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International and sectoral variation in industrial energy prices 1995–2015[☆]

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ABSTRACT

Energy price rises for industry are a major political concern. Access to cheap energy is often considered a key factor for the competitiveness of industry. To enable international comparisons, and to foster further empirical research on the impacts of energy price or tax differentials on a wide range of outcomes, such as international trade and investment patterns, we construct sector level energy prices for 12 industrial sectors in 48 countries for the period 1995 to 2015. Our prices are constructed as weighted averages of fuel-specific prices by fuel consumption. We provide guidelines for the use of our energy price data, which is made available for download, as well as a set of stylized facts on major trends and variations, and illustrative applications.

1. Introduction

Do high industrial energy prices 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 highly politicized issue particularly in countries and regions facing relatively high primary fuel and end-user prices such as Europe and Japan. In addition, discrepancies in energy prices have been widening, especially for natural gas and electricity (IEA, 2013). Several trends contribute to these growing cross-country differences including the shale gas boom in the US with the consequent fall in energy prices for US manufacturers, the transitioning from fossil fuel and nuclear to renewable energy sources notably in Europe and the introduction of climate change and other environmental policies.

With many countries facing slow economic recovery, concerns that high energy prices might deter investment and lead to outputs and jobs shifting to low energy cost regions are important, particularly in fuel importing countries. Differences in energy price across countries are driven by many factors including fossil fuel endowments, energy market structures, production costs, transport costs, differences in contractual terms and trade restrictions. However, a substantial share of cross-country variation comes from differences in taxes and levies charged on energy consumption such as environmental taxes, as well as the exemption rules or rebate schemes applied (Grave et al., 2015). For example, the UK government gives exemptions to energy intensive sectors from

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electricity costs relating to supporting renewables.[1] In Germany, energy intensive sectors can apply for exemptions from the grid utilization charges (Matthes et al., 2017) as well as for charges to support renewable energy generation.[2]

Competitiveness concerns have shaped policy designs 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 to the industrial and business sectors (European Commission, 2014b). Similarly, exemptions from environmental taxation for manufacturing sectors are often made in many European countries (Ekins and Speck, 1999). The EU Emissions Trading Scheme also compensates energy intensive and trade intensive sectors with free allowance allocation as well as rebates for the carbon costs priced in the electricity market. Indeed, an analysis on sector level energy taxes and exemptions by OECD (2013) finds that there is substantial differentiated taxation between industrial and non-industrial sectors for certain fuel types.

While such regulatory practices are commonplace, policy makers need to understand to what extent industrial performance respond to energy prices in practice to ensure the effectiveness of exemptions and compensation measures. So far the evidence is mixed (Dechezleprêtre and Sato, 2017). At the country level, the shares of energy costs per unit of GDP are fairly constant across countries and higher prices have not ultimately resulted in higher proportionate energy expenditure, as energy systems are able to adapt to prices over time (Bashmakov, 2007; Grubb et al., 2018). At the sector level, energy costs are expected to impact competitiveness for a handful of energy intensive sectors whereas for the large majority of manufacturing sectors, they represent a fraction of total production costs (Sato et al., 2014; IEA, 2013). The empirical literature has studied the impacts of energy prices on a broad range of outcomes, e.g. industrial supply and demand (Aldy and Pizer, 2015), plant location (Kahn and Mansur, 2013), employment (Deschenes, 2011; Cox et al., 2014; Marin and Vona, 2017), productivity (Gonseth et al., 2015) and technology (Popp, 2002).[3] These studies usually exploit variation in energy price within a country (e.g. across States in the US). International competitiveness outcomes have been less studied partly due to the lack of comparable energy price data, particularly for non-OECD countries.

The lack of information about relative energy costs across sectors and countries is one of the major barriers to empirically assessing the effects of energy related costs on competitiveness (Dechezleprêtre and Sato, 2017). Most previous studies rely on country level energy prices for estimation (e.g. Gonseth et al., 2015). Yet more recent work using microdata highlight the importance of within country heterogeneity (e.g. Marin and Vona, 2017), suggesting that using industry-level energy prices can improve estimation in cross-country studies substantially. First, the energy price can vary considerably between sectors because they do not use similar proportion of fuels for production, such that using country-level energy price would introduce a measurement error that reduces the capacity to perform hypothesis testing properly.[4] Second, the determinants of competitiveness also differ significantly across sectors. These factors include labour costs, production technologies as well as trade policies. In addition, some sectors such as textiles or machinery are more footloose than others such as steel or paper (Ederington et al., 2005). Therefore, the weight of the energy price in the determination of competitiveness is likely to differ between sectors. Using energy prices at the sector level allows to account for these differences by estimating models with industry specific parameters.

This paper contributes by building a dataset of industrial energy prices indices with considerably improved coverage than previous studies. While energy prices for electricity generation and households are readily available, energy prices faced by industrial sectors are harder to obtain. For most OECD countries, internationally comparable industrial energy prices are often published only at the country level (averaged across all industrial sectors), and with frequently missing data points.[5] Our original dataset covers 48 countries for the period 1995 to 2015, covering 12 industry sectors (mostly in manufacturing).[6] We construct an industry level energy price called the Variable weights Energy Price Level (VEPL), which is a weighted average of fuel prices by fuel consumption. We also construct an index where the weights are fixed over time, called the Fixed weights Energy Price Index (FEPI). The latter supports empirical investigations as a readily available instrumental variable including but not restricted to the impacts on competitiveness outcome.

Some previous works also constructed weighted energy price indices (e.g. Noailly, 2012; IEA, 2013; Linn, 2008; Aldy and Pizer, 2014; Steinbuks and Neuhoff, 2014) but the indices 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 construction of the FEPI as an instrument addresses an important issue around the endogeneity of fuel choice. Fourth, having the two indices allow to separately analyse the two components of energy price variation: technological (fuel mix) and institutional (taxes) factors. Fifth, our method provides a flexible way of estimating sector-level energy prices across countries and the methodology used is documented. The sector-level dimension is shown to be key for the analysis of competitiveness impact of energy price policies. Sixth, the VEPL is calculated with both market exchange rates (MER) and purchasing power parity rates (PPP). Exchange rate assumptions are important for cross-country comparison of energy prices particularly when including developing countries. Lastly, the dataset is made available for download with this article, and is designed for flexible use e.g. categorical variables are created to enable discarding observations that have been imputed using different techniques.

The resulting energy price index reveals a number of insights including the following: (i) across countries and over 20 years, the energy price gaps widened in real terms, the highest price being six times bigger than the lowest in 2015, (ii) for cross-sectional variation, the cross-country variation matters considerably more than the cross-sector variation (iii) for time-series variation, changes to fuel prices matter more than changes to fuel composition (iv) policies and taxation are a major source of variation in the energy price between countries. In addition, we illustrate how the energy price index can be used in empirical analysis and find that there is substantial heterogeneity across sectors regarding the relationships between energy price and energy intensity as measured by energy expenditure as share of gross value added. Finally, we compute the energy price increases due to a hypothetical carbon price and show that they vary importantly between and within countries.

[1] See UK Government (2017).

[2] See the European Commission (2013) press release for the state aid case on the Renewable Energy Act rebates. An agreement has been reached in April 2014 (New Europe, 2014).

[3] For a recent review of the impacts of energy prices and environmental policies on competitiveness outcomes, see Dechezleprêtre and Sato (2017)

[4] Measurement error in the regressor leads to biased coefficient and standard error estimations.

[5] Disaggregated industrial energy price data are sometimes available at the country level (e.g. Matthes et al., 2017 develop an Energy Costs Index for German industry).

[6] Table 4 lists the industrial sectors covered.

Table 1
Overview of VEPL and FEPI.

	VEPL	FEPI
Coverage in years	1995–2015, (Some non-OECD countries: 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, aggregate manufac., aggregate industry (manufac.+mining+construction)	
Coverage of country-sector-years	69% non-missing of *48* countries, 12+2 sectors and 21 years (92% of 36 countries)	85% non-missing of *48* countries, 12+2 sectors and 21 years of *FEPI_fw*2010
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: IV or reduced form
Price data dummy	*flag_VEPL*: -1 = missing, 0 = observed data points, 1 = imputed with respective fuel price index, 2 = imputed with an aggregate index	*flag_FEPI*: -1=missing, 0=observed data points, 1=imputed with respective fuel price index, 2=imputed with an aggregate index
Biofuel variable	*biofuel_share* indicates the time-variant weight of biofuels.	
Caveats	- Designed for descriptive statistics. In regression analysis combine with FEPI. - 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 combined with country (or more granular) fixed effects. When combined with sector-country fixed effects all arbitrary cross-country measurement errors in the *underlying* prices is controlled for (see Appendix A.3). - 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.

This paper is structured as follows. Section 2 describes the methodology, and Section 3 describes the data employed in the construction of the indices and discusses the strategies used to tackle missing data issues. Section 4 provides some stylized facts that emerge from the energy price data. Section 5 illustrates how the energy price index can be used in the assessment of competitiveness impacts of energy and carbon prices. The last section offers some discussions and suggestions for future research.

2. Methodology: constructing the energy price database

2.1. Conceptual framework

In this paper, we construct energy price indices that vary by sector, country and year. The price indices are a weighted average of the energy prices for different fuel types, with weights given by the share of fuel consumption in the sector's energy mix. The underlying fuel prices vary by country and time. The fuel prices are inclusive of tax and other policies and four fuel types are covered (oil, gas, coal and electricity). Fuel prices mainly reflect institutional factors, policies and scarcity. The variation across sectors *within* countries comes from different fuel compositions of sectors. The idea is to utilise the observable variation in the fuel mix to improve the measurement of energy prices faced by sectors in a given country and year. The fuel consumption weights mainly represent technology. For example, in some countries, the steel sector relies heavily on coal (e.g. China and Germany where there is more primary production), whereas electricity is the main source of energy in other countries (e.g. Italy and Spain where secondary production is predominant). This methodology assumes that there is limited within-country variation in fuel prices across sectors. Section 4.5.2 presents evidence to support this assumption, and demonstrates that this methodology performs well capturing the between sector variation in energy prices.

The Variable weight Energy Price Level (VEPL) is the main index. As the name suggests, the fuel weights vary over time. Thus it captures both the changes in underlying fuel prices and developments in technology (fuel mix). It thus reflects the effective energy price level for each sector at a particular point in time.[7]

In panel data analysis, the fuel substitution embedded in the VEPL presents an endogeneity concern as it also captures firms' responses to prices via changes in their energy mix choices. We therefore also construct an alternative index where weights are fixed over time, called the Fixed weight Energy Price Index (FEPI).[8] By construction, the FEPI is a good instrument in such analyses. It captures the variation in fuel prices alone, including policies and taxation, and switches off the source of price variation that is endogenously related to the technological choices of the firm.

The key features of the VEPL and FEPI are summarized in Table 1 and the choice of methodology is discussed in the context of the price indices literature in Appendix A.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 9 in Appendix A.11).

The basic methodology (i.e. a weighted average price) is not a new idea[9], but compared to previous literature, our published index covers a broader set of countries, sectors and years, partly due to the way we deal with missing data as explained below. Furthermore, we provide a readily available instrument (FEPI) that takes care of some part of the endogeneity problem as well as some measurement error when combined with fixed effects. The indices are also constructed at the aggregate manufacturing level, and at the industry level (i.e. manufacturing sectors + mining and quarrying + construction, see Appendix A.2).

