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Abstract

We investigate whether the costs of an input to production embodied in the supply chain can be a source of comparative advantage. Motivated by the fact that most industrial energy use takes place in the supply chain, we focus on the case of energy costs. Using a disaggregated dataset on trade flows in manufacturing industries around the world, we find that both direct and indirect energy costs passed on through intermediate goods have a significant effect on the pattern of international trade. We also show that industries in countries with high energy prices attempt to mitigate these effects by importing energy-intensive, intermediate goods from countries that have lower energy prices. We consider the economic significance of our results by calculating the effects of the energy price increases that occurred in the European Union in the mid-2000s onwards. We find that EU manufacturing exports decline anywhere from 6.8 percent to 15 percent, depending on the elasticity of input substitution. Our results demonstrate that there is a substantial difference in the estimated effect of energy prices on international trade when indirect energy costs are taken into account.

Keywords: Energy prices, Intermediate goods, Comparative advantage, Exports

JEL Classifications: Q5, Q4, F1, L2.

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1 Introduction

There is a large and growing empirical literature that investigates sources of comparative advantage. Early empirical studies emphasized the importance of factor abundance for the pattern of trade, supporting the predictions of the Heckscher-Ohlin framework. For example, Romalis (2004) adopted an empirical strategy that exploits both cross-industry variation in the intensity of input use, and cross-country variation in factor endowments, to demonstrate that countries will tend to export differentially more in industries that make intensive use of their abundant factors of production. More recent empirical studies have used a similar strategy to show that comparative advantage is driven by various other factors, including the legal framework (e.g., Nunn, 2007), financial development (e.g. Manova, 2008), labour market flexibility (Cunat and Melitz, 2012), skill dispersion (Bombardini et al., 2012), water resources (Debaere, 2014), interpersonal trust (Cingano and Pinotti, 2016) and demography (Cai and Stoyanov, 2016).

While the intensity of an industry's own (direct) input use therefore plays an important role in understanding the pattern of international trade, industries also use inputs *indirectly* through the intermediate goods they use to produce their output. Moreover, the cost of the inputs used in the production of these intermediate goods in the supply chain may be passed on to downstream industries, in turn affecting their export competitiveness. Whether a country has a comparative advantage in a particular industry may therefore be affected by that industry's *indirect* use of inputs, and industries may organize their supply chains to mitigate these indirect costs. However, there is limited empirical evidence on whether indirect input costs are a source of comparative advantage.

Indirect costs are likely to be particularly important in the case of energy. While many industries require relatively little use of energy in their own production processes, they may use a substantial amount of energy indirectly in the supply chain. This is because industries that produce intermediate goods are often highly energy intensive – such as the steel, aluminum, petrochemical, and cement industries, among others. In fact, most energy use takes place in the supply chain.[1] Figure 1 demonstrates this point by calculating the indirect use of energy in the US manufacturing sector by stages of production; as shown, the indirect energy costs that take place through the supply chain exceed the direct costs.[2] Industries in countries with high energy prices that use energy-intensive intermediate inputs may therefore have

[1] The input-output literature also emphasizes the importance of indirect energy consumption through intermediate goods (Bordigoni et al., 2012; Sato et al., 2016).

[2] We compute the indirect energy use by stages of production following the methodology outlined in Owen et al. (2018) using the 2002 US input-output account. We thank Trevor Tombe for suggesting this metric.

a comparative disadvantage, even if the industry itself is not energy intensive. However, firms in these industries may be able to dampen the negative effects of such indirect costs if they can substitute locally supplied, energy-intensive intermediate inputs with those produced in foreign countries that have lower energy prices.

The linkages between energy costs and competitiveness are of particular concern for Europe, because both electricity and natural gas prices have increased substantially in most European countries over recent years (see Figures 2a and 2b). These trends are partly due to the common energy and environmental policies implemented across the European Union (EU). Business leaders and analysts have suggested the rising energy prices will erode Europe's market share in producing electricity- and natural gas-intensive exports (Financial Times 2013, 2014). Given the highly integrated nature of supply chains across the EU, European manufacturing firms may also lose their market share in producing goods with high *indirect* energy costs.

In this paper, we provide empirical evidence on whether the indirect costs of a production input (energy) are a source of comparative advantage. We ask two specific research questions: First, how do energy price differences across countries directly *and* indirectly affect their pattern of exports? That is, we study both the effect of an industry's own energy costs on its exports (the "direct effect"), and the effect of the energy costs embodied in an industry's supply chain on its exports (the "indirect effect"). Second, do industries aim to structure their supply chains to mitigate indirect energy costs? That is, we examine whether industries exploit energy price variation across countries by increasing their consumption of energy-intensive intermediate goods from countries with lower energy prices. We address these questions using the Rajan-Zingales difference-in-differences empirical strategy that is widely used in the literature. This method involves estimating the effect of interaction terms between industry and country characteristics.[3] Specifically, we regress trade flows on an interaction of country-level energy prices and industry-level (direct and indirect) energy intensities, as well as country and industry fixed effects. We therefore identify the effects by comparing the difference between exports from countries with different energy prices, and between the goods that require different energy intensities to produce.

From our regression results, we find evidence that both direct and indirect energy costs are a source of comparative advantage. We find our results are robust to various concerns about omitted variables, reverse causality, and different samples of data. By combining the direct and indirect effects, we compute the *short-run*, *aggregate effect* of energy prices. We find that this effect is larger by an order of magnitude

[3] The method was first used by Rajan and Zingales (1998) to show that industrial sectors that are more dependent on external finance grow more quickly in countries with a high level of financial development.

than the effect of direct energy costs alone. Furthermore, because there is a positive correlation between the direct and indirect energy costs, the magnitude of the direct effects of energy costs tends to be overestimated if the indirect effects are not controlled for in the regression. Thus, controlling for both direct and indirect energy costs is important, even if one is only interested in the magnitude of the effects of direct energy costs. When decomposing the effect of energy costs by separate energy commodities (electricity and natural gas), we find the indirect effect is largely driven by indirect natural gas costs rather than by indirect electricity costs. Using the regression results for intermediate goods, we also find evidence that energy price differentials lead industries to adjust their supply chain to lower the energy costs embodied in their intermediate goods. This effect mediates the short-run overall effects. Thus, we interpret the combined effect as the *long-run, aggregate effect* of energy prices.

We use these estimates – of the direct, short-run and long-run effects – to generate three sets of predictions for the effects of a shock to energy prices on export patterns. We illustrate the difference of these effects by simulating the increase in energy prices that has occurred in the EU since the mid-2000s. We find that the 33 percent increase in energy prices experienced during this period translates to a 6.8 percent drop in EU exports, and up to a 15 percent drop when taking into account the increase in prices of intermediate goods as a result of the energy price hike. Once we allow firms to adjust their imports of intermediate goods, the estimated decrease in EU exports is 11 percent. Therefore, to accurately quantify the long-run effects of energy prices on trade, our findings suggest it is important to take into account the indirect effects of energy costs, as well as the pattern of trade in intermediate goods.

Our paper and its findings contribute to three main strands of the literature. First, we add to the literature that provides econometric evidence on sources of comparative advantage (e.g., Romalis, 2004; Nunn, 2007; Bombardini et al., 2012; Manova, 2008; Cunat and Melitz, 2012; Manova, 2013; Debaere, 2014; Cingano and Pinotti, 2016; Cai and Stoyanov, 2016). To the best of our knowledge we are the first to establish that the indirect cost of a factor of production (energy) is itself a statistically significant source of comparative advantage. A few studies in the literature take indirect costs into account by measuring the *aggregate* intensity of input use in the industry, combining both the direct use and indirect use (e.g., Debaere, 2014; Arezki et al., 2017). However, we are the first to establish that the indirect cost of inputs per se can be a source of comparative advantage. Furthermore, we provide empirical evidence that global supply chains are organized to mitigate these indirect costs. Our analysis therefore suggests that indirect costs and supply chain adjustments should be taken into account to accurately quantify the effect of input costs on the pattern of trade. Our work shows that a better understanding of the determinants of comparative advantage can be achieved by examining both direct and indirect costs than by analyzing direct costs alone.

Second, we contribute to the literature on global value chains and trade. Over the past 10 years, there has been considerable interest in the field of international economics about the role of intermediate goods (e.g., Miroudot et al., 2009; Johnson and Noguera, 2012; Baldwin, 2013), and, more recently, about the organization of firms and intra-firm trade (e.g., Antràs and Chor, 2013; Antràs, 2015; Antràs et al., 2017; Alfaro et al., 2019). Several papers attempt to explain the flows of intermediate goods. For example, in a study of the sourcing strategies of firms, Blaum et al. (2019) find that large firms import significant amounts of high-quality inputs from countries that specialize in their production. Using a gravity model framework, Conconi et al. (2020) show that trade of intermediate goods has a higher elasticity to distance. Our paper extends this literature by demonstrating how the cost of producing intermediate goods can act as a source of comparative advantage in the trade of downstream goods.

Third, we contribute to the empirical literature on the relationship between energy prices and trade. A few recent studies have analyzed the effect of energy prices on the pattern of specialisation for the U.S. using within-industry adjustments over time (Aldy and Pizer, 2015; Arezki et al., 2017). In terms of the analysis of global trade, Sato and Dechezleprêtre (2015) focus on the direct impact of energy price gaps between bilateral trading partners on the volume of trade using a sample of 42 countries over the period from 1991 to 2011. Some papers concerned with energy or environmental issues specifically focus on the role of intermediate goods. Martin (2012) finds that a reduction in tariffs on intermediate inputs significantly improves energy efficiency within a firm. Cherniwchan (2017) finds a similar effect on emissions by examining the effect of lowered trade costs for intermediate inputs from Mexico following the introduction of the North American Free Trade Agreement (NAFTA). Using a sample of Japanese manufacturing firms, Cole et al. (2014) find that domestic regulation leads firms to outsource emission-intensive production abroad. Our paper complements these studies by highlighting the role of intermediate goods in shaping the composition of trade, and by examining whether the intensive use of energy in the supply chain can act as a source of comparative advantage.

The rest of this paper is organized as follows: Section 2 describes the data. Section 3 provides preliminary evidence on the EU's specialization in energy-intensive production. Section 4 presents our main empirical analysis and results. We show how energy prices can both directly and indirectly affect the pattern of exports. Using a similar methodology, we also present empirical evidence on how energy prices affect the supply chain. Section 5 uses the regression results to predict the effects of energy price adjustments on the pattern of trade when taking indirect costs and supply-chain adjustment channels into account. Section 6 concludes.

2 Data

We combine data on country-level exports by industry, energy prices by country and energy intensity by industry. Tables of descriptive statistics as well as a full list of variable definitions and sources are provided in the Data Appendix (Appendix A).

2.1 Trade flows of exports and intermediate goods

We use trade data from the UN Comtrade Database and extract the value of exports $Exports_{ijk}$. We index exporting countries with i, importing countries with j, and industries with k throughout the paper. For each exporting country we have data for exports into 60 importing countries. The number of exporting countries in the sample varies according to the regression specification. For our main results that explicitly model the effect of energy prices on the pattern of trade, we use trade data for 2012, although we test the robustness of our results for other years as well. We use the industrial classification provided by the U.S. Bureau of Economic Analysis (US BEA) Benchmark Input-Output Accounts, which includes 249 manufacturing industries. Our disaggregated analysis allows us to capture the differences in energy use across industries in the same sector.[4] While studies focused on US trade patterns have exploited within-sector variation in energy use (Aldy and Pizer, 2015; Arezki et al., 2017), cross-country studies in the literature on global trade patterns and energy costs have not (e.g., Gustavsson et al., 1999; Gerlagh et al., 2015). We also offer greater country coverage than the previous studies, which means the estimates are externally valid to the pattern of specialization across a wide range of countries. Our more recent time frame (post-2000) is also important because the results can be interpreted in the context of the greater levels of global trade, particularly between industrialized countries and emerging economies such as China, and the associated increase in competitiveness concerns.

[4] A good example of this variability can be seen in aluminum production and use (within the Alumina and Aluminum Production and Processing category, classification 3313 of the North American Industry Classification System (NAICS)). Electricity intensity, defined as electricity us as a share of value added, is about 10 times greater for the refining and production of aluminum than for the manufacturing of products that use purchased aluminum. Estimates based on US BEA data show that energy intensity is 0.56 for refining and production of aluminum, and 0.06 for manufacturing using purchases aluminum. Petrochemical manufacturing (Basic Chemical Manufacturing (NAICS 3251)) shows a similar pattern. Petrochemical manufacturing is about 10 times more natural gas intensive than industrial gas manufacturing. Natural gas intensities, defined as natural gas use as a share of value added, are 0.30 for petrochemical manufacturing and 0.03 for industrial gas manufacturing.) Likewise, within Basic Chemical Manufacturing (NAICS 3251), petrochemical manufacturing is about 10 times more natural gas intensive than industrial gas manufacturing (where the natural gas intensities, defined as natural gas use as a share of value added, are 0.30 and 0.03, respectively, based on US BEA data).

