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Energy Abundance, Trade and Industry Location

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Summary

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Keywords: Trade and the Environment, Pollution Haven, Factor Endowments, Industry Location

JEL Classification: Q56

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Energy abundance, trade and industry location[1]

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Abstract

We study the effect of countries' energy abundance on trade and sector activity, conditional on sector's energy intensity, using an unbalanced panel with 14 high-income countries from Europe, America and Asia, 10 broad sectors, and years 1970-1997. We find that (i) countries with large energy endowments have low energy prices, and are thus energy abundant both on micro and macro level. (ii) Energy abundant countries have a high level of energy embodied in exports relative to imports. (iii) Energy intensive sectors export from and (iv) have higher economic activity in energy abundant countries. (v) The trade and location effects increase with a sector's exposure to international trade. In short, energy is a major driver for sector location through specialisation. We show that capital and energy are complements in the production function and use various controls in our analysis. The results give insights into delocalisation effects that may take place among rich countries with heterogeneous energy policy.

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1. Introduction

As trade flows tie countries to each other, the international effects through changes in trade and industry location need to be included when assessing the effectiveness of environmental policy. This is especially true for climate policy, where location of greenhouse gas emissions is irrelevant to the climate change problem, and a potential relocation of emissions may make domestic policy ineffective. Over the past decade, a literature has been developed that studies the nexus between trade and environment. Two different branches can be distinguished (Copeland and Taylor 2003, Taylor 2005). The first branch takes changes in trade costs as the starting point, while the second branch starts with changes in (or differences between) environmental policies. A typical query of the first strand of the literature is whether trade liberalization leads to improved environmental conditions or to increased damages; shortly, whether free trade is good or bad for the environment. The second strand of the literature typically asks how domestic environmental policy works its way through trade flows and industry location decisions. A re-occurring question in this strand is whether developed countries can implement strict environmental regulation without the need to fear that pollution-intensive firms will react to such policies by moving to less developed countries with laxer

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regulations, a phenomenon know as the pollution haven effect. When applied to energy, the question becomes whether countries can reduce their CO_2 emissions effectively through energy savings, or that such policies will necessarily lead to energy-intensive firms moving to non-abating countries, a problem known as carbon leakage. In the context of the environment-trade literature, we might as well call the tendency to relocate an 'energy haven effect'.[3]

This paper contributes empirically to the second strand of the literature. For a selection of industries we ask whether differences between countries regarding export performance and industry-location can partly be traced back to differences between the countries regarding energy abundance. Energy (and also capital) are in fact not simply exogenously fixed factor endowments, but are factors of production that are also produced and that can be traded. Hence the observed abundance of energy depends on natural energy resource endowments as well as on energy and fiscal policies. For firms the important variable is the effective price of energy, and we treat energy abundance as the inverse thereof. The contribution of this paper is twofold. On the one hand, we develop a new method to estimate energy abundance based on the profit maximisation condition of firms. These energy abundance estimates are later instrumented to control for potential endogeneity. On the other hand, we investigate econometrically the role of energy as a determinant of trade and production performance. This second part is based on the framework of Romalis (2004), which gives a particular importance to interaction terms between factor abundance and factor intensities.

Our dataset covers a large diversity of sectors from manufacturing sectors to agriculture and services, covering both energy extensive (e.g. Services) and energy intensive sectors (e.g. Non-metalic Minerals). Data for this range of sectors is available for industrialised countries from Europe, North America and Japan, leading to a relatively homogenous group of countries in terms of institutions, cultural attitudes and climate conditions. The country sample puts our analysis between two groups of literature. The first group studies trade patterns within a country (typically US or UK), or bilateral trade between one country and a set of trade partners. The second group has a wider international scope trying to understand the relation between high-income and low-income countries. Limited heterogeneity of the country sample as we have has the advantage of reducing the risk of omitted variables biases. It also has the obvious drawback of a reduced variability in the data. It might therefore prove difficult to find significant effects but if these are found results may be more reliable. We furthermore notice that the countries in our sample make up a large part of world trade and are major trading partners for each other. Regarding energy, the dataset covers both countries with high energy use per unit labour (e.g. Norway and Canada) and countries with low energy use (e.g. Italy) introducing sufficient variation in the main factor of analysis.

In the first part of the paper, we develop our measure of energy abundance. We propose a measure of energy abundance that is independent of a country's sector structure. More precisely, we decompose in our panel data (country, sector, year) the observed energy per labour use into a country specific and a sector-specific component. We derive from the firm's optimality conditions that the country-specific component can be interpreted as a country-characteristic measure of relative effective factor prices within a country, while the sector-attribute component reflects the sector-specific energy-share in production. The constructed country-specific energy abundance measure is thus a proxy for marginal energy costs, and may result from either energy endowments or from policies. On the one hand, this means that we are capturing all factor price effects relevant to the firms. On the other hand, the drawback is that we are not able to distinguish the different channels through which energy abundance may change and hence we cannot isolate empirically energy endowment from energy policy effects.

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[3] Notice that the carbon leakage literature does not restrict its focus to sector relocation issues. The energy market also plays an important role. See Gerlagh and Kuik (2003) for an overview, and Sato et al. (2007) for an application to the EU ETS and its impact on competitiveness.

To ensure that causality does not run from sector structure to energy abundance, we present the analyses with instruments for energy abundance.[4] One may suspect reverse causality, through political economy arguments, from an energy-intensive sector structure to lax or supporting energy policies. For the instrument we use measures of energy endowments rather than policy variables because, for the period 1970-1996 studied, better data are available for the former and energy endowments probably were more important than environmental considerations. For example, Norway has large hydro and oil reserves but also strict environmental policies. Norway also has about the highest energy use per employment in our sample, suggesting that the reserves seem to be more important. We notice though that, despite the empirical argument in favour of interpreting our results as measuring the effect of energy endowments on industry location, from the analytical perspective, the results can still more broadly be interpreted as measuring possible consequences of future energy-related policy.

Our empirical analysis provides strong evidence for the following statements. (i) Large energy endowments lead to lower energy prices and thus to energy abundance on the level of the firm. (ii) Countries abundant in energy have higher levels of energy embodied in their net exports. (iii) All else equal, energy intensive sectors tend to export from countries abundant in energy, and (iv) have, partly because of the trade effect, higher activity levels in these countries. Our findings for energy contrast with our findings for capital. We do not find evidence for the factor-endowments hypothesis, which in this context typically states that capital abundance relative to labour will also lead to specialization in energy-intensive industries, which are also capital intensive. This result is surprising because, overall, our data confirms the general notion that capital is a more important production factor than energy, if we take the output-elasticity as the measure of importance. Moreover, we do find clear evidence of complementarity between capital and energy in the production function. In our sample, the variation in energy-abundance between countries and energy-intensity between sectors is however much larger than the variation in capital-abundance and capital-intensity, respectively. Thus, though capital is a more important production factor, its supply and use is also more evenly spread.

As mentioned above, we cannot interpret the empirical support for an energy-haven effect as a suggestion that, in our dataset, energy policies have affected industry location. Yet, our empirical results have implications for environmental policy. At first glance, one may interpret our results as suggesting that energy saving policies are ineffective in the international context when energy-intensive industries relocate. But the reverse conclusion appears if coordinated policies could level energy abundance between countries. Consider a currently energy abundant country with low levels of effective energy costs, and with a high share in energy-intensive sectors. When such a country would raise the effective energy costs to a level comparable with the average country, part of the energy-intensive industries might relocate to other countries, and when adapting to local factor costs, use less energy per output. Global emissions would fall. As energy carriers are easily tradable and homogeneous commodities, economic efficiency also suggests equal factor prices between countries. The benefit of levelled energy costs could thus be both environmental and economic, leading to a double-dividend.

The next section briefly discusses the literature and our contribution thereto. The third section provides a brief formal analysis of the mechanisms underlying our econometric procedures. The fourth section describes the data. The fifth section presents main results, and the last section concludes.

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[4] For a recent study on endogeneity of environmental policy see Ederington and Minier (2003), and for an earlier theoretical analysis Markusen et al. (1995).

2. Literature

A first effect of trade is that it enables sectors to separate location from demand so that they tend to move to countries abundant in factors for which the sectors need relative large inputs. Polluting industries will tend to move to countries with lax environmental regulations. The naïve argument, though, needs two important qualifications (Ederington et al. 2005). First, sectors require many inputs such as capital, labour, energy, natural resources, and stringency of environmental regulation often determines but a small part of the overall costs of production. It is thus important to understand how various production factors correlate with each other, between sectors and countries. When capital and pollution intensity are positively correlated over sectors, as is often found in empirical studies, and capital-rich countries tend to have stringent environmental policy, then trade liberalization will lead to two opposing forces. For capital-intensive sectors will tend to move to the capital abundant countries, but as the same sectors are also pollution intensive, they would tend to move to the environmentally lax countries as well. The net effect will depend on the relative strength of the two factors. In short, for each factor, there is an interaction between country abundance and sector intensity, and to assess the effects of freer trade we need to compare the interaction effects for multiple factors. The second qualification is that sectors differ substantially with respect to trade costs and hence their trade exposure and mobility. If polluting industries are overall less mobile, then the effect of freer trade will mainly go through the relocation of cleaner industries rather than through the relocation of dirty industries (Ederington et al. 2005). Both the complementarity between capital and energy and the trade exposure will play an important role in our empirical strategy.