2.2. Variable-weight Energy Price Level (VEPL)

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

$$VEPL_{ist} = \sum_j w^j_{ist} \cdot P^j_{it}, \text{where: } w^j_{ist} \equiv \frac{F^j_{ist}}{\sum_j F^j_{ist}} \tag{1}$$

F^j_{ist} is the input quantity of fuel type j in tonnes of oil equivalent (toe) for the industrial sector s in country i at time t and P^j_{it} denotes the real price of fuel type j per toe for aggregate industry in country i

[7] The index reflects average rather than marginal prices.

[8] Note that there could be further endogeneity issues, for example, if the fuel substitution impacts the underlying prices.

[9] Noailly (2012) for example constructs a weighted average in PPP terms, but focusing on the residential sector alone. Linn (2008) constructs a weighted average with fixed weights, but only for the US and for a period up to the 90s. Steinbuks and Neuhoff (2014) construct a weighted average for the aggregate manufacturing sector and Fowlie et al. (2016) for California using more detailed firm-level data.

Table 2
Imputation procedure for *prices underlying* VEPL and FEPI.

Steps	OECD	Non-OECD	Flags and observations
0	Observed prices	Observed prices	*flag_VEPL*=0 (25%), *flag_FEPI*=0 (31%)
1	$IN^j_{i,t}$: IEA fuel-country specific *real energy price index*	$IN^j_{i,t}$: IEA fuel-country specific *wholesale price index*	*flag_VEPL*=1 (24%), *flag_FEPI*=1 (17%)
2	$IN^j_{i,t}$: IEA country specific real industrial energy price index *or* IEA OECD fuel specific industrial price index	-	*flag_VEPL*=2 (21%), *flag_FEPI*=2 (21%)

Notes: The flag variables take the value -1 for all missing values, 0 for observed values, 1 for values imputed with the respective fuel price indices, 2 for values imputed with one of the aggregate energy price indices.

in constant 2010 USD.[10] The weights w^j_{ist} thus vary by country, sector and year.

For oil and coal, underlying 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 enable cross-country comparison, the VEPL is based on a consistent set of sub-fuel types[11] and only constructed for country-years where price series for *all* four fuel types are available, but this restriction will be relaxed for the FEPI to increase 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 a given point in time. As noted, the VEPL captures both the variation from developments in fuel price and fuel-mix over time. 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 sectors in different countries.[12] 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 MERs.[13]

2.3. Fixed-weight Energy Price Index (FEPI): an instrument

The fixed-weight price index (FEPI) is constructed using time invariant weights and prices in logs *according to the following equation:*

$$FEPI_{ist} = \sum_j w^j_{is} \cdot \log\left(P^j_{it}\right) \text{ where:} w^j_{is} = \sum_j \frac{F^j_{is}}{\sum_j F^j_{is}} \tag{2}$$

where F^j_{is} are the input quantity of fuel type j in tons of oil equivalent (toe) for sector s in country i and P^j_{it} again denotes the real price of fuel type j per toe for aggregate industry in country i at time t in constant 2010 USD. The weights w^j_{is} are fixed over time. The prices P^j_{it} are transformed into logs before applying the weights so that the log of the individual prices enter linearly in the equation.[14] This is a useful feature for panel data estimations as it addresses some measurement error when combined with fixed effects as explained below.

Table 3
Data sources.

Variables	Data source
Industrial energy price	IEA Energy Prices and Taxes (2012, 2016b), Ministério de Minas e Energia (2016), Ministry of Petroleum and Natural Gas (2012), Department of Energy (2014), destatis (2015)
Sector fuel use	IEA World Energy Balances (2016c)
Energy price indices	IEA Energy Prices and Taxes (2012, 2016b)
Exchange rates	World Bank (2017), National Statistics of the Republic of China (Taiwan) (2013)
PPP conversion factor	World Bank (2017)
GDP deflator	World Bank (2017), National Statistics of the Republic of China (Taiwan) (2013)

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.[15] Real prices, P^j_{it}, are based on a different set of sub-fuel types across countries, unlike the VEPL which uses 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, but makes it less suitable for direct cross-country comparisons. Within any one country-sector, a consistent set of sub-fuel type is used through time. In general, the cross-price elasticity of sub-fuel types through time is almost unitary. Thus the FEPI is able to capture the relative industrial energy prices over time despite heterogeneous base prices across countries. With country-sector fixed effects these differences in sub-types across countries are controlled for (see Appendix A.3).

The FEPI captures 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 advantage for use in empirical analysis to address endogeneity concerns. Sector-level energy prices based on variable fuel weights, as provided by VEPL, may be 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 therefore lends itself as a suitable ready made instrument for the VEPL in panel data regressions, or alternatively as a standalone in a reduce form regression, being free from fuel substitution effects.

Note that the FEPI is expressed in logarithmic and real terms. Its change reflects a ratio that is consistent with usual

[10] In theory, weights could also be based on expenditure shares but data availability prohibits this.

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

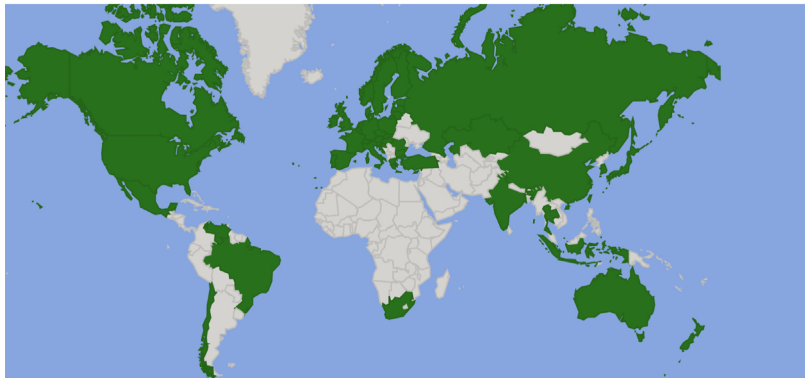
[12] Using PPP instead of MER implies a time-constant multiplicative shift in the prices which results in upward scaling of the VEPL for generally "cheap" countries and downward scaling for relatively "expensive" countries.

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

[14] Note that taking the exponential of the FEPI yields the weighted geometric mean of the different fuel prices, so Eq. (2) is the log of the weighted geometric mean.

[15] This allows users to choose the adequate pre-sample period weights in order to mitigate endogeneity in sample period.

Table 4
Country and sector coverage.



Legend: Dark = available, grey = unavailable

48 Countries			12 + 2 sectors
Australia	Greece	Poland	Chemical & petrochemical
Austria	Hungary	Portugal	Construction
Belgium	India	Romania	Food & tobacco
Brazil	Indonesia	Russian Federation	Iron & steel
Bulgaria	Ireland	Slovakia	Machinery
Canada	Italy	Slovenia	Mining & quarrying
Chile	Japan	South Africa	Non-ferrous metals
China	Kazakhstan	Spain	Non-metallic minerals
Croatia	Korea, Republic of	Sweden	Paper, pulp & print
Cyprus	Latvia	Switzerland	Textile & leather
Czech Republic	Lithuania	Taiwan	Transport equipment
Denmark	Luxembourg	Thailand	Wood & wood products
Estonia	Mexico	Turkey	(aggregate) Manufacturing
Finland	Netherlands	United Kingdom	(aggregate) Industry
France	New Zealand	United States of America	
Germany	Norway	Venezuela	

(ILO/IMF/OECD/UNECE/Eurostat/The World Bank, 2004) index calculations hence further transformations in this regard are not necessary when used in regression analysis. To reap the advantages of the log transformation of isolating any time-constant fuel type specific measurement errors in prices as well as any discrepancies in the choice of the sub-type fuel, panel data analysis using the various versions of the FEPI should always include country-sector fixed effects to neutralise them (Eq. (A.3)). 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.[16]

3. Data sources and missing data management

This paper brings together a variety of data sources to construct an energy price index (see Table 3 for sources and Table 4 for coverage). We first discuss the underlying price data which is combined with fuel use data (weights) which are discussed thereafter.

3.1. Fuel price data

The primary source for price data is the IEA Energy End-Use Prices database, and specifically the prices for the industrial sector (IEA, 2012, 2016b). The data points are 12-month averages and available in national currency per tonne of oil equivalent (toe). This represents the final industrial energy prices including taxes paid by industry for different fuels, and excluding VAT and recoverable taxes and levies.[17] To enhance international comparability of the data, the IEA uses a questionnaire, which for OECD Member countries are filled by official bodies such as national statistics offices.[18] In non-OECD countries, the data are collected directly from government and industry contacts and from national publications.

We deem this to be the most suited publicly-available data source for internationally comparable industrial energy prices covering a large number of countries. Yet there is room for measurement error. Microdata analysis shows that within-sector variations in energy prices can be considerable for example due to quantity discounts. Many countries also offer tax exemptions and other subsidies to specific users including energy intensive ones, but this is not consistently reflected accurately in official data (European Commission, 2014a; OECD, 2013). These exemptions can be important, for example in Germany, despite the expensive low-carbon

16 See Appendix A.4

17 The IEA defines this 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). Self-generation or consumption of by-products is not included as it is energy purchase data.

18 For EU countries, the data is largely consistent with Eurostat (data collected as part of EU reporting requirement), but data collection methodologies between countries can vary, for example with regards the choice of consumption bands.

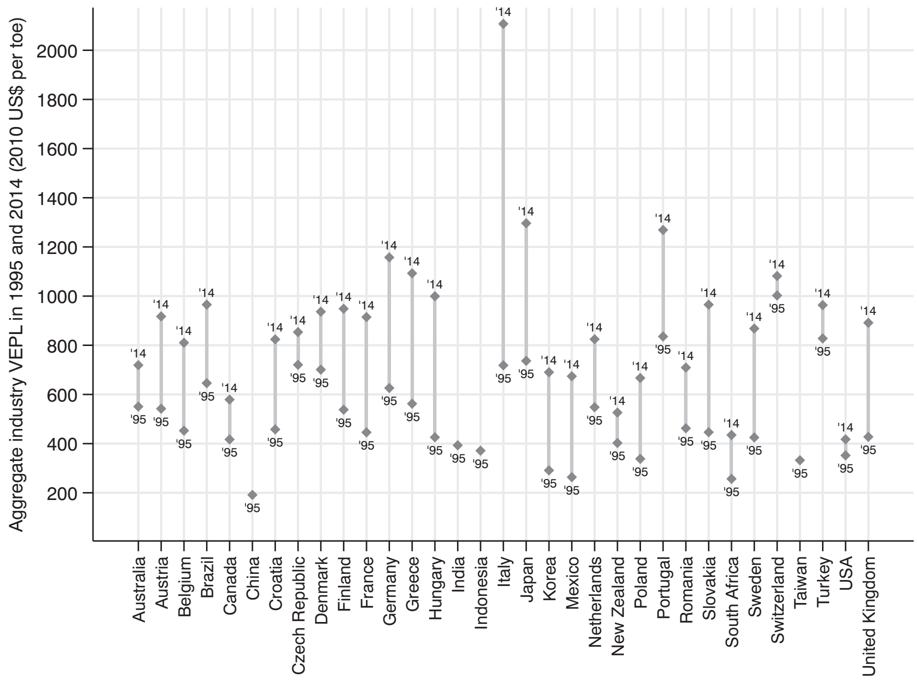


Fig. 1. VEPL for aggregate industry in 1995 and average growth.
Notes: The country level industrial energy price VEPL (in 2010$) is depicted for 1995 and 2014 using Market Exchange Rate.

energy system transition which is financed by levies, energy intensive users 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 harmonized 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, mainly for non-OECD countries where IEA stopped publishing energy price data after 2011. Industrial gas prices for India, for example, are derived from the Ministry of Petroleum and Natural Gas (2012), Brazilian industrial coal, gas, oil and electricity prices are obtained from Ministerio de Minas e Energia (2016), additional South African coal, gas, oil and electricity prices from the Department of Energy (2014), and a German coal price index from destatis (2015). The variable *flag_addprice* identifies datapoints based on these additions.