We use the global input-output tables provided from the World Input-Output database (WIOD) (Timmer et al., 2015) to record imports of intermediate goods, where industry k imports from another industry l (potentially located in a different country). The WIOD data cover 43 countries. The WIOD data are available only at the two-digit level of the International Standard Industrial Classification of All Economic Activities. This covers 18 manufacturing industries. For our main results, we focus on cross-country flows of intermediate goods from 18 manufacturing industries in 2012.

2.2 Energy prices and intensities

We take two different approaches to measuring the energy price of the country and the energy intensity of the industry. One approach uses the electricity price and natural gas price ($ElectricityPrice_i$ and $NaturalGasPrice_i$ respectively) from the International Energy Agency (IEA) Energy Prices and Taxes database. We interact each price with the corresponding intensity ($ElectricityIntensity_k$ and $NaturalGasIntensity_k$) calculated using data from the 2002 U.S. Bureau of Economic Analysis (BEA) Input-Output Tables.[5] We define electricity (natural gas) intensity as total electricity (natural gas) consumption as a share of value added. The interaction terms allow us to determine whether energy prices have a heterogeneous effect across industries and, therefore, whether the prices drive the pattern of specialisation.

The other approach uses the energy price index compiled by Sato et al. (2019) ($EnergyPriceIndex_i$). This index is a weighted average energy price for all fuels (electricity, natural gas, coal and oil). The weights are the consumption of each fuel type in the manufacturing sector in each country. We interact the energy price index with the energy intensity of the industry ($EnergyIntensity_k$), defined as the cost of electricity and fuels as a share of the total value added. Hence, this measure of energy intensity includes the consumption of all energy commodities. These industry data are taken from the 2002 US NBER-CES Manufacturing Industry Database (Bartelsman and Gray (1996), updated to 2011).

The advantage of using $EnergyPriceIndex_i$ is that it captures the price of all fuels, and accounts for possible interfuel substitution. However, it is available for a smaller sample of countries than the electricity and natural gas price variables due to missing data. In addition, estimating separate effects for electricity and natural gas prices allows us to assess their relative importance and offers more flexibility (with

[5] To calculate intensities, we chose input-output accounts from 2002 instead of those from a later year (i.e., 2007) because we are concerned about the effect of the change in US energy prices due to the shale gas revolution, and the effect of recession on the use of energy inputs in 2007. Furthermore, we want to test the sensitivity of our results over time from 2004. Fixing the intensity at the beginning of our sample period also allows us to minimize endogeneity concerns.

fewer parametric restrictions) than assuming a single common effect from all energy prices. Focusing specifically on electricity and natural gas prices may also get closer to the sources of comparative advantage, because the prices of these energy sources vary to a greater degree across countries than the prices of oil and coal.[6]

Our use of U.S. data to calculate the factor intensities of production is the standard approach of studies in the trade literature that investigate sources of comparative advantage (e.g., Nunn, 2007; Bombardini et al., 2012; Manova, 2013; Debaere, 2014; Cai and Stoyanov, 2016). The need to proxy intensities with one country's technology matrix reflects the fact that disaggregated technology matrices are not widely available across countries. We use the US as the reference country because it is a very large and diversified economy in terms of manufacturing production. Observed energy intensities are therefore likely to be more generally representative of the underlying technological characteristics of production processes. Using data for the US (rather than country-specific energy intensity data) also has the advantage of reducing the potential for the measures to respond endogenously to a given country's pattern of trade. While our identification strategy does not require that industries in every country have the same levels of electricity intensity and natural gas intensity as they have in the US, it does rely on the U.S. ranking of industries remaining fairly stable for other countries (i.e., the assumption of no factor intensity reversals).

Based on the US factor intensity assumption, we construct our measures of indirect energy intensities using the Benchmark Input-Output Model from the US BEA. The Benchmark Input-Output Table provides an industry-by-industry total requirement matrix that shows the requirements from each (column) industry to produce a dollar worth of product from each (row) industry. Therefore, we observe at a disaggregated level how many inputs each industry requires from all other industries. Using this information, and defining the cost as the price multiplied by the intensity of use, we then construct an aggregate cost vector as follows:

$$\overrightarrow{AggCost} = (1 - \mathbf{A})^{-1}\overrightarrow{Cost} \tag{1}$$

where $\overrightarrow{AggCost}$ and $\overrightarrow{Cost}$ are column vectors containing each industry's aggregate and direct energy costs, and matrix $\mathbf{A}$ is the industry-by-industry total requirement matrix described above. We apply this formula for each cost vector for each country to compute a country-specific aggregate cost measure for

[6] Electricity and natural gas are relatively hard to trade long distances, and so prices can vary substantially according to local energy abundance and energy policies. By contrast, while petroleum products are an important fuel for manufacturing industries, they are easily traded internationally, and so prices are determined on world markets with less variation in different parts of the world. Coal is also internationally traded, and manufacturing industries make relatively little direct use of coal in the production process. In addition, oil and coal prices are only available across countries for certain sub-fuel types, making cross-country price comparisons more difficult to measure accurately.

each country i and industry k. The indirect energy cost (intensity) is simply the difference between the aggregate and direct energy cost (intensity). We define the interaction term between an industry's direct (indirect) energy intensity and the log energy price as the industry's direct (indirect) energy costs.

Following Romalis (2004) and the Hecksher-Ohlin theory of factor abundance, in all our regressions we include controls for the exporting country i's endowment of skilled labor and physical capital, interacted with the skill and capital intensity of production in industry k. If countries that are abundant in a factor of production specialize in industries that use that factor intensively then we expect the coefficients on these two factor endowment interactions to be positive. Controlling for physical capital costs is particularly important because energy-intensive industries tend to be capital intensive. We also consider the robustness of our results to including a host of controls for other possible sources of comparative advantage emphasized by the existing literature.

2.3 Descriptive statistics

Table A.1 in the Data Appendix shows the most and least energy-intensive industries in our sample (based on their consumption of all energy commodities). Three of the most energy-intensive industries are in the Non-metallic Mineral Product Manufacturing (NAICS 327) sector; two are in the Chemical Manufacturing (NAICS 325) sector, and two are in the Primary Metal Manufacturing (NAICS 331) sector. We note that the Food Manufacturing (NAICS 311) sector and the Chemical Manufacturing (NAICS 325) sector both comprise some of the most and least energy-intensive industries. This underscores the value of a highly disaggregated analysis that can take the within-sector heterogeneity into account.

Table A.1 provides the direct electricity and natural gas intensities of these industries. We find that some industries are far more electricity (natural gas) intensive than natural gas (electricity) intensive. For example, Industrial Gas manufacturing (NAICS 325120) is nearly 10 times more electricity intensive than natural gas intensive. Similarly, Petrochemical manufacturing (NAICS 325110) is over four times more natural gas intensive than electricity intensive. Electricity prices and natural gas prices may therefore have very different effects on the location of these industries. Our analysis explicitly takes this into account by estimating separate effects for electricity and natural gas prices that are conditional on the intensity of use.[7] Table A.1 also provides the aggregate (direct plus indirect) electricity and natural gas intensities of these industries. We find that aggregate intensities are sometimes more than double the

[7] We drop from the sample two industries due to outlying observations for natural gas and electricity intensity. These are Fertilizer Manufacturing (NAICS 325310), which has a natural gas intensity of 0.92, and Alkalies and Chlorine Manufacturing (NAICS 325181) which has an electricity intensity of 0.69.

direct intensities; among the 10 most energy-intensive industries, this is the case for three sectors: Iron and Steel Mills manufacturing (NAICS 331110), Petroleum refineries (NAICS 324110), and Petrochemical manufacturing (NAICS 325110). For these industries, most energy use is indirect use that takes place through the supply chain.

Table A.2 in the Data Appendix provides summary statistics for the variables used in the regression analysis. $ElectricityPrice_i$ and $NaturalGasPrice_i$ are available for 40 countries for our main results using export data for 2012. Table A.3 reports the observed values for these two variables by country. We find substantial variation in energy prices across countries. Italy has the highest value for electricity prices, more than eight times higher than the country with the lowest price index (Saudi Arabia). Other countries with very high electricity prices include Slovakia, Brazil and Japan. The countries with the highest natural gas prices are Denmark, Switzerland, and Japan. By contrast, India, Russia, and Saudi Arabia have the lowest natural gas prices. The energy price variable $EnergyPriceIndex_i$ that measures the prices of all fuels is observed for fewer countries (32 countries in 2012) due to missing data, and so when using this alternative measure our sample size is smaller.

Table A.4 in the Data Appendix provides correlations between the country-industry interaction terms that enter into the regression equations. As expected, both the electricity and natural gas interaction terms are highly correlated with the interaction between the overall energy price index and energy intensity. There is a fairly strong, positive correlation between the energy price interaction terms and the capital abundance/intensity interaction term. Hence, we include the capital abundance/intensity interaction term in our regressions to mitigate possible omitted variable bias. The correlation between the electricity price/intensity-interaction and the natural gas price/intensity-interaction terms is 0.58. We should therefore be able to separately identify their effects without concerns about multicollinearity.

3 Preliminary Evidence

To set the stage for our formal estimations of the effect of energy prices on trade, we present graphical evidence on the EU's specialization in energy-intensive production. As previously shown in Figure 2, energy prices have risen substantially over time in many EU countries. We plot average energy prices for EU and non-EU countries in Figures 3a and 3b. These figures reveal a growing energy price gap over time, with energy prices in EU countries far higher than those in non-EU countries during the period from 2009 to 2014. EU industries that rely heavily on energy in their production processes may therefore face higher costs and suffer a negative competitiveness effect from this price increase.

Does the change in energy prices in the EU relative to other countries have material effects on the pattern of EU trade? We calculate the energy intensity of aggregate exports over time separately for EU and non-EU countries. We then plot how these energy intensities change over time in Figure 4. Following the divergence of energy prices in the mid-2000s, we can see that there is a decrease in the energy intensity of exports in EU countries relative to non-EU countries. This suggests that the energy price gap is correlated with energy-intensive production gradually shifting away from EU countries.

Motivated by the findings in Figure 4, we estimate the effects of these increasing relative energy prices on the EU pattern of specialisation. Here we consider both direct effects and indirect effects through intermediate goods consumption. We examine the effect of the energy price changes implicitly by estimating cross-sectional regressions for different years, both before and after the energy price adjustments documented in Figures 3a and 3b. We consider whether non-EU (EU) countries export to a differentially greater degree in relatively energy-intensive (non-energy-intensive) industries in later years when the energy price gap emerged. We expect this to be the case because energy-intensive industries should have relatively more to gain in terms of potential cost reductions than non-energy-intensive industries (holding all else constant) by locating outside of the EU when there are lower energy prices in non-EU countries.

Using cross-country trade data for 59 exporting countries and 249 manufacturing industries, we specify the regression equation as follows:

$$\log(Exports)_{ik} = \beta_1 (EU)_i \times (EnergyIntensity)_k + \lambda X_{ik} + \alpha_i + \alpha_k + v_{ik} \tag{2}$$

where $Exports_{ik}$ is the value of exports from county i in industry k to the rest of the world. EU is a dummy variable equal to one if country i belongs to the EU-28 countries (including the United Kingdom), and zero otherwise. $EnergyIntensity_k$ is the energy intensity of production in industry k defined in Section 2.2. We include direct energy intensity only, and then augment the regression by including both the direct and indirect energy intensity (both interacted with the EU dummy variable). X_{ik} includes interaction terms between the EU dummy and other industrial intensities for other inputs (i.e., physical capital and human capital). α_i is an exporter fixed effect and α_k is an industry fixed effect. Finally, v_{ik} is an error term.

We estimate regression (2) using ordinary least squares (OLS) separately for each year of our available sample (2002-2013). The coefficient of interest is β_1 on the interaction term between EU_i and $EnergyIntensity_k$. If higher energy prices do indeed reduce the EU's export competitiveness relatively more in energy-intensive industries, we would expect β_1 to decrease over time. The exporter fixed effect α_i captures any unobserved country-level variables, while α_k captures various industry-specific characteristics. EU_i and $EnergyIntensity_k$ do not enter directly into equation (2) because their direct effects are captured by α_i and α_k, respectively. The total volume of a country's exports across all industries is captured by the exporter fixed effect α_i. Therefore, β_1 is identified only from differences in country i's exports across industries. Similar to many other studies of comparative advantage (e.g., Nunn, 2007; Bombardini et al., 2012), this means that identification only comes from variation in the pattern of trade (i.e., the composition of trade), not from the total volume of trade.