Antweiler et al. (2001) and Copeland and Taylor (2003) introduced another important element into the debate. Increased trade often increases jointly income and overall production. Whereas the increase in output tends to increase pollution, the increase in income tends to increase demand for a cleaner environment, because environmental quality is a normal good, leading to tighter environmental regulations. Indeed, a series of empirical studies showed that insofar local pollution is considered, a typical finding is that the positive effect of trade on policy – through income – is sufficiently large to offset the possible negative consequences of trade. The conclusion from this literature is that through endogenous environmental policy, trade in general is good for the environment (Antweiler et al. 2001, Copeland and Taylor 2003, Ederington and Minier 2003, Frankel and Rose 2005, Cole and Elliot 2003, Cole 2006[5], and Managi et al. 2009). Whereas the pollution haven hypothesis (PHH) literature studies the effect of trade on the environment, we study the relation the other way around, from environmental policy (more precisely energy policy) to trade. The relevant mechanism, that strict policies may scare polluting industries, is known as the pollution haven effect (Taylor 2003). In this literature, the income effect is less important.

The empirical literature on both the pollution haven hypothesis and the pollution haven effect can be classified into three strands depending on the level of aggregation at which the studies address the question. Starting from the micro-level, several studies use firm level data. List and Co (2000) and Javorcik and Wei (2001) investigated the effect of environmental regulation on foreign direct investment. Dominquez and Brown (2007) and Barajas et al. (2007) looked at the environmental performance post-NAFTA in Mexico. In all these cases, the pollution haven effect is weak at most.[6]

At the sectoral level, contributions covering all manufacturing sectors often focus on the US because of data availability. Ederington and Minier (2003) and Ederington et al. (2005) estimate the effect of pollution regulation and other industry characteristics on trade patterns

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[5] Cole 2006 finds no positive policy effect for energy.

[6] List and Co (2000) for example find a negative effect of environmental regulation on FDI, but find no difference between pollution intensive industries and 'clean' industries.

during the period 1978-1994. They notice that for most industries pollution abatement costs are a small component of total costs and that those industries with the largest pollution abatement costs also happen to be the least geographically mobile. Still, they obtain a significant effect of pollution abatement costs on US imports from developing countries.

In another paper, Ederington et al. (2004), they find no connection between trade liberalisation and the shift towards cleaner industries and find no evidence that pollution-intensive industries have been disproportionately affected by tariff changes. Frankel and Rose (2005) confirm these results. Levinson and Taylor (2008) look at net trade flows among the US, Canada and Mexico in 130 manufacturing industries over the period 1977-1986 and find that industries whose abatement costs increased most are also the ones that experienced the largest increase in net imports. Grether et al. (2010) calculate the pollution content of imports at the country level and estimate the relative effect of environmental regulation versus the abundance of other factors.

The third strand directly looks at the country level. Antweiler et al. (2001) find that through improved efficiency of production, SO_2 concentrations mostly decrease with trade. Cole and Elliott (2003) apply the same methodology for NO_X, CO_2 and BOD, and while they confirm the main mechanisms studied in Antweiler et al. (2001), they conclude that for the other substances the overall effect of trade is not clear-cut. Cole (2006) applies the framework to energy but concludes that trade liberalization is likely to increase per capita energy for most countries. Managi et al. (2009) apply the framework to emissions of SO_2, CO_2 and BOD. They find that trade benefits the environment in OECD countries, but has a negative effect on SO_2 and CO_2 emissions in non-OECD countries. For BOD the effect of trade is beneficial in both groups of countries. Moreover the paper shows that the impact is rather small in the short term but becomes larger in the long term.

In this paper, we combine the sector and country level. We ask whether sectors tend to locate in countries that are abundant in factors intensively used by those sectors, and whether sectoral net export is the channel through which economic activity is affected. We also assess energy embodied in trade on a country level. We consider three factors: capital, labour, and energy (for an early study on the link between these three factors and international trade, see Hillman et al., 1978). Whereas capital and labour are mostly immobile in the short run, energy carriers such as oil and coal are major tradable goods with well established world prices. A country's energy abundance, in terms of the use of energy in production all else equal, does not purely measure a country's endowments, but will also be affected by its energy policies. When we thus measure the effect of capital and energy abundance (relative to labour) on trade and sector location, we indirectly assess the possible effects of energy policies on the economic structure. Capital itself is also produced, and thus, in the long-term capital abundance may also be considered a pseudo-endowment. To capture this notion, throughout the paper, we will use the term abundance rather than endowments for energy and capital. Similarly Rauscher (1997) has used the terms "true endowment" and "de facto endowment" to distinguish between scarcity determined by physical factors and preferences and scarcity determined by the political process.

Our empirical analysis is methodologically related to Midelfart-Knarvik et al. (2000), Romalis (2004)[7], and Mulatu et al. (2009). Midelfart-Knarvik et al. (2000) study sector location in OECD countries dependent on the country characteristics' interaction with sector characteristics for education, innovation, agricultural input. Romalis (2004) provides a formal model allowing for product differentiation that underlies the interaction effect and shows empirically that for US imports countries' abundance interacts with sectoral intensities: sectors with high skill intensity show high import levels from countries with high education levels. Mulatu et al. (2009) apply the interaction model to environmental policy and conclude that

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[7] Nunn (2007), Levchenko (2007) and Essaji (2008) use a broadly similar framework and Essaji (2008) also uses country-specific dummy variables.

within Europe stringent policies tend to attract clean industries while lax policies attract polluting industries.

This paper contributes to the empirical literature in four ways. First, we analyse in a comprehensive way, questions related to the trade-environment nexus that have previously been addressed separately. We construct embodied factors in trade, sectoral net-trade flows, and sectoral location based on a panel dataset. Second, compared to Midelvart-Knarvik et al. (2000), Romalis (2004), and Mulatu et al. (2009), we provide a method to isolate the country abundance measures (pseudo-endowments) and sector intensities from the observed panel input data that is sector, country and year specific. This approach has the advantage that we do not need to rely on weak proxies for environmental regulation and/or pollution intensity (or abatement costs) and factor intensities, nor do we need to rely on a binary classification of industries into dirty and clean sectors. Third, we include energy abundance as an additional and important factor of production in the analysis. Fourth, through using weights and trade as controlling variables, we explicitly include the interaction of our independent variables with trade exposure to investigate the role of trade in the industry-location analysis. This allows us to avoid a binary classification of sectors into internationally exposed and sheltered sectors.

3. Methodology

3.1. Interaction between factor abundance and factor intensities

Romalis (2004) directly derives from theory an estimating equation relating commodity trade shares of a given country to factor endowments and industrial intensities. He integrates a many-country version of a Heckscher-Ohlin model with a continuum of goods with Krugman's (1980) model of monopolistic competition and transport costs. In his seminal paper Romalis (2004) allows for different production costs between countries, and varieties of goods within sectors, leading to differences in factor prices between countries. This departure from factor price equalisation implies that a country's factor abundance can be measured as the inverse of that country's factor price.

Romalis fully determines the commodity structure of production and bilateral trade. The theoretical model has the following base elements. Production uses two factors, say skilled and unskilled labour, which are fully employed. Factors are fully mobile between sectors within countries. Countries are divided in a homogeneous group of North and South countries, where the North has a higher skilled-labour versus unskilled labour ratio. There is a continuum of industries, ranked from low shares to high shares of skilled labour input. Within each industry, factor shares are constant. Consumers spend a given fraction of their income to each industry, but the number of varieties within an industry is endogenous. Each variety has monopolistic supply, set up costs, constant marginal costs, and constant elasticity of demand. The model incorporates bilateral iceberg trade costs.

Romalis (2004) shows that under these assumptions, the sector output price in the North countries relative to the South countries declines in the intensity of skilled labour and that northern countries gain larger shares of world production in skill-intensive industries. He states further that these results based on two production factors can easily be extended to more factors. For the general case, countries' trade and production shares in specific sectors are a function of relative sector output prices, which in turn depend on the interaction between sector factor intensities and country factor prices.

