ISSN 2042-2695

CENTRE *for* ECONOMIC PERFORMANCE

CEP Discussion Paper No 1454

November 2016

On the Comparative Advantage of U.S. Manufacturing: Evidence from the Shale Gas Revolution

Rabah Arezki
Thiemo Fetzer
Frank Pisch

LSE THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Abstract
This paper provides novel empirical evidence of the effects of a plausibly exogenous change in relative factor prices on United States manufacturing production and trade. The shale gas revolution has led to (very) large and persistent differences in the price of natural gas between the United States and the rest of the world reflecting differences in endowment of difficult-to-trade natural gas. Guided by economic theory, empirical tests on output, factor reallocation and international trade are conducted. Results show that U.S. manufacturing exports have grown by about 10 percent on account of their energy intensity since the onset of the shale revolution. We also document that the U.S. shale revolution is operating both at the intensive and extensive margins.

Keywords: manufacturing, exports, energy prices, shale gas
JEL codes: Q33; O13; N52; R11; L71

This paper was produced as part of the Centre's Trade Programme. The Centre for Economic Performance is financed by the Economic and Social Research Council.

Acknowledgements
We thank Tim Besley, Olivier Blanchard, Prakash Loungani, Guy Michaels, Akito Matsumoto, Gian Maria Milesi-Ferretti, Caroline Freund, Maury Obstfeld, Gianmarco Ottaviano, Rick van der Ploeg, Daniel Sturm, Tony Venables, Wei Xiong and numerous IMF colleagues for detailed comments and discussions. Fetzer acknowledges support from the Kondrad-Adenauer Foundation, STICERD and CAGE. Pisch acknowledges support from the German Academic Scholarship Foundation and CEP.

Rabah Arekzi, Research Department of the International Monetary Fund, Washington DC. Thiemo Fetzer, University of Warwick. Frank Pisch, Centre for Economic Performance, London School of Economics.

Published by
Centre for Economic Performance
London School of Economics and Political Science
Houghton Street
London WC2A 2AE

> Our 100-year supply of natural gas is a big factor in drawing jobs back to our shores. Many are in manufacturing – the quintessential middle-class job. During the last decade, it was widely accepted that American manufacturing was in irreversible decline. [...] And today, American manufacturing has added more than 700,000 new jobs. It's growing almost twice as fast as the rest of the economy. [1]
>
> - President Barack Obama

> We came to the conclusion this – the shale revolution – will be a sustainable advantage for the United States. That is why we are comfortable making an investment.[2]
>
> - Hans-Ulrich Engel, BASF North America Chief

1 Introduction

The United States is in the midst of an energy revolution. It all started in the 1980s with an independent company founded by the late George Mitchell. His company had been experimenting with the application of different hydraulic fracturing techniques – a well stimulation technique in which rock is fractured by a hydraulically pressurized liquid – eventually finding the right approach to economically extract the natural gas in the Barnet shale formation in Texas. Later on, the combination of hydraulic fracturing and directional, i.e. non-vertical, drilling was widely adopted by the gas industry, in turn spawning a natural gas boom in North America in the 2000s. The surge in the production of shale gas has made the United States the largest natural gas producer in the world. Anecdotal evidence from news reports indicates that the dynamics in manufacturing capacity expansions have accelerated as a result of U.S. shale employment, with non U.S.-based chemical producers having recently announced USD 72 billion worth of investment in new plants.[3] As exemplified by the quotes above, the shale gas

[1] Excerpt from remarks at Northwestern University on October 2, 2014. See http://www.whitehouse.gov.

[2] Excerpt from an interview with Bloomberg News on June 27, 2014, http://www.bloomberg.com

[3] See http://www.bloomberg.com.

revolution has sparked a policy debate on the potential implications of this revolution on the U.S. economy.

The present paper addresses a basic economic question, namely what are the effects of a change in the price of a production input (natural gas), in one country relative to other countries, on the pattern of production and trade. The shale gas revolution provides a quasi-natural experiment to explore such a question. The identifying assumption throughout this paper is, indeed, that the international difference in natural gas prices resulting from a shock to natural gas endowment in the U.S. is unanticipated and quasi-exogenous.

