory stringency used in Table 6

Indicator	Description	Data source
Energy intensity	Total energy use (kg of oil equivalent) per $1,000 GDP (constant 2005 PPP USD)	World Bank (2013)
CO_2Emissions Intensity	Total CO_2 emissions in kg per 2011 PPP USD of GDP	World Bank (2013)
Stock Climate Law	The discounted (15%) stock of climate law from the GLOBE database	(Nachmany et al., 2014)
WEF Env. Stringency	An ordinal measure computed from scores given by executives to the question: "How would you assess the stringency of your country's environmental regulations? (1 = Very lax ; 7 = Among the world's most stringent)"	Executive Opinion Survey from the World Economic Forum (2010)
The Environmental Performance Index (EPI) 2012 version	Ranks 132 countries on 22 performance indicators in several policy categories: Environmental Health, Water, Air pollution, Water Resources, Biodiversity & Habitat, Forests, Fisheries, Agriculture, and Climate Change.	(Emerson et al., 2012)
EPI (2014 version)	Calculation and aggregation of 20 indicators reflecting national-level environmental data. These indicators are combined into nine issue categories: health impacts, air quality, water and sanitation, water resources, agriculture, forests, fisheries, biodiversity and habitat, climate and energy.	(Hsu et al., 2014)
Climate Change & Energy of 2014 EPI	One of the components of the EPI (2014) and weights 25% in the EPI (2014). It is computed based on country trend in CO_2 emissions per kWh, change of trend in carbon intensity, trend in carbon intensity.	(Hsu et al., 2014)
Industry Adjusted Emission Intensity (IAEI) combustion and process	Covers 6 sectors: construction, machinery, textiles, transport equipment, wood and wood products, and other sectors (ISIC 4 Divisions 22, 31 and 32). The variable is computed for 22 countries: Austria, Belgium, Columbia, the Czech Republic, Germany, Denmark, Eritrea, Finland, France, Hungary, Italy, Jordan, the Kyrgyz Republic, the Republic of Korea, Morocco, Mexico, Netherlands, Senegal, Slovenia, Sweden, the United States of America, and Vietnam	Brunel and Levinson (2013) 's methodology using data on CO_2 emissions from fuel combustion comes from IEA (2013a) and data on CO_2 process emissions come from UNFCCC (2013)
IAEI combustion	Computed using only CO_2 emissions from fuel combustion to increase data availability. It covers 9 sectors: chemical, construction, food and tobacco, non-metallic minerals, paper pulp and print, textiles, transport equipment, wood and wood products, and other sectors (ISIC 4 Divisions 22, 31 and 32). The variable is computed for 32 countries: Austria, Azerbaijan, Belgium, Bulgaria, Brazil, Canada, Colombia, Cyprus, the Czech Republic, Germany, Denmark, Egypt, Eritrea, Estonia, Finland, France, Hungary, Italy, Jordan, Japan, the Kyrgyz Republic, the Republic of Korea, Sri Lanka, Lithuania, Morocco, Mexico, Malaysia, Netherlands, the Russian Federation, Senegal, Slovenia, and Vietnam.	

Table 6: Correlation between VEPL and alternative measures of climate regulatory stringency for 2010

Coefficient of correlation (Obs.)	VEPL Industry	Energy Intensity	CO_2 Emissions Intensity	Stock Climate Law	WEF Env. Stringency	2012 EPI	2014 EPI	Climate & Energy of 2014 EPI	IAEI combustion and process	IAEI combustion
VEPL Industry	1 (30)									
Energy Intensity	-0.65*** (30)	1 (128)								
CO_2 Emissions Intensity	-0.67*** (30)	0.41*** (126)	1 (182)							
Stock Climate Laws	0.32 (22)	-0.20 (59)	-0.03 (64)	1 (65)						
WEF Env. Stringency	0.31* (30)	-0.26*** (118)	-0.05 (138)	0.08 (61)	1 (59)					
2012 EPI	0.57*** (30)	-0.40*** (124)	-0.38*** (127)	0.17 (61)	0.64*** (139)	1 (132)				
2014 EPI	0.44** (30)	-0.38*** (126)	0.20*** (171)	0.15 (63)	0.73*** (139)	0.66*** (132)	1 (178)			
Climate Change & Energy of 2014 EPI	0.45** (30)	-0.14 (107)	-0.17* (125)	-0.01 (54)	0.26*** (111)	0.28*** (111)	0.48*** (129)	1 (129)		
IAEI combustion and process	0.59** (14)	-0.39* (22)	-0.41* (22)	0.33 (15)	0.70*** (21)	0.74*** (22)	070*** (22)	0.66*** (19)	1 (22)	
IAEI combustion	0.77*** (16)	-0.47*** (32)	-0.44** (32)	0.39 (18)	0.75*** (31)	0.66*** (32)	0.63*** (32)	0.22 (29)	0.92*** (20)	1 (32)