Results. We plot the coefficients on the interaction term between the EU dummy and the energy intensity of the industry for each year (see Figure 5).[8] The shaded areas indicate the 95 percent confidence intervals. From this figure we can easily assess how the coefficients on the interaction terms change over time. In Panel A we plot the estimated coefficients when including the direct energy intensity only in the regression. These findings document a very similar story to that shown in Figure 4. Before the divergence of energy prices between the EU and non-EU countries (i.e., in 2002), there is no statistically significant difference in energy intensive exports for the two groups of countries. However, for 2006 and later years, the interaction term between EU_i and $EnergyIntensity_k$ is negative and statistically significant at the 5 percent level, and the magnitude of the coefficient increases over time. Thus, as energy prices rise in the EU, we find that energy intensive exports from the EU do indeed become progressively smaller relative to non-EU countries over time.

Next, we augment equation (2) by including an additional interaction term between the EU dummy variable and the indirect energy intensity. The indirect energy intensity is computed as the difference between the aggregate energy intensity defined in equation (1) and the direct energy intensity, as discussed in Section 2.2. Including this second interaction term allows us to test whether EU countries are more or less likely to specialize in industries that use energy-intensive inputs to production (relative to non-EU countries) over time.

The results from the augmented regression are reported in Panel B of Figure 5. We find the direct energy intensity interaction term exhibits a similar pattern as it did before. It gradually increases in size, becoming more negative over time. However, the effect of direct energy costs is smaller than in

[8] These results are also given in table format in Appendix Table B.1.

Panel A. The effect only becomes significant at the 5 percent level in the latter years of the sample (2009 and 2011-2013). This result suggests that when the regression includes only direct energy costs, the estimated coefficient on the direct energy cost is overestimated because it partly captures the effect of indirect energy costs. In Panel B we also find that the indirect energy intensity interaction with the EU dummy is negative and statistically significant at the 5 percent level in all years. This result suggests that EU countries have a comparative disadvantage in industries with high energy use in the supply chain. However, unlike the direct cost, the magnitude of the indirect effect is fairly stable over time. It does not increase in absolute terms. Thus, higher relative energy prices in the EU over time do not seem to further reduce exports in industries with high indirect energy use by raising the cost of producing their intermediate inputs. This finding may reflect that EU industries are able to source energy-intensive intermediate goods from countries with lower energy prices. (We further investigate this mechanism in Section 4.2.)

In summary, the preliminary evidence provided in this section suggests that the EU has to some extent developed a comparative disadvantage in goods with relatively high direct energy costs after the energy price gap with non-EU countries emerged. However, the degree of the EU's specialization in goods with high indirect energy costs has not changed very much over time. While these findings are informative of the EU's comparative advantage in energy-intensive production, the effect of energy prices is only being modeled implicitly. In the following section, we therefore model energy prices explicitly to estimate the impact of energy prices per se on trade, and we quantify their impact relative to other channels. This allows us to consider how much of the difference in trade patterns is due to the variation in energy prices across countries.

4 Main Results

In this section we use regression analysis to present more detailed and structured empirical evidence on whether energy prices are a source of comparative advantage. Throughout this section, the underlying identification strategy is a difference-in-differences model that compares the propensity to export manufacturing goods in countries with high or low energy prices, and in energy-intensive industries or non-energy-intensive industries. The empirical strategy uses cross-sectional variation across countries in the pattern of specialization, and we do not allow identification to come from the time dimension. This is the conventional approach that has been taken in the trade literature to investigate sources of comparative advantage (e.g., Romalis, 2004; Nunn, 2007; Bombardini et al., 2012; Cunat and Melitz, 2012; Debaere, 2014) and reflects that trade patterns are highly persistent over time. Therefore, sources of comparative advantage do not usually change substantially from one year to the next. The EU provides a case in point; as outlined in Section 3, the specialization of the EU in energy-intensive production has evolved only gradually over time during our sample period, despite substantial increases in relative EU energy prices in that time frame.

We focus on cross-sectional evidence for the year 2012. We choose 2012 because we observe energy prices for a large number of countries in this year. For earlier years, energy price data for fewer countries are available. In addition, the sharp increases observed in energy prices in the EU are fairly stable from 2009 onwards. Therefore, using export data for 2012 allows us to evaluate the equilibrium trade patterns that emerge following the increase in energy prices in the EU. Although we use the standard cross-sectional approach, we are mindful of the changes that have taken place in energy prices over time. Therefore, we explore the robustness of our cross-sectional evidence to using data for other time periods.[9]

We proceed as follows: First, we explicitly quantify the impact of energy price variation across countries on trade patterns, and we explore the impact of direct and indirect costs (see Section 4.1). Second, we explicitly quantify the effects of energy price variation across countries on the decision by industries to import their energy-intensive intermediate inputs (see Section 4.2).

4.1 Explicit effects of energy prices

To explicitly model the effect of energy prices on the pattern of trade, we estimate a cross-sectional regression similar to equation (2) above, but we replace the EU dummy with the observed energy price in each country. Thus, the regression equation now takes the following form:

$$\log(Exports)_{ik} = \beta_1 (EnergyPriceIndex)_i \times (EnergyIntensity)_k + \lambda X_{ik} + \alpha_i + \alpha_k + v_{ik} \quad (3)$$

The dependent variable ($Exports_{ik}$) is the value of exports from country i in industry k to the rest of the world in 2012. $EnergyPriceIndex_i$ is the index of energy prices for all fuels in country i, explained above in Section 2.2. For each country we use the average energy prices observed over a three-year period (2009–2011) to capture prices over a longer run and to ensure that our results are not driven

[9] Like others in the trade literature (e.g., Romalis, 2004; Nunn, 2007; Bombardini et al., 2012), we consider only positive exports. Therefore, we consider only how differences in the energy cost environment across industries affect exports at the intensive margin. The effect that energy costs have on trade at the extensive margin (i.e., on the decision to export in a given industry) is not captured in our estimates.

by a county-specific price shock in an individual year. We do not include contemporaneous energy prices in this average because we do not expect trade flows to respond instantaneously to input costs. X_{ik} includes interaction terms between the physical capital and human capital endowments of each country and the corresponding industry intensity; this is to control for standard Heckscher-Ohlin sources of comparative advantage (in the spirit of Romalis (2004)). As before, $EnergyIntensity_k$ is the energy intensity of production in industry k, α_i is an exporter fixed effect, α_k is an industry fixed effect, and v_{ik} is an error term.

As before, $EnergyPriceIndex_i$ and $EnergyIntensity_k$ do not enter directly into equation (3) because their direct effects are captured by α_i and α_k respectively; the coefficient of interest is instead on β_1, the interaction term between $EnergyPriceIndex_i$ and $EnergyIntensity_k$. If high energy prices do indeed reduce a country's export competitiveness relatively more in energy-intensive industries, we would expect β_1 to be negative and significant.

We estimate alternative specifications where $EnergyIntensity_k$ is measured as the direct energy intensity or the aggregate energy intensity, where the latter includes direct plus indirect use of energy in the intermediate inputs of a good, and we compare the magnitudes of the estimated coefficients. We expect aggregate energy intensity to have a larger effect in absolute terms if indirect costs passed on through the supply chain have an additional negative impact on competitiveness (over and above the effect of direct costs alone). In addition, we estimate a specification in which direct and indirect energy intensity enter as separate variables (each interacted with the energy price), to allow for us to identify if indirect energy costs per se drive the specialization of production. To unpack the channels through which overall energy prices affect trade patterns, we then also estimate the same regression as (3) but using separate interaction terms for electricity and natural gas prices (rather than the energy price index for all fuels).

Notwithstanding that comparative advantage changes little on an annual basis, the results from our cross-sectional equation (3) for 2012 may not necessarily hold for other years of analysis. Energy prices may have gradually become a more important determinant of comparative advantage over recent years because price differences across countries have widened, especially for electricity and natural gas prices (IEA, 2013). Shocks to the global economy such as the 2008 financial crisis may have also affected patterns of specialization in energy-intensive industries over time. Furthermore, data on energy prices are available for a different sample of countries in different years, and the findings for one sample may not be externally valid to a different sample. To address these concerns, we consider the robustness of our results when estimating the same specification separately for 10 different years of data (2004-2013).[10] This exercise allows us to flexibly reveal if the pattern of cross-country specialization in energy-intensive industries has adjusted over time.

Results. We now present our results from the OLS estimation of equation (3) above using data on total exports for up to 40 exporting countries and 249 manufacturing industries in 2012. (The 40 exporting countries are listed in Table A.3 in the Data Appendix.) Standardized (beta) coefficients are reported with standard errors in parentheses.

Table 1 reports results for regressions that use the overall (weighted average) energy price (*Energy Price* $Index_i$) interacted with the (overall) energy intensity. Because we lack energy price data for some countries, these regressions include 32 exporting countries. In column (1) of Table 1 we include the interaction term between the energy price index and direct energy intensity. We find the estimated coefficient is negative and statistically significant, a result that supports the hypothesis that low energy prices are a source of comparative advantage in energy-intensive industries. Reassuringly, the signs on the coefficients for both factor endowment interaction terms are positive, which is consistent with our *a priori* expectations. The skilled labor interaction is significant at the 1 percent level, while the capital interaction is statistically significant at the 5 percent level. Because we report standardized beta coefficients, we can directly compare the relative magnitudes of the energy price interaction with the skilled labor interaction. Our findings suggest that the effect of energy prices on the pattern of trade is greater (in absolute terms) than the effects of both human capital and physical capital differences across countries. A one-standard-deviation increase in the energy price decreases bilateral exports by 0.77 of a standard deviation on average; a one-standard-deviation increase in the skilled labor abundance increases bilateral exports by 0.39 of a standard deviation.

In column (2), we replace the direct energy intensity with the aggregate energy intensity (measuring both direct and indirect energy use in the supply chain) to give the aggregate energy cost as defined in equation (1). The results are similar. The coefficient on the aggregate energy cost interaction term is positive and statistically significant, and is slightly larger in magnitude than the coefficient on the direct energy cost interaction term in column (1).

In column (3), we include the interaction of the energy price index with indirect energy intensity as a separate variable (alongside the interaction with direct energy intensity). This specification allows us to test whether indirect energy costs per se are a source of comparative advantage. The coefficient on

[10] For each year we use average country-level energy prices over the previous three years.

this indirect energy cost term is statistically significant and negative, albeit with a smaller coefficient compared to the direct intensity-interaction term. Even though the direct energy cost is more important, our results suggest that a low indirect energy cost through the supply chain can in itself be a source of comparative advantage.

In column (4) of Table 1 we estimate the same regression in column (3) but we now replace the exporter fixed effects with a richer set of exporter-by-sector fixed effects. This specification has the advantage of controlling for possible unobserved (3-digit) sector level determinants of trade flows that are specific to each country. In addition, including exporter-by-sector fixed effects means that identification only comes from within-sector variation in energy costs. Therefore, these results involve a weaker factor intensity reversals assumption – the ranking of industries by energy intensity is only assumed to be fairly stable across countries within sectors. However, the richer set of fixed effects included in column (4) will absorb some of the variation in energy costs that we wish to use for identification. Hence, the regression in column (3) remains our preferred specification for testing the importance of indirect energy costs for the pattern of trade. Nonetheless, we find the results are robust. The indirect energy cost term remains statistically significant in column (4), at the 5 percent significance level.

In Table 1 we use an energy price index that is comprised of four types of energy commodities: electricity, natural gas, coal, and oil. Therefore, these results show that low *overall* energy prices increase exports for energy-intensive industries. There may be heterogeneous effects on trade across energy commodities, however. We investigate this possibility by estimating separate effects of electricity and natural gas prices on trade. As previously discussed, we focus on electricity and natural gas prices because they exhibit the most variation across countries, allowing us to more precisely pinpoint the likely source of comparative advantage.

Table 2 presents estimation results for the same four regressions as estimated in Table 1, but now including separate interaction terms for electricity and natural gas prices. For these regressions we have the full sample of 40 exporting countries. In column (1) we find both electricity and natural gas interactions have the expected negative sign, although the magnitude of the interaction term for natural gas prices is larger and the coefficient for the electricity price interaction is not statistically significant. This suggests that the effect of the overall energy price on export patterns is largely driven by natural gas price differences rather than electricity prices. In column (2), we find that the coefficient on the aggregate natural gas cost interaction term is negative and significant at the 1 percent level. Thus, industries that have high aggregate (i.e., direct plus indirect) natural gas intensity and are in countries with high natural gas prices have significantly lower exports. The coefficient on the aggregate energy cost interaction is also significant but only at the 10 percent level. In column (3) we introduce the indirect cost terms separately for both electricity and natural gas costs. Similar to the results with the energy price index, we find that both indirect electricity and gas costs have a negative sign, indicating that industries in high energy-price countries that intensively use *indirect* energy also record lower exports than others. We find statistically significant results for direct and indirect gas costs, but not for direct and indirect electricity costs. In column (4) we estimate the effect of the direct and indirect cost interaction terms while including exporter-by-sector fixed effects. Again, we find similar results: the coefficients on direct and indirect electricity costs are negative but insignificant, while the coefficients on the direct and indirect natural gas costs are both negative and statistically significant (at the 5 percent level or lower). Overall, we conclude our findings in Table 1 are robust to an alternative way of measuring of energy costs and a larger sample of countries.