Natural gas has the lowest energy density, measured by the amount of energy stored in a given unit of matter, among all fossil fuels (petroleum products, natural gas, and coal). Even with pipelines, long distance trade of natural gas from the point of extraction becomes uneconomical quite quickly, as the gas in the pipeline needs to be cooled and pressurized, which uses up significant amounts of energy. Liquefaction at origin and re-gasification at destination are the only other means for long distance trade. However, the laws of physics governing liquefaction and re-gasification imply an exogenously given lower bound on transport costs, which is substantial: the energy loss from the liquefaction process alone is estimated to range between 11-30 percent. Add to that the costs of transportation, storage and operating.[4]

Natural gas markets are much less integrated compared to markets for other fossil fuels.[5] It is not surprising, therefore, that following the shale gas boom in the U.S. natural gas prices have fallen sharply and are effectively decoupled from those in the rest of the world. Figure 1 presents the tight relationship between the estimated U.S. natural gas reserves, a measure of the natural gas endowment, and the absolute price gap between the US and an OECD Europe average. The estimated technologically recoverable natural gas reserves have more than doubled since 1997 due a combination of horizontal drilling and hydraulic fracturing, rendering shale deposits accessible. We use this unanticipated exogenous shock to provide us with the necessary identifying variation for our empirical analysis.

[4]Appendix A.1 provides more details on the physics of natural gas transportation and the implied transportation costs.

[5]In Appendix Figure A2 we document that there is very limited trade in natural gas. The only significant direct natural gas export is trade between the US and Mexico and Canada; our results are robust to removing these countries from the analysis.

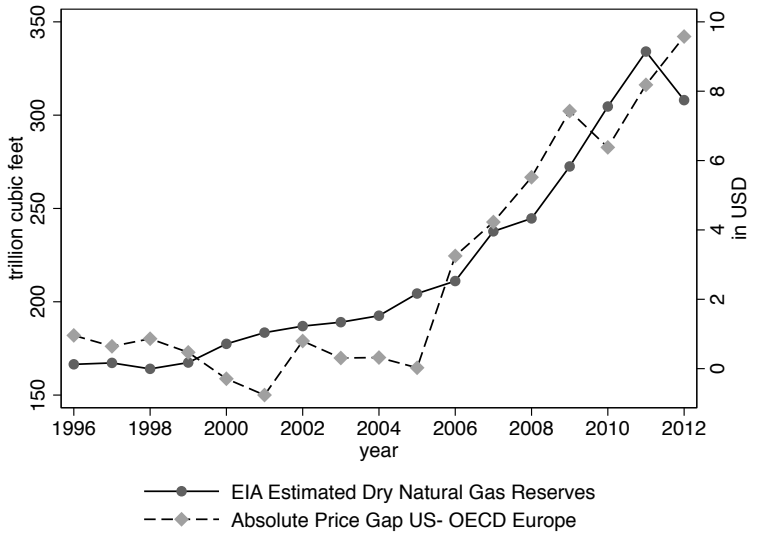


Figure 1: Evolution of estimated Natural gas reserves and absolute US-OECD Natural Gas Price Gap

Notes: On the left axis the figure presents EIA estimates of natural gas reserves, the right axis presents the industrial use natural gas price gap between the U.S. and OECD Europe.

As indicated in Figure 1, the expansion of the recoverable natural gas reserves closely tracks the evolution of the natural gas price difference between the US and the OECD average. For instance, in August 2014 U.S. natural gas sold at 4 dollars per million British thermal units, compared to 10 dollars in Europe and close to 17 dollars in Asia. Figure 1 also illustrates that the price differences arising from the shale gas production boom can econometrically serve as a measure of the U.S. endowment shock.

To help guide our empirical investigation and facilitate a discussion of the mechanisms at play, we rely on a theoretical framework that provides several testable predictions for the effects of a change natural gas prices on output, factor re-allocation, and trade. We derive our main predictions from a state-of-the-art two country, two factors, two industries model with heterogeneous firms as in Bernard et al. (2007). This modelling choice is motivated by a large literature in international trade that highlights the important role heterogeneous firms play for aggregate exports and imports.[6] Indeed, shocks that increase competition in

[6]For a recent overview of this literature see Melitz and Redding (2014).

an industry lead to exit of the least productive firms and hence boost aggregate productivity in that sector.[7] This is an important channel in our context, since the famous Heckscher-Ohlin results may cease to hold in such a world: If the industry that uses energy relatively *less* intensively is left much more competitive after a positive energy endowment shock, selection may make it sufficiently more productive to actually attract resources and increase its output relative to the energy intensive sector. Similarly, exporters in the *less* energy intensive industry might become more productive or more numerous, thus overturning the standard international trade implications found in neo-classical models. We prove, however, that selection forces actually *reinforce* the standard reallocation mechanisms and therefore the main predictions of our model amount to standard "Heckscher-Ohlin specialization according to comparative advantage" in that an increase in the price gap between the U.S. and other countries will increase (decrease) output, factor usage, and the volume of US exports (imports) differentially more in relatively more energy intensive industries.