We adapt the model to focus on capital, energy, and labour. The production technology for country *i*, sector *s*, and firm *h*, is characterized by the total cost function, and is assumed to be Cobb-Douglas with capital, energy and labour as factors.

$$TC_{i,s,h}(q_{i,s,h}) = (\alpha + q_{i,s,h})a_i b_s r_i^{\alpha_s} v_i^{\beta_s} w_i^{1-\alpha_s-\beta_s} \,. \tag{1}$$

The α_s and β_s are output elasticities, which are assumed different between sectors but identical between countries, that is, they are sector attributes. The model abstracts from the possibility of factor reversal. Furthermore, each sector has a specific (inverse) productivity parameter b_s, and countries are also allowed to have a different overall level of technology captured through the (inverse) productivity parameter a_i.[8] All production factors are assumed perfectly mobile within a country, leading to factor price equalization between sectors, with r_i, v_i, and w_i the prices for capital, energy and labour, respectively.

Given an assumed elasticity of substitution between varieties of σ, each firm will supply the same output level $q=\alpha(\sigma-1)$, at the price

$$p_{i,s} = \frac{\sigma}{\sigma-1} a_i b_s r_i^{\alpha_s} v_i^{\beta_s} w_i^{1-\alpha_s-\beta_s} . \tag{2}$$

Romalis (2004) shows that factor prices are inversely proportional to factor endowments, and the number of varieties, $n_{i,s}$ in country i for sector s, decreases with the production costs.[9] Lower factor prices (relative to labour) translate in lower production costs for sectors that intensively require these factors. In turn, lower costs result in a higher number of varieties and higher export shares. Romalis (2004) investigates the three-way relationship between trade shares, factor intensities, and factor abundance using an econometric model that resembles the econometric model developed by Midelfart-Knarvik et al. (2000):

$$S_{is} = \alpha_s + \sum_{f=1}^{F} \gamma_f (\theta_{f,i} - \overline{\theta}_f)(\pi_{f,s} - \overline{\pi}_f) + \varepsilon_{is} \tag{3}$$

where $S_{i,s}$ is the share in world imports from country i for industry s, the index f stands for a particular factor (i.e. capital, energy) relative to (unskilled) labour, $\theta_{f,i}$ is the country factor endowment, $\pi_{f,s}$ is the sector intensity of factor use, and $\overline{\theta}_f$ and $\overline{\pi}_f$ are the cut-off points. The model predicts a positive sign for the estimated coefficient γ_f for all factors f.

3.2. Identifying factor abundance and factor intensity

Romalis (2004) uses country data to approximate factor endowments, and in turn factor endowments are shown analytically to be an inverse proxy for factor costs. We extend the empirical method from Midelfart-Knarvik et al. (2000) and Romalis (2004) by showing that one does not need a country-measure for factor endowments, but one can directly estimate country factor abundance – the inverse of factor costs – from the country-sector input data. Based on the above structure, aggregate output $Y_{i,s}=n_{i,s}q$, is given by

$$Y_{i,s} = A_i B_s K_{i,s}^{\alpha_s} E_{i,s}^{\beta_s} L_{i,s}^{1-\alpha_s-\beta_s} , \tag{4}$$

where A_i and B_s are country and industry specific productivity parameters inversely proportional to a_i and b_s; $K_{i,s}$ is the aggregate use of capital in country i in sector s, $E_{i,s}$ is energy input, and $L_{i,s}$ is labour input.

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[8] See Bowen et al. (1987) and Trefler (1993, 1995) for a discussion of the importance to allow for different technology levels between countries.

[9] Note that each firm produces one variety.

Aggregate production cost are given by $C_{i,s} = r_i K_{i,s} + q_i E_{i,s} + w_i L_{i,s}$. Considering varieties in production does not change the first order conditions that determine relative input shares between the factors. Cost minimization yields the first order conditions in logs:

$$\ln\frac{K_{i,s}}{L_{i,s}} = \ln\frac{\alpha_s}{1-\alpha_s-\beta_s} - \ln\frac{r_i}{w_i}, \tag{5}$$

$$\ln\frac{E_{i,s}}{L_{i,s}} = \ln\frac{\beta_s}{1-\alpha_s-\beta_s} - \ln\frac{v_i}{w_i}. \tag{6}$$

These equations can be directly estimated. Data on the left hand-side (relative production inputs) are available, and the right hand side can be identified through sector and country-specific effects. The sector effects specify differences between sectors in the value share of the considered factor and reflect therefore sector factor intensities. The country effects specify the relative prices of factors in each country, or inversely, the relative abundance of the factors. Hence this allows us to construct our measure of factor abundance. For the analysis, it is not important whether energy abundance differs between countries because of endowments or due to differences in regulations.

The econometric model becomes

$$ln\frac{E_{i,s}}{L_{i,s}} = \pi_{E,s} + \theta_{E,i} + \varepsilon_{E,i,s}, \; ln\frac{K_{i,s}}{L_{i,s}} = \pi_{K,s} + \theta_{K,i} + \varepsilon_{K,i,s} \tag{7}$$

The relationship (3) can then be applied using the estimated country factor abundance variables for $\theta_{E,i}$, $\theta_{K,i}$ and the estimated sector factor intensity variables for $\pi_{E,s}$ and $\pi_{K,s}$. When we add country and sector dummies, we can leave out the linear terms that are constant over countries or sectors and obtain:

$$S_{is} = \sum_{f=1}^{F} \gamma_f \hat{\theta}_{f,i} \hat{\pi}_{f,s} + \delta_i + \phi_s + \varepsilon_{is} \tag{8}$$

In the empirical analysis we rely on a broader interpretation of the dependent variable that captures various performance measures such as net exports or sector activity, measured as value added or employment.[10]

3.3. Empirical implementation

The econometric method for the interaction analysis is intuitive and one can straightforwardly include other factors of production, such as environmental resources, energy, or pollution intensity as in Mulatu et al. (2009). Our contribution is that we show how factor abundance and sector intensities can be constructed from the panel data set. The method has an important advantage compared to various previous studies where the interaction between pollution intensity and environmental policy is captured by splitting the sectors in samples with pollution intensive and pollution extensive sectors (e.g. Levinson and Taylor 2008).

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[10] In appendix 3, we test this method on a constructed dataset, and find a slight downward bias for the estimated coefficient of the interaction term. Such a downward bias is common to independent variables that are imperfectly observed. We also report bootstrapped standard errors.

The empirical implementation faces additional challenges: capital data are missing for some observations, thus reducing considerably our sample; dynamic effects can be identified by adapting the set of dummy variables; using trade weighted regressions allows controlling for the importance of trade exposure; relying on a "constructed regressor" may bias our results; and implementing instrumental variable techniques alleviates possible endogeneity biases of the results.

First, data available for the factor input capital can be suspected to be of bad quality and are available only for a subset of observations, reducing our sample size. Hence we also present estimations where capital is not directly included in the equation, but a missing variable bias is avoided by following an agnostic approach by introducing additional control variables. That is, for each sector we assume that land size, population, income level, and savings rate, may have an effect on sector activity. Hence, we control that the interaction coefficient does not come from any of these omitted variables.

We restrict the factor interaction analysis to energy and include the control variables and the time-dimension of our panel, so that equation (8) can be restated as:

$$S_{i,s,t} = \gamma\hat{\theta}_{i,t}\hat{\pi}_s + \sum_m \alpha_{m,s} Z_{m,i,t} + \delta_{i,t} + \phi_{s,t} + \varepsilon_{i,s,t} \tag{9}$$

where $Z_{m,i,t}$ are the M country characteristics that we control for.

Second, in the above equation, we do not include sector-country dummies, as suggested by Rajan and Zingales (1998), Essji (2008) and de Simone (2008). The reason is that our data shows small variation over time in the sector energy intensity and country energy abundance. The estimated sector intensity turns out to be almost constant, consistent with the model we use as explained below, and thus we omit the time subscript from the variable π. Therefore, our panel data mainly explains differences between country-sector pairs. In our main analysis, presented in the first part of the results section (section five) we will focus on differences between countries and sectors, while controlling for sector effects associated with country characteristics. We expect error terms to be clustered within groups of country-sector pairs, and we will apply the relevant estimation technique. At the end of there results section, we also present the results when we include country-sector dummies. For these regressions, we exclude the sector specific country-characteristics control variables as these are almost constant over time and thus become redundant when we have country-sector dummies. The econometric model then describes the dynamic relation: how changes over time in the interaction term affect changes over time in sector-activity.

$$S_{i,s,t} = \gamma\hat{\theta}_{i,t}\hat{\pi}_s + \delta_{i,t} + \phi_{s,t} + \beta_{i,s} + \varepsilon_{i,s,t}\,. \tag{10}$$

Third, we expect that the abundance-intensity interaction effect is larger for import competing sectors. We control for the trade exposure effect by weighing the observations with the square root of gross trade over value added. The weights are capped at the 5 and 95 percentiles.