Robustness. We now consider some possible concerns about the results reported in Tables 1 and 2. One concern is that the omission of other determinants of comparative advantage may be a source of bias if they are correlated with our energy price-interaction terms of interest. We therefore explore the robustness of our results to including a host of additional controls for other likely determinants of trade patterns that are not included in equation (3). First, it might be expected that technologically advanced countries will specialise in industries that display rapid technological progress. Similarly, high-income countries may have a comparative advantage in lucrative, high value-added industries. We capture these effects by interacting country-level total factor productivity (TFP) (TFP_i) with industry TFP growth ($TFPGrowth_k$), and interacting log income per capita ($Incomepc_i$) with the share of value added in shipments for each industry ($ValueAdded_k$). Second, we include controls for a number of institutional characteristics of exporting countries. Cunat and Melitz (2012) emphasize the importance of labor-market regulations for comparative advantage. We include the interaction term $LaborFlex_i \times SkillIntensity_k$ to control for the possibility that skill-intensive industries locate in countries with flexible labour markets (as well as abundant stocks of human capital). Following Nunn (2007), we include an interaction between country judicial quality ($RuleofLaw_i$) and industry contract intensity ($ContractIntensity_k$). This term captures the expectation that the ability to enforce contracts affects a country's comparative advantage in the production of goods requiring relationship-specific investments. Finally, we control for the effect of credit constraints on trade flows by interacting the availability of external finance ($FinancialDevelopment_i$) with the industry's dependence on external finance ($ExtFinancialDep_k$) (see Manova (2008)).

We include these additional controls in the specifications estimated in columns (1) and (3) of Tables 1 and 2. We report these results in Table B.2 in the appendix.[11] The direct and indirect energy price index interaction terms remain significant and of similar magnitude (column (2)). We also find that direct and indirect natural gas costs remain statistically significant, and we find that indirect electricity costs are now significant at the 5 percent level (column (4)). The additional control interaction terms have the expected signs but only the rule of law and financial development interaction terms have statistically significant coefficients across all specifications. Overall, we conclude that our main finding that indirect energy costs are a source of comparative advantage is robust to the inclusion of these additional interaction terms.

Another concern is that the results may be affected by reverse causality. Energy prices and intensities may themselves be affected by the pattern of international trade, resulting in a simultaneity bias. On the one hand, a country that specializes in energy-intensive industries will increase its demand for energy, leading energy prices to rise. On the other hand, countries that specialize in energy-intensive industries may have a greater incentive to implement environmental and energy policies that reduce domestic energy prices. These feedback effects from specialization to energy prices may bias the estimates of β_1 in equation (3). Although we use average energy prices from 2009 to 2011, the period before we observe the trade data (2012), there may still be concerns that reverse causality is present due to the persistence of trade flows and energy prices over time.

To address these concerns, following the arguments in Bombardini et al. (2012), we note that the orthogonality condition needed for the consistent estimation of β_1 in equation (3) is:

$$E(EnergyIntensity_k \times EnergyPriceIndex_i \times v_{ik}) = 0 ... \forall k, i \tag{4}$$

By the law of iterated expectations:

$$E(EnergyIntensity_k \times v_{ik} | EnergyPriceIndex_i) = 0 ... \forall k, i \tag{5}$$

which requires that, for every exporter in our sample, energy intensity is uncorrelated with the error term. Since we measure energy intensity using US data, we can remove the US from our set of exporting countries. To the extent that the US energy intensity is not significantly affected by bilateral trade

[11] To conserve space we include all controls at once in all regressions. The results are also robust if we add controls one at a time, or if we use aggregate intensities and threshold-based approaches. These results are available on request.

flows between other countries, this procedure substantially decreases the likelihood of feedback effects (Bombardini et al., 2012).

The results when dropping the US are reported in Table B.3 (using the energy price index) and Table B.4 (using electricity and natural gas prices) in the appendix. The findings are robust and, if anything, slightly stronger than before, with slightly larger coefficients on the energy cost-interaction terms. Overall, we continue to find that energy prices are a source of comparative advantage in energy-intensive industries, and that the effect is relatively large in magnitude and driven by both direct energy costs and indirect costs.

Adjustments in comparative advantage over time. In the above analysis, we estimate a static cross-sectional model because we do not expect comparative advantage to change substantially on an annual basis. However, a natural question is whether our findings are robust if we study alternative years of trade data. Therefore, we investigate whether direct and indirect energy costs remain a source of comparative advantage in alternative years. We do so by estimating equation (3) separately for 10 different years of data covering the 2004–2013 period. We estimate the specifications that separately identifies the effect of direct and indirect energy cost terms (column (3) in Tables 1 and 2). For each year *t*, we use energy prices averaged over the previous three years (*t*-1 to *t*-3) for each country. The sample of countries will change over time to some extent according to the availability of the energy price data; this allows us to consider the external validity of our findings when using data for 2012.

The results of this exercise are given in Table 3. Panel A presents results for the specification with the overall energy cost interaction term, while Panel B presents results for the specification with separate electricity and natural cost interaction terms. We find in Panel A that the direct cost interaction term is always negative and statistically significant, and that the magnitude of the coefficient becomes larger for more recent years. Thus, direct energy costs seem to become a more important source of comparative advantage over time. However, while the coefficient on the indirect energy cost variable is negative for all years, it is only significant at the 10 percent level (or lower) from 2008 onwards. Hence, this suggests that indirect energy costs have become a more important driver of international competitiveness in more recent years than they have been in the past.

Turning to Panel B in Table 3, we find that all direct and indirect electricity and natural gas cost terms are of the expected negative sign. Both direct and indirect natural gas costs are statistically significant for every year. Thus there is robust evidence that natural gas costs passed on through the supply chain do affect the pattern of specialization. The effect of electricity costs is somewhat less robust. Direct electricity costs become insignificant for four years during and after the global financial crisis (2009 to 2012). This suggests that the substantial reduction in international trade flows that took place during the global financial crisis may have reduced the extent to which countries with low electricity prices exported differentially more from electricity-intensive industries. However, the direct electricity cost-interaction term is significant in the other six years (2004 to 2008, and 2013). Meanwhile, indirect electricity costs are mostly insignificant at the 10 percent level except in three years (2007 to 2009). Overall, these results suggest that our finding that (overall) energy prices are a source of comparative advantage is robust to considering different years of trade data, and that direct and indirect natural gas costs are particularly important for this relationship.

4.2 Energy price effects on intermediate goods

In the previous subsection, from the results of our Rajan-Zingales regression model, we show that producers of energy-intensive goods in countries with high energy prices experience a lower level of exports than similar producers in countries with lower energy prices. We also show that industries respond to both the direct and indirect energy costs. That is, our results suggest that while the energy intensity of an industry's own production process matters, the energy intensity of its intermediate goods is also a significant determinant of its international competitiveness.

One question remains: Can industries reorganize their global supply chain to minimize indirect energy costs? Put differently, can industries choose to import intermediate goods from countries with low energy prices to reduce their indirect energy costs?

To study this question, we employ the World Input-Output Database (WIOD; Timmer et al., 2015), which provides data on the interdependence of firms' inputs at the industry level across 43 countries, including countries that are members of the Organisation for Economic Co-operation and Development (OECD) and countries that are not. With the data from the WIOD, we are able to measure how much intermediate inputs each industry in each country demands from each of the other industries, by country of origin. Despite the availability of these data over time, we have decided to study the cross-sectional patterns rather than changes over time. We take the cross-sectional approach for similar reasons to before: Network relationships tend to be stagnant, and we would not expect a substantial change in trading relationships within a short time frame, or in response to intermittent changes in input prices.

We employ a similar Rajan-Zingales formulation to that used in the previous section, but we adapt the model to explain the cross-sectional variation in trade of intermediate goods. The full specification of the model is as follows:

$$\log(Imports)_{ijkl} = \delta_1 (EnergyPriceIndex)_j \times EnergyIntensity_l + \gamma X_{ijkl} + \alpha_{ij} + \alpha_{kl} + \mu_{ijkl} \quad (6)$$

where $Imports_{ijkl}$ is defined as the value of intermediate goods (in millions of US dollars), imported by industry k in country i, from industry l in country j. (That is, the intermediate goods are produced by industry l and in country j.)[12] X_{ijkl} captures other sources of comparative advantage, such as human capital and physical capital. α_{ij} and α_{kl} are country-pair and industry-pair fixed effects, respectively. These variables capture unobservable determinants of trading relationships between countries (e.g., it is more common for EU countries to import intermediate goods and materials from other EU countries) and compatibilities between industries (e.g., certain inputs may be commonly used in production of certain products). As before, we estimate the effect of the (overall) energy price index variable ($EnergyPriceIndex_i$), and we then test the robustness of our results to using electricity and natural gas prices in subsequent regressions.

In Section 4.1, we included the energy prices in the exporting country only; now our specifications examine the importing country. We take the default position for the producing industry to be that it uses intermediate inputs manufactured domestically. In this case, firms have an incentive to reorganize their supply chains only if the costs of inputs are cheaper elsewhere. This suggests that firms are more likely to import intermediate goods from abroad if the country in which the firm is based has higher energy costs than those in other places in the world.

To investigate if the cost difference, rather than the level of energy costs in other countries, provides the motivation for trade, we construct a new measure of energy cost differentials, defined as $EnergyPriceDiff_{ij} \equiv EnergyPriceIndex_i - EnergyPriceIndex_j$. That is, the energy price in the importing country minus the energy price in the exporting country. We then replace the $EnergyPriceIndex$ measure with this variable in the estimation equation (6), giving:

$$\log(Imports)_{ijkl} = \delta_1 (EnergyPriceDiff)_{ij} \times EnergyIntensity_l + \gamma X_{ijkl} + \alpha_{ij} + \alpha_{kl} + \mu_{ijkl} \quad (7)$$

[12] Unlike the specification in Section 4.1, here we use data on intermediate goods that are as disaggregated as possible, rather than data that are aggregated to the level of variation of energy prices (i.e., at jl level). We do this because of the limited number of industries and countries in the WIOD data. These limitations result in a small number of observations, leading to statistically insignificant results (although the signs are still correct). In the specification below (i.e., equation (7)) in which we are able to aggregate data to the ijl level, both approaches yield similar results. All these results are available upon request.

If $EnergyPriceDiff_{ij} > 0$, it means that the importing country has higher energy costs, suggesting that industries in this country are more likely to import energy-intensive components from abroad (i.e., $\delta_1 > 0$). This coefficient will identify the "elasticity" of the imports, the measure we use in Section 5 for our simulation analysis. The identification of the parameter of interest (i.e., δ_1) relies on comparing the cross-country differences in energy prices (or energy price differentials) across different intermediate goods with different levels of energy intensity.

Results. Table 4 presents the results for intermediate goods using the overall energy price index variable. As before, the table reports standardized coefficients. Columns (1) and (2) give results from the estimation of equation (6). We expect the coefficients on energy prices to be negative; producers in country *i* are less likely to purchase energy-intensive intermediate goods from country *j* if energy prices are higher in country *j*. The findings in column (1) support our expectations: energy prices in the countries that produce intermediate goods negatively affect imports of energy-intensive intermediate goods. In column (2) we control for human capital and physical capital interactions. We find that the energy price interaction term remains negative and significant. The interaction terms for both human and physical capital have positive coefficients, suggesting the same cost-minimizing motive for intermediate goods that require a high intensity of skilled labor or physical capital.

Next, we estimate equation (7). This regression allows us to examine whether the pattern of intermediate goods trade can be explained by the energy price difference between the importing country and exporting country (i.e., between the country that imports the intermediate good and the country that produces the intermediate good). The coefficients are reported in columns (3) and (4). Aligning with our expectations, in column (3) we find that a higher energy price differential (as defined above) leads to more imports from the country that produces energy-intensive intermediate goods. That is, producing firms located in countries with energy prices that are above those in other countries are more likely to import energy-intensive intermediate goods from those countries where energy prices are lower. Our results remain statistically significant in column (4) after controlling for other sources of comparative advantage.

To identify whether the source of comparative advantage is concentrated in electricity or natural gas costs, we repeat the same regression model but substitute the energy price index interaction term for separate electricity and natural gas price interaction terms. We report these results in Table 5. All of our results are qualitatively similar to those in Table 4. We find that both electricity and natural gas prices appear to explain the pattern of cross-border trade in intermediate goods. That is, both explain why countries import intermediate goods. As we can compare standardized coefficients across variables, it appears that the difference in electricity prices between countries is slightly more important than the difference in natural gas prices – but both of them are statistically significant.