Even crude motivational summary statistics reveal evidence in support of these theoretical predictions. Figure 2 presents a measure of the energy intensity of overall U.S. manufacturing sector output, exploring energy intensity coefficients drawn up from time-varying input-out (IO) tables. The dynamic of the absorption of energy in output co-moves tightly with the natural gas price gap between the U.S. and OECD Europe. In the empirical exercise, we show that there is robust evidence that the U.S. economy behaves much in the way theoretically predicted. Manufacturing sector output of energy intensive industries expands relative to less energy intensive sectors in response to the endowment shock. Further, we present evidence suggesting that other factors of production, labor and capital, have also differentially moved towards those manufacturing sectors that are energy intensive.

The theoretical predictions moreover suggest that in response to the endowment shock U.S. manufacturing exports should absorb more of the now abundant factor. Again, there is evidence suggesting that this is taking place in the raw data. Figure 3 suggests that the rise in U.S. manufacturing exports weighted by their 2002 energy intensity moves in line with the rise in the price gap (our proxy for the endowment shock) between the U.S. and the rest of the world. In the empiri-

[7] See Melitz (2003).

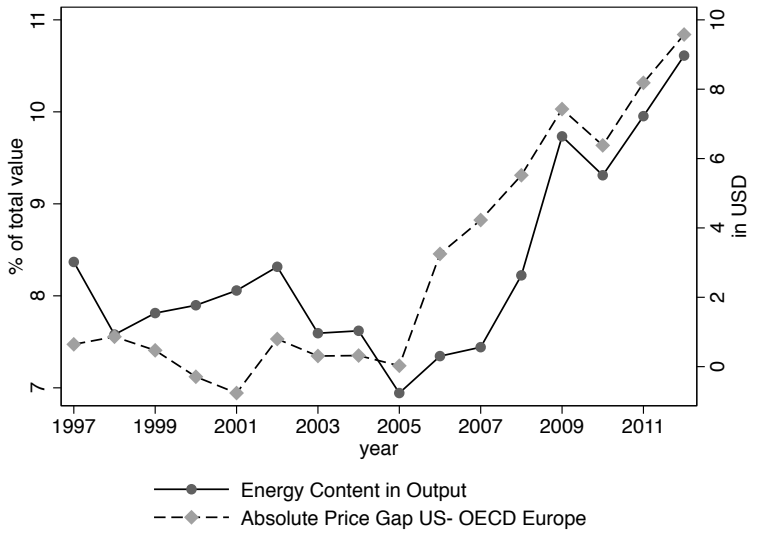


Figure 2: Evolution of the energy content of US Exports and absolute US-OECD Natural Gas Price Gap

Notes: On the left axis the figure presents a time varying measure of the energy intensity of U.S. manufacturing output, using IO tables produced by the BEA for the years 1997-2012. The right axis presents the industrial use natural gas price gap between the U.S. and OECD Europe.

cal exercise, we show that this finding is robust to highly demanding fixed effects specifications, which allow us to absorb many of the classical omitted variables, such as time-varying trade costs, that make it difficult to estimate and causally interpret estimated coefficients in gravity equations. The results suggest that energy intensive manufacturing sectors significantly benefit from reduced natural gas prices due to the shale gas shock. A back of the envelope calculation suggests that energy intensive manufacturing sector exports increased by USD 101 billion for 2012 due to the shale gas boom.

This paper and its findings contribute to several strands of the literature. First, we add to a substantial body of work devoted to testing the central prediction of what is known as the Heckscher-Ohlin-Vanek (HOV) framework, namely that countries net export the factors they are relatively abundantly endowed with.[8]

[8]For very good reviews of this research see Baldwin (2008) and Feenstra (2015). Seminal contributions include Leontief (1953), Trefler (1995), Davis and Weinstein (2001), and Choi and Krishna (2004). More recently, Debaere (2014) has shown that water abundant countries export water intensive goods, using a cross country regression approach.