Fourth, econometric problems related with the fact that energy intensity and energy abundance have themselves already been estimated before being used as regressors (they are "constructed" regressors) are discussed in Appendix 3 and seem not to influence our analysis.

Finally, we are conscious about the possible endogeneity problem of our energy abundance measure. We therefore test for endogeneity and use instruments whenever necessary. This issue is discussed in detail in the next section.

4. Data

The methodology described above requires a country-year-sector panel data set. Sector activity, trade flows (note that we use total trade flows and not only trade flows within the sample) and factors of production are needed, disaggregated by sectors and countries, to identify the importance of country-sector interaction terms in the determination of production and international trade. The International Sectoral Database with Energy (ISDB-E) offers these detailed data for 14 OECD countries and 10 sectors over the period 1970-1997.[11] This database combines economic data from the International Sectoral Database (ISDB) and the Structural Analysis database (STAN), published by the OECD with energy data from the Energy balances (IEA). Tables A1-A3 in the Appendix list countries and sectors in the sample and describe the variables used.

Before we start processing the data, to ease interpretation, we normalize all variables by expressing them in per capita terms, taking logs, and imposing an average over countries that is zero. We do not normalize the spread of the relative trade variables. Normalization of the logs of capital, energy, labour, and value added, reduces the standard deviation from 1.89, 1.84, 1.67 and 1.82 to 0.48, 0.82, 0.41, and 0.44, respectively. That is, the use of capital and labour, and the value added in a sector is to a very large degree explained by the relative size of the country and sector, while for energy use there is more variation not related to size.

4.1. Production elasticities

We then assess the importance of capital and energy in production. Formally, we use the Cobb Douglas production function (4), but assume identical parameters between sectors. Thus, we estimate:

$$\ln(Y_{i,s,t}) = \alpha \ln(K_{i,s,t}) + \beta \ln(E_{i,s,t}) + \gamma \ln(L_{i,s,t}) + \delta_{i,t} + \phi_{s,t} + \varepsilon_{i,s,t}, \qquad (11)$$

for the normalized variables. As normalization has removed all variation due to scale differences between countries and sectors, the fixed effects do not explain much of the variation. This is also apparent from the high values for the β-coefficients. A one standard deviation increase in labour use (of the normalized values) explains an increase in value added of 85% of the standard deviation (of the normalized values). Results are as expected. Labour is the most important production factor, followed by capital, and the elasticity of output with respect to energy is rather small. Based on these coefficients, one would expect capital to be more important than energy in industry location.

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[11] We are grateful to Peter Mulder and Henri de Groot for providing us with the detailed database. A limited version of the dataset is available at: www.henridegroot.net; the data has also been used in Mulder and de Groot (2007). See appendix 1 for a description of the data.

TABLE 1. *Importance of capital, energy, and labour in output.*

	Value added (1)
Capital	0.086***
	(0.118)
Energy	0.019***
	(0.048)
Labour	0.829***
	(0.847)
R^2_{adj}	0.782
FE country *year + sector*year	266+276
N	1738

Notes: all variables in logs, beta-coefficients in parenthesis, * significant at 10%, ** significant at 5%, ***significant at 1%.

To assess the responsiveness of energy to prices, we estimate the energy use per labour as dependent on the capital intensity and energy price over wages (results are shown in Appendix Table A4). We find a clear suggestion of energy and capital being complementary to each other. When for given labour use, the capital use increases, all other things equal, energy use increases as well. We find a remarkably large elasticity of energy use with respect to prices, close to minus one, also when we take first differences. We interpret this finding as a suggestion that the value share of energy relative to labour remains fairly stable.

4.2. Constructing the interaction variables

The first step in our methodology is to separate country-sector specific energy and capital use into a country-specific and a sector-specific component. In the model we consider a 3-factor model with capital, energy and labour, and assume a Cobb-Douglas production function as in (4). Our data cover many years, but we assume that the sector characteristics, that is, the elasticity of total output α_s, and β_s, are constant. We thus assume that the sector fixed effects are constant over time, while country-specific effects can vary with time. The model is estimated without assuming a prior distribution for the fixed effects. Table 2 presents the results of the decomposition analysis. We have also included energy prices in our decomposition, to check whether the country energy abundance variable we construct can indeed be interpreted as coming from differences in energy prices between countries. The first row entry presents the overall standard deviation. The second row presents annual increase in per-labour energy use, capital use, and energy prices. Energy use per labourer has increased by about 3 per cent per year, while capital use per labourer has increased by about 2.3 per cent per year. The third row entry presents the variation when year fixed effects are taken out. The fourth and fifth row present the variation that can be attributed to differences between sectors, and countries, respectively. When these random effects are taken out, we have the residual, which contains only a small part of the initial variation.

The decomposition in Table 2 shows that there is about twice as much variation in energy per labour use compared to capital, suggesting a potentially important role for the energy-interaction mechanism. Furthermore, it shows that most of the variation in energy and capital can be explained by differences between sectors that are common over countries, but that differences between countries and over time, even in this homogeneous sample, are still substantial. The large explained variation of 0.86 and 0.88, respectively, suggests that, within our sample, factor reversal is not an issue. Furthermore, we see that for energy per labour the variation between sectors takes a much larger share as for energy prices, suggesting that not only energy prices but also technology differences between sectors play a marked role. In general, the results seem to validate the decomposition in equations (5) and (6) through (7).

TABLE 2: *Relative factor use decomposition in time, sector and country-effects, as in eq.* (7)

	Energy per labour (2)	Capital per labour (3)	Energy price (4)
Standard deviation	1.72	0.80	0.45
Time trend (increase per year)	0.030	0.023	–0.004
Within year standard deviation	1.70	0.78	0.44
Source of variation*			
Between sectors standard deviation	1.54	0.66	0.24
Between countries standard deviation	0.39	0.23	0.26
Standard deviation residue	0.65	0.27	0.27
Explained variation**	0.86	0.88	0.63

Notes:* By construction, the between-sector and between-countries variation are almost orthogonal to each other and to the variation in the residue. Thus the squares of the three rows below approximately sum to the square of the within-year standard deviation. ** Explained by variation as captured by sector and country dummies.

4.3. Correlates between factor abundance and factor prices

Figure 1 plots relative capital intensity against relative energy intensity of sectors as computed for our sample. The figure shows a clear correlation. Overall, capital intensive sectors also are energy intensive sectors, confirming the result by Mani and Wheeler (1998) for manufacturing sectors. The Services sector is the main outlier as it is a capital-intensive sector, but not particularly energy-intensive. The figure also makes clear that if we estimate the significance of energy-intensity for trade and location, we need to include capital in our analysis to prevent omitted variable bias, or we need to use additional controls with sector-specific coefficients. We do so throughout the analysis.

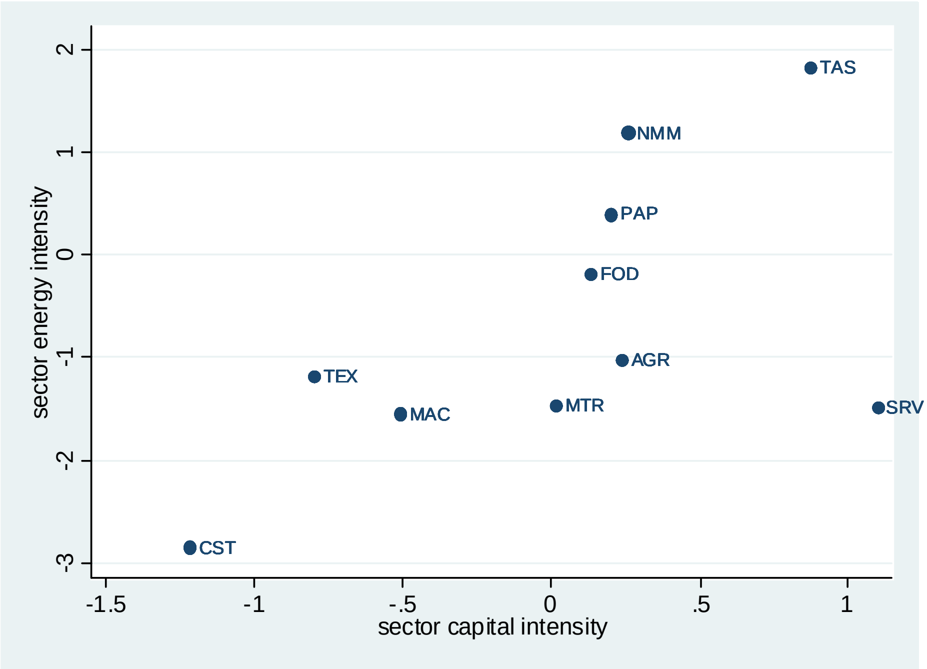

FIGURE 1: *Relative capital and energy intensity of sectors (average over sample period)*[12]

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[12] See appendix table A2 for a description of the sectors.

