**Misato Sato and Antoine Dechezleprêtre**

# Asymmetric industrial energy prices and international trade

## Article (Accepted version)
## (Refereed)

**Original citation:**
Sato, Misato and Dechezlepretre, Antoine (2015) *Asymmetric industrial energy prices and international trade.* Energy Economics. ISSN 0140-9883

DOI: 10.1016/j.eneco.2015.08.020]

# Asymmetric industrial energy prices and international trade*

Misato Sato† and Antoine Dechezleprêtre‡

**Abstract**

This paper measures the response of bilateral trade flows to differences in industrial energy prices across countries. Using a panel for the period 1996-2011 including 42 countries, 62 sectors and covering 60% of global merchandise trade, we estimate the short-run effects of sector-level energy price asymmetry on trade. We find that changes in relative energy prices have a statistically significant but very small impact on imports. On average, a 10% increase in the energy price difference between two country-sectors increases imports by 0.2%. The impact is larger for energy-intensive sectors. Even in these sectors however, the magnitude of the effect is such that changes in energy price differences across time explain less than 0.01% of the variation in trade flows. Simulations based on our model predict that a €40-65/t$CO_2$ price of carbon in the EU ETS would increase Europe's imports from the rest of the world by less than 0.05% and decrease exports by 0.2%.

JEL classification: F18, F14, Q56Keywords: energy prices, international trade, carbon taxes

*We would like to thank Rob Elliot, Reyer Gerlagh, Scott Taylor, Farid Toubal and two anonymous referees for many helpful comments. Participants at seminars in CEPREMAP Trade and Environment Conference (Paris), 19th Annual Conference of the European Association of Environmental and Resource Economists (Prague), the 5th Atlantic workshop on energy and environmental economics (A Toxa) and 12th IAEE European Conference (Venice) have all improved the paper. We acknowledge financial support from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 308481 (ENTRACTE), the Global Green Growth Institute, the Grantham Foundation and the ESRC through the Centre for Climate Change Economics and Policy.

†Grantham Research Institute on Climate Change and the Environment, London School of Economics. M.Sato1@lse.ac.uk

‡Grantham Research Institute on Climate Change and the Environment and Centre for Economic Performance, London School of Economics, A.Dechezlepretre@lse.ac.uk

# 1 Introduction

Do higher energy prices cause sectors to lose industrial export competitiveness? The rising price of energy remains a politically sensitive issue, particularly in energy import dependent regions such as Europe and Japan. Several new trends contribute to this: the slow recovery since the 2008 financial crisis, the shale gas boom in the US with the consequent fall in energy prices for US manufacturers, the costly transition from fossil fuel and nuclear to renewable energy sources notably in Europe, and the increased competition from emerging economies. Standard trade models predict that by making domestic production more costly, policies that increase energy price will put domestic firms at a strategic disadvantage relative to foreign rivals facing lower energy prices. This result forms the basis of the so-called Pollution Haven Hypothesis (Taylor & Copeland, 2004; Levinson & Taylor, 2008), which postulates that uneven environmental policies influence the distribution of polluting industries between countries. According to this theory, producers of energy intensive products respond to higher energy prices by producing fewer energy-intensive goods which may lead to a decline in net exports and the partial relocation of production to a region with low energy prices (Hanna, 2010). However, energy costs are only one of many factors that influence imports and relocation. These include labor costs, infrastructures, institutions, proximity to customers, and many others (Demailly & Quirion, 2008). For this reason, the extent to which changes in relative energy prices might influence trade and competitiveness is unclear and is partly an empirical question. The objective of this paper is to determine the magnitude of this impact using historical data on trade and energy prices from 1996 to 2011 covering 42 countries and 62 sectors representing 60% of global merchandise trade during that period.

The question of whether trade has historically responded to energy price differences remains largely unanswered empirically. As a consequence, our understanding of the impact of regional asymmetries in carbon prices on trade is limited, as is our understanding of the environmental efficacy of such policies. Yet, as countries implement carbon pricing policies at different speeds, there is considerable interest in assessing the potential trade impacts of climate change mitigation policies, particularly for energy intensive trade-exposed sectors. The literature on the links between climate policy and international trade[1] and in particular on "carbon leakage" (whether part of the emissions reductions achieved by a carbon emissions reduction policy is directly offset by an increase in emissions outside of the regulated region) has so far relied on *ex-ante* model simulation

[1] See Levinson & Taylor (2008); Levinson (2010) ; Copeland & Taylor (2003); Jaffe et al. (1995); Jeppesen et al. (2002) for reviews of the wider literature on effects of environmental policies on trade.

strategies, typically using CGE models[2] (e.g. Babiker, 2005; Burniaux & Martins, 2000; Gerlagh & Kuik, 2007; Kuik & Gerlagh, 2003; Paltsev, 2001) or partial equilibrium analysis in the context of the EU ETS[3] (e.g. Demailly & Quirion, 2008; Monjon & Quirion, 2009; Demailly & Quirion, 2006; Hourcade et al., 2007) but the results are decisively mixed, highlighting the need for empirical analysis in order to better understand the nature and magnitude of these effects. The lack of empirical evidence may be attributable to several factors. Firstly, although carbon mitigation policies targeting industry sector emissions have recently proliferated across the world – including the European Union Emissions Trading Scheme (EU ETS), New Zealand's ETS, the UK's Climate Change Levy, California's climate programme, British Columbia's carbon tax scheme and China's pilot emissions trading schemes – the nascent nature of the majority of schemes means there is a lack of observed data. An exception is the Kyoto protocol which was ratified in 1997. Aichele & Felbermayr (2012) derive a gravity equation for the carbon content of trade and find that commitment to the Kyoto protocol is associated with a decrease in domestic emissions by 7%, but also with an increase in the share of imported embodied carbon emissions over domestic emissions by about 14%. Using a matching method, Aichele & Felbermayr (2011) finds that Kyoto countries' exports are reduced by 14% compared to a counterfactual scenario. However, since the paper uses country-level data a concern is that the Kyoto dummy variable also captures other macro-economic shocks correlated with both exports and Kyoto ratification, such as China's accession to the WTO in 2002 (Branger & Quirion, 2013). Secondly, where carbon prices have existed, the levels have been low, preventing researchers from disentangling the effect of small carbon prices from the multitude of more dominant factors that drive trade and investment decisions, such as exchange rates, transport costs, trade agreements, and relative costs of labour, capital and other input costs. Thirdly, it is difficult to compare the relative stringency of existing carbon pricing policies in a meaningful way. Complications arise, for example, in the EU ETS where allowances were allocated for free to most sectors in the first two implementing phases.

This paper aims to overcome these limitations and to establish whether changes in energy price differences between trading partners affect trade flows between these

[2] See Dröge (2009) and Zhou et al. (2010) for a review of this literature. This group of studies simulate different emission reduction targets under the Kyoto Protocol and have estimated a wide range of carbon leakage rates.

[3] These studies examine the potential impacts of climate policies on trade and investment for heavy industry and highlight sectoral differences in carbon leakage rates estimated in these models reflect the differences in parameters such as carbon intensity of production, abatement potential, ability to pass through abatement costs to consumers, as well as different levels of sensitivity to multiple barriers of trade (e.g. product differentiation, service differentiation, transport costs, capacity constraints and import restrictions). Higher carbon leakage rates are estimated for the steel sector which exhibit high product differentiation but also higher abatement potential, relative to the cement sector, which is characterised by homogeneous products but high transport costs relative to value.

countries, based on a large dataset covering 42 countries at varying levels of economic development (over 1600 country pairs) and 62 sectors for the period 1996 to 2011. Contrary to the stringency of climate change regulations, energy prices have the advantage of being comparable across countries, sectors and time, and to be available for a large set of countries and a long time period. Following Aldy & Pizer (2011), we postulate that historic asymmetries in industrial energy prices offer insights into the impact of asymmetric carbon prices in the future, owing to the fact that carbon prices work by increasing the effective price of energy for industry. The analysis is conducted at the sector level, allowing us to control for country-level macroeconomic shocks and for factors that affect bilateral trade and might be correlated with energy price differences, such as exchange rates, transport costs, trade agreements, and relative labour costs. The richness of the data allows us to include a large range of country, sector and time fixed effects, thereby purging the estimates from a range of potential confounding factors.

This paper contributes to a small recent literature which seeks to empirically examine the relationship between historic energy prices and trade. Aldy & Pizer (2011) focus on the US and use historical variation in industrial electricity price across states to investigate its effect on sectoral production and consumption. This enables an empirical investigation of the impact of carbon pricing on US industrial supply and demand, despite the absence of carbon pricing in the US historically. They show that an increase in energy prices in the US following the introduction of a 15$/ton carbon tax would induce a domestic production decline of between 3 and 4 percent among energy-intensive sectors and a roughly 1 percent increase in imports. The authors also find evidence that responses to energy prices are bigger for industries with higher energy intensity. Gerlagh & Mathys (2011) use a country specific energy abundance measure to proxy for marginal energy costs, and investigate its impact on net exports using a panel of 14 high income (OECD) countries over 28 years. The authors find that there is high correlation between energy abundance and price, and that energy abundant countries have a high level of energy embodied in exports relative to imports. These results therefore provide support to the existence of a carbon leakage effect. Our paper builds on these studies, using a much wider dataset, covering 62 sectors in 42 countries over 15 years.

We find evidence that a widening of the energy price gap has a statistically significant but small effect on bilateral exports: a 10% increase in the energy price gap between two countries within a given sector translates on average into a 0.2% increase in imports. This result is robust across a wide range of alternative model specifications and estimators. Consistent with expectations, we find that energy price differences have a larger impact on trade in energy-intensive sectors. However, even in these sectors the impact is small. Overall, energy price differences across time explain less than 0.01% of the variation in trade flows, suggesting that differences in energy prices are a marginal driver of trade globally.

We also use our estimates to conduct policy simulations and evaluate the degree to which stricter carbon pricing policies in Europe would affect trade patterns. Our results suggest that a €40-65/t$CO_2$ price of carbon in the EU ETS would increase Europe's imports from the rest of the world by around 0.04% and decrease exports by 0.2%. To put things into perspective, consider that imports from European countries have grown at an average annual rate of 6.5% between 1995 and 2011 and at the rate of 15.6% since 2009. Hence, the impact of higher EU ETS prices on European imports would appear to be small compared with other drivers of trade.