The raw industrial energy price data are combined with GDP deflators and exchange rate data (or the PPP conversion factor) to construct the prices in constant 2010 US$. The nominal exchange rate, the PPP conversion factor and the GDP deflator data are taken from World Bank (2017) except for Taiwan which we take from the National Statistics of the Republic of China (2013). The price data in local currency units ($P^{LCU}_{nominal}$) are first deflated by the national GDP deflator ($Deflator^{LCU}$) with a consistent base year 2010 and then converted into constant 2010 USD by applying a fixed ratio between

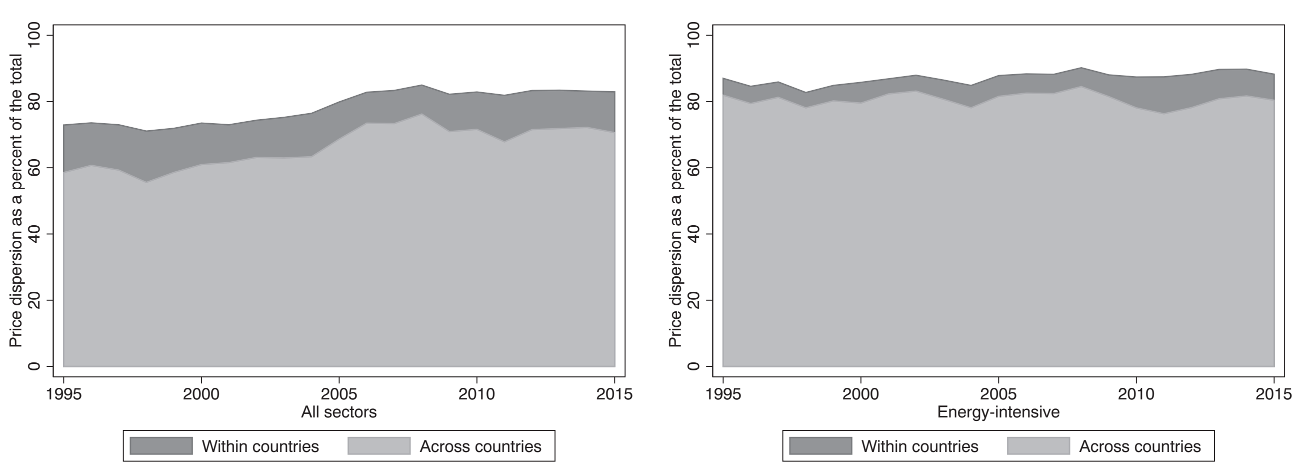


Fig. 2. Variance decomposition of VEPL by year.
Notes: energy intensive sectors include iron & steel, chemicals & petrochemicals, pulp & paper and non-metallic minerals.

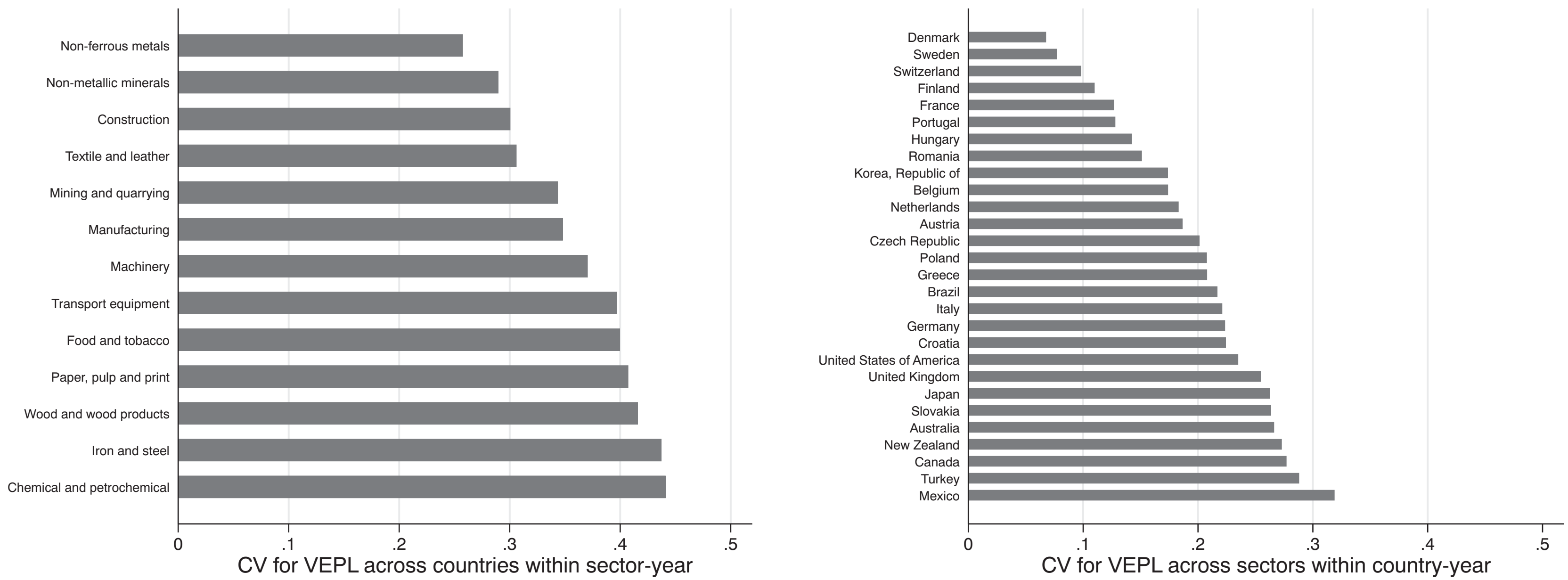


Fig. 3. CV for the VEPL across countries in 2014.
Notes: The coefficient of variation is shown, based on the VEPL in MER.

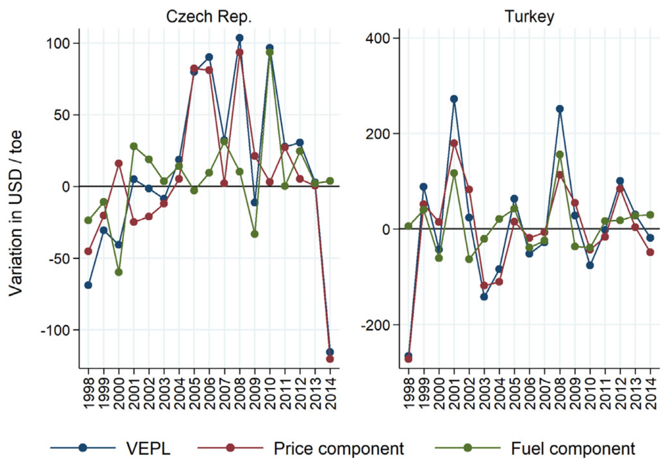


Fig. 4. Fuel switching and price variation are equally responsible for changes in VEPL over time: Czech Republic and Turkey.

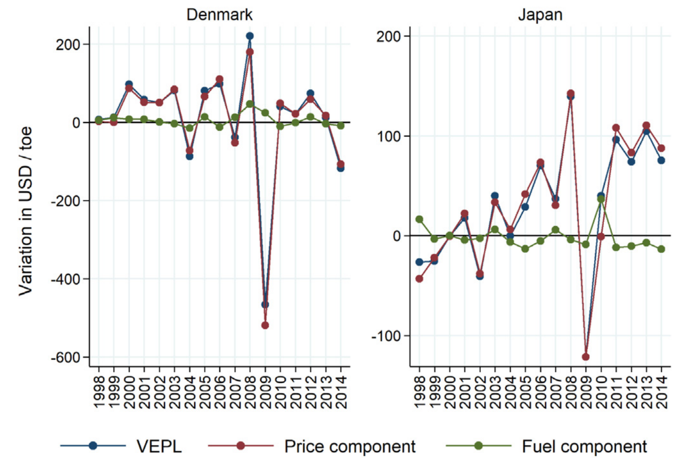


Fig. 5. Variation of VEPL over time is mostly explained by changes in fuel prices: Denmark and Japan.

the 2010 deflator ($Deflator^{LCU}_{2010}$) and 2010 nominal exchange rate ($ER^{LCU/USD}_{2010}$) or PPP conversion factor to all years. In short (analogous for PPP prices):

$$P^{USD}_{constant} = \frac{P^{LCU}_{nominal}}{Deflator^{LCU}} * \frac{Deflator^{LCU}_{2010}}{ER^{LCU/USD}_{2010}}. \tag{3}$$

For a few countries, inflation was extremely high in some years (e.g. Kazakhstan or Turkey). We include an inflation rate variable in the dataset, which allows excluding observations where inflation rates are high. The prices that go into the calculation of the VEPL and FEPI are thus in real terms and only capture price increases in the fuel basket relative to the general economy-wide price inflation.

3.1.1. Missing data management in fuel prices

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 industrial real price index for each fuel type (oil, gas, coal, electricity) within the same database (IEA, 2012, 2016b), which tends to have less gaps than the fuel price series themselves (and also includes taxes, but no VAT as described in Footnote 17). 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. Our approach thus relies on observed data rather than statistical imputation methods such as multiple imputation, which is less transparent.

Our general formula for imputation of a missing price point $P^j_{i,t}$ is

$$P^j_{i,t} = \frac{1}{2}P^j_{i,t-1}\left(1 + \frac{IN^j_{i,t} - IN^j_{i,t-1}}{IN^j_{i,t-1}}\right) + \frac{1}{2}P^j_{i,t+1} \Big/ \left(1 + \frac{IN^j_{i,t+1} - IN^j_{i,t}}{IN^j_{i,t}}\right)$$

where $IN^j_{i,t}$ is a real price index of fuel j in country i (for non-OECD countries it is the wholesale price index). As a second step if the indices are missing, we apply the same formula using a more aggregate index. Appendix A.5 describes the imputation method in detail.

By creating two additional variables, *flag_VEPL* and *flag_FEPI*, users are able to include or exclude observations based on imputed values in the analyses. The share of observations associated with the flags are shown in Table 2 – using the described approach, we are able to reduce the share of missing values in the VEPL from 75% to 30% and in the FEPI from 69% to 31%. We can further reduce the missing values in the FEPI to 15% as described in Appendix A.6.

3.2. Fuel use data for weights

The fuel use data in toe is derived from the IEA World Energy Balances (IEA, 2016c) for all countries, reflecting consumption by fuel type at the sector level.[19] In order to combine it with the price data, all fuel sub-types are aggregated into four groups of consumption in toe: oil, gas, coal and electricity.[20] 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.