* $p < 0.1$, ** $p < 0.05$,*** $p < 0.01$. All data refer to 2010. Number of observations in brackets.

The last group contains industry-adjusted emission intensity (IAEI) measures. We calculate these measures based on the methodology proposed in Brunel and Levinson (2013). Their approach is based on Keller and Levinson's industry-adjusted compliance cost measure of environmental stringency. As argued by Brunel and Levinson (2013), this measure has many advantages compared to previous ones. Instead of using compliance cost, for example, that suffer from several biases[32], they propose to use emission levels of pollutant. We implement their measure with CO_2 emissions making it specific to climate change and energy policy. The main merit of this index is to tackle, although not completely, the industrial composition bias problem in measuring climate and energy stringency[33]. This measure is cardinal and, therefore, captures different degrees of stringency. Given these desirable properties, we believe that the IAEI is so far, as far as we are aware, the most appropriate way to capture climate and energy policy stringency. As detailed in Appendix B, we implement two versions of the IAEI according to the scope of CO_2 emissions considered.

Table 6 shows the estimated coefficients of correlation between the CountryVEPL and alternative measures of regulatory stringency for 2010. We chose 2010 for two mains reasons. First, it has greater data availability. Second, 2010 better depicts the recent trend in climate policy stringency that started in 2005 with the launch of the EU ETS Phase I. We find that industrial energy prices are positively correlated with every alternative measures of stringency except two: energy intensity and the stock of climate laws. The negative correlation between industrial energy price and energy intensity is not surprising since the higher energy prices induce greater efficiency and, therefore, less energy consumption per unit of output. We do not find a significant correlation between industrial energy prices and the stock of climate laws. As the stock is not correlated with any other measures, we believe it fails to capture climate policy stringency.

The correlation are relatively high for four of the alternative measures: energy intensity, emission intensity, the 2012 EPI, and the two versions of the IEAE[34]. We obtain similar results when computing the correlation coefficients for every year between 2004 and 2009.[35] This contrasts with the weak correlations obtained by Brunel and Levinson (2013) between energy intensity and other measures of stringency including EPI, Pollution Abatement Cost and Expenditure, and the environmental stringency variable from the WEF survey. The highest coefficient we find (0.77) refers to the IAEI-combustion measure, which is our favoured measure given its desirable properties. IAEI-combustion covers a higher number of sectors than IAEI-combustion-and-process and thus better represents a country's industrial composition. In comparison with the latter the IAEI-combustion show a higher correlation with energy prices most likely because energy prices directly influence the quantity of fuel to consume and do not directly relate to process emissions. This results supports the use of CountryVEPL as a proxy for climate policy stringency at the country level. Its main advantage over the IAEI is that it is available for many more countries and years, which is a clear practical advantage for empirical applications.

[32]For example, it is difficult to correctly report compliance costs from 'integrated' green technologies as they may have been adopted to decrease energy expenditure and not specifically to cut emissions

[33]The more detailed is the sector disaggregation, the better the industrial composition bias is tackled.

[34]Note that the coefficient is negative with the energy intensity and the emission intensity because the higher the country stringency, the lower its energy intensity and its emission intensity.

[35]Tables available upon request. The IEAI variables are not computed for these years.

7.5 Limitations of VEPL as a proxy for emissions policy

Our country-level VEPL does not capture the stringency towards CO_2 emissions generated by processes other than fuel combustion. Industrial production emits CO_2 through fossil fuel combustion and other processes that do not involve combustion. Process GHG emissions are, therefore, the by-products of industrial processes generated most of the time by a chemical reaction and are particularly relevant in the cement and metal sectors. When process emissions represent a high share of total GHG emissions, our country-level VEPL might not be a good proxy of climate policy stringency.