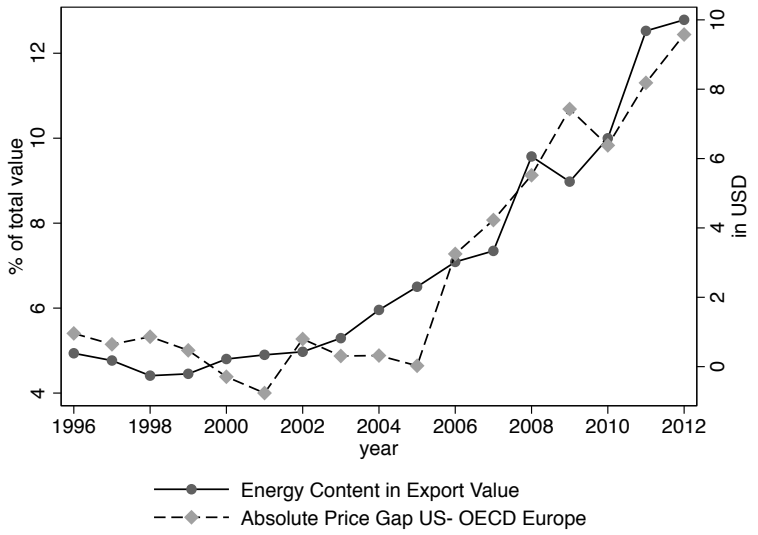


Figure 3: Evolution of the energy content of US Exports and absolute US-OECD Natural Gas Price Gap

Notes: On the left axis the figure presents U.S. manufacturing exports weighted by their total energy intensity according to energy cost shares derived from the 2002 U.S. IO table. The right axis presents the industrial use natural gas price gap between the U.S. and OECD Europe.

This literature uses data for a range of countries and relates a country's factor content of net trade to that country's relative endowment structure. It generally finds that (under the assumption of different technologies in different countries) there is reasonable empirical support for the HOV prediction. Our work proposes an alternative test using quasi-experimental variation in the data for a single country – to our best knowledge this has not been done before. We show that the HOV prediction is accurate: holding energy contents constant at pre-levels, we show that energy intensive trade differentially grows due to an increase in the U.S. endowment with natural gas. Moreover, using the same empirical strategy, we also provide evidence that the neo-classical predictions regarding specialization according to endowment driven comparative advantage on the domestic production side (known as the Rybczynski Theorem[9]) appear to obtain in the data; both output and production factors are reallocated towards energy intensive industries

[9]Other work that tests the Rybczynski Theorem includes Harrigan (1995), Harrigan (1997), and Bernstein and Weinstein (2002).

as a consequence of the shale gas boom.

The second strand of literature explores the economic consequences of lower energy prices, and specifically natural gas prices, following the shale gas revolution. Most of the existing work has focused on the first order local economic effects of the shale gas boom. These papers study the direct effects of resource extraction activity on incomes, the distribution of income, and the local economic structure.[10] Some of the available estimates indicate that the fracking boom in the U.S. may have created between 400,000 and 800,000 new jobs over the last 10 years (see Feyrer et al., 2015; Fetzer, 2014). This paper contributes by exploring the indirect effects of the shale gas boom, not at the point of extraction, but rather how it propagates via lower energy cost, stimulating economic activity in the energy intensive manufacturing sectors. It also relates to Hausman and Kellogg (2015) who estimate the welfare gains from lower natural gas prices to natural gas consumers and producers.[11] Our paper contributes to this literature by widening the scope of analysis of the effect of the shale gas boom to international trade.

Lastly, by focusing on the U.S. manufacturing sector, this paper also relates to a strand of literature investigating the evolution of U.S. manufacturing. Important contributions in this literature have explored the employment implications of U.S. trade liberalization, mainly vis-à-vis China. Implicitly, that amounts to testing the importance of China's comparative advantage in terms of lower labor costs. Pierce and Schott (2012b) find evidence for the link between the sharp drop in U.S. manufacturing employment and a change in U.S. trade policy that eliminated potential tariff increases on Chinese imports. Harrison and McMillan (2006), using firm-level data, find that off-shoring by U.S. based multinationals is associated with a (quantitatively small) decline in manufacturing employment.[12]

[10] See for example Allcott and Keniston (2013), Fetzer (2014) and Feyrer et al. (2015) in the context of the US and Aragón and Rud (2013), Sachs and Warner (1995), van Wijnbergen (1984) in context of developing countries.