3.2.1. Missing data management in fuel use

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 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).[21] This is because the coefficient of variation (CV) in the average weights is generally

[19] This data reflects energy used, including feedstock.

[20] Biofuels and waste fuel use is not considered in calculating the index, in part because the IEA price and fuel data do not match biofuel sub-types well. However, we provide a variable called *biofuel share* which indicates the time-variant share of biofuel in the original fuel input data on the sector level. This variable allows researchers to decide whether they should or should not include particular observation with a high biofuel share in their analysis.

[21] To identify the observations that rely on any of these imputations in the underlying data we provide a multinominal variable *flag_euse* indicating the underlying fuels use data imputation: −2=extrapolated, −1=interpolated, 0=observed, 1–5= the number of sectoral fuel weights replaced by industry average weights. Negative numbers mean no replaced weights, positive numbers could have inter- or extrapolated weights. The number 5 implies that actually all 5 fuels (including biofuels) have been replaced, as replacing 4 out of 5 is not feasible.

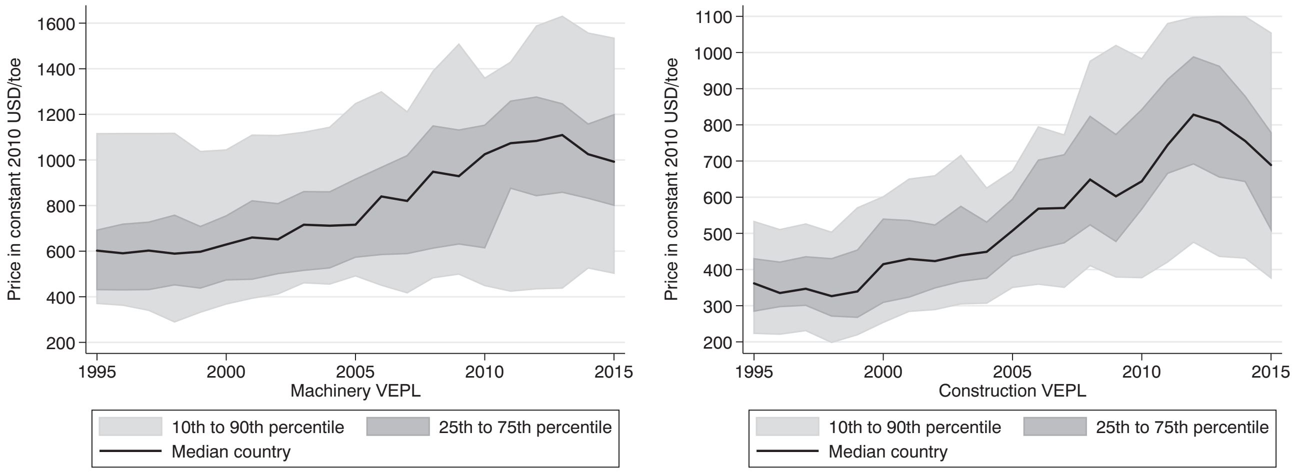


Fig. 6. Dispersion of the VEPL across countries within selected sectors.
Notes: The solid line represents the median of the industry VEPL across countries, and the shaded areas the interquartile range and the 10th and 90th percentile of the distribution of countries at a time for the specified sectors. VEPL is based on MER.

lower within a country, compared to weights within a sector across countries (Section 4.2 expands on this point).

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 & waste category was excluded from calculating the VEPL as there is no clear association that can be established between the fuel price data and the weights. For example, the wood & wood products sector may use some of its residue as fuel and declare it as biofuels & waste. Biofuels is a significant fuel only in sectors “Paper, Pulp & Print”, “Wood & Wood Products” and “Food & 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.

4. Industrial energy prices: stylized facts

4.1. Mind the gap: general trends in international variation in industrial energy prices

In 1995, average industrial energy price ranged between 191 USD/toe in China and 1003 USD/toe in Switzerland. Since then, energy prices in real terms have risen dramatically in some countries while it has stayed fairly constant in others. As shown in Fig. 1, average industrial energy prices in 2014 vary substantially more across countries than in 1995, raising concerns about competitiveness impacts.[22] In 2014, the top 10% average energy price was 2.4 times larger than the bottom 10%[23]. Energy prices are now higher in heavily industrialized European countries such as Germany, France as well as Japan. Among OECD countries, the lowest energy prices are observed in the USA (417 USD/toe). Between Italy (2107 USD/toe) and the USA, there is a price gap of a factor of five. However, there is heterogeneity across EU countries. The aggregate industry VEPL for the UK, for instance, is 113% higher than in the US in 2014, whereas Germany is 177% and Italy 405% higher in real terms.[24]

With regards to emerging economies, energy prices have also been rising during the sample period, but at varying speeds. Fig. 12 in Appendix A.7 plots the aggregate industry VEPL for Brazil, China, India, Russia, South Africa and Germany and the USA for comparison using two exchange rate assumptions (left MER and right PPP). A comparison of the two graphs reveals the importance of the choice of the underline exchange rates for these countries (particularly for India, China and Russia). It highlights the difficulty of comparing prices 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 except in some 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 easily the inputs and outputs of the industry are traded on international markets, which rely on MER rather than PPP rates. Nonetheless, large energy price gaps are observed. In 2010, the largest gap was between Kazakhstan (216 USD/toe) and Italy (1703 USD/toe) and equal to a factor of 7.8.

4.2. Sources of cross-sectional variation: country variation matters more than sector variation

We find that cross-country variations explain a large share of the total variance in energy prices. As shown from an analysis of variance in Fig. 2, spatial price differentials never account for less than 50% of the overall price variation. Price dispersion across countries has also been increasing over time. The country component explained about 55% of the total variance in 1995 while it reached 68% in 2015. On the other hand, cross-sector dispersions never account for more than 15% of the total price variance.[25] This disparity is more evident when we narrow the focus to energy-intensive sectors (Fig. 2, right panel). The percentage of the total variance explained by country effects is often above 80% while the sector component rarely reaches 10%. This

[22] See also Fig. 11 in Appendix A.7 for a comparison of six OECD countries over time. These concerns peaked in the wake of the shale gas boom in the USA in the mid-2008, which lead to the ballooning of wholesale gas price differentials between the US and other regions (IEA, 2013). While oil and gas prices in Europe and Japan have since come down with the softening of global oil prices from around 2013, large differences in industrial energy price differences persist.

[23] The 5% and 95% percentiles have a factor of 3.0.

[24] The relatively high price of energy in Italy is mainly explained by a significantly higher electricity price, which unlike in most countries also increases with the total quantity of electricity consumed (OECD, 2003). Other data sources find a similar pattern (Eurostat, 2017).

[25] With the rest of the variation due to country-sector variation in each year.

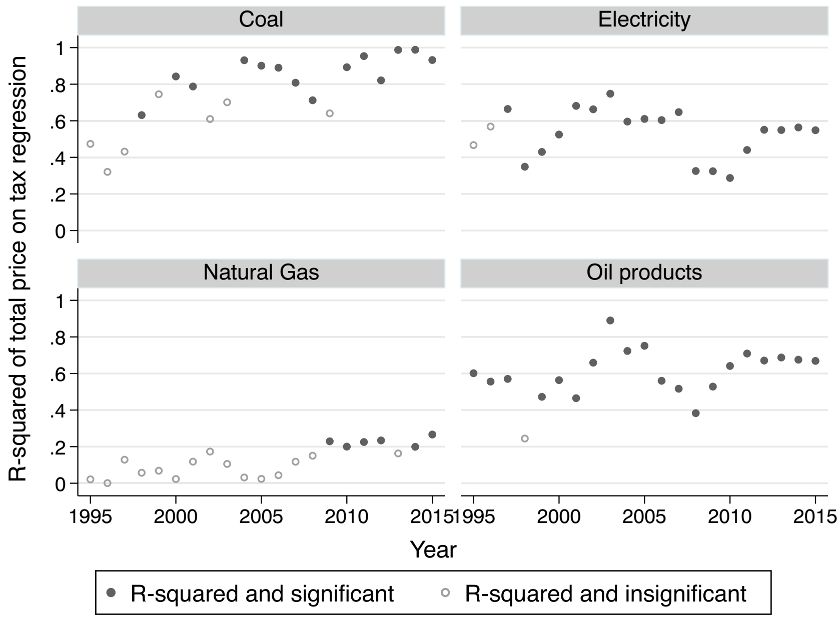


Fig. 7. Percentage of aggregate industry VEPL variation explained by taxes.
Notes: The four panels plot R-squared against time for the associated fuel types. The R-squared are calculated from regressions of the net industry fuel price on a constant and the tax component (based on MER) for a particular year. Solid dots represent R-squared from a significant association at the 5% level for a particular year.

can be partly explained by the fact that, once we reduce possible heterogeneity in fuel portfolios, the policy component (i.e. the country component) becomes more important.

Yet, the pattern is more complex. A closer examination shows that cross-country variations are more pronounced in the chemicals & petrochemicals, iron & steel, and wood sectors, but less variation is observed within the non-ferrous metal, non-metallic minerals and construction sectors (left panel of Fig. 3).[26] Similarly, the degree of variation across sectors differs by country, as shown in the right panel of Fig. 3. Cross-sectoral energy price gaps are more pronounced in Mexico, Turkey and Canada but less in Denmark, Sweden and Switzerland. Greater within-country heterogeneity can be related to differences in sectors' energy portfolios, particularly the share of electricity. Appendix A.9 follows up on the role of electricity shares and fuel switching.

Interestingly, despite such cross-country differences we find that the ordering of sectors in terms of the level of energy price is similar across countries. Non-metallic minerals, iron & steel (and often construction) tend to have low energy prices whereas the non-ferrous metals, wood & wood products and machinery sectors have relatively higher energy prices due to underlying fuel mix[27].

4.3. Sources of time-series variation: changes to fuel prices (including taxes) matter more than fuel mix

Aggregate industrial energy prices generally increased during the sample period. Between 2000 and 2012, energy prices increased on average by around 87% in real terms or equivalently by an average of 5.4% every year during that period.[28] The steady increase in energy prices was disrupted temporarily by the financial crisis in 2008/2009, then continued again after 2010. After 2013, energy prices have been declining, most notably due to world oil price collapse.

We find that the time series variation is largely attributed to changes in individual fuel prices, which include taxes and other institutional choices, whereas changes in technology (i.e. the fuel mix) plays a minor role. Appendix A.10 presents a decomposition methodology. As shown in Table 8, on average 70% of the variation in VEPL is explained by variation in fuel prices. The share is higher than 65% for three quarters of the countries. This result suggests that institutional factors impacting fuel prices, such as taxes, are potentially responsible for a significant part of the variation in the energy price over time. We also observe significant heterogeneity across countries. In China, Turkey, and the Czech Republic, fuel switching and fuel price variation are equally responsible for changes in VEPL. Fig. 4 illustrates this finding for Turkey and the Czech Republic.[29] In contrast, for countries such as Japan and Denmark, 80% of the variation in VEPL is due to variation in fuel prices as illustrated by Fig. 5. Table 8 also shows that the importance of the two components varies over time but there is no general trend. Finally, we find that when the fuel price component is positive, the fuel mix component is negative only in 25% of the cases. Therefore, it appears that technological change does not significantly reduce the impact of individual fuel prices on the effective energy prices.