To understand the country characteristics, we first consider the relation between energy abundance (energy per labour) and energy prices. Figure 2 clearly shows the negative relation. It is consistent with theory, but we need to be cautious, as energy prices may depend on policy decisions and reverse causality might be suspected. We therefore also consider the relation between energy prices and per capita energy production. Figure 3 clearly shows a negative correlation. Causality must run from production to prices as otherwise higher prices would pull production, leading to a positive correlation. Yet, we prefer to use revealed marginal costs of energy through energy use, that is, the energy abundance measure. Figure 4 shows the relation between energy abundance and energy self-sufficiency. The self sufficiency measure is defined as domestic energy production divided by energy use. In the figure, we do not correlate to energy production as such a relation could not be used to distinguish the direction of causality. A higher demand for energy might also spur energy production, but it seems unlikely that energy production is increased more than one-to-one, so that a *positive* causality running from energy consumption to the self-sufficiency ratio is unlikely. Figure 4 shows a clear positive relation from energy endowments (proxied through self-sufficiency) to energy abundance. Throughout the figures we see that Canada, Norway and Australia have the largest endowments, highest energy abundance, and lowest prices. Canada and Norway are both countries that enjoy large oil and hydro endowments. Italy and Japan come out as countries with the least endowments, lowest energy abundance, and highest prices.

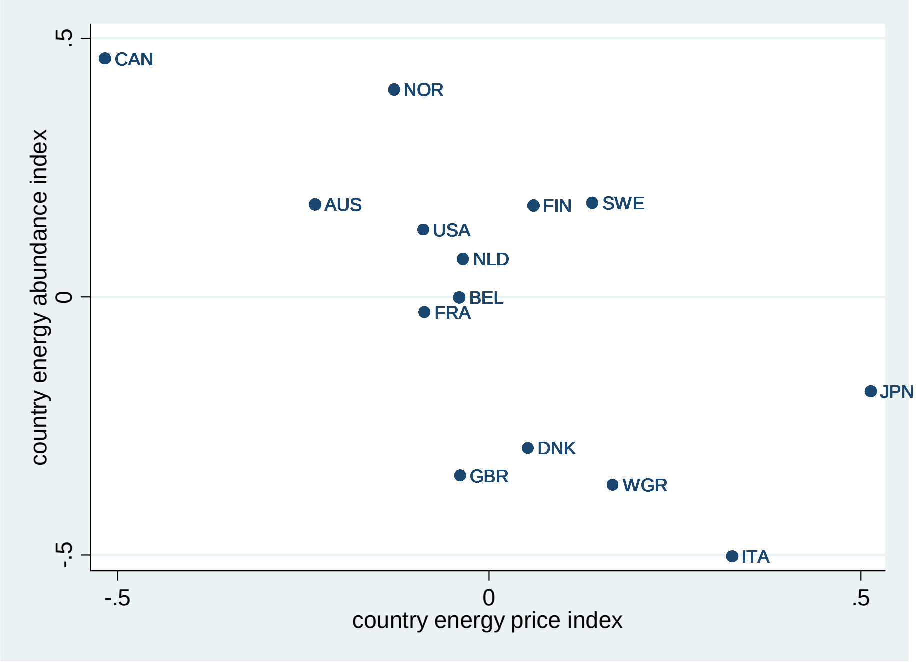

FIGURE 2: *Country energy prices vs. abundance (average over sample period)*

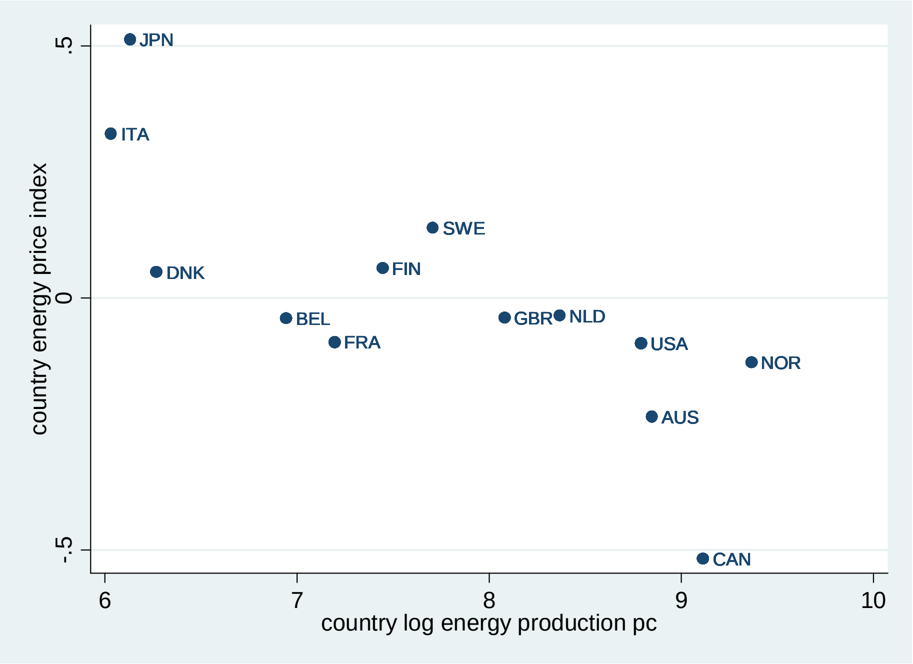

FIGURE 3: *Country per capita energy production vs. energy prices (average over sample period)*

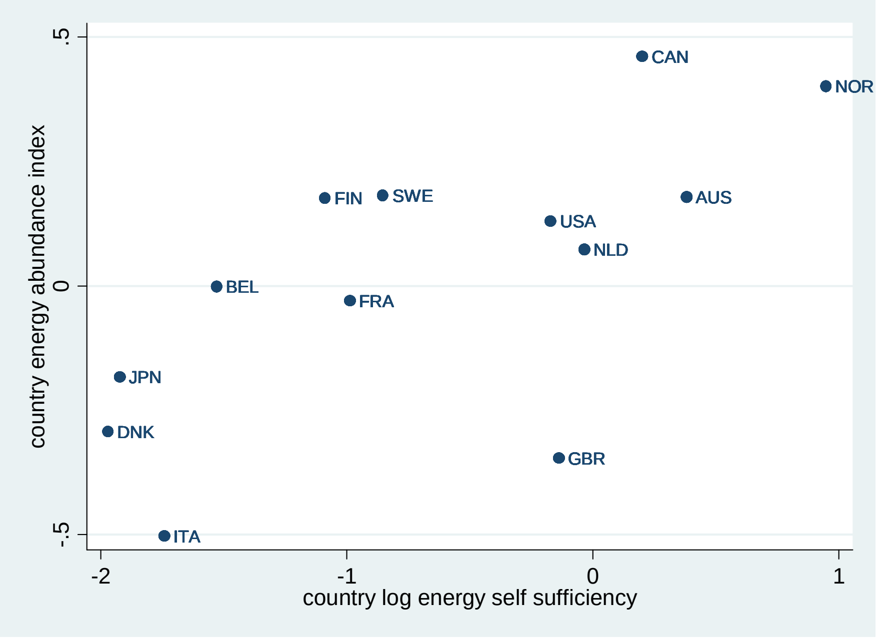

FIGURE 4: *Self-sufficiency index vs. energy abundance (average over sample period)*

Table 3 provides the estimations that give more depth to the figures.[13] We control for land, population, income and savings and use errors clustered within countries to control for persistence. The dependence of energy abundance on the self sufficiency ratio is not significant when controlling for all the other variables. A plausible reason is the high correlation of self sufficiency with land, so there might be a multicollinearity problem. When we leave out land,

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[13] Regression (7), (5), and (8) are associated with Figure 2, Figure 3, and Figure 4, respectively.

the self-sufficiency ratio becomes significant. When we use a robust estimator rather than clustered error terms, we also find highly significant coefficients. In the remainder of the analyses, when we use the self-sufficiency ratio as instrument, we test for its weakness or strength. These aggregate variables are unlikely to be correlated with uncontrolled heterogeneity of trade and economic activity in our sample of sectors. We use the inverse of the energy price as estimated through (5), and regression (8) to instrument for energy abundance throughout the remainder of the text. The interaction terms that multiply the (instrumented) country energy (capital) abundance and sector energy (capital) intensity are normalized to have mean zero and standard deviation unity.