Another issue is that electricity is not only produced by emissions intensive fuel combustion, but also by renewable sources and nuclear power. In theory, electricity production through renewable sources bears higher costs. Supporting renewable energy is a form of emission reduction policy that is, therefore, coherent with higher energy prices. However, a problem arises with nuclear power. It has lower greenhouse gas emissions than any combustion-based fuel source. This means we cannot compare countries like Italy, that has no nuclear plants, with France whose energy production depends for 85% on nuclear. As nuclear production costs are low, then the VEPL for Italy is higher than that of France, but whether or not emissions policies are less stringent in France is debatable. On the contrary, it could for example be argued that France has a stricter climate policy than Italy that favours low-carbon power generation. One way to control for this would be to gather data on the share of electricity produced by nuclear plants, and take this into account when comparing country-level VEPLs to infer countries relative regulatory stringency. In other words, we should only compare countries with similar shares of nuclear capacity.

Whereas the IAEI tackles the industrial composition bias (even though this is not perfect since the sector-level data used here are still broad and combines many different industries), it was not possible to address the industrial composition bias in the VEPL, given that energy prices are available only at the country level. In addition, as acknowledged before, the VEPL can also capture factors unrelated to stringency, while this is less of a concern with the IAEI. Of course, it is also possible that some confounding factors are also affecting the IAEI. For example, two steel plants located in different countries with the same level of energy consumption may have different emission intensity levels even if regulatory stringency is identical, possibly due to different technologies. However, the existence of these other factors is less obvious than in the case of energy prices. The high correlation between the IAEI and the CountryVEPL, however, is encouraging and suggests that both proxies may be useful in providing quantitative measures for empirical investigations into the impact of climate policy instruments.

8 Conclusions

The lack of good and comprehensive measures of relative emissions policy stringency has been a major obstacle for advancing empirical analysis on whether the frontrunner countries in tackling carbon emissions will harm or boost the competitiveness of the domestic sectors they regulate. In particular, there is limited information about the relative stringency of policies in the emerging economies, and this is problematic because the regions undertaking relatively ambitious climate policy such as the EU are most worried about competition from these economies with rapidly growing industrial output.

This paper has shown that there is relatively high correlation between energy prices (i.e. the VEPL or Variable-weights Energy Price Level constructed in this paper) and various measures of policy stringency. We considered both existing policy stringency measures used in the literature and constructed an indicator of carbon intensity (the IAEI or industry-adjusted emission intensity) as proposed by Brunel and Levinson (2013).

We show that international differences in energy prices have grown over the past decade, and have become more pronounced in the recent year following the shale boom in the US. This has raised much political fear in other regions of the world, where energy prices are projected to increase much more. The major concern is that permanent differences in the stringency of policy stringency may lead to the movement of manufacturing capacity to countries with relatively lax policies in the long run. These concerns have existed since the 1970s and are as old as environmental regulations themselves, but have become ripe again with the growing need to address climate change. Competitiveness concerns, however, continue to represent the main obstacle for countries pursuing more ambitious climate policy, and it is reflected in the prevalence of cautious climate policy or contradictory signals from government which deter necessary investments for the low carbon transition of industrial sectors. For example, fossil subsidies remain prevalent globally and heavily distort the carbon externality which climate policies aim to correct. The European Council resolutions on the EU 2030 Climate and Energy Policy Framework also indicate that free allocation will continue over the next decade under the Emissions Trading System to compensate sectors in case of competitiveness effects, and that "consideration to ensure affordable energy prices.....will be taken into account" (European Council, 2014).

Improved evidence on how past asymmetric energy prices have affected business performance is likely to help identifying the specific cases where such special considerations or compensations are necessary, as well as, assessing the magnitude and direction of these effects. Indeed, while the political debate centres around the negative effects from climate policy on exports, market share or profitability, there is also growing evidence to support the positive effects from environmental regulation on induced innovation (see Popp et al. (2010), Popp (2010), and Ambec et al. (2013) for recent surveys) as well as positive effects from higher energy prices on energy efficient technologies (Popp (2002); Verdolini and Galeotti (2011)). Whether the positive effects outweighs the negative ones remains to be shown empirically. Either way, improved evidence would help fine tuning policies. Better targeted policies would in turn lower the overall cost of achieving mitigation targets thus improving welfare outcomes. A recent study has utilised the energy price index constructed in this paper to estimate the effect of asymmetric energy price on international trade and found a small effect (Sato and Dechezleprêtre, 2015). It is our hope that the dataset will contribute towards the development of the empirical literature.