Robustness. Regression equations (6) and (7) both suffer from the same potential endogeneity problem outlined in Section 4.1; specialization according to comparative advantage may have a feedback effect on energy intensity. In addition, unobserved macro-shocks such as productivity shocks can lead to changes in both energy intensity and the level of imports of intermediate goods. Therefore, we employ the same approach by excluding the intermediate goods that originated from the US and intermediate goods imported into the US, while keeping the energy-intensity measure that is calculated by using the US input-output accounts. Tables B.5 and B.6 in the appendix show the results for this robustness test. Most of results are qualitatively similar to our main results, with the coefficients generally slightly larger in magnitude.[13]

We further test the robustness of our results over time by re-running our regressions for each year. Table 6 reports the findings when using the energy price index (and its differential).[14] We find that across all sample years, the differences in energy prices across countries can explain the pattern of countries' imports of intermediate goods. Thus, the results for intermediate goods are remarkably stable over time. This provides reassurance that the cost-minimization motive (in optimizing the input bundles) is similar across the sample period.

5 Implications

To understand the implications of an increase in energy costs for manufacturing exports, we combine the results from Sections 4.1 and 4.2. Specifically, we use the estimation results for 2012 to simulate the impact of the increase in energy prices observed in the EU from 2004 to 2012 on the equilibrium trade patterns, to understand the implications for EU competitiveness in 2012. We measure the extent of the increase in the EU's energy prices using the average adjustment in energy prices that took place in non-EU countries over this period as the counter-factual. This translates to a 68 percent increase in EU electricity prices and an 87 percent increase in EU natural gas prices, or a 33 percent increase in the energy price index, depending on the specification.

[13] Our findings are also robust if we include other sources of comparative advantage, besides physical and human capital costs. These results are available upon request.

[14] Our findings are robust if we replace energy price index interaction term with electricity and natural gas prices interaction terms (and their differentials), or omit the human and physical capital interactions as controls.

We predict three sets of results. The first set examines the direct impact of energy prices, ignoring the impact of intermediate goods and indirect energy costs. The second set measures the aggregate impact of energy prices by examining how energy prices can affect manufacturing firms through both direct and indirect routes. We label this as the aggregate effect in the short run. The third set examines the effect of energy price increases, when also accounting for the changes in intermediate goods imports. We label this as the aggregate effect in the long run.

In the first two sets of results, we use the preferred regression formulation in which we estimate the effect of both direct and indirect energy costs (Tables 1 and 2, column (3)). The aggregate impact (in the short run) that we generate assumes that firms are not able to substitute the now-more-expensive intermediate goods, and assumes all costs are passed through to the producer. However, we have shown that this is not the case as an increase in energy price differentials between countries leads to an increase in intermediate goods imports (Section 4.1). Therefore, we can derive the third set of predicted effects of the energy price increase, after accounting for the changes in intermediate goods imports as well.

To derive this third set of simulated impacts, we have to make some assumptions about how the imports are substituted. This is because our end goods regressions in Section 4.1 assume all intermediate goods originate from within the home country, when, in reality, EU countries import roughly 20 percent to 50 percent of their intermediate goods (mostly from other EU countries). We proceed as follows: Using our results in Tables 4 and 5, we predict the percentage changes in intermediate goods imports, taking into account the existing trading relationships (in intermediate goods) in EU and non-EU countries, such that only the energy price differentials between EU and non-EU countries have changed.[15] We then assume that this percentage remains the same across all intermediate goods substitutions for EU countries, and assume that this percentage of intermediate goods does not experience an increase in energy prices. We believe that this is likely to *overestimate* the substitution. Therefore, we should interpret this effect as the lower bound of the underlying effect.

Table 7 presents our predictions of how exports in each of the EU countries change as a result of the hike in EU energy prices. In this specification, we employ the regression results that emerge when we use the energy price index (instead of electricity and natural gas prices); we then simulate a 33 percent increase in the energy price index in EU countries, and we compute the changes in manufacturing exports in the EU. Overall, we estimate that the direct effect of the hike in EU energy prices leads to a 6.8 percent drop in manufacturing exports across the EU, with effects higher in the EU countries that export more

[15] In the main results we use the energy price differentials (i.e., column (4) in Tables 4 and 5) as the benchmark. Our results remain robust if we use energy price levels (i.e., column (2)).

energy-intensive goods.

If we combine the direct effect and indirect effect of energy prices, assuming that countries do not have the ability to substitute the now-more-expensive intermediate goods (i.e., short run aggregate effects), the effect of the energy price increase grows significantly to 15 percent. With such a huge increase in energy prices, we expect firms to react by reducing their reliance on expensive intermediate goods in their production where possible. With this in mind, we compute the long-run, aggregate impact (by combing with our regression results for intermediate goods). Here we find that the aggregate negative impact on manufacturing exports drops to about 11.5 percent.

Instead of simulating an increase in the energy price index, we next simulate an increase in electricity and natural gas prices only. We report these simulation results in Table 8. This simulation shows a slightly larger direct effect (9 percent instead of 7 perent) and a larger aggregate effect in the long-run (17.2 percent instead of 11.5 percent). It is not entirely surprising that this simulation yields a much higher predicted effect on exports because the simulated changes in electricity prices (a 68 percent increase) and gas prices (a 87 percent increase) are much higher than the change in the energy price index (an increase of 33 percent). This result also potentially yields an overestimate because we do not allow any inter-fuel substitution (as there has not been any significant changes in coal and oil prices).

Our simulation results yield two important implications. First, we find that the impact of intermediate goods is economically significant. Even after taking into account the substitutability of intermediate goods, the indirect impact of energy prices on exports via increased costs of intermediate goods is evident. Second, to understand the impact of intermediate goods, it is important to model how supply chains are organized, and to have a picture of the elasticity of substitution of intermediate goods following changes in domestic or international prices. Failure to model this may yield an overestimate of such indirect effects.

6 Conclusion

Differences in production costs around the world are often found to be a source of comparative advantage in international trade. The same argument also applies to differences in costs of components and the extent that industries rely upon these components in their production process. In this paper, we demonstrate the importance of indirect cost channels for comparative advantage by demonstrating how both direct *and* indirect energy costs can have significant effects on trade patterns. Indirect costs are particularly important for energy costs because energy is an essential input to many manufacturing sectors that supply components, both domestically and internationally.

Our paper uses a Rajan-Zingales-style difference-in-differences approach to study the effect of direct and indirect energy costs. Specifically, we examine whether industries with higher direct and indirect energy intensities would have lower exports from countries with higher energy prices. We compute indirect energy costs by using highly disaggregated input-output data from the US, and we apply this to all industries in the world assuming no factor intensity reversals. Our results show that both direct and indirect energy costs can explain the composition of trade around the world, conditional on other sources of comparative advantage, such as institutional quality and skilled labor abundance. Our results are robust to using data for different years and to the various measures of energy costs we use.

We repeat our analysis on a sample of intermediate goods to see if energy prices directly affect what kind of intermediate goods that firms decide to import. We find that higher energy prices lead to a reduction in imports of energy-intensive intermediate goods. Taking both of our results together, we simulate the direct and aggregate impacts following the observed energy price increase from 2004 to 2012 in the EU relative to non-EU countries. We find that this increase led to a 6.8 percent reduction in exports in the EU; this is the case if we take into account only the direct cost of energy. By contrast, this number rises to 15 percent if we take into account the indirect effects of energy prices on the pattern of trade via the intermediate goods channel. If we allow firms in the EU to substitute their more expensive intermediate goods, this aggregate effect declines to 11.5 percent, but is still significantly higher than the effect predicted through the direct effect only.

Using a reduced-form approach, our paper demonstrates that the indirect effects of energy prices can be of high economic significance. Though we focus on the impact of energy prices, our qualitative results may also hold for other costs that affect trade patterns – such as labor costs. Our paper underscores the importance of taking into account the indirect costs when calculating sources of comparative advantage. At the same time, our approach likely captures only a lower bound of one indirect cost channel. We believe that future work can take a more structural approach in modeling how and when industries substitute their inputs, and the implications for comparative advantage. Such work has the potential to lead to better understanding of how these indirect cost channels affect international trade.

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Figures

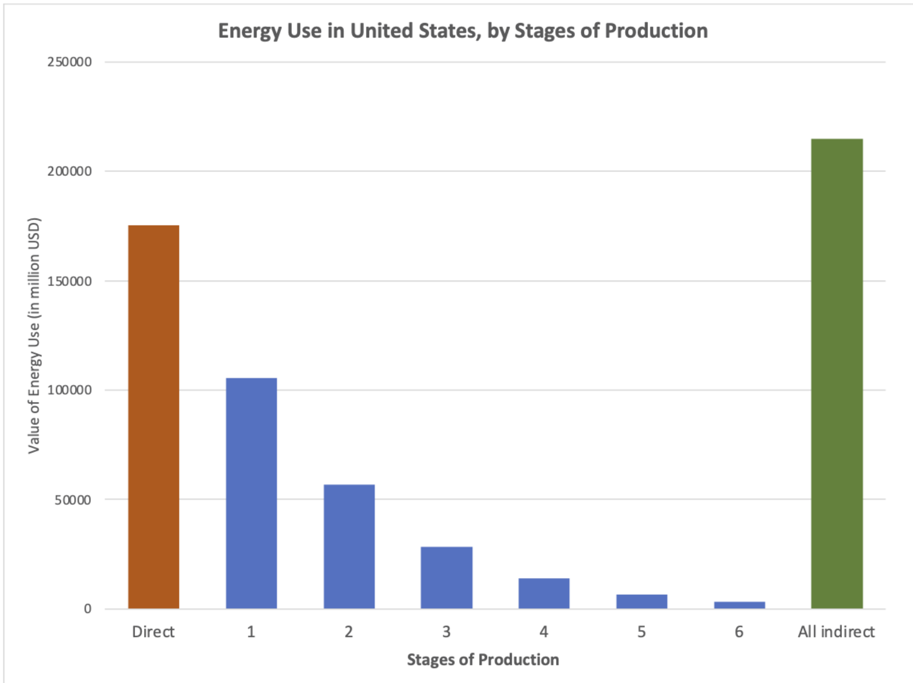
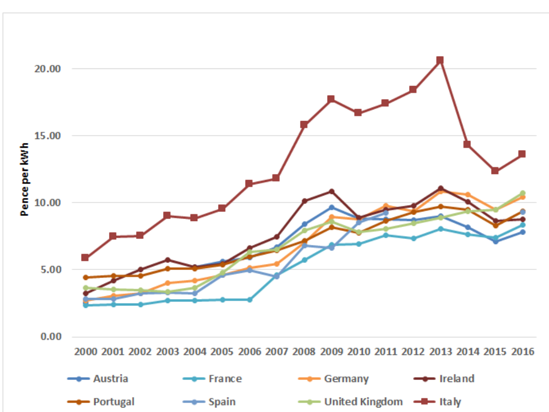


Figure 1: Energy use in the United States manufacturing, by stages of production, 2002

(a) Electricity prices



(b) Natural gas prices

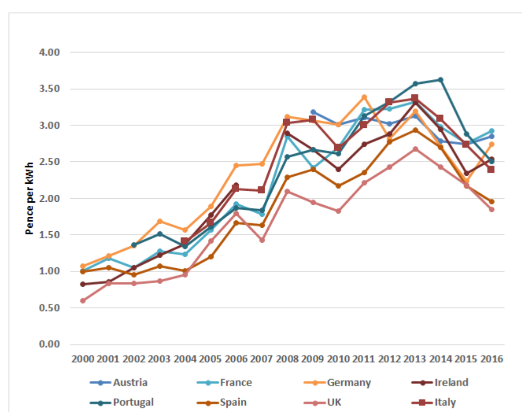
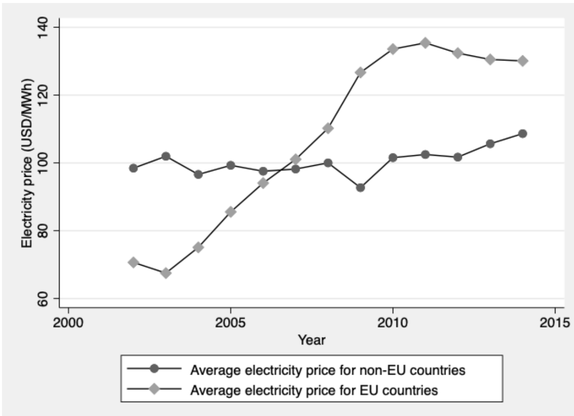