This paper has important policy implications. It suggests that concerns about carbon leakage are not unfounded but may have been largely overplayed. While efforts to price carbon are spreading globally, governments are consistently pressured to compensate energy intensive trade-exposed sectors, because of the assumed adverse impacts of climate change policies on their export competitiveness. European industries actively lobby for continued free allocation of permits within the EU ETS and in the US, proposals to use output-based allocation for the upcoming emission trading schemes are also justified on fear of leakage effects, although subsidising output reduces efficiency of the overall system as it shields product prices from the real cost of carbon (Fischer & Fox, 2007; Hepburn et al., 2006). Our results suggest that, although energy price differences have some impact on trade, the magnitude of this effect is small, in particular when compared to other factors affecting trade relationships.

The structure of this paper is as follows. Section 2 presents our conceptual framework and empirical strategy. The data is described in Section 3. Section 4 reports and discusses the empirical results and the magnitude of the effect. In Section 5 we use our estimations results to simulate the impact of a higher carbon price in the EU ETS on European imports and exports. The final section offers some concluding remarks.

## 2 Conceptual framework and empirical strategy

### 2.1 Conceptual framework

A large theoretical literature has investigated the consequences of unequal environmental regulatory stringency on trade and competitiveness. Most models consider a local pollutant that is emitted during the production process of the final good and pollution emissions taxes imposed to reduce polluting emissions, but the framework equally applies to energy or carbon taxes implemented to reduce carbon emissions. Standard models predict that by making domestic production more costly, policies that increase energy price will put domestic firms at a strategic disadvantage relative to foreign rivals if companies are competing with foreign counterparts with lower energy prices. This results forms the basis of the so- called Pollution Haven Hypothesis (Taylor & Copeland, 2004; Levinson & Taylor, 2008). For producers of energy intensive products, higher energy prices could increase marginal production costs considerably. Depending on the degree to which they can pass the increased costs onto the consumer (i.e. the degree of competition they face) and on the magnitude and persistence of the energy price difference vis-a-vis their competitors, they may respond by producing fewer energy-intensive goods, which may lead to a decline in net exports and the partial relocation of production to a region with low energy prices (Hanna, 2010).[4]

It is easy to see that in a model where two countries are identical except for differences in environmental policy (or energy taxes), the country with weaker policy will specialise in the production of the polluting good, and export that good to the "virtuous" country. In practice, however, many factors influence production costs, including labor costs, infrastruc- tures, institutions, and proximity to customers (Demailly & Quirion, 2008). Hence, only if environmental costs dominate these other costs would one expect a change in relative environmental policy stringency to induce some relocation of activities (Copeland & Taylor, 2003). Another possibility is that even if marginal production costs increase, producers may be able to pass on the increase in energy prices to their consumers because of high transport costs or product differentiation from imports such that their trade and investment decisions are unaffected by rising energy costs. The Porter hypothesis (Porter, 1991; Porter & van der Linde, 1995) even asserts that environmental regulations, by inducing firms to innovate in new pollution-control technologies, might have a positive impact on productivity and profitability, which may increase firms' export competitiveness. Hence, understanding the relationship between changes in relative energy prices and trade is partly an empirical question.

### 2.2 Empirical approach

In this paper we estimate the reduced-form short-term effects of energy price differences on bilateral trade at the sector level. Relative industrial energy prices affect trade flows through the induced change in relative production costs between trading partners. Because carbon prices work by increasing the effective cost of energy for industry, the results can be used to infer the effects of potential asymmetries in carbon price on future trade patterns5, with the obvious limitation that it is not possible to simulate the impact of carbon price differences larger than what has been observed in the past. This is useful because while experience with carbon prices is still limited globally, historic data on industrial energy prices exists for many countries and many years. Moreover, Sato et al. (2015) show that most of the variation in energy price differences between countries comes from variation in energy taxes. Hence, energy price differences reflect differences in energy and carbon policies between countries.

[4] In a general equilibrium framework, sectors unaffected by pollution taxes then benefit from factor reallocation and could then see an increase in net exports.

[5] This is because the level of carbon emissions are largely attributable to energy combustion in production (although in some processes, there are non-energy related emissions also such as process emissions in cement production).

We use a gravity framework and, in line with the recent empirical trade literature, we estimate the gravity equation in its multiplicative form (Santos Silva & Tenreyro, 2006). Since the value of trade between two countries in any period is a non-negative integer, it is natural to model the conditional mean as a log-link function of explanatory factors and use a Poisson maximum likelihood estimator.[6] Our empirical model is:

$$imports_{ijst} = exp\left(\lambda_p \sum_{p=1}^{n} imports_{ijs(t-p)} + \beta_1 epgap_{ijct-1} + \beta_2 gdpt_{ijt-1} + \beta_3 gdpsim_{ijt-1} + \beta_4 rfac_{ijt-1} + \beta_5 wagegap_{ijct-1} + \beta_6 reerratio_{ijt-1}\right)\eta_{ijs} + \nu_{ijst} \quad (1)$$

where $imports_{ijst}$ is the value of annual imports by country *i* from country *j* for sector *s* at time *t* and $v_{ijst}$ is the error term. Our main variable of interest, the difference in energy price between two trading partners, is defined as $epgap_{ijst\text{-}1}$ which is the difference in the logs of energy prices, or in other words the log of the ratio of energy prices:

$$epgap_{ijst\text{-}1} = ln(Ep_{ist\text{-}1})\ ln(Ep_{jst\text{-}1})$$

where $Ep_{ist\text{-}1}$ and $Ep_{jst\text{-}1}$ are the real industrial energy price respectively in country *i* and *j* in sector s at time *t-1*. A positive value of $epgap_{ijst\text{-}1}$ implies that the importer i has a higher industrial energy price than the exporter. We lag prices by a year to reflect delayed response and also mitigate contemporaneous feedback effects. The primary objective of the study is to estimate the coefficient $\beta_1$.

The choice of control variables is derived from recent advances in the gravity literature. First, we control for overall bilateral economic size, relative economic size (similarity of GDP) as well as differences in relative factor endowments (similarity of capital-labour ratios) (Baltagi et al., 2003; Wang et al., 2010; Egger, 2000). These three variables are specified as follows:

$$gdpt_{ijt} = ln\ (GDP_{it} + GDP_{jt})$$

$$gdpsim_{ijt} = ln\left[1 - \left(\frac{GDP_{it}}{GDP_{it} + GDP_{jt}}\right)^2 - \left(\frac{GDP_{jt}}{GDP_{it} + GDP_{jt}}\right)^2\right]$$

[6] Non-linear models initially developed for count data analysis can be successfully applied to continuous variables such as trade data (Wooldridge, 2010). Studies have shown that log-linearised models estimated by OLS can be inefficient and biased where the data is heteroskedastic (Santos Silva & Tenreyro, 2006), as is often the case with bilateral trade data.

$$rfac_{ijt} = \left| ln\left(\frac{GDP_{it}}{CAPITA_{it}}\right) - ln\left(\frac{GDP_{ij}}{GDPCAPITA_{jt}}\right) \right|$$

Overall bilateral economic size reflects the fact that the volume of exports should be higher, the bigger the overall market size. $gdpsim_{ijt}$ measures the similarity in the levels of GDP in the trading partners, hence captures the relative size of the two trading partners. Before the log-linear transformation, this variable can take the value between 0 and 0.5. A higher value indicates that the two trading partners are similar in size (GDP), with 0.5 indicating equal country size. Theory predicts that the higher this value, the greater the expected share of inter-industry trade (Egger, 2000). $rfac_{ijt}$ measures the similarity in capital-labour ratios, or in other words, the relative factor endowments. A value of 0 represents equal factor endowments proportion. Bergstrand (1990) illustrates empirically using the gravity model that bilateral trade between high income countries is positively related to similarity in relative factor endowments (reflecting similarity in preferences). In addition, we control for two idiosyncratic factors that might be correlated with energy price differences: the country-pair-sector specific difference in wages and the country pair specific real effective exchange rate ratio defined as follows:

$$wagegap_{ijst} = ln(wage_{ist})\ ln(wage_{jst})$$

$$reerratio_{ijt} = ln(reer_{it})\ ln(reer_{jt})$$

where $wage_{ist}$ and $wage_{jst}$ are the average real wage in country *i* and *j* in sector *s* in year *t* expressed in current USD and $reer_{it}$ and $reer_{jt}$ are the real effective exchange rates in country *i* and *j* at time *t* against the US dollar. A positive value of $wagegap_{ijst}$ implies that the importer *i* has a higher real wage price than the exporter. The FDI and industry location literature, as well as the trade literature have examined the role of labour price differentials in international trade patterns and found mixed evidence on their effect (Baltagi et al., 2007). Exchange rate dynamics have also been explored as a possible determinant of international trade decisions Egger & Egger (2005).

As is common with trade data, the sectoral trade data used in this analysis displays strong persistence. Thus it is important to account for trade in past periods, by including lags of the dependent variable. Lagged dependent variables enter as $\sum_{p=1}^{n} imports_{ijs(t-p)}$, where *n* is the number of lags. We experimented with different values of *n* and use *n* = 3 in our baseline specification for the reason that the coefficient on the lagged dependent variables becomes statistically insignificant from *n* = 4 onwards, but we test the sensitivity of our results to this choice.

To minimise the possibility of biases due to omitted variables, our model includes country- pair-sector fixed effects $\eta_{ijs}$, to control for time invariant country pair-specific determinants (such as distance, common language, common borders, common currency, colonial ties) but also for sector specific characteristics such as product differentiation, market structure, transportation costs and trade intensity.