Appendix

Appendix A: Review of the index literature

A wealth of literature which examines the calculation of various price indices (e.g. Boskin et al. (1998), Braithwait (1980), Caves et al. (1982), Diewert (1976), Klein and Rubin (1947), Shapiro and Wilcox (1996, 1997) Ulmer (1946))[36] informs the methodology used for the construction of the FEPI and VEPL.

[36] See Reinsdorf and Triplett (2010) for a 'review of reviews' on the consumer price index (CPI).

Most of this research is directed towards methods to weight price data with quantities or expenditure shares to construct a more efficient and less biased cost-of-living index (e.g. CPI), as is summarised by ILO/IMF/OECD/UNECE/Eurostat/The World Bank (2004). A large body of the literature also evolves around how to tackle the problem of the lack of data regarding quantities or expenditure shares. This is because these shares are taken as weights for the calculation of indices and if they are only available for limited points in time, can result in fixed weights or "anchor points" for the index. Anchor points do not account for changes in consumption patterns and have long been known to create a substitution bias in an index (e.g. Ulmer (1946)). The discussions in this literature around substitution bias, fixed and variable weights are particularly relevant for the construction of the FEPI and VEPL, as is the discussion around arithmetic and geometric indices.

First we focus on the VEPL, which uses arithmetic, variable weights. By their nature, price data are much easier and more frequently collected than quantity data. Therefore, the price indices are often based on a fixed quantities or fixed 'basket' of goods which have an anchor point corresponding to the year providing the quantity data. Price indices are typically constructed by taking the prices and weighting them by a fixed basket of expenditure shares (instead of quantity weights) to ensure comparability of goods denoted in different units. In the case of constructing sector level energy prices, given that all quantities of energy in our data are measured in TOE, we can use quantity weights, which are more direct and precise than using expenditure shares.

For the frequently used *arithmetic* Lowe, Laspeyres and Paasche index, weighting by expenditure shares (ExpS) or quantities actually result in the same expression, once we compare two different points in time:

$$\text{VEPL} \;\hat{=}\; \text{(arithmetic)} \quad \left.\begin{array}{r} \text{Laspeyres index}_{t,b=0} \\ \text{Lowe index}_{t,b} \\ \text{Paasche index}_{t,b=t} \end{array}\right\} = \frac{\sum_j P_t^j F_b^j}{\sum_j P_0^j F_b^j}$$

The anchor point b is the point in time of the fixed weight derived from either quantities or ExpS. The point in time of the anchor point is thus the only difference in these widely used indices and the Laspeyres and Paasche being special cases of the Lowe index where the anchor corresponds to the base or evaluation year respectively.

The centrepiece of the debate about these indices evolves around the elasticity of substitution between different goods and the related substitution bias caused by fixed weights (anchor points) [37]. Essentially, since the ExpS cancel into quantities, which are held fixed, an elasticity of substitution of zero is implicitly assumed in these indices. Therefore, if market participants in reality substitute towards relatively cheaper goods, the Laspeyres overstates and the Paasche index understates inflation. As argued above, the scarcer availability of expenditure shares often precludes using variable weights, which would minimise this bias.

The VEPL, however, uses fully variable weights, and therefore is not biased from an elasticity of substitution point of view. This is because there is no implicit assumption about this elasticity, but the actual quantities are taken from the data for each point in time. It is straightforward to see that if the

[37] There have been some empirical estimations of this substitution bias in the context of consumer preferences (e.g. Klein and Rubin (1947) or Braithwait (1980).

VEPL had fixed weights from year *b*, then taking the ratio of the VEPL from year *t* and year *0* would correspond to one of the above indices.

The interpretation of an index with variable weights should be of one that measures the actual costs faced by firms (or consumers). If some of the fuel types (or goods) become more expensive, but the firm simply switches to the relatively cheaper ones, then the *effective* average prices do not change (as much). On the other hand, the underlying *market* (not effective) prices based on a fixed basket change comparatively more. Vice versa, if there are no changes in the prices, but the fuel shares change, the VEPL with variable weights, an *effective* price, also changes despite constant real *market* prices. Since we calculated the VEPL with variable weights, it should be interpreted as *effective* energy prices which varies also according to the relative importance of different fuel types for a sector, which is arguably more interesting for e.g. competitiveness analysis.