Figure 2: Energy prices in European countries

(a) Electricity prices



(b) Natural gas prices

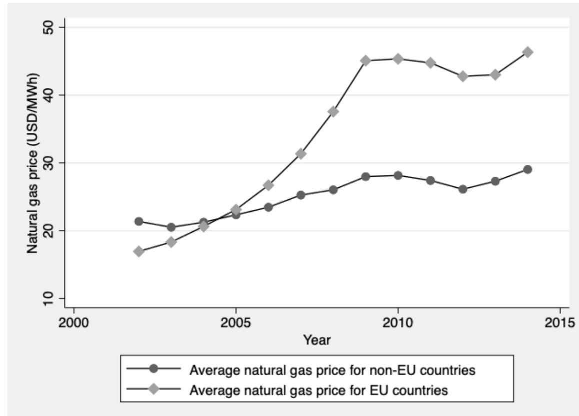


Figure 3: Differences in energy prices between non-EU and EU countries

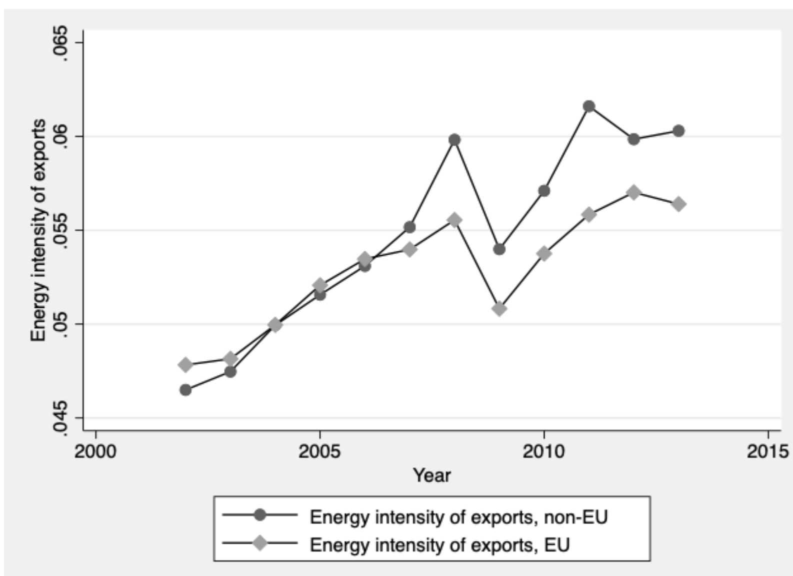


Figure 4: Differences in energy intensity of exports between non-EU and EU countries

(a) Direct energy costs

(b) Direct and indirect energy costs

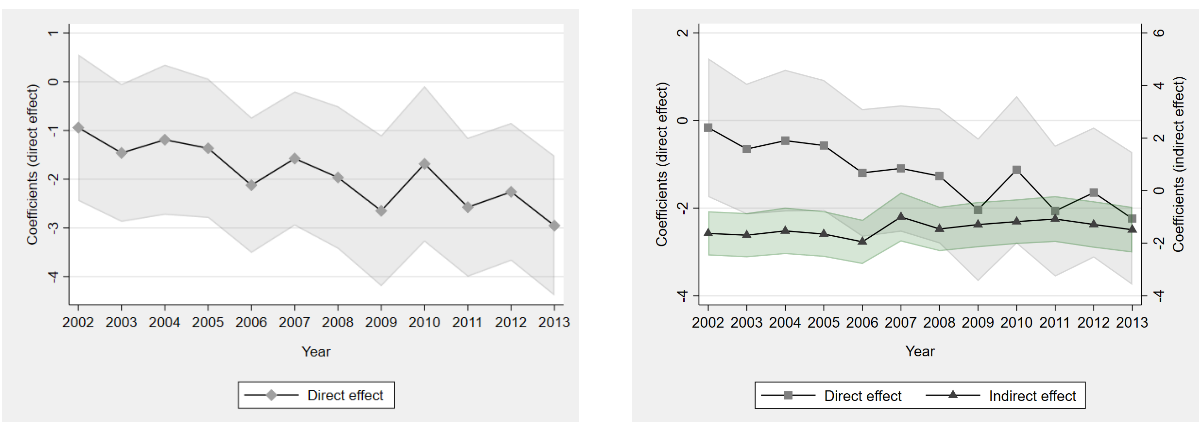


Figure 5: Plot of coefficients giving effect of direct and indirect energy intensity interacted with EU status on the pattern of trade by year

Tables

Table 1: Results - Energy price index

	(1)	(2)	(3)	(4)
Energy price index$_i$ × Direct energy intensity$_k$	-0.767***		-0.613***	-0.707***
	(0.136)		(0.150)	(0.154)
Energy price index$_i$ × Indirect energy intensity$_k$			-0.360***	-0.232**
			(0.134)	(0.112)
Energy price index$_i$ × Aggregate energy intensity$_k$		-0.813***		
		(0.136)		
Skill abundance$_i$ × Skill intensity$_k$	0.393***	0.400***	0.396***	0.348***
	(0.055)	(0.055)	(0.055)	(0.076)
Capital abundance$_i$ × Capital intensity$_k$	0.559***	0.587***	0.607***	0.271
	(0.166)	(0.166)	(0.166)	(0.179)
Exporter Fixed Effects	Yes	Yes	Yes	No
Industry Fixed Effects	Yes	Yes	Yes	Yes
Exporter-by-Sector Fixed Effects	No	No	No	Yes
Observations	7915	7915	7915	7908
Adjusted R^2	0.719	0.719	0.719	0.781

Note: The dependent variable is log of aggregate exports from country i in industry k. Robust standard errors are reported in the parentheses. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table 2: Results - Electricity and gas prices

	(1)	(2)	(3)	(4)
Electricity price$_i$ × Direct electricity intensity$_k$	-0.130		-0.085	-0.141
	(0.091)		(0.096)	(0.092)
Natural gas price$_i$ × Direct gas intensity$_k$	-0.229***		-0.167***	-0.174***
	(0.055)		(0.054)	(0.053)
Electricity price$_i$ × Indirect electricity intensity$_k$			-0.134	-0.022
			(0.084)	(0.090)
Natural gas price$_i$ × Indirect gas intensity$_k$			-0.131***	-0.106**
			(0.037)	(0.043)
Electricity price$_i$ × Aggregate electricity intensity$_k$		-0.174*		
		(0.090)		
Natural gas price$_i$ × Aggregate gas intensity$_k$		-0.256***		
		(0.045)		
Skill abundance$_i$ × Skill intensity$_k$	0.281***	0.285***	0.284***	0.194***
	(0.047)	(0.047)	(0.047)	(0.064)
Capital abundance$_i$ × Capital intensity$_k$	0.357***	0.411***	0.409***	-0.054
	(0.133)	(0.135)	(0.136)	(0.141)
Exporter Fixed Effects	Yes	Yes	Yes	No
Industry Fixed Effects	Yes	Yes	Yes	Yes
Exporter-by-Sector Fixed Effects	No	No	No	Yes
Observations	9871	9871	9871	9859
Adjusted R^2	0.713	0.714	0.714	0.774

Note: The dependent variable is log of aggregate exports from country i in industry k. Robust standard errors are reported in the parentheses. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table 3: Robustness - pattern of specialization by year

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Panel A: Overall energy price regressions										
Energy Price Index$_i$ × Direct Energy Intensity$_k$	-0.312**	-0.275*	-0.386***	-0.439***	-0.475***	-0.522***	-0.468***	-0.544***	-0.613***	-0.675***
	(0.159)	(0.151)	(0.144)	(0.137)	(0.132)	(0.137)	(0.131)	(0.129)	(0.150)	(0.165)
Energy Price Index$_i$ × Indirect Energy Intensity$_k$	-0.113	-0.145	-0.178	-0.152	-0.230*	-0.235**	-0.280**	-0.250**	-0.360***	-0.309**
	(0.104)	(0.103)	(0.114)	(0.113)	(0.125)	(0.119)	(0.115)	(0.116)	(0.134)	(0.135)
Observations	8140	8391	8393	8454	8427	8402	8408	8396	7915	7605
Adjusted R^2	0.710	0.712	0.718	0.728	0.735	0.735	0.734	0.737	0.739	0.739
Panel B: Electricity and natural gas price regressions										
Electricity Price$_i$ × Direct Electricity Intensity$_k$	-0.262***	-0.278***	-0.286***	-0.312***	-0.208***	-0.075	-0.090	-0.099	-0.085	-0.243**
	(0.090)	(0.091)	(0.091)	(0.086)	(0.078)	(0.098)	(0.087)	(0.083)	(0.096)	(0.099)
Natural Gas Price$_i$ × Direct Natural Gas Intensity$_k$	-0.187**	-0.191**	-0.225***	-0.253***	-0.203***	-0.131**	-0.151***	-0.189***	-0.167***	-0.111**
	(0.075)	(0.077)	(0.074)	(0.076)	(0.053)	(0.052)	(0.054)	(0.053)	(0.054)	(0.055)
Electricity Price$_i$ × Indirect Electricity Intensity$_k$	-0.028	-0.092	-0.108	-0.138**	-0.167***	-0.136*	-0.087	-0.087	-0.134	-0.057
	(0.073)	(0.068)	(0.068)	(0.065)	(0.061)	(0.078)	(0.073)	(0.075)	(0.084)	(0.092)
Natural Gas Price$_i$ × Indirect Natural Gas Intensity$_k$	-0.107*	-0.108*	-0.141***	-0.133***	-0.181***	-0.201***	-0.189***	-0.165***	-0.131***	-0.164***
	(0.055)	(0.056)	(0.045)	(0.044)	(0.034)	(0.040)	(0.041)	(0.039)	(0.037)	(0.039)
Observations	6415	6667	7399	7439	8153	9363	9867	10091	9871	9549
Adjusted R^2	0.693	0.697	0.714	0.718	0.745	0.740	0.735	0.735	0.735	0.733
Skilled Labour and Capital Interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The dependent variable is log of aggregate exports from country i in industry k. Robust standard errors are reported in the parentheses. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively. All coefficients are standardized.

Table 4: Results for intermediate goods – Energy price index

	(1)	(2)	(3)	(4)
Energy price index$_j$ $\times$ Energy intensity$_l$	-1.371***	-1.403***		
	(0.067)	(0.067)		
Capital abundance$_j$ $\times$ Capital intensity$_l$		0.088**		
		(0.039)		
Skill abundance$_j$ $\times$ Skill intensity$_l$		0.452***		
		(0.025)		
Energy price index differential$_{ij}$ $\times$ Energy intensity$_l$			0.080***	0.082***
			(0.009)	(0.011)
Capital abundance differential$_{ij}$ $\times$ Capital intensity$_l$				-0.012
				(0.015)
Skill abundance differential$_{ij}$ $\times$ Skill intensity$_l$				-0.177***
				(0.022)
Observations	404028	404028	263088	263088
Adjusted R^2	0.634	0.638	0.587	0.589
Exporter-Importer Fixed Effects	Yes	Yes	Yes	Yes
Industry Pair Fixed Effects	Yes	Yes	Yes	Yes

Note: The dependent variable is log of intermediate goods imported from country i industry k, originated from country j and industry l. In columns (1) and (2), standard errors are clustered at the country j by industry l; in columns (3) and (4), standard errors are clustered at the country pair ij by industry l. All coefficients are standardized. All differentials in this regression are computed as the price/endowment of importing country minus that of the exporting country (i.e., producers of the intermediate goods). *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table 5: Results for intermediate goods – Electricity and gas prices

	(1)	(2)	(3)	(4)
Electricity price$_j$ × Electricity intensity$_l$	-0.829***	-0.895***		
	(0.051)	(0.052)		
Natural Gas price$_j$ × Natural Gas intensity$_l$	-0.370***	-0.433***		
	(0.023)	(0.020)		
Capital abundance$_j$ × Capital intensity$_l$		0.450***		
		(0.056)		
Skill abundance$_j$ × Skill intensity$_l$		0.477***		
		(0.020)		
Electricity price differential$_{ij}$ × Electricity intensity$_l$			0.095***	0.102***
			(0.007)	(0.007)
Natural gas price differential$_{ij}$ × Natural gas intensity$_l$			0.040***	0.047***
			(0.006)	(0.007)
Capital abundance differential$_{ij}$ × Capital intensity$_l$				-0.052***
				(0.013)
Skill abundance differential$_{ij}$ × Skill intensity$_l$				-0.187***
				(0.016)
Observations	459756	459756	342144	342144
Adjusted R^2	0.638	0.643	0.602	0.605
Exporter-Importer Fixed Effects	Yes	Yes	Yes	Yes
Industry Pair Fixed Effects	Yes	Yes	Yes	Yes

Note: The dependent variable is log of intermediate goods imported from country *i* industry *k*, originated from country *j* and industry *l*. In columns (1) and (2), standard errors are clustered at the country *j* by industry *l*; in columns (3) and (4), standard errors are clustered at the country pair *ij* by industry *l*. All coefficients are standardized. All differentials in this regression are computed as the price/endowment of importing country minus that of the exporting country (i.e., producers of the intermediate goods). *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table 6: Results for intermediate goods – robustness by year