TABLE 3: *Energy endowments, prices and abundance*

	Energy Price (5)	Energy Price (6)	Energy abundance (7)	Energy abundance (8)	Energy abundance (9)
Energy price			–0.465**		
			(–0.333)		
Primary energy	–0.110***			0.110**	
production	(–0.621)			(0.476)	
Energy self-		–0.099***			0.075
sufficiency ratio		(–0.360)			(0.202)
R^2 adj	0.470	0.446		0.412	0.376
N (clusters)	245 (13)	245 (13)		343 (13)	343 (13)

Notes: all variables in logs, beta coefficients in parenthesis, * significant at 10%, ** significant at 5%, *** significant at 1%. Error terms clustered within countries. All regressions include 19 year fixed effects and controls for land, income, savings, and population.

5. Hypotheses and results

In this section, four hypotheses are tested that measure the importance of energy abundance in the determination of three different measures of interest: energy content of trade, net exports and economic activity (value added and employment). The first hypothesis considers the traditional factor content of trade.

HYPOTHESIS 1*: Factor content of trade:* Energy abundant countries export more embodied energy per labour relative to imports.

To measure the factor content of trade, we first construct gross exported (imported) embodied capital, energy, and labour through:

$$K_{i,s}^{X} = K_{i,s}\frac{X_{i,s}}{Y_{i,s}} \;,\; E_{i,s}^{X} = E_{i,s}\frac{X_{i,s}}{Y_{i,s}} \;,\; L_{i,s}^{X} = L_{i,s}\frac{X_{i,s}}{Y_{i,s}} \qquad (12)$$

$$K_{i,s}^{M} = K_{i,s}\frac{M_{i,s}}{Y_{i,s}} \;,\; E_{i,s}^{M} = E_{i,s}\frac{M_{i,s}}{Y_{i,s}} \;,\; L_{i,s}^{M} = L_{i,s}\frac{M_{i,s}}{Y_{i,s}} \qquad (13)$$

where (superscripts) $X_{i,s}$ ($M_{i,s}$) refer to exports (imports) of country i in sector s. We omit the time index for convenience. In fact we are focussing on displaced factor content, in the sense that we are computing the factor content that would be used in the importing country had those imports been produced domestically. This might understate the factor content embodied in trade since importing countries are likely to employ less of the factor if it used location production instead of imports. Since our analysis is not bilateral, we are restricted to this approach. Relative energy intensity of exports (imports), $EI_i^X \left(EI_i^M\right)$, is subsequently constructed through:

$$EI_i^X = \frac{\sum_s E_{i,s}^X}{\sum_s L_{i,s}^X} \quad , \quad EI_i^M = \frac{\sum_s E_{i,s}^M}{\sum_s L_{i,s}^M} \quad , \quad KI_i^X = \frac{\sum_s K_{i,s}^X}{\sum_s L_{i,s}^X} \quad , \quad KI_i^M = \frac{\sum_s K_{i,s}^M}{\sum_s L_{i,s}^M} \tag{14}$$

The relative energy content of trade considers the ratio between EI^X and EI^M. If this ratio exceeds one, then the country exports in sectors that are more energy-intensive compared to the sectors it imports from. A similar measure can be calculated for capital. We take logs and call the variable the energy embodied in trade index. If this index is positive then a country ‘exports’ energy through trade. If this index is negative, the country ‘imports’ energy through trade.

The first hypothesis is concerned with differences between countries; it states that the export-import ratio of embodied energy per labour positively depends on the relevant country endowments:

$$ln\frac{EI_{i,t}^X}{EI_{i,t}^M} = \gamma_E \hat{\theta}_{E,i,t} + \gamma_K \hat{\theta}_{K,i,t} + \phi_t + \varepsilon_{i,t} \tag{15}$$

with $\gamma_E > 0$, and $\hat{\theta}_{E,i,t}, \hat{\theta}_{K,i,t}$ the constructed country pseudo-endowments for both factors. As energy and capital are complements between sectors (Figure 1), we also expect a positive coefficient for $\gamma_{E,K}$. We add year-dummies (φ_t) to control for common shocks such as those on the world market, and assume errors clustered within countries to control for persistence.

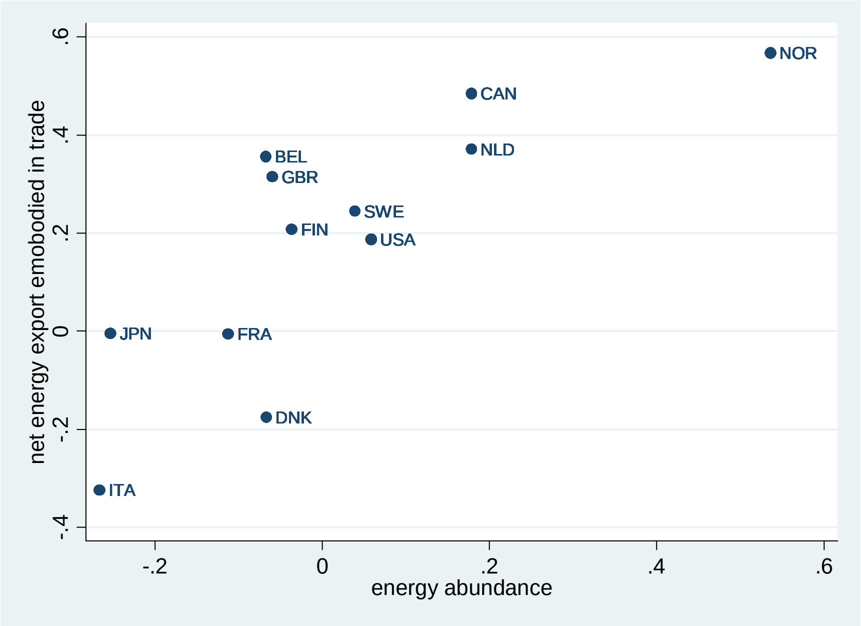

FIGURE 5: *Trade embodied energy vs. energy abundance (average over sample period)*[14]

Figure 5 shows the results qualitatively. Most countries in our sample are net energy exporters embodied in trade. The exceptions are Italy and Denmark, both countries with low levels of energy per labour use. Apparently, countries that have low energy prices (so that sectors have high energy per labour use) export relatively more embodied energy than they import. The figure is supported by the econometric results reported in Table 4. Column (10) shows that energy abundance increases the energy embodied in trade index, that is, it stimulates the export of energy intensive sectors. But the same regression suggests that capital abundance has a negative effect on energy embodied in trade. The result is counter-intuitive, but consistent with the literature on the Leontief (1954) paradox. As the use of capital data substantially reduces our sample, we also estimate in column (11) the relation with various country characteristics substituting for the constructed capital abundance measure. These country characteristics control for differences in sector structure that are related to natural resource abundance (proxied by land), preferences (proxied by income), capital abundance (proxied by savings), and scale effects (proxied by population). We then test robustness of our results using energy production and the energy self-sufficiency ratio for energy abundance in columns (12) and (13), respectively. The robust conclusion emerging from Table 4 is that energy abundance leads to an increased net export of embodied energy.

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[14] In the figure, energy abundance is represented through the energy self-sufficiency ratio as in regression (13). Note that our trade flows are total trade flows and are not limited to the partner countries in the sample.

TABLE 4: *Relative country energy abundance as determinant of relative embodied energy in net trade as in eq.* (15)

	Relative Energy Embodied in Net Trade			
	(10)	(11)	(12)	(13)
Energy abundance	0.523*** (0.657)	0.499** (0.694)		
Energy production pc			0. 222*** (0.928)	
Energy self-sufficiency				0.201*** (0.693)
Capital abundance	–0.426* (–0.270)			
Controls: Land, Population, Income, Savings	no	yes	yes	yes
R^2 adj	0.520	0.494	0.694	0.594
N (clusters)	204 (10)	314 (12)	314 (12)	314 (12)

Notes: all variables in log, beta-coefficients in parenthesis, * significant at 10%, ** significant at 5%, *** significant at 1%. Error terms are clustered in country groups. Seemingly unrelated regressions give similar results. All regressions include 28 year fixed effects.

The second hypothesis tunes in on a more disaggregate level and estimates equations of the form (8). Whereas Romalis (2004) uses a database with trade flows from many countries to one importing country (US), we have a database with gross exports and imports for various countries. We construct two measures of relative net exports and use these as dependent variables. The first measure uses net export per value added, $(X–M)/Y$, while the second measure uses net export per total trade $(X–M)/(X+M)$.

HYPOTHESIS 2*: Trade specialisation:* Energy intensive sectors export more from and import less into countries that have high energy abundance.

We test the hypothesis through a two-way fixed effect model with country*year and sector*year dummies. For the net exports over value added, the econometric model (9) applied with the net export measure as dependent variable. Recall that the fixed effects do not contribute much to the explained variation, as aggregate trade ensures that the average net export is close to zero. Notice also that we do not need to include the linear terms of the interaction variable as the fixed effects cover these linear terms. The hypothesis states that the coefficient on the energy interaction should be positive.