4.4. Divergence and convergence of industrial energy prices: a mixed picture emerges

We find that energy prices are converging internationally in some industrial sectors but diverging in others. For example, in the machinery sector (Fig. 6 left) energy prices are generally rising while their dispersion is not increasing over time suggesting convergence in energy prices. In other sectors such as construction, dispersion is increasing over time (Fig. 6 right). According to the coefficient

[26] Fig. 13 in Appendix A.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 in Fig. 14, the average energy price in Germany is 25% higher in construction and 145% higher in the non-ferrous metals sector, which is more electricity intensive.

[27] The Spearman rank correlation tests yield almost always positive correlations of the sector rankings between country pairs, on average 0.42 in 2014. This can also be seen, with some exceptions, in Fig. 14 of Appendix A.8 for Germany and the US.

[28] Energy prices increased for all countries in our sample.

[29] We do not plot China because the last years of observation are missing.

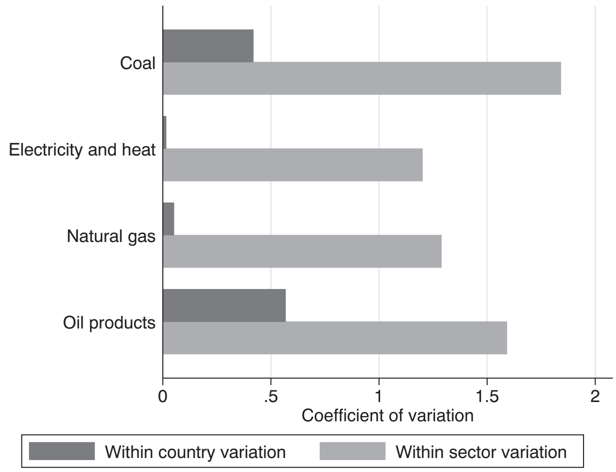


Fig. 8. Comparing sector-level tax variation within countries across sectors (dark) with across countries within sectors (light).
Notes: The dark grey bars are the mean of the coefficients of variation in taxes for each country, across its industrial sectors. The light grey bars are the mean of the coefficients of variation in taxes for each industrial sector, across all countries. The year of the data is 2012 and is from the OECD (2013).

of variation, a standard measure of dispersion, we do not find a common trend across sectors.

4.5. Policy drivers and taxation

4.5.1. Across countries, taxes represent a key driver in industrial energy price variation

Energy prices paid by firms reflect various elements that are influenced by both markets and government policy. It includes energy and supply costs (fuel and generation costs and other operational costs borne by the generator and supplier), network costs (transmission and distribution infrastructure costs including maintenance and expansion of grids, system services and network losses), as well as taxes and levies. The latter may include general taxation (the IEA data excludes VAT), or energy specific levies, for example to finance energy and climate policies and create incentives for the promotion of energy efficiency or renewable technologies. It may also include exemptions.

We assess to what extent the cross-country variation in the tax component contributes to the variation in the final industrial fuel prices. For a subset of countries and years, mostly OECD countries, the IEA reports also average industrial fuel prices *excluding* taxes, allowing us to derive implicit taxes. For each year, we regress the after-tax fuel price on the tax component and a constant term. Fig. 7 reports the R-squared of each regression.[30] We find that the tax component plays a major role in explaining the variation in coal, electricity and oil prices across countries. Specifically, it explains between 80% to 90% for coal, 30% to 70% for electricity and 40% to 80% for oil.[31] For variation in gas prices, the explanatory power of taxes is lower at around 20%, as gas prices are strongly conditioned on the geography of the gas transport infrastructure.

4.5.2. Within countries, fuel prices and taxes vary little across industrial sectors

The VEPL is a weighted average of country-level fuel prices for industry, hence relies on the assumption that fuel prices do not vary significantly between *industrial* sectors within a country. Here we investigate if fuel taxes indeed vary within countries and across sectors, using a unique database collected by the OECD (2013) on effective tax rates on different fuels at the sub-industrial sector level in OECD countries in 2012. This allows us to assess the variation in the tax component across industrial sectors. We calculate the coefficient of variation (CV) of the tax rates across sectors for each country and fuel (oil, coal, gas, electricity). Within-country variations in energy taxes across industrial sectors (dark bars in Fig. 8) are found to be small compared to within-sector (across countries) variations (light bars in Fig. 8). There is some within-country variation for coal and oil while for electricity and natural gas =, similar tax rates tend to be applied across industrial sectors within a country.[32]

The OECD (2013) database also allows us to perform an important robustness check. We can test if the VEPL is a good proxy for the *observed* variation in energy taxation across industrial sectors. We construct a “VEPL_tax” indicator where the sector level variation in energy prices are introduced using observed variations in sector level energy taxes.[33] 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 (0.99 with an R^2 of 0.99, and 0.98 with an R^2 of 0.95 when country and sector fixed effects are partialled out) indicating that there is little omitted heterogeneity in the VEPL from only using underlying country level industrial fuel prices.

5. Illustrative applications

5.1. Energy prices and industrial energy costs

One important question surrounding the effects of energy prices on industrial competitiveness is the link between energy prices and energy costs. Higher energy prices do not necessarily translate into higher energy costs if firms undertake fuel switching or adopt energy saving innovations to reduce exposure to price hikes.

Existing studies looking at the response to energy prices tend to be country specific.[34] Our energy price index can be used to investigate these issues in an international context. Here, we investigate sectors' short-term associations between energy prices and i) energy intensity defined as energy use in toe per gross value added (GVA)[35] and ii) energy costs (total energy expenditure) per GVA.[36] To do so, we regress energy intensity and energy costs separately on the logged VEPL, which we instrument with the FEPI to address the potential endogeneity of firm energy mix choices, as outlined in Section 2. We control for unobserved heterogeneity at the country level via country fixed effects and also include year fixed effects. All regressions are run individually by sector.

Table 5 presents the estimation results for sectoral energy intensity. The result is heterogeneous across sectors. For four sectors, we

[30] The R-squared is used as it is straightforward to interpret as the percentage of explained 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 is lower (6-8).

[31] The high R-squared for coal can be attributed to the fact that there is not much differences in coal prices (non-tax component) across countries.

[32] Variation in tax rates within countries is high between industrial and *non-industrial* sectors, for example in the case of oil used by industry versus oil as transport fuel.

[33] We calculate the “VEPL_tax” by adjusting the underlying average prices for different sector level taxes. The underlying fuel prices P_{it}^j are an average across sectors, so we first remove the average tax, and then add the sector specific tax to get a more granular P_{ist}^j. Since we only have the tax data for 2012, we can drop the time index t. That is $P_{is}^j = P_i^j - tax_i^j + tax_{is}^j$, where tax_{is}^j is taken from OECD (2013) and the weighted average tax for fuel j is $tax_i^j = \sum_s tax_{is}^j w_s$ with weights w_s reflecting sectoral fuel use.

[34] For example Anderson and Newell (2004) and Linn (2008) use US plant level data to examine how energy prices impact energy saving technology adoption.

[35] GVA data is taken from UNIDO (2016).

[36] We do not claim causality here, as there are remaining potential endogeneity concerns, for example, if a sector's output prices (and therefore gross value added) are correlated with energy prices, or reversed causality through energy demand effects on energy prices.

Table 5
Regressions of energy intensity (energy use per GVA) on energy prices

	(1) All manu-facturing	(2) Chemical and petrochemical	(3) Food and tobacco	(4) Iron and steel	(5) Machinery	(6) Non-ferrous metals	(7) Non-metallic minerals	(8) Paper, pulp and print	(9) Textile and leather	(10) Transport equipment	(11) Wood and wood products
VEPL (log)	0.075	−0.49**	−.61*	−0.52	0.13	0.15	1.1	0.042	0.062	0.22	−0.12
	(0.24)	(0.24)	(0.36)	(0.66)	(0.26)	(0.49)	(0.74)	(0.17)	(0.45)	(0.36)	(0.40)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	110	183	188	171	181	130	187	188	187	176	166

Notes: Two-stage least squares regressions with country and year fixed effects. The dependent variable is logged energy use over gross value added of the sector. The log of VEPL is instrumented with FEPI_fw2010. Robust standard errors clustered at the country level are in parentheses.
* indicates significance at 10% and ** indicates significance at 5%.

Table 6
Regressions of energy costs per GVA on energy prices.

	(1) All manu-facturing	(2) Chemical and petrochemical	(3) Food and tobacco	(4) Iron and steel	(5) Machinery	(6) Non-ferrous metals	(7) Non-metallic minerals	(8) Paper, pulp and print	(9) Textile and leather	(10) Transport equipment	(11) Wood and wood products
VEPL (log)	1.1***	0.53**	0.39	0.48	1.1***	1.1**	2.1***	1.0***	1.1**	1.2***	0.86**
	(0.25)	(0.23)	(0.36)	(0.66)	(0.26)	(0.49)	(0.74)	(0.17)	(0.45)	(0.36)	(0.40)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	110	183	188	171	181	130	187	188	187	176	166

Notes: Two-stage least squares regressions with country and year fixed effects. The dependent variable is logged energy costs over gross value added of the sector. The log of VEPL is instrumented with FEPI_fw2010. Robust standard errors clustered at the country level are in parentheses.
* indicates significance at 10%, ** indicates significance at 5% and *** indicates significance at 1%.

find a negative estimated elasticity, suggesting that a higher energy price is inducing energy efficiency improvements – these are chemical & petrochemical and food & tobacco where the coefficient is negative and significant, and iron & steel and wood products, where the estimate is negative but not significant. A positive but not statistically significant relationship is found for machinery, non-ferrous metals, non-metallic minerals, paper, textile & leather and transport equipment. For overall manufacturing[37] the size of the correlation between energy prices and energy intensity is very small.

Table 6 shows the estimation results for value added unit energy costs. For overall manufacturing, we find a positive and significant elasticity larger than one: 110% of the energy price increase is reflected in higher energy costs. This is consistent with the energy price elasticity of energy intensity being positive but close to zero. However, this aggregate result hides substantial heterogeneity across sectors with the estimates ranging between 0.39 and 2.1.[38] Sectors that have large energy cost elasticities also have small energy intensity elasticities. In other words, sectors that do not reduce their energy intensity in response to higher energy price in the short-run see their costs affected more than other sectors. This application illustrates how sector-specific energy price indices can be used in empirical analysis.

These results show generally limited response, but significant sectoral heterogeneity in short-term elasticities of energy input efficiency with respect to energy price, broadly in line with the literature (e.g. Linn, 2008; Steinbuks and Neuhoff, 2014; Kaltenegger et al., 2017). This does not contradict the findings that in the long run, capital stocks and economic structures adjust to long-term variation in energy prices (Grubb et al., 2018).

5.2. Carbon price impacts

To estimate the impact of carbon pricing policies, a number of recent studies exploit the historic variation in energy prices, taking advantage of the fact that carbon prices directly raise energy prices (e.g. Aldy and Pizer, 2015; Sato and Dechezleprêtre, 2015).[39] Indeed our energy price index is suitable for estimating the short-term impact of energy prices on outcome variables such as turnover, value added, employment, profits, innovation. In order to infer carbon price impacts from the elasticities estimated using the historical energy price, we additionally provide a variable that reflects the resulting energy price increase for each country-sector from carbon prices at different levels (10, 20, 30, 40 and 50 $/tCO_2$).