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Panel A: Price levels										
Energy price index$_j$ × Energy intensity$_l$	-0.119*	-0.442***	-0.790***	-1.038***	-1.294***	-1.190***	-1.062***	-0.967***	-1.339***	-1.655***
	(0.069)	(0.065)	(0.069)	(0.076)	(0.085)	(0.084)	(0.083)	(0.081)	(0.088)	(0.091)
Observations	417960	431892	431892	431892	431892	431892	431892	431892	404028	390096
Adjusted R^2	0.678	0.650	0.648	0.643	0.644	0.646	0.642	0.643	0.638	0.637
Panel B: Price differentials										
Energy price index differential$_{ij}$ × Energy intensity$_l$	0.020***	0.030***	0.050***	0.067***	0.084***	0.080***	0.074***	0.070***	0.078***	0.093***
	(0.007)	(0.006)	(0.006)	(0.007)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.008)
Observations	281880	301320	301320	301320	301320	301320	301320	301320	263088	244944
Adjusted R^2	0.689	0.611	0.611	0.604	0.601	0.603	0.600	0.601	0.589	0.583
Skilled labour and capital interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter-Importer fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry pair fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The dependent variable is log of intermediate goods imported from country i industry k, originated from country j and industry l. In Panel A, standard errors are clustered at the country j by industry l; in Panel B, standard errors are clustered at the country pair ij by industry l. All coefficients are standardized. The energy price index differential is computed as the energy price index of importing country i minus the energy price index of the intermediate good producing country j. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table 7: Simulated impact of an increase in energy prices in EU – energy price index

Country	Direct	Aggregate SR	Aggregate LR
Belgium	9.48%	21.54%	16.86%
Croatia	6.25%	14.08%	12.34%
Czech Republic	4.46%	9.24%	8.51%
Denmark	5.12%	11.79%	10.39%
Finland	11.84%	25.36%	16.68%
France	5.90%	12.09%	9.76%
Germany	5.23%	10.68%	8.92%
Greece	13.71%	36.83%	18.43%
Hungary	4.47%	10.05%	8.69%
Italy	6.27%	12.85%	9.86%
Netherlands	10.99%	28.77%	17.11%
Poland	5.83%	11.65%	10.45%
Portugal	6.71%	13.77%	11.35%
Romania	5.39%	10.65%	9.41%
Slovakia	6.06%	13.57%	12.78%
Sweden	8.48%	19.16%	17.26%
United Kingdom	7.32%	17.01%	12.14%
EU Total	**6.77%**	**14.99%**	**11.46%**

Note: The simulation is based on a simulated 33% increase in energy price index in EU, based on estimations in Tables 1 and 4.The percentages show the decrease in exports due to the increase in energy price, based on the observed 2012 value and trading relationships. 'Direct' shows the direct impact of energy price on exports; 'Aggregate SR' shows the aggregate (direct plus indirect) impact of energy price on exports; 'Aggregate LR' shows the aggregate impact, after adjusting for the potential substitution of intermediate goods.

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Table 8: Simulated impact of an increase in energy prices in EU – electricity and gas prices

Country	Direct	Aggregate SR	Aggregate LR
Belgium	12.78%	55.04%	24.83%
Croatia	7.32%	36.20%	27.06%
Czech Republic	4.69%	18.26%	15.30%
Denmark	7.89%	32.56%	23.07%
Estonia	7.10%	32.94%	15.84%
Finland	13.56%	60.64%	17.27%
France	7.66%	27.58%	14.88%
Germany	6.25%	22.91%	13.41%
Greece	19.09%	111.37%	20.42%
Hungary	5.86%	23.80%	14.61%
Ireland	12.79%	48.48%	16.46%
Italy	7.54%	29.25%	12.16%
Lithuania	20.01%	130.29%	64.16%
Netherlands	16.78%	85.53%	20.77%
Poland	6.67%	24.54%	18.20%
Portugal	8.85%	33.21%	24.28%
Romania	5.48%	20.53%	13.47%
Slovakia	6.94%	31.89%	26.13%
Slovenia	7.83%	30.76%	19.93%
Spain	10.18%	38.74%	17.54%
Sweden	10.11%	47.87%	36.17%
United Kingdom	9.36%	45.12%	15.78%
EU Total	**8.94%**	**37.75%**	**17.20%**

Note: The simulation is based on a simulated 68% increase in electricity price as well as a simulated 87% increase in natural gas price in EU, based on estimations in Tables 2 and 5. The percentages show the decrease in exports due to the increase in energy price, based on the observed 2012 value and trading relationships. 'Direct' shows the direct impact of energy price on exports; 'Aggregate SR' shows the aggregate (direct plus indirect) impact of energy price on exports; 'Aggregate LR' shows the aggregate impact, after adjusting for the potential substitution of intermediate goods.

Online Appendices

A Data Appendix

Table A.1: Electricity and natural gas intensities for the most and least energy intensive industries

IO industry code	Industry title	Electricity		Natural Gas	
		Direct	+ Indirect	Direct	+ Indirect
Least energy intensive industries					
311930	Flavoring syrup and concentrate manufacturing	0.004	0.030	0.002	0.014
334111	Electronic computer manufacturing	0.003	0.019	0.001	0.010
3122A0	Tobacco product manufacturing	0.003	0.004	0.002	0.002
333611	Turbine and turbine generator set units manufacturing	0.004	0.013	0.001	0.007
325620	Toilet preparation manufacturing	0.006	0.011	0.009	0.012
334510	Electromedical and electrotherapeutic apparatus manufacturing	0.009	0.009	0.002	0.002
334517	Irradiation apparatus manufacturing	0.008	0.008	0.001	0.001
315230	Women's and girls' cut and sew apparel manufacturing	0.008	0.010	0.020	0.022
334516	Analytical laboratory instrument manufacturing	0.011	0.014	0.003	0.004
334210	Telephone apparatus manufacturing	0.005	0.011	0.007	0.010
Most energy intensive industries					
327211	Flat glass manufacturing	0.074	0.086	0.126	0.131
322130	Paperboard mills	0.108	0.206	0.123	0.190
331110	Iron and steel mills and ferroalloy manufacturing	0.145	0.417	0.092	0.230
324110	Petroleum refineries	0.092	0.702	0.214	0.797
311221	Wet Corn Milling	0.315	0.351	0.462	0.489
325120	Industrial gas manufacturing	0.327	0.360	0.035	0.054
3274A0	Lime and gypsum product manufacturing	0.084	0.098	0.155	0.164
327310	Cement manufacturing	0.160	0.180	0.117	0.132
325110	Petrochemical manufacturing	0.069	0.207	0.304	0.410
33131A	Alumina refining and primary aluminum production	0.559	0.700	0.098	0.153

Table includes the 10 most and least energy intensive industries, based on the cost of electricity and fuels as a share of value added. Electricity and natural gas intensities are defined as expenditure as a share of value added calculated from the U.S. BEA IO Tables.

Table A.2: Summary statistics

Variable	Unit	Obs.	Mean	Std. Dev.	Min	Max
(a) Variables at exporter-industry-year level						
Exports_{ijk}	Billions US dollars	9,871	0.87	3.84	0.00	141.46
(b) Variables at exporter-level						
$\text{Energy Price Index}_i$	Index	32	805.95	273.59	252.22	1724.94
$\text{Electricity Price}_i$	US dollars	40	115.49	43.01	31.98	270.05
$\text{Natural Gas Price}_i$	US dollars	40	35.28	15.67	2.56	66.19
Skill Abundance_i	Index	40	3.12	0.46	2.01	3.72
$\text{Capital Abundance}_i$	US dollars per worker	40	267610.00	144063.10	23603.43	540278.00
TFP_i	Level at PPP (US = 1)	39	0.72	0.20	0.38	1.34
Incomepc_i	US dollars per capita	39	26621.00	19923.40	1449.67	83208.69
Labour Flex_i	Index	37	63.35	19.64	28.00	97.00
Rule of Law_i	Index	40	0.79	0.84	-0.82	1.95
$\text{Financial Development}_i$	%	39	53.29	37.90	5.20	169.92
(c) Variables at industry level						
$\text{Direct Energy Intensity}_k$	Exp Share	249	0.04	0.06	0.00	0.52
$\text{Direct Electricity Intensity}_k$	Share	249	0.04	0.05	0.00	0.56
$\text{Direct Natural Gas Intensity}_k$	Share	249	0.02	0.05	0.00	0.46
Skill Intensity_k	Share	249	0.41	0.14	0.14	0.81
$\text{Capital Abundance}_i$	Exp Share	249	0.06	0.03	0.01	0.28
TFP Growth_k	Share	249	0.01	0.08	-0.28	0.36
Value Added_k	Exp Share	249	0.52	0.12	0.14	0.87
$\text{Contract Intensity}_k$	Share	249	0.53	0.22	0.02	0.98
$\text{Ext Financial Dep}_k$	Exp Share	249	0.14	1.59	-1.86	5.47

Notes: Exports and exporter-level variables summarized in table are for the year 2012. Exp share refers to expenditure share.

Table A.3: Electricity and natural gas prices for OECD and non-OECD countries in sample

OECD	Electricity Price	Natural Gas Price	non-OECD	Electricity Price	Natural Gas Price
Belgium	133	38	Bulgaria	82	34
Canada	71	15	Brazil	173	30
Colombia	118	15	Croatia	115	41
Czech Republic	150	47	India	102	6
Denmark	114	66	Indonesia	72	22
Estonia	92	36	Malaysia	89	16
Finland	101	41	Philippines	148	34
France	111	43	Romania	117	23
Germany	143	48	Russia	50	9
Greece	118	47	Saudi Arabia	32	3
Hungary	144	45	Thailand	74	27
Ireland	151	40	Vietnam	60	12
Italy	270	45			
Japan	171	58			
Lithuania	132	37			
Netherlands	124	38			
New Zealand	71	21			
Poland	120	39			
Portugal	129	44			
Slovakia	179	46			
Slovenia	127	53			
South Korea	60	51			
Spain	127	36			
Sweden	94	57			
Switzerland	113	63			
Turkey	143	37			
United Kingdom	128	31			
United States	68	17			

Notes: Table shows the electricity and natural gas price data we use when we explicitly model their effects on the pattern of trade using export data for the year 2012. The variables are in US dollars per MWh and are the average prices observed over the period between 2009 to 2011 for each country.

Table A.4: Correlation matrix between interaction terms

	Energy Price Index$_i$ × Direct Energy Intensity$_k$	Electricity Price$_i$ × Direct Electricity Intensity$_k$	Natural Gas Price$_i$ × Direct Natural Gas Intensity$_k$	Skill Abundance$_i$ × Skill Intensity$_k$	Capital Abundance$_i$ × Capital Intensity$_k$	TFP$_i$ × TFP Growth$_k$	Incomepc$_i$ × Value Added$_k$	Labour Flex$_i$ × Skill Intensity$_k$	Rule of Law$_i$ × Contract Intensity$_k$	Financial Development$_i$ × Ext Financial Dep$_k$
Energy Price Index$_i$ × Direct Energy Intensity$_k$	1.00									
Electricity Price$_i$ × Direct Electricity Intensity$_k$	0.86	1.00								
Natural Gas Price$_i$ × Direct Natural Gas Intensity$_k$	0.67	0.58	1.00							
Skill Abundance$_i$ × Skill Intensity$_k$	-0.28	-0.22	-0.15	1.00						
Capital Abundance$_i$ × Capital Intensity$_k$	0.51	0.39	0.36	-0.07	1.00					
TFP$_i$ × TFP Growth$_k$	0.10	0.09	0.11	-0.13	0.04	1.00				
Incomepc$_i$ × Value Added$_k$	-0.23	-0.25	-0.26	0.38	-0.12	0.04	1.00			
Labour Flex$_i$ × Skill Intensity$_k$	-0.23	-0.18	-0.14	0.83	-0.07	-0.11	0.27	1.00		
Rule of Law$_i$ × Contract Intensity$_k$	-0.21	-0.22	-0.15	0.45	-0.03	-0.07	0.44	0.39	1.00	
Financial Development$_i$ × Ext Financial Dep$_k$	0.10	0.11	0.10	0.21	0.15	0.05	0.09	0.19	-0.03	1.00

Note: Correlations are computed on the basis of the sample observations used in baseline regressions.

Dependent Variable

Log of exports from country i to country j in billion US dollars. Data are from the UN COMTRADE Database, reported at 6-digit Harmonized Commodity Description and Coding System (HS) level. Using the concordance provided by Pierce and Schott (2012), we convert the trade data to the NAICS level. We then aggregate the data to the Bureau of Economic Analysis (BEA) benchmark input-output (IO) accounts level using the concordance provided by the BEA. We use trade data from 2012 in the cross section analysis. We use the trade values reported by importers, which are usually regarded as more reliable as duties are often imposed on imports.

Explanatory Variables

(i) Country level variables

$EnergyPriceIndex_i$ Log of energy price index from Sato et al. (2019) defined as a weighted average real energy price for all fuels (electricity, natural gas, coal and oil). We use the energy price index for the aggregate manufacturing sector level, where weights are the consumption of each fuel type in the manufacturing sector in each country. We use the variable weight index that allows for cross-country level comparisons.

$ElectricityPrice_i$ Log of total (after tax) end-use electricity prices for industry consumers in US dollars per MWh from the International Energy Agency energy prices and taxes database. For non-OECD countries the IEA industrial data are supplemented with data from various national official government reports. Energy prices from government reports are reported in current prices denominated in local currencies. We convert local currencies into U.S. dollars using exchange rates reported by the World Bank.