When variable weights are not available, more efficient and less biased indices in the realms of fixed weights have been proposed in the literature and often involve geometric averages instead of arithmetic averages (e.g. Diewert (1976), Caves et al. (1982)). A more advanced geometric index would, for example be the Törnqvist index, but also the traditionally used Lowe, Laspeyres and Paasche index can be formulated as weighted geometric versions. Because of different underlying units, the ExpS is usually taken instead of the quantities as for the arithmetic version, however, for weighted geometric averages, the two are not the same anymore:

$$\text{(geometric, ExpS)} \quad \left.\begin{array}{r}\text{Laspeyres index}_{t,b=0}\\ \text{Lowe index}_{t,b}\\ \text{Paasche index}_{t,b=t}\end{array}\right\} = \prod_j \left(\frac{P_t^j}{P_0^j}\right)^{\frac{Expenditure_b^j}{\sum_j Expenditure_b^j}}$$

$$\text{FEPI} \triangleq \quad \text{(geometric, quantity)} \quad \left.\begin{array}{r}\text{Laspeyres index}_{t,b=0}\\ \text{Lowe index}_{t,b}\\ \text{Paasche index}_{t,b=t}\end{array}\right\} = \prod_j \left(\frac{P_t^j}{P_0^j}\right)^{\frac{F_b^j}{\sum_j F_b^j}}$$

In the first equation, the expenditure share is taken and in the second equation, the quantity share is used to calculated the weighted geometric average. Taking logs of the second, quantity weighted version corresponds exactly to the change of the FEPI from year *0* to year t[38]. Therefore, the FEPI can be interpreted as the log of the geometric Lowe, Laspeyres or Paasche index with quantity weights. Since our fuel use data is measured in a common unit TOE, we can actually use this more precise version of weights and diverge in this sense from the usual geometric CPI indices that rely on expenditure shares. It is commonly noted that holding expenditure shares fixed corresponds to a perfect elasticity of substitution of one in these geometric indices, since the relative quantities are assumed to adjust perfectly to relative price changes so that the expenditure shares stay constant. In contrast, since we keep the quantities fixed for the FEPI, we implicitly assume an elasticity of substitution of zero.

Having fixed quantity weights at different anchor points can be interpreted as accounting for the

[38] $FEPI_{ist} - FEPI_{is0} = \sum_j \frac{F_{isb}^j}{\sum_j F_{isb}^j} log\left(\frac{P_{it}^j}{P_{i0}^j}\right)$, which is exactly the same as the log of the quantity weighted geometric indices.

relative importance of the prices once (in the anchor year) and then measuring the price changes in this fixed basket of fuels. This is essentially the variation in the *market* price, driven amongst others by e.g. environmental regulation. It does not measure the *effective* prices, i.e. the impact of the price changes on the energy costs of firms, precisely, since the fuel composition may change, but in contrast measures variation in the underlying *market* prices precisely.

Appendix B: Calculation of the Industry Adjusted Emission Intensity

Industry-adjusted emission intensity is defined as follows: $S_i = \frac{\widehat{e_i}}{e_i}$. Stringency in country i ,S_i, equals the ratio between the country predicted emission intensity, $\widehat{e_i}$, and its actual emission intensity, e_i. Actual emission intensity equals the total CO_2 emissions divided by country GDP: $e_i = \frac{\sum_k E_{ik}}{\sum_k VA_{ik}}$. E_{ik} denotes country i's CO_2 emissions in sector k and VA_{ik} is the value added of country i in sector k. Country i 's predicted emission intensity measures what would be country overall emission intensity if it had an emission intensity a_k by sector equals to the global average. Predicted emission intensity is calculated as follows: $\widehat{e_i} = \frac{\sum_k VA_{ik} a_k}{\sum_k VA_{ik}}$ with $a_k = \frac{\sum_i E_{ik}}{\sum_i VA_{ik}}$. In short, $S_i > 1$ means that country i performs better in terms of CO_2 emissions than the average country given its industrial composition.