TABLE 5: *Determinants of sector net exports as in eq.* (9)

	Net exports / value added		Net exports / total trade	
	(14) IV Unweighted	(15) IV weighted	(16) IV unweighted	(17) IV Weighted
Energy abundance * energy intensity	0.310*** (0.743)	0.715** (1.711)	0.230** (0.509)	0.529** (1.171)
N (clusters)	3197 (124)	3197 (124)	3401 (130)	3401 (130)
Endogeneity test (p-value)	<1%	<1%	1%	<1%
Identification test (p-value)	<1%	3%	<1%	3%
Weak instrument test (F-stat)	26	6	24	6

Notes: beta-coefficients in parenthesis, * significant at 10%, ** significant at 5%, *** significant at 1%. Error terms are clustered in country-sector groups. Weights based on trade exposure capped at 5 and 95 percentile are used. All regressions include sector-specific controls for land area, population, income and savings. Energy abundance is instrumented with energy self-sufficiency ratio. All regressions include sector*year and country*year fixed effects. Endogeneity test: Ho: regressor is exogenous, Kleinbergen-Paap rk LM Identification test: Ho: underidentification, Weak instrument test: rule of thumb: First stage F-statistic should be at least 10.

Table 5 confirms the aggregate results on the sector level. Energy abundant countries tend to export more in energy-intensive sectors, and this effect increases with exposure to trade. Columns (14) and (15) present results for net exports relative to value added, while columns (16) and (17) report results for net exports relative to total trade, so that the variable is scaled from –1 to 1. All regressions include sector-specific coefficients for land, population, income and savings (in logs), to control for sector structure as influenced by natural resource abundance, scale effects, preferences, and capital availability. Column (14) and (16) do not differentiate between trade-exposed and sheltered sectors. However, not all sectors have the same exposure to international trade. Some sectors are more sheltered and will less easily relocate. In these sectors we would expect to see rather small interaction effects.[15] Hence, column (15) and (17) weigh all observations with the square root of gross trade over value added, capped at the 5 and 95 percentile. All regressions are run allowing error terms to be clustered by country-sector groups and using the energy self-sufficiency ratio to instrument for our energy abundance measure. The coefficients increase when we weigh the observations, showing that the interaction effect is more pronounced for trade-exposed sectors. Note however that there is some risk that the instrument is weak. Weighing by trade exposure is used for all subsequent regressions. The high levels for the β coefficients (in brackets) show that the energy interaction effect is an important variable explaining a good share of the variation in net exports.

The first two hypotheses concerned embodied factors in trade and net trade per sector. We now move to the third step by considering sector activity. If factor abundance indeed is important for industry location as suggested by the trade results above, then one also expects to find the same effect in sector activity measures. Hence, the next question asked is whether highly energy endowed countries have higher economic activity in energy intensive sectors.

HYPOTHESIS 3*: Sector specialization:* Energy intensive sectors have higher activity in energy abundant countries and trade exposure is a transmission channel for sector specialization.

We have data on value added as measure of sector output. We notice though that value added and sector output do not precisely match, not only because of inputs of intermediates, but more

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[15] See for instance Ederington et al (2005) for a deeper analysis into this argument.

importantly, because the observed value added variable includes a price element. Higher prices for factors intensively used will result in higher production costs and lower output levels. Value added, which multiplies prices by volumes, may give ambiguous results. For net trade, used above, the problem does not arise because taking ratios removes the price element. But when we take value added as a measure of sector activity, we may need to instrument it through factor use. Here we consider employment as an alternative measure of activity. Table 6 reports the results for employment, while Table 7 reports the results for value added. Notice that employment and value added have been corrected for population size and the typical sector size so that the fixed effects do not account for much of the explained variation, but only capture unobserved (minor) country and sector characteristics.

TABLE 6: *Determinants of log employment as in eq.* (9)

	(18) IV	(19) IV	(20) OLS	(21) OLS
energy abundance*intensity	0.429*	0.450*	0.030	0.022
	(1.049)	(0.960)	(0.065)	(0.046)
Net exports/value added			0.283**	
			(0.262)	
Net exports/total trade				0.625***
				(0.022)
N (clusters)	4313 (172)	2994 (121)	2994 (121)	2994 (121)
Endogeneity test (p-value)	<5%	<5%	n.a.	n.a.
Identification test (p-value)	<1%	1%	n.a.	n.a.
Weak instrument test (F-stat)	10	9	n.a.	n.a.

Notes: beta-coefficients in parenthesis, * significant at 10%, ** significant at 5%, *** significant at 1%. Error terms are clustered in country-sector groups. Observations are weighed with trade exposure capped at 5 and 95 percentile. All regressions include sector-specific controls for land area, population, income and savings. Energy abundance is instrumented with the energy self-sufficiency ratio in the first two columns. For the last two columns the hypothesis of energy abundance as an exogeneous regressor could not be rejected. Instrumenting net exports by its own lag would lead to very similar results. For comparison, the second column repeats the specification of the first estimation using the sample of the subsequent regressions. All regressions include sector*year and country*year fixed effects. Endogeneity test: Ho: regressor is exogenous, Kleinbergen-Paap rk LM Identification test: Ho: underidentification, Weak instrument test: rule of thumb: First stage F-statistic should be at least 10. n.a. stands for not applicable.

TABLE 7: *Determinants of log value added as in eq.* (9)

	(22) IV	(23) IV	(24) OLS	(25) OLS
energy abundance*intensity	0.728***	0.753***	0.093***	0.083***
	(1.707)	(1.416)	(0.174)	(0.155)
Net exports/value added			0.400***	
			(0.295)	
Net exports/total trade				0.699***
				(0.554)
N (cluster)	4312 (166)	3103 (120)	3103 (120)	3103 (120)
Endogeneity test (p-value)	<1%	<1%	n.a.	n.a.
Identification test (p-value)	<1%	1%	n.a.	n.a.
Weak instrument test (F-stat)	10	9	n.a.	n.a.

Notes: see note Table 6

Results confirm the hypothesis. Relative energy abundance is a significant determinant of economic activity. Energy abundant countries have higher value added and to a less important extent employment in energy-intensive sectors. Finally, when we include net export as explanatory variable, the coefficients for the interaction terms drop substantially, suggesting that trade is a major transmission channel.

HYPOTHESIS 4*: Dynamics:* testing the above hypotheses over time

The above regressions analyze the tendency of energy-intensive sectors to export from and locate in energy-abundant countries. Here, by including fixed effects for all country-sector pairs, these fixed effects will explain all constant export and location effects and the interaction term will capture only a part of the relation that varies over time. Adding country-sector fixed effects is thus a way to capture the dynamics of the relation we're interested in. As both sector energy-intensity and country energy abundance are persistent phenomena, we expect to find reduced coefficients. Notice that as we capture persistence through dummies, we remove the clustered errors.

The results are presented in Table 8. The first observation is that the full fixed effects set increases the explained variation to levels very close to one. Still energy-abundance and energy intensity can add to the explanatory power and are highly significant for all regressions apart for net exports divided by value added. The coefficients are smaller than in the previous regressions, as expected, but still economically important. The significance of energy abundance as an explanatory variable for export performance and industry location is robust.

TABLE 8: *Determinants of trade, employment, and value added as in eq.* (10)

	net exports / value added (26) IV	net exports / total trade (27) IV	employment§ (28) IV	value added (29) IV
energy abundance*intensity	0.057 (0.117)	0.076*** (0.168)	0.051** (0.123)	0.424*** (0.993)
N	3297	3501	4413	4452
Endogeneity test (p-value)	6%	<1%	14%	<1%
Identification test (p-value)	<1%	<1%	<1%	<1%
Weak instrument test (F-stat)	39	40	46	61

Notes: beta-coefficients in parenthesis, * significant at 10%, ** significant at 5%, *** significant at 1%. Observations are weighed with trade exposure capped at 5 and 95 percentile. Energy abundance is instrumented with self-sufficiency. All regressions include year and country*year fixed effects. Increased multicollinearity prevents us from adding additionally sector*year fixed effects. Endogeneity test: Ho: regressor is exogenous, Kleinbergen-Paap rk LM Identification test: Ho: underidentification, Weak instrument test: rule of thumb: First stage F-statistic should be at least 10.

§: The endogeneity test is not able to reject exogeneity of the regressor. When doing simple OLS, the coefficient and its beta-coefficient is given by: 0.021*** (0.050).

6. Conclusion

In this paper we have seen that within a sample of high-income OECD countries, those countries more abundant in energy have higher net exports and attract higher activity in energy-intensive sectors. As we consider the interaction between abundance and intensity, we can also reversely say that those countries with lower energy abundance attract industries that do not require much energy. For the most trade-exposed sectors, the interaction between energy abundance and intensity increases (or decreases) employment and value added by about 10-20 per cent for about one third of the observations.