$NaturalGasPrice_i$ Log of total (after tax) end-use natural gas prices for industry consumers in US dollars per MWh from the International Energy Agency energy prices and taxes database. For non-OECD countries the IEA industrial data are supplemented with data from various national official government reports. We convert local currencies into U.S. dollars using exchange rates reported by the World Bank.

$SkillAbundance_i$ Log of human capital index, based on years of schooling and returns to education. From the Penn World Tables (Feenstra and Timmer (2015)).

$CapitalAbundance_i$ Log of physical capital stock at current PPPs (in millions of US dollars) per worker (in millions). From the Penn World Tables (Feenstra and Timmer (2015)).

TFP_i Total factor productivity level at current PPPs (U.S. = 1) from the Penn World Tables (Feenstra and Timmer (2015)).

$Incomepercapita_i$ Log GDP per capita in U.S. dollars. from the World Bank national accounts data.

$LaborFlex_i$ 100-point integer scale indicating labor market flexibility taken from Table 1 in Cunat and

Melitz (2012).

$RuleofLaw_i$ Indicator for rule of law taken from the World Governance Indicators, measuring the extent to which agents have confidence in and abide by the rules of society.

$FinancialDevelopment_i$ The ratio of stock market capitalisation to GDP from the World Bank Global Financial Development Database.

$Petroleum_i$ Petroleum reserves per worker from the U.S. Energy Information Administration.

$Coal_i$ Coal reserves per worker from the World Energy Council 2004 Survey of energy resources.

(ii) Industry level variables

$AggEnergyIntensity_k$ The cost of electricity and fuels as a share of the total value added. Calculated using data from the U.S. NBER-CES Manufacturing Industry Database (Bartelsman and Gray (1996), updated to 2011).

$ElectricityIntensity_k$ Purchase value (in producer prices) in the electric power generation, transmission and distribution industry as a share of value added. Calculated using data from the 2002 U.S. BEA Input Output tables.

$NaturalGasIntensity_k$ Purchase value (in producer prices) in the natural gas distribution industry as a share of value added. Calculated using data from the 2002 U.S. BEA Input Output tables.

$SkillIntensity_k$ One minus production worker wages as a share of total wages in 2002. Calculated using data from the U.S. NBER-CES Manufacturing Industry Database (Bartelsman and Gray (1996), updated to 2011).

$CapitalIntensity_k$ Total capital expenditure as a share of value added in 2002. Calculated using data from the U.S. NBER-CES Manufacturing Industry Database (Bartelsman and Gray (1996), updated to 2011).

$TFPGrowth_k$ 5-factor TFP annual growth rate in 2002 from the U.S. NBER-CES Manufacturing Industry Database (Bartelsman and Gray (1996), updated to 2011)

$ValueAdded_k$ Total capital expenditure as a share of value added in 2002. Calculated using data from the U.S. NBER-CES Manufacturing Industry Database (Bartelsman and Gray (1996), updated to 2011).

$ContractIntensity_k$ Importance of relationship-specific investments from Nunn (2007).

$ExtFinancialDep_k$ External finance dependence of industry from Manova (2013).

B Additional Tables

Table B.1: Results - EU Interactions

	(1)	(2)	(3)	(4)	(5)
Year	2002	2005	2008	2011	2013
Panel A: Direct energy intensity only					
$EU_i \times$ Direct energy intensity$_k$	-0.941	-1.366*	-1.965***	-2.577***	-2.955***
	(0.768)	(0.730)	(0.748)	(0.728)	(0.734)
Physical and human capital interactions	Yes	Yes	Yes	Yes	Yes
Exporter fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	14298	14313	14379	14366	14308
Adjusted R^2	0.730	0.738	0.746	0.744	0.741
Panel B: Direct and indirect intensities					
$EU_i \times$ Direct energy intensity$_k$	-0.160	-0.569	-1.267	-2.066***	-2.238***
	(0.809)	(0.763)	(0.786)	(0.764)	(0.773)
$EU_i \times$ Indirect energy intensity$_k$	-1.626***	-1.650***	-1.458***	-1.080***	-1.487***
	(0.430)	(0.445)	(0.431)	(0.446)	(0.442)
Physical and human capital interactions	Yes	Yes	Yes	Yes	Yes
Exporter fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	14298	14313	14379	14366	14308
Adjusted R^2	0.730	0.738	0.747	0.744	0.741

Note: In Panels A and B, the dependent variable is log of aggregate exports from country i in industry k. *EU* is a dummy variable that takes the value of one if it is one of the EU-28 (including the United Kingdom) countries, zero otherwise. We have excluded Switzerland in all specifications. Robust standard errors are reported in the parentheses. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table B.2: Robustness tests: Omitted variable bias

	(1)	(2)	(3)	(4)
Energy price index$_i$ × Direct energy intensity$_k$	-0.751***	-0.621***		
	(0.136)	(0.151)		
Energy price index$_i$ × Indirect energy intensity$_k$		-0.312**		
		(0.135)		
Electricity price$_i$ × Direct electricity intensity$_k$			-0.149	-0.093
			(0.092)	(0.096)
Natural gas price$_i$ × Direct natural gas intensity$_k$			-0.244***	-0.180***
			(0.059)	(0.058)
Electricity price$_i$ × Indirect electricity intensity$_k$				-0.163**
				(0.081)
Natural gas price$_i$ × Indirect natural gas intensity$_k$				-0.135***
				(0.038)
Skill abundance$_i$ × Skill intensity$_k$	0.349***	0.356***	0.113**	0.122**
	(0.071)	(0.071)	(0.056)	(0.056)
Capital abundance$_i$ × Capital intensity$_k$	0.588***	0.623***	0.438***	0.477***
	(0.169)	(0.169)	(0.143)	(0.141)
TFP $_i$ × TFP growth$_k$	-0.004	-0.005	0.050**	0.051**
	(0.027)	(0.027)	(0.021)	(0.021)
Income per capita $_i$ × Value added$_k$	0.148	0.130	0.054	0.035
	(0.092)	(0.092)	(0.085)	(0.086)
Labor market flexibility $_i$ × Skill intensity$_k$	0.016	0.014	0.180***	0.179***
	(0.038)	(0.038)	(0.029)	(0.029)
Rule of law $_i$ × Contract intensity$_k$	0.015	0.014	0.055***	0.051**
	(0.023)	(0.023)	(0.021)	(0.021)
Financial development $_i$ × External financial dependence$_k$	0.055***	0.053***	0.054***	0.052***
	(0.010)	(0.010)	(0.009)	(0.010)
Exporter Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes
Observations	7176	7176	6930	6930
Adjusted R^2	0.712	0.712	0.712	0.712

Note: The dependent variable is log of aggregate exports from country i in industry k. All coefficients are standardized. Robust standard errors are reported in the parentheses. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table B.3: Robustness tests: Reverse causality – energy price index

	(1)	(2)	(3)	(4)
Energy Price Index$_i$ × Direct Energy Intensity$_k$	-0.883***		-0.714***	-0.768***
	(0.145)		(0.159)	(0.168)
Energy Price Index$_i$ × Indirect Energy Intensity$_k$			-0.403***	-0.309***
			(0.149)	(0.118)
Energy Price Index$_i$ × Aggregate Energy Intensity$_k$		-0.929***		
		(0.152)		
Skill abundance$_i$ × Skill intensity$_k$	0.364***	0.374***	0.368***	0.332***
	(0.056)	(0.056)	(0.056)	(0.078)
Capital abundance$_i$ × Capital intensity$_k$	0.604***	0.636***	0.661***	0.312*
	(0.169)	(0.169)	(0.168)	(0.182)
Exporter Fixed Effects	Yes	Yes	Yes	No
Industry Fixed Effects	Yes	Yes	Yes	Yes
Exporter-by-Sector Fixed Effects	No	No	No	Yes
Observations	7665	7665	7665	7658
Adjusted R^2	0.708	0.709	0.709	0.772

Note: The dependent variable is log of aggregate exports from country i in industry k. All coefficients are standardized. All exports from the US are excluded from the sample. Robust standard errors are reported in the parentheses. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table B.4: Robustness tests: Reverse causality – electricity and natural gas prices

	(1)	(2)	(3)	(4)
Electricity price$_i$ × Direct electricity intensity$_k$	-0.150		-0.100	-0.151
	(0.095)		(0.099)	(0.095)
Natural gas price$_i$ × Direct gas intensity$_k$	-0.233***		-0.170***	-0.174***
	(0.056)		(0.055)	0.055
Electricity price$_i$ × Indirect electricity intensity$_k$			-0.149*	-0.047
			(0.085)	0.090
Natural gas price$_i$ × Indirect gas intensity$_k$			-0.133***	-0.109**
			(0.038)	(0.044)
Electricity price$_i$ × Aggregate electricity intensity$_k$		-0.199**		
		(0.092)		
Natural gas price$_i$ × Aggregate gas intensity$_k$		-0.260***		
		(0.046)		
Skill abundance$_i$ × Skill intensity$_k$	0.257***	0.261***	0.261***	0.179***
	(0.049)	(0.048)	(0.048)	(0.050)
Capital abundance$_i$ × Capital intensity$_k$	0.362***	0.421***	0.419***	-0.045
	(0.134)	(0.137)	(0.137)	(0.141)
Exporter Fixed Effects	Yes	Yes	Yes	No
Industry Fixed Effects	Yes	Yes	Yes	Yes
Exporter-by-Sector Fixed Effects	No	No	No	Yes
Observations	9621	9621	9621	9609
Adjusted R^2	0.704	0.705	0.705	0.766

Note: The dependent variable is log of aggregate exports from country *i* in industry *k*. All coefficients are standardized. All exports from the US are excluded from the sample. Robust standard errors are reported in the parentheses. *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table B.5: Robustness tests: Reverse casuality for intermediate goods – Energy price index

	(1)	(2)	(3)	(4)
Energy price index$_j$ × Energy intensity$_l$	-0.979***	-1.181***		
	(0.089)	(0.082)		
Capital abundance$_j$ × Capital intensity$_l$		0.415***		
		(0.049)		
Skill abundance$_j$ × Skill intensity$_l$		0.376***		
		(0.025)		
Energy price index differential$_{ij}$ × Energy intensity$_l$			0.075***	0.089***
			(0.008)	(0.009)
Capital abundance differential$_{ij}$ × Capital intensity$_l$				-0.066***
				(0.014)
Skill abundance differential$_{ij}$ × Skill intensity$_l$				-0.166***
				(0.020)
Observations	408240	408240	281880	281880
Adjusted R^2	0.631	0.634	0.591	0.593
Exporter-Importer Fixed Effects	Yes	Yes	Yes	Yes
Industry Pair Fixed Effects	Yes	Yes	Yes	Yes

Note: The dependent variable is log of intermediate goods imported from country *i* industry *k*, originated from country *j* and industry *l*. In columns (1) and (2), standard errors are clustered at the country *j* by industry *l*; in columns (3) and (4), standard errors are clustered at the country pair *ij* by industry *l*. All coefficients are standardized. All intermediate goods flow from or to the US are excluded from the sample. All differentials in this regression are computed as the price/endowment of importing country minus that of the exporting country (i.e., producers of the intermediate goods). *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.

Table B.6: Robustness tests: Reverse casuality for intermediate goods – Electricity and gas prices

	(1)	(2)	(3)	(4)
Electricity price$_j$ × Electricity intensity$_l$	-0.861***	-0.910***		
	(0.053)	(0.055)		
Natural gas price$_j$ × Natural gas intensity$_l$	-0.439***	-0.585***		
	(0.033)	(0.033)		
Capital abundance$_j$ × Capital intensity$_l$		0.633***		
		(0.060)		
Skill abundance$_j$ × Skill intensity$_l$		0.414***		
		(0.025)		
Electricity price differential$_{ij}$ × Electricity intensity$_l$			0.092***	0.097***
			(0.007)	(0.007)
Natural gas price differential$_{ij}$ × Natural gas intensity$_l$			0.044***	0.059***
			(0.007)	(0.008)
Capital abundance differential$_{ij}$ × Capital intensity$_l$				-0.081***
				(0.014)
Skill abundance differential$_{ij}$ × Skill intensity$_l$				-0.175***
				(0.015)
Observations	449064	449064	342144	342144
Adjusted R^2	0.640	0.644	0.607	0.610
Exporter-Importer Fixed Effects	Yes	Yes	Yes	Yes
Industry Pair Fixed Effects	Yes	Yes	Yes	Yes

Note: The dependent variable is log of intermediate goods imported from country *i* industry *k*, originated from country *j* and industry *l*. In columns (1) and (2), standard errors are clustered at the country *j* by industry *l*; in columns (3) and (4), standard errors are clustered at the country pair *ij* by industry *l*. All coefficients are standardized. All intermediate goods flow from or to the US are excluded from the sample. All differentials in this regression are computed as the price/endowment of importing country minus that of the exporting country (i.e., producers of the intermediate goods). *,**, and *** indicated statistical significance level at 90%, 95% and 99% respectively.