### 2.3 Dynamic count data models with fixed effects

Accounting both for dynamics and fixed effects in count data models raises a number of issues. Introducing lagged dependent variables violates the strict exogeneity assumption which makes the Hausman et al. (1984) fixed effect method (the count data equivalent to the within groups estimator) unsuitable as it requires strict exogeneity. To simultaneously account for fixed effects and lagged dependent variables we use the pre-sample mean count data estimator introduced by Blundell et al. (1999) and Blundell et al. (2002), who suggest conditioning on the pre-sample average of the dependent variable to proxy out the fixed effect. Applications to environmental issues include Jug & Mirza (2005) and Egger et al. (2011). The pre-sample mean estimator requires long pre-sample history of realisations of the dependant variable and is thus particularly suitable to the study of trade data. Because the pre-sample average of the dependent variable may fail to capture every aspect of time- invariant country-pair heterogeneity, we include standard gravity variables (including the log of population-weighted geographical distance, contiguity, common official language and common currency) as well as importer, exporter and sector dummy variables. The inclusion of this large set of dummy variables combined with the skewed distribution of the dependent variable poses computational problems to which the Poisson pseudo-maximum likelihood (PPML) estimator developed by Santos Silva & Tenreyro (2006) offers an attractive solution. Santos Silva & Tenreyro (2006) show that the model can provide a consistent estimator of bilateral trade in gravity models. However, we check the robustness of our results to the use of alternative estimators.

## 3 Data and descriptive statistics

### 3.1 Data

This paper brings together a variety of datasets to determine the impact of relative energy prices on trade. Our panel covers 42 countries (including high, middle and low income) and 62 sectors for the period 1996 to 2011. The data is disaggregated at 2-digit sector resolution using SITC Revision 3 (see Appendix B for a list of countries and sectors). The energy price data can only be disaggregated at a broader level, and we have prices for 12 sectors incorporating the 62 sectors at which the analysis is carried out.

#### Bilateral trade data

Bilateral trade data is taken from the CEPII's BACI database[7] which contains detailed bilateral import and export statistics from the UN Commodity Trade (COMTRADE) database. Although the trade data is available at a more granular level, the chosen level reflects a trade-off between several considerations. A finer level of sector

[7] http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=1

disaggregation can be advantageous particularly for heterogeneous sectors, enabling to control for sub-sector specific characteristics. However, moving to the three or four-digit level substantially increases the number of zero or missing values in the dependent variable and results in a very skewed distribution. At 62 sector level, there are no observations with zero or missing trade, and the share of observations where the trade in value is very small (less than 0.01 million USD) is around 5%, which is manageable for the estimation techniques used.
Depending on the year, the bilateral trade data in the sample covers between 55 and 65% of world trade obtained from the WTO Statistics Database (World Trade Organisation, 2012). Exports (in value terms) on an aggregate level rose steadily during the 1990s decade from $3,515 billion USD in 1991 to $6,494 billion in 2002. It then increased at a faster rate until disrupted by the financial crisis and subsequent economic recession in 2008, when world exports fell sharply (dropping from $16,140 billion to $12,542 billion between 2008 and 2009). Since 2009, aggregate exports have been on an upward trend again, reaching $18,255 billion in 2011.

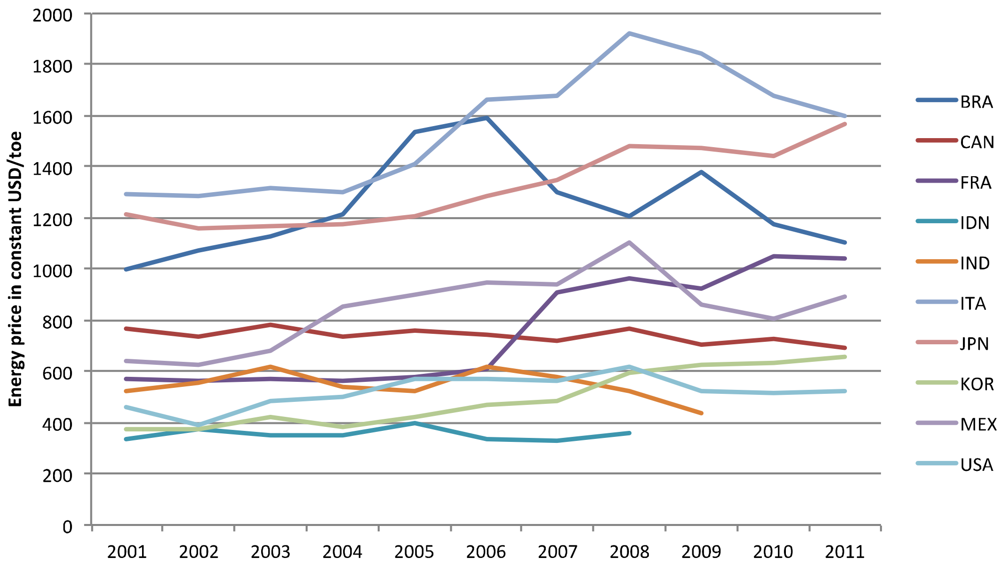
**Energy prices**

We use a unique and comprehensive dataset of industrial energy prices indices at the country and sector level covering 48 countries and 12 industry sectors, constructed in Sato et al. (2015). This sector level energy price index covers four key types of fuel carriers (electricity, gas, coal and oil), provides greater coverage of sectors, countries and years than previously available energy price data, and is constructed using a consistent and transparent method. The energy price index for a given sector *s* in country *i* in year *t* is constructed by weighting fuel prices for four carriers (oil, gas, coal and electricity) by the consumption of each fuel type in that sector-country (*si*) (see Appendix A for more detail on the construction of the price index). This method addresses the important issue of heterogenous fuel mix observed across sectors and countries and the index hence captures the change in energy price level (including taxes) over time for a specific country-sector. This is useful because data on energy prices faced by different industrial sectors are hard to obtain for most countries, while energy price for electricity generation and households are readily available. For most OECD countries, industrial energy prices are published only at the country level (averaged across all industrial sectors) rather than for individuals sectors, and often with considerable missing data points. The energy price index uses fixed fuel weights (representing fuel consumption in 2005) over time hence captures the *within*-sector variation, and uses transparent and consistent methods to reduce missing data-points as documented in Sato et al. (2015). The fuel prices are transformed into logs before applying the fuel weights hence the resulting energy price index is not expressed in monetary units.[8] A

[8] It is important for econometric analysis to keep the weights fixed so that the only variation in the price variable comes from underlying variations in energy prices. This makes the interpretation of the coefficient straightforward and prevents some potential endogeneity issues. The results are robust however to using time-varying weights (see section 4.4).

version of the energy price in USD/TOE terms using time-varying fuel weights – hence corresponding to observed energy prices faced by industry – also available from Sato et al. (2015) is shown in Figure 1.

*Figure 1:* Cross-country differences in the energy prices (including tax) for average industry, for 10 sample countries




Source: Sato et al. (2015) Note: The panels show the country level variable weights price level (in 2010$) based on market exchange rates. BRA=Brazil, CAN=Canada, FRA=France, IDN=Indonesia, IND=India, ITA=Italy, JPN=Japan, KOR=South Korea, MEX=Mexico

The price index uses industrial energy price data from the IEA Energy End-Use Prices database (IEA, 2012a) as the primary source of fuel price data for industrial sectors. This represents the final industrial energy prices including taxes paid by industry for different fuels and excluding VAT and recoverable taxes and levies and is expressed in real terms (underlying prices are net of inflation).[9] The sector level fuel consumption data is taken from the IEA World Energy Balances (IEA, 2012a). It is important to note that this industrial energy price index represents an approximation of the true prices paid by each sector and may not be the true prices, for example because some countries offer tax exemptions and other subsidies to

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

energy users. However, in the absence of comprehensive data on observed energy price data at the sector level, it provides a good alternative solution.

There has historically been considerable variation in industrial energy prices across countries as shown in Figure 1. In 2001, prices were below 600US$/TOE in the USA, South Korea, India, Indonesia and France, but were twice as high in Italy and Japan. While real industrial energy prices remained relatively unchanged over the next decade (below 800US$/TOW in 2008) for Canada, South Korea, USA, India and Indonesia, in contrast, prices tended to rise for Italy, France, Mexico, Brazil and Japan but went down in Canada and India. As a consequence, there has been considerable variation across time in energy price differences that we can exploit in our empirical setting.

**Other data**

GDP and population data are obtained form the International Monetary Fund's World Economic Outlook (IMF, 2012).[10] GDP data are available in US$ in current prices. These are converted into real prices using the GDP deflator index, which is also available from the same database. Because the latter has different base years for different countries, we adjust the deflator index, using 2005 as the baseline for all countries.

Data on wages were obtained from United Nations Industrial Development Organization (2011). It was constructed by deflating nominal annual wage by sector using a GDP deflator variable from the World Bank, then converting to constant US dollars (2005) using exchange rate data from UNIDO. Data on the real effective exchange rates (reer) are taken from Darvas (2012). Finally, standard gravity model variables are obtained from the Gravity Dataset provided by CEPII (CEPII, 2012).

## *Table 1:* Descriptive statistics

| | *Overall* | | | | *Between* | | | *Within* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Min | Max | SD | Min | Max | SD | Min | Max |
| $trade_{ijst}$ | 106.726 | 720.863 | 0.001 | 97522.29 | 624.083 | 0.001 | 50421.11 | 210.041 | -24169.8 | 47270.91 |
| $epgap_{ijst-1}$ | -0.005 | 0.623 | -2.505 | 2.505 | 0.624 | -2.504 | 2.504 | 0.141 | -0.785 | 0.791 |
| $wagegap_{ijst-1}$ | -0.039 | 1.838 | -7.459 | 8.909 | 1.823 | -6.294 | 8.741 | 0.127 | -3.23 | 3.25 |
| $reerratio_{ijst-1}$ | -0.001 | 0.157 | -0.742 | 0.742 | 0.128 | 0.63 | 0.742 | 0.096 | 0.481 | 0.557 |
| $gdpt_{ijt-1}$ | 9.203 | 2.439 | 3.571 | 14.934 | 2.41 | 3.597 | 14.847 | 0.085 | 8.839 | 9.586 |
| $gdpsim_{ijt-1}$ | -2.414 | 2.005 | -11.135 | -0.693 | 2.006 | -11.135 | -0.693 | 0.052 | -2.921 | -2.217 |
| $rfac_{ijt-1}$ | 2.097 | 2.007 | 0.0006 | 9.602 | 1.935 | 0.004 | 9.576 | 0.063 | 1.797 | 2.462 |

Notes: These are the values from our regression sample of 348771 observations across 64763 country pair sectors, between 2001 and 2011.

[10] For Taiwan, GDP data was obtained from Taiwan national statistics (National Statistics of Republic of China (Taiwan), 2012).