In one version of this measure, we consider both process CO_2 emissions and CO_2 emissions resulting from fuel combustion. Data on CO_2 emissions from fuel combustion come from IEA (2012) and data on CO_2 process emissions come from the UNFCC 2013 GHG inventory. To increase sectoral coverage and country coverage, we also calculate the measure where only CO_2 emissions resulting from fuel combustion are considered that we denote IAEI combustion. Data on value added in nominal USD come from the United Nations Industrial Development Organisation (UNIDO) Industrial Statistics Database (INDSTAT2) and from the OECD STructural ANalysis (STAN) database. We end up with 6 sectors and 22 countries for IAEI combustion and process and with 9 sectors and 32 countries for IAEI combustion.[39]

[39] The economy is divided in 12 sectors. We drop sector for which data availability is bad in order to obtain a sufficient number of countries. There is a trade-off between the relevance of the measure which is having a high number of sectors and the number of countries for which we can calculate the measure.

Appendix C: Table 7. Codebook of the variables in the dataset

Variable	***Description***
isoalpha3code	Country 3-letter code according to ISO
country	Country name (ISO)
OECD	Dummy = 1 if country member of OECD
year	Year (annual data)
inflation	Inflation rate calculated from GDP-deflator
price_source	Dummy =1 if underlying price data point is from other source than IEA industrial energy price dataset (e.g. national source).
sector	Sector name
biofuel_share	Share of biofuel in the TOE fuel mix of the country-sector in the underlying data
flag_VEPL	Multinomial variable indicating price data imputation for the VEPL. 1 = observed data, 2 = imputed using a respective real fuel price index, 3 = imputed using a total energy price index
flag_FEPI	Multinomial variable indicating price data imputation for the FEPI. 1 = observed data, 2 = imputed using a respective real fuel price index.
VEPL_MER	Variable weights Energy Price Level using market exchange rate, constant 2010 US$. Weighted arithmetic average. Underlying prices are net of inflation.
VEPL_PPP	Variable weights Energy Price Level using purchasing power parity rates, constant 2010 international $. Weighted arithmetic average. Underlying prices are net of inflation.
FEPI_fw1995	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 1995. Log of weighted geometric average. Data points where fuel types with missing price data make up at less than 12% of the energy mix of the sector in total and in all years are constructed by ignoring these fuel types. Underlying prices are net of inflation.
FEPI_fw2000	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 2000. Log of weighted geometric average. Data points where fuel types with missing price data make up at less than 12% of the energy mix of the sector in total and in all years are constructed by ignoring these fuel types. Underlying prices are net of inflation.
FEPI_fw2005	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 2005. Log of weighted geometric average. Data points where fuel types with missing price data make up at less than 12% of the energy mix of the sector in total and in all years are constructed by ignoring these fuel types. Underlying prices are net of inflation.

FEPI_fw2010	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 2010. Log of weighted geometric average. Data points where fuel types with missing price data make up at less than 12% of the energy mix of the sector in total and in all years are constructed by ignoring these fuel types. Underlying prices are net of inflation.
FEPI_fwavg_95_11	Fixed weights Energy Price Index (real). Time-invariant weights are the simple average of the weights 1995-2011. Log of weighted geometric average. Data points where fuel types with missing price data make up at less than 12% of the energy mix of the sector in total and in all years are constructed by ignoring these fuel types. Underlying prices are net of inflation.
FEPI_fwavg_00_11	Fixed weights Energy Price Index (real). Time-invariant weights are the simple average of the weights 2000-2011. Log of weighted geometric average. Data points where fuel types with missing price data make up at less than 12% of the energy mix of the sector in total and in all years are constructed by ignoring these fuel types. Underlying prices are net of inflation.
FEPI_allfuels_fw1995	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 1995. Log of weighted geometric average. Underlying prices are net of inflation.
FEPI_allfuels_fw2000	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 2000. Log of weighted geometric average. Underlying prices are net of inflation.
FEPI_allfuels_fw2005	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 2005. Log of weighted geometric average. Underlying prices are net of inflation.
FEPI_allfuels_fw2010	Fixed weights Energy Price Index, in real terms. Year of time-invariant weights used as reference is 2010. Log of weighted geometric average. Underlying prices are net of inflation.
FEPI_allfuels_fwavg_95_11	Fixed weights Energy Price Index (real). Time-invariant weights are the simple average of the weights 1995-2011. Log of weighted geometric avg. Underlying prices are net of inflation.
FEPI_allfuels_fwavg_00_11	Fixed weights Energy Price Index (real). Time-invariant weights are the simple average of the weights 2000-2011. Log of weighted geometric avg. Underlying prices are net of inflation.

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