To do so, we use detailed data on the emission factors of all recorded sub-types of fuels that come from the standard 2006 Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and the country specific emission factors of electricity generation from IEA (2016a) to calculate the carbon intensity of the fuel mix of each country-sector from their fuel use data.[40] Multiplying the carbon intensity of fuel mixes with carbon prices gives the resulting increase in the energy price.

[37] We use total manufacturing instead of aggregate industry to match the UNIDO GVA data.

[38] The association is above one for machinery, non-ferrous metals, non-metallic minerals and textile & leather and transport equipment suggesting that energy efficiency worsens with energy price increases. The association is smaller and significantly different from unity below one only for chemicals and wood products. It is below one and not significant for iron & steel and food & tobacco.

[39] This presents an alternative, empirically grounded way to estimate the impact of carbon prices on competitiveness outcomes in contrast to studies that use partial and general equilibrium models (e.g. Demailly and Quirion, 2008) and Rivers (2010).

[40] We therefore implicitly assume a full carbon cost pass-through from the electricity generating sector to industries.

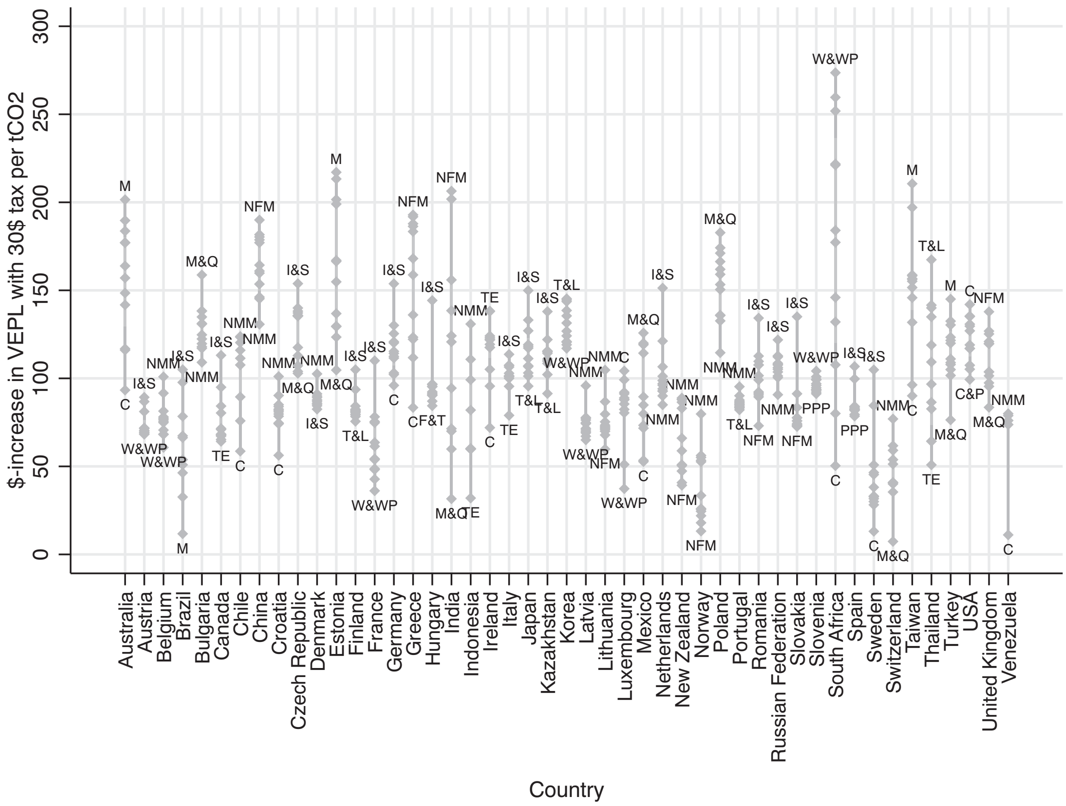


Fig. 9. Energy price increase due to hypothetical carbon tax of $30/tCO$_2$.
Notes: Plotted is the increase in the energy price calculated from the VEPL methodology based on fuel weights and emission factors in 2010. Legend for sectors: “C&P” = “Chemical and petrochemical”, “C” = “Construction”, “F&T” = “Food and tobacco”, “I&S” = “Iron and steel”, “Mach” = “Machinery”, “M&Q” = “Mining and quarrying”, “NFM” = “Non-ferrous metals”, “NMM” = “Non-metallic minerals”, “PPP” = “Paper, pulp and print”, “T&L” = “Textile and leather”, “TE” = “Transport equipment”, “W&WP” = “Wood and wood products”.

The variables FEPI_fw2010_tax_10 (...-50) in our dataset contain the hypothetical price increase (on a log scale) induced by a carbon tax of 10 \$/tCO$_2$ (five variables for 10–50 \$/tCO$_2$ in 10 unit steps), based on the FEPI_fw2010.[41] Therefore, the fuel use weights as well as the emission factor of electricity are taken from 2010 (the IPCC emission factors for other fuels are time-invariant). Note that the hypothetical carbon tax is additional to any already existing carbon tax. As the weights are fixed, any reduction in energy prices that carbon taxes may induce through fuel substitution is not accounted for. Hence this variable is suitable for estimating the short-term effects of carbon prices.[42]

Fig. 9 gives an overview of how a carbon tax of 30 \$/tCO$_2$ would increase the energy price level per toe.[43] On average, the energy price increases by 100 \$/toe or 11%. This significant increase hides substantial heterogeneity: both across countries and within countries across sectors. The sectors with the highest increase, up to 200 \$/toe, are typically iron & steel and non-metallic minerals, mainly due to their reliance on high carbon fuels like coal. However, the ordering of sector exposure varies greatly across countries and there are sectors which have the highest exposure in one country and the lowest exposure in another. Some countries like Portugal, Slovenia and Spain show little variation across sectors while sectors in countries like South Africa and India would experience important difference in terms of energy price increases. This result emphasizes the importance of using sector specific price indices when estimating the impact of carbon pricing on competitiveness.

6. Conclusions

The lack of good and comprehensive measures of relative industrial energy prices has been a major obstacle for advancing empirical analysis on competitiveness impacts and prospects of a ‘race-to-the-bottom’ industrial energy price competition among governments. In particular, there is limited information about relative industrial energy prices and taxes in emerging economies, and this is problematic because regions with high energy prices, such as the EU, are most worried about competition from these economies with rapidly growing industrial output.

[41] It is a time-invariant variable (one-off hypothetical price increase) intended to be used together with the FEPI_fw2010 only. It is constructed by calculating a FEPI_fw2010 including the hypothetical carbon tax and then taking the difference. As in the fuel use data, the energy inputs include combustion and feedstocks.

[42] As an example, one might estimate the output elasticity of energy prices by regressing logged output on logged VEPL instrumented with the FEPI_fw2010 (since it already is on a log scale) country-sector fixed effects and other control variables (or via reduced form regressing directly on the FEPI_fw2010). The coefficient is the elasticity, and multiplied by the variable FEPI_fw2010_tax_10 yields the country-sector specific percentage change in the outcome (output) induced by the energy price increase through the carbon tax.

[43] Note that for this figure we used the methodology of the VEPL for cross-sectional descriptives, not the FEPI variable described in the previous paragraph which is intended for analysis.

We show that international energy price differentials have grown over the past two decades in some industries but not all. Many factors have influenced the widening of price differentials including shifts in the energy balance away from fossil fuels towards renewables in some regions, the development of shale gas in the US, as well as the introduction of environmental and climate policies. This has fuelled concerns in the high energy cost regions of the world and moderated their ambition in terms of climate policy. While these competitiveness concerns have long existed, the evidence to support the link between higher energy costs and loss of competitiveness is far from concrete.

Improved evidence on how past asymmetric energy prices have affected business performance is likely to help in identifying the specific cases where such special considerations or compensations are necessary, and help in focusing policy support. Currently, competitiveness concerns continue to represent the main obstacle for countries pursuing more ambitious energy and environmental policy, such as carbon taxation. This 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 fuel subsidies remain prevalent globally and heavily distort the carbon externalities which climate policies aim to correct. The European Council resolutions on the EU 2030 Climate and Energy Policy Framework also indicate that the Emissions Trading System will continue to compensate sectors with free allocation in case of competitiveness effects, and that "consideration to ensure affordable energy prices.....will be taken into account" (European Council, 2014).

Indeed, while the political debate centers around the negative effects from energy or carbon taxes on exports, market shares 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; 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). We found short-run correlations between sector level energy prices and energy intensity andenergy costs, that vary substantially across sectors. More robust evidence, including on whether the positive effects outweigh the negative ones, would help in find tuning policies affecting energy prices. Better targeted policies would in turn lower the overall cost of achieving mitigation targets thus improving welfare outcomes. A number of recent studies have utilized the energy price index constructed in this paper to estimate the effect of asymmetric energy price on competitiveness outcomes including international trade, FDI and investments (Sato and Dechezleprêtre, 2015; Garsous and Kozluk, 2017; Dlugosch and Kozluk, 2017). It is our hope that this dataset will contribute towards the development of the empirical literature.

Appendix A

A.1. 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)[44] informs the methodology used for the construction of the VEPL and FEPI. 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 summarized 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 tonnes of oil equivalent (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:

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

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

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 centerpiece 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)[45]. 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 minimize 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 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 type, 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, then the VEPL with variable weights which is an *effective* price, will also change 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 example for analysis of competitiveness effects.

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 formulatedas 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 no longer the same:

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

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

In the first equation, the expenditure share is taken and in the second equation, the quantity share is used to calculate 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[46]. 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 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 the quantities are fixed for the FEPI, we implicitly assume an elasticity of substitution of zero.

[45] 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.)

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

Having fixed quantity weights at different anchor points can be interpreted as accounting for the 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 among other factors 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.

A.2. Aggregate industry and manufacturing VEPL and FEPI

We also construct a VEPL (Variable weights Energy Price Level) and FEPI (Fixed weights Energy Price Index) at the aggregate industry level and for aggregate manufacturing. The manufacturing VEPL includes all the sub-sectors listed except mining and quarrying and construction. The aggregate industry VEPL also includes mining and quarrying and construction and non-specified but industrial sectors. The prices also include taxes and are constructed analogously to the sector level VEPL and FEPI:

$$VEPL_{it} = \sum_j \frac{F^j_{it}}{\sum_j F^j_{it}} \cdot P^j_{it} = \sum_j w^j_{it} \cdot P^j_{it} \tag{4}$$

$$FEPI_{it} = \sum_j \frac{F^j_i}{\sum_j F^j_i} \cdot \log\left(P^j_{it}\right) = \sum_j w^j_i \cdot \log\left(P^j_{it}\right) \tag{5}$$

where F^j_{it} is the input quantity of fuel type j in tonne of oil equivalent (toe) for the whole industrial sector (or just manufacturing) in country i at time t and P^j_{it} denotes the average real industrial energy price per toe for fuel type j in the including taxes, in country i at time t in constant 2010 USD. The weights w^j_{it} applied to the prices vary on a yearly basis and across countries. This represents the industry (or manufacturing) 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. In the data, the aggregate industry and the manufacturing VEPL and FEPI are recorded as separate sectors.