### 3.2 Descriptive statistics

Descriptive statistics for our estimation sample are provided in Table 1. At the country-pair- sector level, there is considerable variation in exports as shown in the first row. With a mean of $112 million, bilateral exports at sector level range from zero up to over $97 billion. More variation comes from the sector heterogeneity (in trade intensity and value) than from the bilateral-pair heterogeneity.

The variation in the energy price gap variable is shown in the second row of Table 1. The mean is zero because of the symmetrical nature of the data – the energy price gap between US and UK is expressed as a negative value when considering UK imports to the US, and as a positive value of the same magnitude when considering US imports to the UK. The within-group standard deviation of the energy price ratio is high, suggesting that historical fluctuations in the energy price gap, due not to climate policies but to underlying factors (e.g. energy taxes, energy supply and demand), have been considerable.

As Table 1 shows, the between country-pair-sectors variation is greater than the within variation for all variables, highlighting the importance of using panel data to control for heterogeneity across country-pairs and sectors.

## 4 Regression results

### 4.1 All sectors

Table 2 presents our main estimation results. We construct the pre-sample mean of the dependent variable over the years 1996 to 2000[11] and estimate over the period 2001-2011 using Poisson pseudo-maximum likelihood.

Column (1) shows that the coefficient on the lagged (tax inclusive) energy price gap is positive and significant. This result is robust to controlling for the wage difference between countries *i* and *j* (column 2), for the exchange rate (column 3), and for both (column 4). The elasticity of 0.021 implies that a 10% higher energy price gap is associated with about 0.21% more imports. The control variables have signs that are consistent with expectations. We find that the use of a dynamic panel estimator is important, as the coefficients for the lagged dependent variables always exhibit a parameter estimate which is significantly different from zero. This suggests that there is indeed strong 'think-back' or 'stickiness' in the level of sectoral trade between two countries as found in recent literature (Olivero & Yotov, 2010, 2012). Increases in total economic mass increases bilateral exports, and the similarity in

---

[11] Using 5 years of data to construct the pre-sample mean is arbitrary and driven by a trade-off between the length of the pre-sample period and the size of the estimation sample. On the one hand, one would use as many years as possible to construct the pre-sample average. On the other hand, as the trade data only starts in 2005, any additional year used to construct the pre-sample average mechanically reduces the size of our estimation sample. We tested the sensitivity of our results to using a pre-sample period of 4, 5 and 6 years, and find that this makes almost no change to the results.

*Table 2: Results for all sectors*

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Eenergy price gap | 0.011* | 0.011** | 0.021*** | 0.021*** |
| | (0.006) | (0.006) | (0.005) | (0.006) |
| *Control variables* | | | | |
| Wage gap | | 0.014 | | 0.001 |
| | | (0.009) | | (0.009) |
| Real eff. ex rate ratio | | | 0.053** | 0.053** |
| | | | (0.025) | (0.027) |
| Relative fact. endow. | -0.007*** | -0.007*** | -0.003 | -0.003 |
| | (0.002) | (0.002) | (0.002) | (0.002) |
| GDP total | -0.262*** | -0.168* | 0.114 | 0.114 |
| | (0.089) | (0.095) | (0.075) | (0.096) |
| GDP similarity | -0.135*** | -0.088* | 0.053 | 0.053 |
| | (0.045) | (0.047) | (0.038) | (0.048) |
| *Gravity Variables* | | | | |
| Distance | -0.012*** | -0.011*** | -0.019*** | -0.018** |
| | (0.004) | (0.004) | (0.004) | (0.007) |
| Common currency | -0.004 | -0.003 | -0.008 | -0.006 |
| | (0.008) | (0.008) | (0.008) | (0.016) |
| Contiguity | 0.006 | 0.007 | -0.003 | 0.018* |
| | (0.006) | (0.006) | (0.005) | (0.010) |
| Common official lang. | 0.005 | 0.004 | 0.009 | 0.002 |
| | (0.007) | (0.007) | (0.006) | (0.012) |
| *Lagged dep. Vars.* | | | | |
| Trade_ij(t-1) | 0.899*** | 0.895*** | 0.880*** | 0.860*** |
| | (0.009) | (0.009) | (0.010) | (0.015) |
| Trade_ij(t-2) | 0.051*** | 0.054*** | 0.058*** | 0.074*** |
| | (0.011) | (0.011) | (0.013) | (0.020) |
| Trade_ij(t-3) | 0.036*** | 0.035*** | 0.041*** | 0.055*** |
| | (0.009) | (0.009) | (0.009) | (0.015) |
| Country-pair sect. FE | Presamp | Presamp | Presamp | Presamp |
| Importer and exporter dum. | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 333055 | 329873 | 317469 | 317382 |

Notes: *,**,***= significant at 10,% 5%, 1%. Standard errors clustered at the country pair level in parentheses. The dependent variable is the value of annual bilateral imports in all columns. Estimation is by Poisson pseudo- maximum likelihood. The country-pair-sector fixed effect is a pre-sample mean of the dependent variable over the years 1996-2000. All regressions include controls for relative factor endowments, overall economic size of the two trading partners, GDP similarity, population weighted distance between the trading partners, and dummies for common currency, contiguity and common official language. All regressions include dummies for years, importer, exporter, and sectors. Column (2) and (4) also controls for wage differences, and columns (3) and (4) control for the real effective exchange rates ratio (reer).

GDP also tends to increase trade. The positive coefficient on the latter suggests existence of intra-industry trade. The coefficient on $rfac_{ijt}$ is negative, suggesting that bilateral trade is negatively related to differences in relative factor endowments, in line with the Linder hypothesis. The real exchange rate ratio is positive and significant, suggesting that real exchange rate dynamics is an important determinant of bilateral trade flows. The coefficient on the wage gap is not statistically different from zero. At least two reasons can explain this surprising finding. First, the data is only available at a broad sectoral aggregation level (22 sectors) and the resulting measurement error should lead to attenuation bias, which may explain why the point estimate is so close to zero. Secondly, we already control for relative factor endowment (defined as the GDP per capita differential), and this variable is likely to already capture part of the variation in wages.

In summary, the results from table 2 offer support to the hypothesis that the energy price gap has a positive and significant effect on bilateral trade. In other words, imports in sector *s* increase in response to the rise in energy prices in the importing country relative to the exporting country. In terms of magnitudes, our results suggest that a 10% increase in the importer's energy price relative to the exporter is associated with a 0.2% increase in imports.

Thus, this effect is statistically significant but very small. We return to this point in Section 4.3..

### 4.2 Examining sector heterogeneity

The results presented in section 4.1 present the average impact of energy price differences on imports across all sectors. However, it is likely that this impact differs across sectors depending on their energy intensity. The importance of sector heterogeneity in the trade impacts of carbon pricing has been explored in partial equilibrium modelling for Europe's heavy industry, as well as in econometric analysis for the EU production sectors (Demailly & Quirion, 2008). This section examines whether similar evidence can be found for a wider geographical scope, taking advantage of the fact that our energy price variable $epgap_{ijst}$ captures variations in energy prices not only across country-pairs but also across sectors. In order to explore the heterogeneity of the impact of energy prices on imports we run the model separately for energy intensive and non-energy intensive sectors. We divided the sectors into energy intensive and non-energy intensive using data on real unit energy costs (RUEC) from the EU27 group in 2009 (European Commission, 2014), defined as the ratio of energy costs over value added. Energy intensive sectors are those whose ratio of energy costs over value added exceeds 10%. The list of sectors considered as energy-intensive and non-energy intensive is available in Table 8 in Appendix B.

The results of our estimations are presented in Table 3. The results give support to the notion that the impacts of the energy price gap on trade are heterogeneous across sectors depending on their energy intensity. The coefficient is positive and statistically significant for both energy-intensive and non-energy intensive sectors.

*Table 3: Results by sector groups*

| | (1) Energy intensive industry | (2) Non-energy intensive industry |
|---|---|---|
| Eenergy price gap | 0.024** | 0.017*** |
| | (0.011) | (0.006) |
| *Control variables* | | |
| Wage gap | 0.023 | -0.028** |
| | (0.019) | (0.012) |
| Real eff. ex rate ratio | 0.014 | 0.127*** |
| | (0.051) | (0.028) |
| Relative fact. endow. | -0.001 | -0.007*** |
| | (0.004) | (0.003) |
| GDP total | 0.382** | 0.176** |
| | (0.163) | (0.085) |
| GDP similarity | 0.193** | 0.081* |
| | (0.081) | (0.042) |
| *Gravity Variables* | | |
| Distance | -0.014* | -0.024*** |
| | (0.008) | (0.004) |
| Common currency | 0.021 | -0.013 |
| | (0.016) | (0.008) |
| Contiguity | 0.015 | -0.016*** |
| | (0.010) | (0.006) |
| Common official lang. | -0.017 | 0.023*** |
| | (0.014) | (0.008) |
| *Lagged dep. Vars.* | | |
| Trade_ij(t-1) | 0.826*** | 0.905*** |
| | (0.031) | (0.013) |
| Trade_ij(t-2) | 0.116*** | 0.007 |
| | (0.029) | (0.018) |
| Trade_ij(t-3) | 0.029* | 0.040*** |
| | (0.018) | (0.012) |
| Country-pair sect. FE | Presamp | Presamp |
| Importer and exporter dum. | Yes | Yes |
| Sector dummies | Yes | Yes |
| Year FE | Yes | Yes |
| Observations | 63477 | 166003 |

Notes: *,**,***= significant at 10,% 5%, 1%. . Standard errors clustered at the country pair level in parentheses. The dependent variable is the value of annual bilateral imports. Estimation is by Poisson pseudo-maximum likelihood. The country-pair-sector fixed effect is a pre-sample mean of the dependent variable over the years 1996-2000. All regressions include controls for wage differences, real effective exchange rates ratio, relative factor endowments, overall economic size of the two trading partners, GDP similarity, population weighted distance between trading partners, and dummies for common currency, contiguity and common official language. All regressions include dummies for years, importer, exporter and sectors.

However, the effect is larger for energy-intensive sectors with an elasticity of 0.024. This is around 50% higher than in non-energy intensive sectors (0.017) and larger than the average impact uncovered in section 4.1 but still fairly small.[12]

### 4.3 Magnitude of the effect

To obtain a better sense of the magnitude of the results, in this section we investigate how much of the overall variation in sectoral bilateral trade is explained by energy price differences. We start by a simple example. Between 2005 and 2006, India's iron and steel sector's real energy price index increased from from 5.03 to 5.09. Over the same period, the real energy price index for the same sector in the UK increased from 5.61 to 5.71. This implies that over this period the energy price gap between the UK and India's steel sector increased by 4%[13].