Our contribution is also methodological. We have developed a method to decompose observed country, sector and year-specific factor use into sector factor intensities and country factor abundance. Our factor abundance measure in this sense captures any effect that changes for the firm relevant factor prices, e.g. energy policy. The decomposition results suggest that, in our sample, factor reversal is not a potential problem and that capital and energy are complements over sectors. It is thus generally recommended to control for capital. As capital data is available for a much reduced sample only, we preferred to control for it by using additional country characteristics with sector-dependent coefficients.

We find that the main variation in energy (capital) use lies with differences between sectors, though even in our homogeneous sample of countries, variation between countries is substantial. We also find that sectors and countries differ much more with respect to energy use per labour as compared to capital use per labour. In this sense, the interaction of country energy abundance with sector energy intensity is potentially important. These results are also confirmed in a dynamic setting.

Our results provide some empirical backing for the pollution haven literature and the carbon leakage literature. The results confirm the hypothesis that energy-intensive firms move to countries that support higher levels of energy use, either through rich endowments or policy measures. Hence we have identified an "energy haven effect" in our sample. Our results do not confirm the hypothesis that capital abundance plays a major role in attracting energy-intensive industries. We notice though that our sample is relatively homogeneous with respect to income and thus to study the role of capital more precisely we need to extend our country sample to include both capital-rich and capital-poor countries. For this reason our results can not be interpreted in the context of carbon leakage between high-income and low-income countries.

Within the sample of high-income OECD countries, insofar as that the differences in energy abundance between countries is caused by differences in policies, levelling the energy abundance can play a role in reducing overall energy use. Norway has abundant supply of hydropower, and the integration of Norway in the Nordic electricity market, and subsequently in the European electricity market may increase the value to Norway of this natural resource. At the same time, such integration may level energy prices across Europe, so that energy prices in Norway may substantially increase and energy intensive industries may consider Norway less profitable. When energy-intensive industries relocate to countries with lower energy abundance, they reduce their energy use. Integration of the energy market may thereby pay both an economic and an environmental dividend.

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Appendix 1. Data Description

TABLE A1: *Countries in the sample*

Abbrevation	Country
AUS*	Australia
BEL	Belgium
CAN	Canada
DNK	Denmark
FIN	Finland
FRA**	France
WGR	Germany, West
ITA	Italy
JPN**	Japan
NLD**	Netherlands
NOR	Norway
SWE	Sweden
GBR	United Kingdom
USA	United States

Notes: * for Australia, there is no data on trade, ** for these countries, capital data is insufficient and hence they are excluded in the analysis when energy and capital are studied jointly.

TABLE A2: *Sectors in the sample*

Abbreviation	Description	ISIC Rev. 2 code
AGR*	Agriculture	10
FOD	Food and Tobacco	31
TEX	Textiles and Leather	32
WOD**	Wood and Wood Products	331, without furniture
CHE**	Chemicals	351+35, includes non-energetic energy consumption, i.e. energy carriers as feedstock
NMM	Non-Metallic Minerals	36
PAP	Paper, Pulp and Printing	34
IAS**	Iron and Steel	371
NFM**	Non-Ferrous Metals	372
MAC	Machinery	381+382+383
MTR	Transport Equipment	384
CST*	Construction	50
SRV*	Services	61+62+63+72+81+83+90
TAS*	Transport	71

Notes: * for these sectors, trade data are missing; ** for these sectors, capital data are missing.
Note that trade data is, apart from agriculture, missing for sectors producing non-tradables and hence this does not further restrict our analysis.

TABLE A3: *Variable Description*

Variable	Description	Dimension	Data source
Capital	Net capital stock, 1990 prices, US$	year-country-sector	ISDB-E
Labour	Total employment	year-country-sector	ISDB-E
Energy	Energy consumption in ktoe	year-country-sector	ISDB-E
Exports	Exports of goods in US$	year-country-sector	ISDB-E
Imports	Imports of goods in US$	year-country-sector	ISDB-E
Value added	Gross value added, 1990 prices, US$	year-country-sector	ISDB-E
Energy Price	Energy price per ktoe, 1990 prices, US$	year-country-sector	ISDB-E
W	Labour payment per employment	year-country-sector	ISDB-E
Energy production	Energy production in kt of oil equivalents	year-country	WBDI 2009
Energy consumption	Energy consumption in kt of oil equivalents	year-country	WBDI 2009
Income	GDP PPP constant international dollars per capita	year-country	WBDI 2009
Land	Area in sq. km	country	IDB 2009
Population	Mid-year population in thousands	year-country	IDB 2009
Savings	Domestic savings per GDP	year-country	WBDI 2009

Notes: ISDB-E: International Sectoral Database with Energy, WBDI: World Bank Development Indicators, IDB: International Database from US Census bureau (www.census.gov/ipc/www/idb/region.php)

Country-sector energy data:

Energy consumption (ISDB-E): Total Final Energy Consumption in kilo tonnes of oil equivalent (Ktoe), a common unit to express total energy consumption from different energy carriers. Ktoe is calculated by converting the different units for the different energy carriers (such as GWh, GJ and Gcal) to one common unit, using standard conversion factors (see www.iea.org/statist/calcul.htm).

Country energy data:

Energy consumption (WBDI 2009): Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. Source: IEA.

Energy production (WBDI 2009): Energy production refers to forms of primary energy--petroleum (crude oil, natural gas liquids, and oil from nonconventional sources), natural gas, solid fuels (coal, lignite, and other derived fuels), and combustible renewables and waste--and primary electricity, all converted into *oil* equivalents. Source: IEA.

Appendix 2. Determinants of relative energy intensity

TABLE A4: Relative energy intensity

	Energy/Labour
Capital/Labour	0.669***
	(0.0717)
Energy price	-0.857***
	(0.065)
N	1070
FE country*year + sector*year	321
R2 within	0.796

Notes: Standard errors in parenthesis, * significant at 10%, ** significant at 5%, ***significant at 1%.

Appendix 3. Testing the methodology

In addition to the two in the text addressed econometric challenges (the endogeneity of energy abundance addressed by the instrumental variable approach and unobserved heterogeneity best controlled for with a set of additional control and dummy variables) we face the problem of generated regressors. Since we computed energy abundance (and energy intensity) with a regression, we have to control for potential biases of our coefficients. Below results are simulated.

To test the two-stage estimation procedure employed in the main text we conducted a Monte Carlo simulation. In the first stage of the estimation procedure, we estimate country abundance characteristics and sector intensity attributes. In the second stage, we use the estimated coefficients as independent variables in another regression. Here we report the results of a test concerning the method's efficiency and possible bias in the estimation of coefficients.

The simulation is run 100 times (iterations). In each iteration, we construct an artificial data set of 10 'countries' by 10 'sectors'. Each country has a factor-abundance characteristic θ_i and each sector has a factor-intensity attribute π_s. Parameters are drawn from the distribution $\theta_i \sim N(0,\sigma(\theta))$ and $\pi_s \sim N(0,\sigma(\pi))$ with $\sigma(\theta)=\sigma(\pi)=1$. Relative factor use in a sector is then constructed following

$$F_{i,s} = \theta_i + \pi_s + \varepsilon_{i,s}, \qquad (16)$$

with $\sigma(\varepsilon)=1$, and sector activity is constructed based on

$$Y_{i,s} = \gamma\theta_i\pi_s + \delta_i + \varphi_s + \mu_{i,s,t}, \qquad (17)$$

with $\sigma(\mu)=\gamma=1$.

After having constructed the data, we start the procedure for estimating γ as used in the main text. We first estimate θ_i and π_s as the fixed effects dummies in (16), and then substitute the estimated parameters $\hat{\theta}_i$ and $\hat{\pi}_s$ in (17) to estimate γ. We collect the estimate for γ and the reported standard deviation over all 100 iterations. The table below reports the results. The results show that the estimate for γ is structurally biased downwards by about 19 per cent. The reported standard error of the estimate is also biased downwards compared to the standard deviation of the reported estimates. Both downwards estimates are common when one uses imperfectly observed independent variables and are thus not a special consequence of the two-stage procedure.

TABLE A5: *Estimates for γ over 100 iterations (true value is 1)*

	Mean value over 100 iterations	Standard deviation over 100 iterations
Reported estimate	0.811	0.194
Reported standard deviation	0.129	0.043

Table A6 compares bootstrapped standard errors (1000 repetitions) with the OLS standard errors and shows that differences are relatively small. Estimates are based on unweighted regressions in Table 5 where the set of dummy variables has been dropped to speed up the runs.

TABLE A6: *Comparison of OLS and bootstrapped standard errors for main specification*

Energy abundance * energy intensity	Net exports / value added	Net exports / total trade
OLS	0.0070099	0.0070069
Bootstrapped	0.0075945	0.006562
% Difference	8.3%	-6.3%
N	3197	3401

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