A.3. Implication of log transformation in FEPI

Consider a measurement error x^a_i, which leads to $\frac{F^a_{is}}{F_{is}} \times \log\left(P^a_{it} * x^a{}_i\right) + \frac{F^b_{is}}{F_{is}} \times \log\left(P^b_{it}\right) = \frac{F^a_{is}}{F_{is}} \times \log\left(P^a_{it}\right) + \frac{F^b_{is}}{F_{is}} \times \log\left(P^b_{it}\right) + \frac{F^a_{is}}{F_{is}} \times \log\left(x^a{}_i\right)$, 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.

A.4. Exchange rate assumption irrelevance in FEPI

The conversion factor from market exchange rates (MER) 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: $FEPI_{ist} = \sum_j \frac{F^j_{is}}{\sum_j F^j_{is}} \times \log\left(P^j_{it} * ConversionPPP_i\right) = \sum_j \left(\frac{F^j_{is}}{\sum_j F^j_{is}} \times \log\left(P^j_{it}\right)\right) + \log\left(ConversionPPP_i\right)$.

A.5. Missing data imputation

We use price indices to impute some of the missing data of the underlying prices of the VEPL and FEPI. As described above, as a first step, we use the IEA real fuel price indices for industry (IEA, 2016b, 2012), which is available at the country level for OECD countries only. We calculate the growth rates in the indices and multiply them with the level of the fuel prices to impute gaps in the raw data. For non-OECD countries, a wholesale price index is available for each fuel type, although with many gaps and only until 2010. The growth rate from this is applied, after deflating it appropriately.[47]

As a second step, which is only performed for OECD countries, we impute some of the remaining gaps using a more aggregate price index. For example, we use an overall country-level energy price index for industry, or a fuel specific index at a regional level. 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. The added data points described here paragraph represent less than 6% of the sample.

[47] The only exception is the gas price for China, which is imputed with the average growth rate in the wholesale indices of oil, coal and electricity from 1998 until 2004 (thereafter the gas price is observed). Applying growth rates from the wholesale energy price to fill gaps in industrial energy price was deemed plausible as it is similarly defined as the IEA real price index (i.e. with taxes but without VAT) and they are highly correlated (usually between 75% and 95% in most countries where both data are available, except for Norway).

It is not clear *a priori* which approach is the better choice (i.e. country specific general energy or fuel specific but regional), so we apply a data driven approach which maximises out of sample prediction precision by country and choose the index accordingly on a per country basis. To this end we perform a leave-one-out cross validation exercise by predicting the observed growth rates in the price levels with the growth rates from either of the indices. We calculated the root mean squared error for both indices for each country and choose the one which is lower. Oil and coal prices are often better predicted by the regional OECD industrial price index, while gas prices are generally better predicted by the country level industrial energy price index (and for electricity it is divided). As described in the main text, the flags *flag_VEPL* and *flag_FEPI* identify the observations where at least one underlying price was imputed.

For the FEPI (not the VEPL) we additionally allow construction of the index if the price data is available consistently for at least 88% of the underlying fuel mix in terms of fuel consumption, which increases non-missing values in the FEPI considerably. Appendix A.6 describes this procedure alongside the rationale for the threshold in more detail.

A.6. Threshold for ignoring missing prices for FEPI construction

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 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 (Fig. 10). 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 69% to 85% (in the FEPI_fw2010 version). If the pattern of the ignored missing values are random 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.*

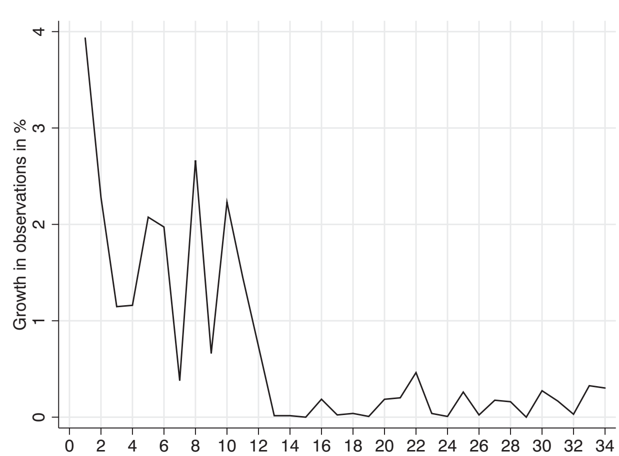


Fig. 10. Trade-off between observations gained and accuracy for the FEPI_fw2010.
Notes: Shows the growth in observations by increasing the threshold (on the horizontal axis) for the FEPI_fw2010. After 12%, the additional growth in observations is less than 0.5% for each percentage point increase in the threshold level.

A.7. Variation in energy prices across countries

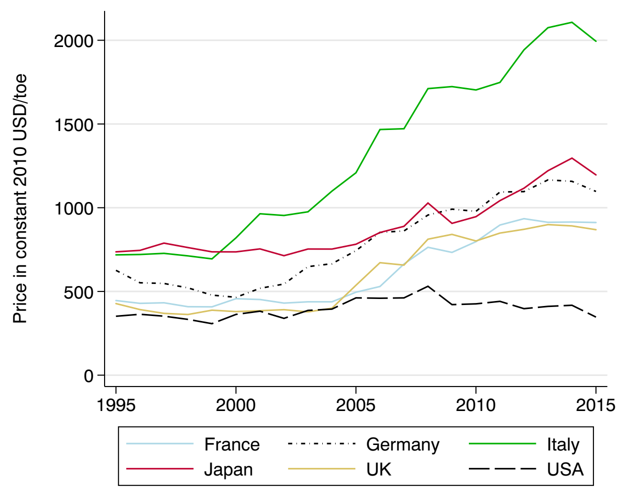


Fig. 11. Aggregate industry VEPL for the six largest OECD economies.
Notes: The panels show the aggregate industry VEPL (in 2010$) for selected OECD economies over time, based on MER.

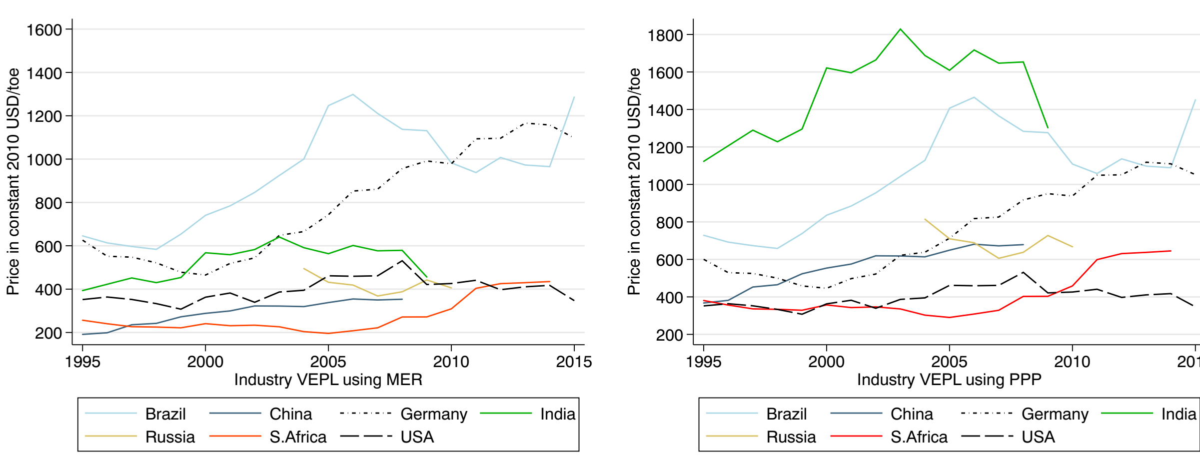


Fig. 12. Aggregate industry VEPL for emerging economies.
Notes: The panels show the aggregate industry VEPL (in 2010$) for selected emerging economies and two OECD economies over time. The left panel is based on MER and the right on PPP rates.

A.8. Variation in energy prices across sectors

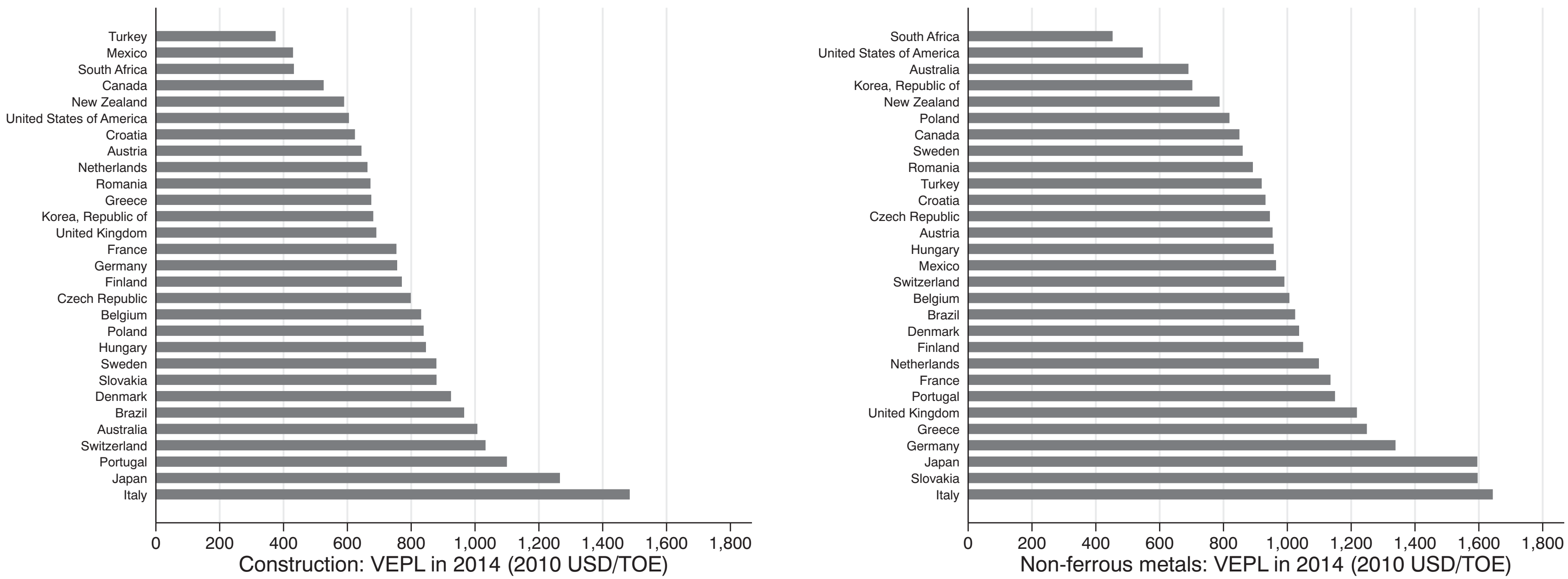


Fig. 13. Construction and non-ferrous metals VEPL (MER) in 2014.
Notes: VEPL (in 2010$) for the construction sector (left) and the non-ferrous metals sector (right) in 2014. All panels are based on MER.