In section 4.2 we found that a 1% increase in the energy price gap in the heavy industry sector was associated with a 0.027% increase in imports. Thus a 4% increase in the price gap between the UK and India is predicted to increase UK's imports in this sector by around 0.1%. However during the same period, India's iron and steel exports to the UK actually grew by 33%. The energy price gap is therefore explaining 0.3% of the observed change in trade volumes.

This example illustrates the small contribution of the variation in energy prices in the overall variation in trade flows in the iron and steel sector. We now generalise this example and analyse the contribution of energy price changes to the overall variance in bilateral trade flows for the two broad sector categories – heavy- and light-industry. To do so we calculate the change in trade flows predicted by our

[12] Ideally, one would want to collect data on the energy intensity of sectors, interact the energy intensity variable with the energy price variable and directly look at the coefficient obtained for the interaction term, which measures how the impact of the energy price varies according to the energy intensity of the sector. The quality of the data is not as good as one would hope, however, for two reasons: first, the RUEC data is only available at a broad level of sector disaggregation (14 sectors, compared to the 60+ sectors we have in our sample) and secondly, the variation in energy costs is partly driven by changes in energy prices, which raises endogeneity concerns, when one would want to use energy intensity. When we include real unit energy costs (grouping sectors into 14 groups) as well as an interaction term between energy prices and unit energy costs in our baseline model, we find that the RUEC term enters as positive and highly significant, with a value 0.0045*** (p-value = 0.000). The coefficient on the energy price gap is 0.016***. The interaction term has a positive sign (0.00048) but is not statistically significant (p-value = 0.129). These results go in the expected direction, but the lack of variation and the fact that energy prices enter into the construction of the energy costs can explain the lack of clear statistical significance. We have unfortunately not been able to obtain better, more disaggregated sector energy intensity data to improve this estimation. This data gap is a prevalent problem in the literature as discussed in Upadhyaya (2010). Other papers have used electricity intensity of sectors to proxy for energy intensity but this method is unsuitable for this analysis, as the energy price variable we use accounts for all major fuel types and not only electricity.

[13] *exp*(5.71 5.61)/*exp*(5.09 5.03) = 1.04. Recall that the energy price gap is defined as $epgap_{ijst}$ $=\ln(EP_{ist}) - \ln(EP_{jst}) = \ln(\frac{EP_{ist}}{EP_{jst}})$

model and compare this to the observed change in trade flow for each observation in our sample. The contribution of energy prices to the variance of trade flows across these sectors is extremely small – around 0.01% for the heavy industry sectors, and even smaller for light industry. This is also clear from the observation that for any particular sector, the country with the lowest energy price among all those trading with that country is not always a net importer. Therefore, energy prices do not appear to be a major determinant of trade patterns. This shows that other explanatory factors, such as underlying trends in transport costs, globalisation and supply chain integration, population growth and economic growth play a much more important role in the variation in trade over time than do energy costs.

### 4.4 Robustness checks

We conducted a large number of robustness checks and report the main ones below.

**Alternative estimators**: As explained in section 2.3, the pre-sample mean Poisson pseudo- maximum likelihood estimator is our preferred estimator, as it is able to address the key characteristics of the data – the combination of fixed effects with lagged dependent variables, the skewed distribution of the dependent variable and the large number of dummy variables. However, we also analyse the sensitivity of our results to the use of alternative models, in line with the recent gravity model trade literature (Gómez-Herrera, 2013). In column (2) of Table 4, we use the Hausman, Hall and Griliches (HHG) method to account for country- pair-sector fixed effects, even though the assumption of strict exogeneity underlying HHG is problematic in our context, as we have a highly dynamic specification. The coefficient is still highly statistically significant and higher than in our baseline model (but not statistically significantly so). In column (3), we reproduce the same specification as in column (4) of Table 2 (also reproduced in column 1 of Table 4) but use a negative binomial estimator instead, which might be better able to handle the large overdispersion of the dependent variable. The coefficient is smaller but in line with our baseline model.

**Fixed effects specification:** Baltagi et al. (2003) experiment with eight different fixed effects models and show the importance of controlling for a full interaction of importer-time and exporter-time fixed effects to analyse bilateral trade flows and thus purge the estimates from a large number of possible confounding factors. In column (4), importer by year and exporter by year fixed effects $\alpha_{it}$ and $\alpha_{jt}$ are included to control for common macroeconomic shocks at the country level, such as the sharp fall in global trade volumes following the financial crisis in 2008 which may have differently affected countries around the world. We find that the coefficient is smaller than the baseline specification, suggesting that if anything the already small elasticity of trade to energy prices might even be slightly overestimated.

**Energy price changes in third countries:** From a general equilibrium point of view, trade between *i* and *j* might also be affected by changes in prices in other

*Table 4: Sensitivity analysis results 1*

| | Baseline model | Alternative model | | Alternative fixed effects | LDV selection | | |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| | Poisson | Poisson fe | Negative binomial | Poisson | Poisson | Poisson | Poisson |
| Eenergy price gap | 0.021*** | 0.055*** | 0.012* | 0.011** | 0.020*** | 0.020*** | 0.021*** |
| | (0.006) | (0.014) | (0.007) | (0.006) | (0.006) | (0.006) | (0.006) |
| *Control variables* | | | | | | | |
| Wage gap | 0.001 | -0.016 | 0.000 | 0.008 | 0.006 | 0.002 | 0.001 |
| | (0.009) | (0.020) | (0.000) | (0.008) | (0.008) | (0.008) | (0.008) |
| Real eff. ex rate ratio | 0.053** | 0.077** | 0.142*** | -0.220*** | 0.040 | 0.049* | 0.053** |
| | (0.027) | (0.038) | (0.028) | (0.073) | (0.026) | (0.025) | (0.025) |
| Relative fact. endow. | -0.003 | -0.057 | -0.007*** | -0.002 | -0.003 | -0.003 | -0.003 |
| | (0.002) | (0.061) | (0.003) | (0.002) | (0.002) | (0.002) | (0.002) |
| GDP total | 0.114 | 0.800*** | 0.176** | -0.035** | 0.215*** | 0.157** | 0.112 |
| | (0.096) | (0.085) | (0.085) | (0.016) | (0.070) | (0.072) | (0.074) |
| GDP similarity | 0.053 | 0.162* | 0.081* | -0.022*** | 0.104*** | 0.074** | 0.052 |
| | (0.048) | (0.090) | (0.042) | (0.008) | (0.035) | (0.036) | (0.037) |
| *Gravity Variables* | | | | | | | |
| Distance | -0.018** | | -0.063*** | -0.021*** | -0.021*** | -0.020*** | -0.019*** |
| | (0.007) | | (0.007) | (0.004) | (0.004) | (0.004) | (0.004) |
| Common currency | -0.006 | | -0.007 | -0.008 | -0.011 | -0.008 | -0.008 |
| | (0.016) | | (0.012) | (0.008) | (0.009) | (0.009) | (0.009) |
| Contiguity | 0.018* | | -0.024* | -0.006 | -0.005 | -0.003 | -0.003 |
| | (0.010) | | (0.013) | (0.006) | (0.006) | (0.006) | (0.006) |
| Common official lang. | 0.002 | | 0.002 | 0.007 | 0.011 | 0.009 | 0.009 |
| | (0.012) | | (0.013) | (0.007) | (0.007) | (0.007) | (0.007) |
| *Lagged dep. Vars.* | | | | | | | |
| Trade_ij(t-1) | 0.860*** | 0.598*** | 0.856*** | 0.881*** | 0.947*** | 0.881*** | 0.879*** |
| | (0.015) | (0.012) | (0.016) | (0.009) | (0.006) | (0.009) | (0.010) |
| Trade_ij(t-2) | 0.074*** | 0.010 | 0.100*** | 0.060*** | | 0.088*** | 0.059*** |
| | (0.020) | (0.013) | (0.017) | (0.012) | | (0.011) | (0.012) |
| Trade_ij(t-3) | 0.055*** | 0.005 | 0.051*** | 0.046*** | | | 0.042*** |
| | (0.015) | (0.009) | (0.012) | (0.009) | | | (0.009) |
| Trade_ij(t-4) | | | | | | | -0.002 |
| | | | | | | | (0.008) |
| Country-pair sect. FE | Presamp | Yes | Presamp | Presamp | Presamp | Presamp | Presamp |
| Importer and exporter dum. | Yes | No | Yes | No | Yes | Yes | Yes |
| imp-yr, exp-year dum. | No | No | No | Yes | No | No | No |
| Sector fixed effects | Yes | No | Yes | No | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | No | Yes | Yes | Yes |
| Observations | 317382 | 309085 | 329873 | 317382 | 317382 | 317382 | 312588 |

Notes: *,**,***= significant at 10,% 5%, 1%. The dependent variable is the annual bilateral imports expressed in value terms. Standard errors clustered at the country pair level in parentheses. Estimation is by PPML , with two exceptions. Column (2) uses Poisson fixed effects and column (3) uses negative binomial. All regressions include controls for wage differences, real effective exchange rates ratio, relative factor endowments, overall economic size of the two trading partners and GDP similarity. Gravity variables are included in all columns except (2), which include the population weighted distance between the trading partners, and dummies for common currency, contiguity and common official language. Column (2) uses country-pair-sector fixed effects, while other columns use a pre-sample mean. All regressions include year dummies, except column (4) which uses importer-year and exporter-year dummies. Importer and exporter dummies and sectors dummies are included in all columns other than (2) and (4).

*Table 5: Sensitivity analysis results 2*

| | Alternative energy price | | | Lag selection | | | Additional energy price gap |
|---|---|---|---|---|---|---|---|
| | 2000 fixed weights | 2010 fixed weights | variable weights | Contempor-aneous | First lag (baseline) | Second lag | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| | Poisson | Poisson | Poisson | Poisson | Poisson | Poisson | Poisson |
| Eenergy price gap | 0.015** | 0.020*** | 0.017** | 0.013** | 0.021*** | 0.008 | 0.019*** |
| | (0.006) | (0.006) | (0.008) | (0.006) | (0.006) | (0.005) | (0.006) |
| *Control variables* | | | | | | | |
| Epgap in 3rd countries | | | | | | | -0.006 |
| | | | | | | | (0.005) |
| Wage gap | -0.002 | -0.002 | -0.003 | 0.013 | 0.001 | 0.010 | -0.005 |
| | (0.009) | (0.009) | (0.01) | (0.010) | (0.009) | (0.008) | (0.007) |
| Real eff. ex rate ratio | 0.051* | 0.053** | 0.03 | 0.087*** | 0.053** | 0.031 | 0.070*** |
| | (0.027) | (0.027) | (0.03) | (0.028) | (0.027) | (0.026) | (0.021) |
| Relative fact. endow. | -0.003 | -0.003 | -0.005* | -0.006*** | -0.003 | -0.007*** | -0.003 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| GDP total | 0.081 | 0.112 | 0.013 | -0.087 | 0.114 | -0.300*** | 0.111 |
| | (0.101) | (0.097) | (0.118) | (0.094) | (0.096) | (0.079) | (0.084) |
| GDP similarity | 0.037 | 0.052 | 0.001 | -0.047 | 0.053 | -0.153*** | 0.052 |
| | (0.051) | (0.048) | (0.059) | (0.047) | (0.048) | (0.040) | (0.042) |
| *Gravity Variables* | | | | | | | |
| Distance | -0.018*** | -0.020*** | -0.016*** | -0.012*** | -0.018** | -0.004 | -0.018*** |
| | (0.004) | (0.004) | (0.004) | (0.004) | (0.007) | (0.004) | (0.004) |
| Common currency | -0.007 | -0.009 | 0 | -0.005 | -0.006 | 0.008 | -0.006 |
| | (0.008) | (0.009) | (0.008) | (0.008) | (0.016) | (0.008) | (0.008) |
| Contiguity | -0.002 | -0.003 | -0.006 | 0.006 | 0.018* | 0.011* | -0.002 |
| | (0.006) | (0.006) | (0.007) | (0.006) | (0.010) | (0.006) | (0.006) |
| Common official lang. | 0.009 | 0.009 | 0.014* | 0.006 | 0.002 | 0.003 | 0.012 |
| | (0.007) | (0.007) | (0.008) | (0.007) | (0.012) | (0.007) | (0.007) |
| *Lagged dep. Vars.* | | | | | | | |
| Trade_ij(t-1) | 0.878*** | 0.880*** | 0.893*** | 0.898*** | 0.860*** | 0.902*** | 0.850*** |
| | (0.010) | (0.010) | (0.011) | (0.009) | (0.015) | (0.010) | (0.011) |
| Trade_ij(t-2) | 0.058*** | 0.058*** | 0.049*** | 0.047*** | 0.074*** | 0.046*** | 0.083*** |
| | (0.012) | (0.012) | (0.013) | (0.010) | (0.020) | (0.012) | (0.015) |
| Trade_ij(t-3) | 0.043*** | 0.041*** | 0.036*** | 0.038*** | 0.055*** | 0.035*** | 0.042*** |
| | (0.009) | (0.009) | (0.01) | (0.008) | (0.015) | (0.009) | (0.010) |
| Country-pair sect. FE | Presamp | Presamp | Presamp | Presamp | Presamp | Presamp | Presamp |
| Importer and exporter dum. | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| imp-yr, exp-year dum. | No | No | No | No | No | No | No |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 310650 | 317067 | 203707 | 348771 | 317382 | 229962 | 374976 |

Notes: *,**,***= significant at 10,% 5%, 1%. The dependent variable is the annual bilateral imports expressed in value terms. Standard errors clustered at the country pair level in parentheses. Estimation is by PPML. All regressions include controls for wage differences, real effective exchange rates ratio, relative factor endowments, overall economic size of the two trading partners, GDP similarity, year dummies, the population weighted distance between the trading partners, and dummies for common currency, contiguity and common official language. All regressions include year dummies, importer and exporter dummies and sectors dummies.

countries $k$. Indeed, a change in energy prices in country $k$ will indirectly affect trade between $i$ and $j$ through a redirection of trade between $i$ and $k$ and $j$ and $k$, so that trade between *i* and *j* will be substituted with trade with other countries. The inclusion of importer-by-year and exporter- by-year fixed effects reported above would control for this issue to a large extent, but in order to directly control for changes in relative prices with other trading partners, we include a variable that measures, for any country-pair *i j*, sector *s* and time *t*, the energy price gap between country *i* and all countries *k* other than *j*. We construct the average price gap between *i* and third countries *k* by weighing the price in country *k* by the value of imports by *i* from *k* in year *t*-1 (to capture the idea that substitution is more likely to occur with countries that already have a trade relationship with *i*). We report the results of this test in column (7) of table 5. The price gap with third countries enters with a negative but not significant coefficient. Importantly, our main variable of interest, the price gap variable, remains highly statistically significant with a point estimate of 0.019. This suggests that not controlling for energy price changes in third countries might actually bias the coefficient downward.

**Lagged dependent variable selection:** As explained in Section 2.1, we experimented with various dynamic specifications. Columns (5), (6) and (7) in Table 4 show the results of our baseline specification when including respectively one, two and four lags of the dependent variable. The results are remarkably stable across these various specifications.

**Specification of the energy price gap:** To test the possibility that the estimated effects are sensitive to the specification of the energy price gap variable, we used different time period to construct the energy mix weights underlying the variable. We use weights based on a pre-sample period in Table 5 column (1) and weights based on 2010 in column (2). None of these variants of the price variable change the results substantially. We also run the regression with the energy price index which uses time-varying weights, rather than fixed weights, as shown in column (3). An advantage of fixing the weights for the entire period is that all the variation in the price gap variable comes from changes in energy prices and not from changes in the energy mix, which makes the interpretation of the results more straightforward. However, this abstracts from the fact that companies may react to changes in energy prices by changing the energy mix they use. When we construct the energy price variable using time-varying weights, the results still hold and the coefficient on the energy price gap is slightly smaller (0.0169**) than in the reference model. This suggests that sectors indeed switch towards cheaper fuels over time.

**Energy price dynamics:** Table 5 reports alternative dynamic specifications for the energy price gap variable. We use energy prices dated in the current year in column (4), lagged one year in our (baseline) of column (5) and lagged two years in column 6). Using contemporaneous prices returns very similar results to the lagged price, but the coefficient on energy prices in year *t* 2 is not statistically significant. This suggests that the reaction of trade to changes in relative energy prices is quick.

## 5 Simulating the trade impacts of carbon pricing policies

In this section we explore the implications of our econometric models for the evolution of future trade flows and how these may be affected by asymmetric changes in the price of energy implied by unequal carbon pricing policies. Few meaningful carbon prices were in place during the time period covered in the data, so that energy price variations have thus far been mostly driven by factors other than climate policies. However, it is likely that the threats posed by climate change will require carbon emissions regulations that lie far outside the bounds of past experience. For example, as part of the "2030 framework for climate and energy policies", the European Union has committed itself to reduce its greenhouse gas emissions by at least 40% in 2030 compared to 1990. The "Roadmap for moving to a low-carbon economy" further suggests that, by 2050, the EU should cut its emissions to 80% below 1990 levels.

Large industrial energy users in the EU have been regulated under the EU Emissions Trading System since 2005. During the period 2005-2011, the average carbon price was around €14.5/t$CO_2$.[14] The 40% greenhouse gas emissions reductions target for 2030 implies considerably higher prices on the European carbon market than the ones observed between 2005-2011. According to Thomson Reuters Point Carbon, the price of carbon should reach €65/t$CO_2$ in 2030, which corresponds to a €50/t$CO_2$ increase from the average 2005-2011 level. Further carbon emissions reductions in line with 2050 targets are likely to push the price up above the €100/t$CO_2$ level. Given the large uncertainty around the energy price increase from carbon pricing, we simulate two scenarios whereby energy prices were 10% and 30% higher throughout Europe than was actually observed. This implies that the average EU ETS carbon price would have been higher by 25-€50/t$CO_2$ for the 10% energy price increase scenario, and by €50-100/t$CO_2$ for the 30% scenario, assuming no free allowance allocation (thus the EU sectors face the full impact of carbon pricing) according to a recent study by the UK Department of Energy and Climate Change[15] (UK Department of Energy and Climate Change, 2011). Using our

[14] The average annual EUA price in Phase I was €22 .3 /tCO2e (2005), €15.1 /tCO2e (2006), €1.3 /tCO2e (2007), and €15.5/tCO2 in Phase II (2008-2012).

[15] 15The study conducted by the UK Department of Energy and Climate Change estimates that the average impact of all energy and climate change policies on business energy (gas & electricity) bills, including UK policies and the EU ETS, compared with bills in the absence of policies for large energy intensive users is between 6-36% assuming a 30GBP/t$CO_2$ EU ETS price in 2020 (DECC, 2011). Energy price impacts are likely to vary considerably according to the energy profile of users (e.g. gas intensive or electricity intensive) as well as model assumptions. Of this estimated range of impacts, a third is attributable to the EU ETS, and two thirds to other climate policies such as the Renewables Obligations support costs. Hence the energy price increase attributable to the EU ETS with 30GBP/t$CO_2$is between 2 - 12% compared to the case with no EU ETS. Using average exchange rate between 2005-2011, 30GBP/t$CO_2$is approximated at €35/t$CO_2$. Instead with a carbon price assumption of 70GBP/t$CO_2$, the same

econometric model, we simulate the impact of a 10% and a 30% increase in energy prices across Europe on the EU's imports and exports, assuming no change in energy prices in the rest of the world. Applying this range of energy price increases induces a significant change in the size of the energy price gap between the EU and its trading partners. Table 6 presents the predicted impacts on Europe's imports and exports16. EU imports are predicted to increase by 0.04% following a 10% increase in energy prices (corresponding to a 40-65 /tCO2 price) and by 0.07 % following a 30% increase in energy prices (corresponding to a €

65-115 /tCO2 price). Exports are predicted to decline by

*Table 6:* Predicted impact of EU ETS carbon prices on EU imports and exports

| Change in EU energy prices | Implied change in carbon price | Impact on imports | Impact on exports |
|---|---|---|---|
| +10% | +25-50 €/t$CO_2$ | +0.04% | -0.2% |
| +30% | +50-100 €/t$CO_2$ | +0.07% | -0.5% |

0.2% to 0.5%.[16] To put things into perspective, consider that imports to European countries have grown at an average annual rate of 6.5% between 1995 and 2011 and at the rate of 15.6% since 2009. Hence, the impact of ambitious unilateral climate change mitigation policies in Europe on trade appears limited. Our estimates are smaller but comparable to the study by Aldy & Pizer (2011) which finds that an 8% increase in the US electricity prices would lead to an approximately 1% decline in net trade.