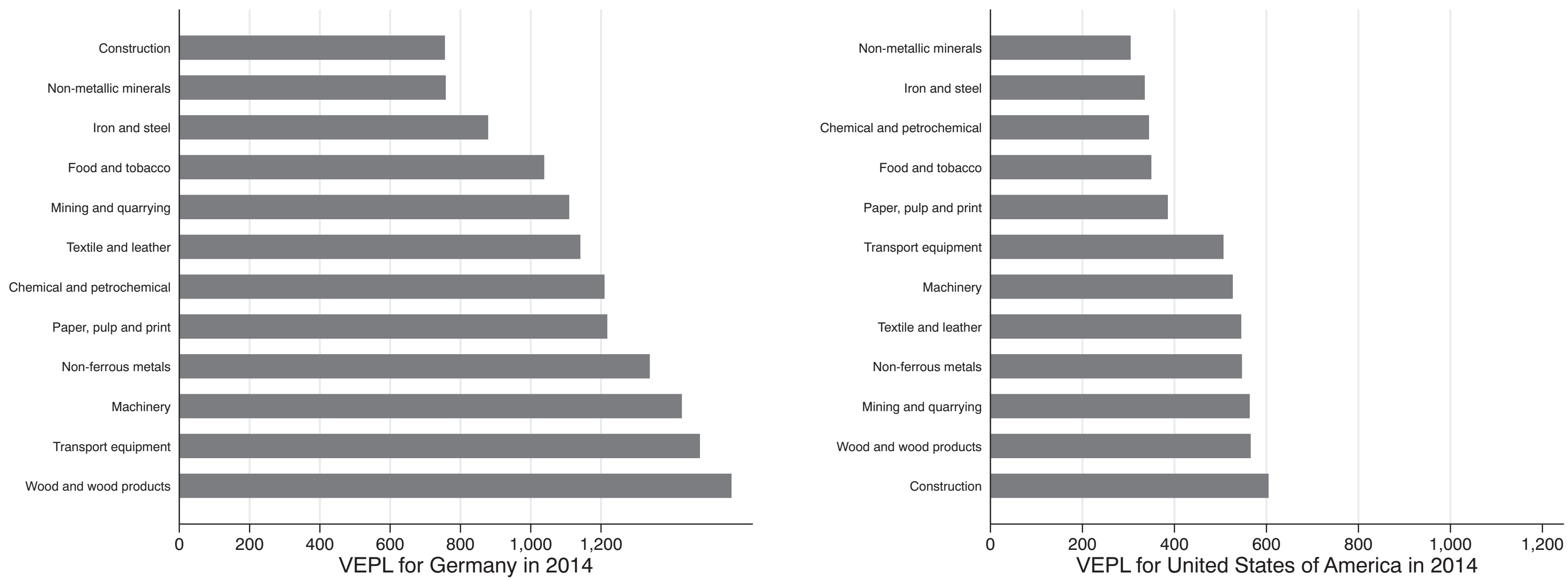


Fig. 14. VEPL (MER) for different sectors in Germany and the USA in 2014.
Notes: VEPL (in 2010$) for all different sectors in Germany (left) and the USA (right) in 2014. All panels are based on MER.

A.9. Role of electricity use and fuel switching

Differences in the share of electricity in the total fuel consumption is a key source of variation in energy prices, not only because electricity is the most expensive carrier but also because it is generally the most important carrier. When aggregating sectors at a global level, electricity accounts for more than 50% in all sectors except the construction and non-metallic minerals sector (see Table 7).[48]

Table 7
The relative importance of the fuel types by sector in the VEPL.

	Oil	Gas	Coal	Electricity
Chemical and petrochemical	0.14	0.20	0.03	0.63
Construction	0.42	0.12	0.04	0.42
Food and tobacco	0.14	0.22	0.03	0.60
Iron and steel	0.06	0.17	0.13	0.63
Machinery	0.08	0.15	0.02	0.75
Mining and quarrying	0.24	0.11	0.03	0.62
Non-ferrous metals	0.08	0.12	0.03	0.78
Non-metallic minerals	0.19	0.24	0.12	0.45
Paper, pulp and print	0.10	0.15	0.03	0.73
Textile and leather	0.12	0.17	0.02	0.69
Transport equipment	0.10	0.15	0.03	0.72
Wood and wood products	0.10	0.09	0.04	0.77
Total	0.15	0.16	0.04	0.65

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.

The degree of electrification also drives convergence/ divergence in energy prices at the country-sector level. Taking the Chemical & petrochemical sector as an example, as shown in Fig. 15, Italy and Sweden 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. Energy prices increased by over three folds for this sector in Italy and Sweden during the two decades. In contrast, we observe stable electricity shares over time in Japan and Russia (from 2000), and the corresponding increase in energy prices were much smaller in magnitude.

Indeed, 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 characterizes a particular sector or country.

While there is substantial 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. Therefore, we recommend the use of the FEPI, either directly or as instrument, for estimations in a panel data setting.

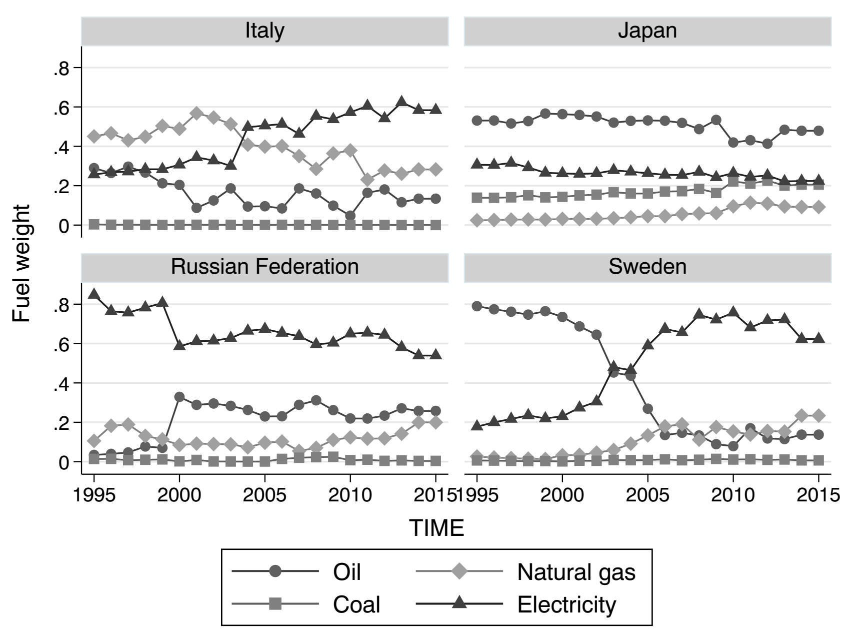


Fig. 15. Fuel consumption shares in the chemical and petrochemical sector.
Notes: Missing data points in fuel consumption shares are calculated as described in Section A.5.

[48] We capture the importance of a fuel component in the VEPL by multiplying 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.

A.10. Share of time series variation in VEPL explained by variation in fuel prices

To quantify how much variation in VEPL is due to change in fuel composition and how much is due to fuel price variation, we differentiate the VEPL Eq. (1) as follows:

$$\underbrace{\Delta VEPL_{it}}_{\text{Total variation}} = \underbrace{\sum_{j} P^{j}_{it} \cdot \Delta w^{j}_{it}}_{\text{Fuel switching}} + \underbrace{\sum_{j} w^{j}_{it} \cdot \Delta P^{j}_{it}}_{\text{Fuel price variation}} \tag{6}$$

where $\Delta VEPL_{it} = VEPL_{it} - VEPL_{it-1}$.[49] The first component is a fuel switching component that quantifies the change in VEPL due to a change in the fuel weights holding fuel price constant. The second component is a fuel price variation component quantifying the change in VEPL due to a change of fuel prices holding the fuel weights constant. We then compute for each country and year the share of total VEPL variation due to variation in the fuel price. The share equals the ratio between the absolute value of the price variation component and the sum of the absolute value of the two components. Table 8 reports for each country the mean of this share for the 1998–2014 period and for 3 sub-periods.

Table 8
Share of variation in VEPL explained by variation in fuel prices.

Country	1998–2002	2003–2008	2009–2014	1998–2014
Japan	86	81	72	81
Taiwan	74	86	n.a.	80
Denmark	62	85	87	80
Sweden	79	86	70	78
Brazil	89	84	62	77
Greece	88	77	67	77
Germany	87	82	63	77
France	71	86	68	76
USA	86	69	71	76
Switzerland	52	89	82	76
Netherlands	63	82	84	76
Austria	75	82	73	75
Australia	57	74	89	74
Canada	56	89	66	73
Belgium	83	83	61	72
Croatia	77	63	72	70
Italy	85	64	69	70
Finland	53	77	82	70
United Kingdom	55	84	66	70
Poland	71	69	61	69
Hungary	54	89	67	68
India	73	61	n.a.	67
Portugal	72	48	82	67
Mexico	61	88	42	67
Romania	63	64	71	66
Slovakia	47	74	65	63
Thailand	71	53	79	62
South Korea	76	52	68	62
Indonesia	75	51	n.a.	62
New Zealand	71	57	50	61
Czech Rep.	50	64	46	53
Turkey	58	49	52	53
China	33	56	n.a.	46
Average	68	73	69	70

[49] We perform this exercise for the aggregate industry VEPL.

A.11. Codebook of variables in the dataset

Table 9
Codebook.

Variable	*Description*
isoalpha3code	Country 3-letter code according to ISO
country	Country name (ISO)
OECD	Dummy = 1 if country member of OECD during data period
year	Year (annual data)
inflation	Inflation rate calculated from GDP-deflator
sector	Sector name (a sector, whole manufacturing or aggregate industry)
biofuel_share	Share of biofuel in the toe fuel mix of the country-sector in the underlying data.
flag_euse	Multinominal variable indicating the underlying fuels use data imputation: -2=extrapolated, -1=interpolated, 0=observed, 1-5=the number of sectoral fuel weights replaced by industry average weights. Negative numbers mean no replaced weights, positive numbers could have inter- or extrapolated weights.
flag_addprice	Dummy=1 if underlying price data point is from other source than IEA industrial energy price dataset (e.g. national sources)
flag_VEPL	Multinomial variable indicating price data imputation for the VEPL: -1=data is missing, 0=observed, 1=index-imputed values with the respective index, 2=for values imputed with one of the aggregate energy price indices.
flag_FEPI	Multinomial variable indicating price data imputation for the FEPI: -1=data is missing, 0=observed, 1=index-imputed values with the respective index, 2=for values imputed with one of the aggregate energy price indices.
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 throughout. 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 throughout. 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 throughout. 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 throughout. 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 throughout. 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 throughout. 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.
FEPI_fw2010_tax_10	Increase in FEPI_fw2010 from an hypothetical carbon tax of 10US$/t$CO_2$.
FEPI_fw2010_tax_20	Increase in FEPI_fw2010 from an hypothetical carbon tax of 20US$/t$CO_2$.
FEPI_fw2010_tax_30	Increase in FEPI_fw2010 from an hypothetical carbon tax of 30US$/t$CO_2$.
FEPI_fw2010_tax_40	Increase in FEPI_fw2010 from an hypothetical carbon tax of 40US$/t$CO_2$.
FEPI_fw2010_tax_50	Increase in FEPI_fw2010 from an hypothetical carbon tax of 50US$/t$CO_2$.

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