## 6 Conclusion

As countries strengthen carbon pricing policies at different speeds, there is considerable interest around the potential trade impacts particularly for the energy intensive trade-exposed sectors. This paper measures the response of bilateral trade to differences in industrial energy prices, using a 16 year panel dataset that includes 42 countries and 62 sectors (covering 80% of global merchandise trade). The coverage and detailed disaggregation of the data used goes well beyond previous work, allowing the first global ex-post analysis of the relationship between trade and energy prices.

We find evidence that changes to the relative energy price between countries have a statistically significant impact on bilateral trade. This result is robust to various estimation techniques and to a wide number of sensitivity tests. The magnitude of this effect, however, is small. A 10% increase in the price of energy in the importer

study predicts industry energy price rise of between 13-60%, the third of which is attributable to the EU ETS (4-20%).

[16] We assume that the impact of the carbon price on energy prices is similar in all European countries, hence intra-EU trade is not affected.

country relative to the exporter country increases imports by around 0.2%. Though slightly larger, the effect remains small in heavy industries, suggesting that trade in energy-intensive sectors may be more resilient to higher energy prices than previously thought.

The findings in this paper suggest that the concerns around short-term impacts on carbon leakage and competitiveness are not entirely ungrounded, but that such concerns may have been overstated, so that concerns around carbon leakage and competitiveness need not dictate the design of carbon mitigation policy instruments. Importantly, the elasticities obtained in this study can be interpreted in a broader geographical context compared to previous studies which examined only industrialised countries. This is important, because carbon pricing policies are being implemented across the world, and carbon leakage is no longer a rich nation's problem. For example, carbon leakage concerns have been raised following China's pledge to achieve significant GDP energy intensity reduction targets largely through changes in sectoral composition of GDP (Tekes, 2011). The estimations from this study predict that changes of production do not imply large changes in trade patterns, at least in the short-term.

An important limitation of our study is that by definition, ex-post empirical evaluations can only cover past or existing policies, but the possibility of larger effects on trade in the future cannot be ruled out if efforts in pollution control diverge significantly across countries. There are stark divergences in the political will to tackle climate change among developed countries' governments, as exemplified by Australia's decision to abolish carbon taxes in 2014 and Germany's ambitious energy transition programme (Energiewende) which aims to reduce greenhouse gas emissions by 80-95 percent by 2050. The regulatory gap might also increase between some emerging economies such as China, Brazil, South Korea, Malaysia and India, which all play a key role in trade and global supply chains. Our results might not be valid for much larger energy price differences across countries than those observed over the last decades.

A key issue for future research is thus to improve the identification of specific economic activities where pollution leakage and competitiveness issues represent a genuine risk; for these specific activities, to assess the various policy options available to prevent adverse impacts on trade whilst avoiding the creation of new distortions; and to determine how environmental policies should be adjusted as other countries' regulations evolve. To carry out these analyses, more disaggregated data on energy prices faced by sectors is necessary. The sectoral level variation in the energy price data used in this paper is estimated using variation in energy mix across sectors, but actual energy prices faced by sectors might vary because of different degrees of competition or the types of contracts used in the industry. As more detailed data become available, incorporating this variation into the analysis will likely enable more robust estimations at the sector level. The availability of better energy intensity data with variation at the country, sector and time level will also allow for additional explorations of how the impact of energy prices on trade varies with energy intensity at the sector level.

It would also be interesting to use the results from this paper to estimate the impacts that fossil fuel subsidy removals might have on trade. The removal of fossil subsidies are likely to impact the price of fossil fuels, as has been modelled by Schwanitz et al. (2014). However, the information needed to estimate the impact of fossil fuel subsidy removal on energy prices implies a level of disaggregation of subsidies (by fuel type, sector and country) that, to the best of our knowledge, is not yet available. We hope that improved understanding of the effects of fossil subsidies removal on energy prices will in the future enable us to pursue this question.

## References

Aichele, R. & Felbermayr, G. (2012). Kyoto and the carbon footprint of nations. *Journal of Environmental Economics and Management*, 63(3), 336–354.

Aichele, R. & Felbermayr, G. J. (2011). Estimating the effects of Kyoto on bilateral trade flows using matching econometrics. Ifo Working Paper No. 119, Ifo Institute for Economic Research. Available from: http://www.cesifo-group.de/portal/pls/portal/docs/1/ 1212805.PDF.

Aldy, J. E. & Pizer, W. A. (2011). The competitiveness impacts of climate change mitigation policies. NBER Working Papers 17705, National Bureau of Economic Research, Inc. Available from: http://www.nber.org/papers/w17705.pdf.

Babiker, M. H. (2005). Climate change policy, market structure, and carbon leakage. *Journal of International Economics*, 65(2), 421–445.

Baltagi, B. H., Egger, P., & Pfaffermayr, M. (2003). A generalized design for bilateral trade flow models. *Economics Letters*, 80(3), 391–397.

Baltagi, B. H., Egger, P., & Pfaffermayr, M. (2007). Estimating models of complex FDI: are there third-country effects? *Journal of Econometrics*, 140(1), 260–281. Available from: http://www.sciencedirect.com/science/article/pii/S0304407606002314.

Barker, T., Junankar, S., Pollitt, H., & Summerton, P. (2007). Carbon leakage from unilateral environmental tax reforms in europe, 1995–2005. *Energy Policy*, 35(12), 6281–6292.

Bergstrand, J. H. (1990). The Heckscher-Ohlin-Samuelson model, the linder hypothesis and the determinants of bilateral intra-industry trade. *The Economic Journal*, 100(403), 1216–1229.

Blundell, R., Griffith, R., & Windmeijer, F. (2002). Individual effects and dynamics in count data models. *Journal of Econometrics*, 108(1), 113–131.

Blundell, R., Griffiths, R., & Van Reenen, J. (1999). Market share, market value and innovation in a panel of british manufacturing firms. *Review of Economic Studies*, 66(3), 529–554.

Branger, F. & Quirion, P. (2013). Climate policy and the 'carbon haven' effect. *Wiley Interdisciplinary Reviews: Climate Change*, [Online First].

Burniaux, J. M. & Martins, J. O. (2000). Carbon emission leakages: A general equilibrium view. OECD Economics Department Working Papers 242, OECD Publishing, Paris. Available from: http://www.oecd.org/dataoecd/13/0/1883806.pdf.

CEPII (2012). The CEPII gravity dataset. Dataset generated by Head, K. and Mayer, T. and Ries, J. Available from: http://www.cepii.fr/anglaisgraph/bdd/gravity.asp [cited 2/8/2012].

Copeland, B. R. & Taylor, M. S. (2003). *Trade and the environment: Theory and evidence*. Princeton: Princeton University Press.

Darvas, Z. (2012). Real effective exchange rates for 178 countries: a new database. Bruegel Working paper.

Demailly, D. & Quirion, P. (2006). Leakage from climate policies and border tax adjustment: lessons from a geographic model of the cement industry. Working Papers halshs-00009337, HAL. Available from: http://halshs.archives-ouvertes.fr/halshs-00009337/en/.

Demailly, D. & Quirion, P. (2008). European emission trading scheme and competitiveness: A case study on the iron and steel industry. *Energy Economics*, 30(4), 2009–2027.

Dröge, S. (2009). Tackling leakage in a world of unequal carbon prices. Report, Climate Strategies, London. Available from: http://www.climatestrategies.org/research/ our-reports/category/32/153.html.

Egger, H. & Egger, P. (2005). The determinants of EU processing trade. *World Economy*, 28(2), 147–168. Available from: http://onlinelibrary.wiley.com/doi/10.1111/j.1467-9701. 2005.00679.x/abstract.

Egger, P. (2000). A note on the proper econometric specification of the gravity equation. *Economics Letters*, 66(1), 25–31.

Egger, P., Jeßberger, C., & Larch, M. (2011). Trade and investment liberalization as determ- inants of multilateral environmental agreement membership. *International Tax and Public Finance*, 18(6), 605–633.

European Commission (2014). Energy prices and costs in europe. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

Fischer, C. & Fox, A. K. (2007). Output-based allocation of emissions permits for mitigating tax and trade interactions. *Land Economics*, 83(4), 575–599.

Gerlagh, R. & Kuik, O. (2007). Carbon leakage with international technology spillovers. FEEM Nota di Lavoro 33.2007, Fondazione Eni Enrico Mattei. Available from: http: //www.feem.it/userfiles/attach/Publication/NDL2007/NDL2007-033.pdf.

Gerlagh, R. & Mathys, N. A. (2011). Energy abundance, trade and industry location. Nota di Lavoro 003.2011, Fondazione Eni Enrico Mattei, Milan. Available from: http: //www.feem.it/userfiles/attach/20111171430134NDL2011-003.pdf.

Gómez-Herrera, E. (2013). Comparing alternative methods to estimate gravity models of bilateral trade. *Empirical Economics*, 44(3), 1087–1111. Available from: http://link. springer.com/article/10.1007/s00181-012-0576-2.

Hanna, R. (2010). Us environmental regulation and fdi: Evidence from a panel of us-based multinational firms. *American Economic Journal: Applied Economics*, 2, 158–189.

Hausman, J., Hall, B. H., & Griliches, Z. (1984). Econometric models for count data with an application to the patents-r & d relationship. *Econometrica*, 52(4), 909–938.

Hepburn, C., Grubb, M., Neuhoff, K., Matthes, F., & Tse, M. (2006). Auctioning of EU ETS phase II allowances: How and why? *Climate Policy*, 6(1), 137–160.

Hourcade, J.-C., Demailly, D., Neuhoff, K., Sato, M., Grubb, M., Matthes, F., & Graichen, V. (2007). Differentiation and dynamics of EU ETS industrial competitiveness impacts. Final report, Climate Strategies. Available from: http://www.climatestrategies.org/ research/our-reports/category/6/37.html.

IEA (2012a). Energy prices and taxes (1st quarter 2012). ESDS International, University of Manchester. Available from: http://dx.doi.org/10.5257/iea/ept/2012q1.

IEA (2012b). *Energy prices and taxes (1st quarter 2012): Methodolgy and notes*. International En- ergy Agency, Paris. Available from: http://wds.iea.org/wds/pdf/EPT_documentation_ 2012q1.pdf.

IMF (2012). World economic outlook database 2012. International Monetary Fund. Available from: http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/index.aspx.

Jaffe, A. B., Peterson, S. R., Portney, P. R., & Stavins, R. N. (1995). Environmental regulation and the competitiveness of US manufacturing: What does the evidence tell us? *Journal of Economic Literature*, 33(1), 132–163.

Jeppesen, T., List, J. A., & Folmer, H. (2002). Environmental regulations and new plant location decisions: Evidence from a meta-analysis. *Journal of Regional Science*, 42(1), 19–49.

Jug, J. & Mirza, D. (2005). Environmental regulations in gravity equations: Evidence from Europe. *The World Economy*, 28(11), 1591–1615.

Kuik, O. & Gerlagh, R. (2003). Trade liberalization and carbon leakage. *Energy Journal*, 24(3), 97–120.

Lanz, B., Rutherford, T., & Tilton, J. E. (2011). Subglobal climate agreements and energy-intensive activities: Is there a carbon haven for copper? CEEPR WP 2011-003, Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research. Available from: http://dspace.mit.edu/bitstream/handle/1721.1/66272/ 2011-003.pdf?sequence=1.

Levinson, A. (2010). Offshoring pollution: Is the united states increasingly importing polluting goods? *Review of Environmental Economics and Policy*, 4(1), 63–83.

Levinson, A. & Taylor, M. (2008). Unmasking the pollution haven effect. *International Economic Review*, 49(1), 223–254.

Monjon, S. & Quirion, P. (2009). Addressing leakage in the EU ETS: Results from the CASE II model. Working paper, Climate Strategies. Available from: http://www. climatestrategies.org/component/reports/category/32/141.html.

National Statistics of Republic of China (Taiwan). Economic and financial data for the Republic of China [online]. (2012). Available from: http://win.dgbas.gov.tw/dgbas03/ bs7/sdds/english/data.htm.

Olivero, M. & Yotov, Y. (2010). Dynamic gravity: Theory and empirical implications. Working paper. Available from: http://faculty.lebow.drexel.edu/OliveroM/research/ dynamic_gravity_April_2010.pdf.

Olivero, M. P. & Yotov, Y. V. (2012). Dynamic gravity: endogenous country size and asset accumulation. *Canadian Journal of Economics/Revue canadienne d'économique*, 45(1), 64–92.

Paltsev, S. V. (2001). The Kyoto Protocol: Regional and sectoral contributions to the carbon leakage. *Energy Journal*, 22(4), 53–80.

Porter, M. E. (1991). Towards a Dynamic Theory of Strategy. *Strategic Management Journal*, 12, 95–117.

Porter, M. E. & van der Linde, C. (1995). Toward a New Conception of the Environment- Competitiveness Relationship. *The Journal of Economic Perspectives*, 9(4), 97–118.

Santos Silva, J. M. C. & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics*, 88(4), 641–658.

Sato, M., Singer, G., Dussaux, D., & Lovo, S. (2015). International and sectoral variation in energy prices 1995-2011: how does it relate to emissions policy stringency? Grantham Research Institute on Climate Change and the Environment Working Paper No.187.

Schwanitz, V. J., Piontek, F., Bertram, C., & Luderer, G. (2014). Long-term climate policy implications of phasing out fossil fuel subsidies. *Energy Policy*, 67, 882–894. Available from: http://www.sciencedirect.com/science/article/pii/S0301421513012597.

Taylor, M. S. & Copeland, B. R. (2004). Trade, growth, and the environment. *Journal of Economic Literature*, 42(1), 7–71.

Tekes (2011). The 12th five-year plan: China's economic transition. Report, Economist Corporate Network, Shanghai. Available from: http://www.finnode.fi/files/51/The_ 12th_Five-Year_Plan_China_s_Economic_Transition.pdf.

UK Department of Energy and Climate Change (2011). Estimated impacts of energy and climate change policies on energy price and bills. DECC Report.

United Nations Industrial Development Organization (2011). UNIDO Industrial Statist- ics Databases – INDSTAT4. Available from: http://www.esds.ac.uk/international/ support/user_guides/unido/indstat.asp.

Upadhyaya, S. (2010). Compilation of energy statistics for economic analysis. UNIDO Work- ing paper 10/2010. Available from: http://www.unido.org//fileadmin/user_media/ Publications/Research_and_statistics/Branch_publications/Research_and_Policy/ Files/Working_Papers/2010/WP%2001%20Compilation%20of%20Energy%20Statistics% 20for%20Economic%20Analysis.pdf.

Wang, C., Wei, Y., & Liu, X. (2010). Determinants of bilateral trade flows in OECD countries: Evidence from gravity panel data models. *The World Economy*, 33(7), 894–915.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT Press Books. Cambridge, MA: The MIT Press, 2 edition.

World Trade Organisation (2012). WTO Statistics Database. Available from: http://stat. wto.org/Home/WSDBHome.aspx?Language=E.

Zhou, X., Kojima, S., & Yano, T. (2010). Addressing carbon leakage by border adjustment measures: Review of current studies. Technical report, Institute for Global Environmental Strategies (IGES). Available from:

http://enviroscope.iges.or.jp/modules/envirolib/upload/3290/attach/bam_literature%20review.pdf.

## Appendix A

Sato et al. (2015) construct an energy price index for a given sector *s* in country *i* , by weighting fuel prices for four carriers (oil, gas, coal and electricity) by the consumption of each fuel type in that sector-country (*si*). While an average industrial energy price level (for all industrial sectors) are readily available for main fuel types, sector specific energy price data is more difficult to obtain for a large panel with many countries. The construction of sector-level prices using fuel consumption as weights then addresses the important issue of heterogenous fuel mix observed across sectors and countries, and is preferable to using the average industry energy price. Sato et al. (2015) constructs two sector level energy price series: the Fixed Weight energy Price Level (FEPI) uses fixed weights, whereas the Variable Weight energy Price Level (VEPL) uses fuel weights which vary over time. The former is an index, which aims to capture the *within*-sector variation, of the change in energy price level over time for a specific country-sector. The FEPI is intended to capture only energy price changes that come from changes in fuel prices, and not through changes in the mix of fuel inputs. It is suitable for use in time-series and panel data analysis and is used in this analysis. The latter is instead designed to capture the *between*-sector variation in energy prices, thus reflecting the effective energy price level (including tax and other policies) for each sector at a particular point in time. This makes it suitable for cross-sectional analysis and is used in this analysis in the robustness check, to test how allowing for changes in the mix of fuel inputs impacts results.

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

$$FEPI_{ist} = \sum_j \frac{F_{is}^j}{\sum_j F_{is}^j} \cdot log\ (P_{it}^j) = \sum_j w_{is}^j \cdot log\ (P_{it}^j) \qquad (2)$$

where $F_{is}^j$ are the input quantity of fuel type *j* in tons of oil equivalent (TOE) for sector *s* in country *i* and $P_{it}^j$ denotes the real TOE price of fuel type *j* for total manufacturing in country i at time t in constant 2010 USD. The weights, $w_{is}^j$, applied to fuel prices are fixed over time. The prices $Pit \quad j$ are transformed into logs before applying the weights so that the log of the individual prices enter linearly in the equation. Within any one country-sector, a consistent set of sub-fuel type is used through time. Anchor years for the fixed weights are taken at 1995, 2000, 2005 and

2010, and the 2005 one is used in the reference model, and we also test in the robustness section, how the results compare using energy prices using weights fixed at 2000 and 2010 levels.

## Appendix B

*Table 7:* List of countries and sectors

| | 2-digit SITC (Rev. 3) sectors included |
|---|---|
| Countries | Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Kazakhstan, South Korea, Lithuania, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Foundation, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, United States |
| Sectors | Animal feed, Animal oils, Apparel products, Beverages, Chemical products, Coal and coke, Coffee and tea, Cork and wood, Cork and wood manufacturers, Cereals, Crude animal and vegetable materials, Crude fertilisers, Crude rubber, Dairy products, Dyeing materials, Electrical machinery, Essential oils and perfume, Fertilisers, Fish, Footwear, Furniture, General industrial machinery, Gold, Hides and skin, Industrial machinery, Inorganic Chemicals, Iron and steel, Leather manufactures, Live animals, Meat, Metal manufacturing, Metal ores and scrap, Metalworking machinery, Non ferrous metals, Non metallic minerals, Non-primary plastics, Office machinery, Oil seeds, Organic chemicals, Other foods, Other manufacturing, Other transport equipment, Paper and paperboard, Petroleum products, Pharmaceuticals, Photographic and optical goods, Power generation equipment, Prefabricated buildings, Primary plastics, Processed animal and veg oils, Pulp and waste paper, Road vehicles, Rubber manufactures, Scientific instruments, Sugars, Telecom machinery, Textile fibres, Textile yarn and fabric, Tobacco, Travel goods, Vegetable fats and Vegetables and fruit. |

*Table 8:* Broad sectors groups

| | 2-digit SITC (Rev. 3) sectors included |
|---|---|
| Energy-intensive | Chemical products; Coal & coke; Crude fertilisers; Fertilisers; Inorganic chemicals; Iron & Steel; Non-metallic minerals; Non-ferrous metals; Organic chemicals; Paper & paper board; Petroleum products; Pulp and waste paper. |
| Non energy-intensive | Apparel products; Beverages; Cork and wood manufactures; Dairy products; Dyeing materials; Electrical Machinery; Essential oils and perfume; Footwear; Furniture; General industrial machinery; Industrial machinery; Leather manufactures; Metal manufacturing; Metalworking machinery; Non-primary plastic manufactures; Other foods; Other transport equipment; Pharmaceuticals; Power generation equipment; Photographic and optical goods; Processed animal and vegetable oils; Prefabricated buildings; Primary plastics; Road vehicles; Rubber manufactures; Scientific instruments; Telecom machinery; Textile fibres; Textile yarn and fabric; Travel goods. |