[11] Two recent studies have exploited sector level data to isolate the effect of lower energy prices on the manufacturing sector but not on trade. Using industry-level data, Melick (2014) estimates that the fall in the price of natural gas since 2006 is associated with a 2.3 percent increase in activity for the entire manufacturing sector, with much larger effects of 30 percent or more for the most energy-intensive industries. Celasun et al. (2014) find that a doubling of the natural gas price differential in favor of the home country would increase manufacturing industrial production by 1.5 percent.

[12] Autor et al. (2013) analyze the effect of rising Chinese import competition between 1990 and 2007 on US local labor markets. The authors find that rising imports cause higher unemployment,

Our contribution to this literature is to document systematic evidence of a noticeable relative expansion of energy intensive manufacturing sector employment in the U.S., which we attribute to significantly lower natural gas prices. We argue that the difference in natural gas prices between the U.S. and the rest of the world is not transitory, but rather persistent in nature due to the physical properties of natural gas and the distance to foreign markets. The sizable gap in natural gas prices between the U.S. and the rest of the world might to some degree help limit U.S. comparative "dis-advantage" in terms of labor costs.

The remainder of the paper is organized as follows. Section 2 discusses the theoretical framework, while Section 3 presents the comparative static exercise that we bring to the data. Section 4 describes the various datasets used, while Section 5 lays out the empirical strategy. Section 6 presents the main results and robustness checks. Section 7 concludes.

2 Conceptual Framework

In this section we outline a theoretical framework that will guide and inform our empirical exercises. As mentioned above, we derive our main predictions from a two country, two factors, two industries model with heterogeneous firms as in Bernard et al. (2007). Since the theoretical model itself is not part of our contribution and has been analyzed in detail before in Bernard et al. (2007), we will keep the exposition brief and spend more time on the four key predictions we derive for a change in the endowment of natural gas.[13]

2.1 Set-up and Industry Technology

There are two countries, indexed by k, l[14] and they are both endowed with energy in the form of natural gas, $\bar{N}^k$, and with an aggregate factor $\bar{L}^k$ that comprises all

lower labor force participation, and reduced wages in local labor markets that house import-competing manufacturing industries. Import competition explains one-quarter of the contemporaneous aggregate decline in US manufacturing employment.

[13] In contrast to this paper, Bernard et al. (2007) only discuss the effects of a trade liberalisation. Huang et al. (2016) analyze the effect of an increase of capital on Chinese trade patterns in a quantified model similar to ours. Since our contribution is identification through quasi-experimental variation, we view their work as complementary.

[14] Our exposition will be limited to expressions for country k whenever sufficient.

other inputs. We do not have to take a stance on the pattern of relative abundance, since this will be the object of our comparative static exercise. Both factors are perfectly mobile across industries, but cannot cross country borders – factor prices w_N^k are equalized across industries.

There are two industries[15], indexed by $i, j \in \{1, 2\}$, whose technologies are available everywhere and whose respective goods are produced by combining the two inputs in a Cobb-Douglas fashion (with energy intensity β_i). Finally, there is a heterogeneous Hicks neutral output shifter denoted by φ, which is specific to every firm in those industries. Marginal costs are therefore

$$MC_i^k(\varphi) = \frac{(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}}{\varphi}.$$

The goods manufactured by the two industries can be produced in an infinite multitude of horizontally differentiated varieties and there is monopolistic competition among active firms in their respective markets. We assume that international trade of merchandise is possible, but costly in the sense that when a quantity x is shipped, only x/τ_i units arrive at the destination. Trade costs are allowed to differ across goods, but not across varieties within the same industry.

2.2 Consumers

The representative consumers in the two countries have CES preferences over all available varieties of either good and spend a share α_i on each industry $i's$ output, where $\alpha_i + \alpha_j = 1$. They are willing to substitute different varieties for each other, but imperfectly so with a constant elasticity of substitution $\sigma > 1$. These assumptions give rise to standard CES demand functions and ideal price indices P_i^k.

[15]While obviously stylized, the $2 \times 2 \times 2$ structure we use for our conceptual framework is rich enough to provide us with a sizable set of predictions, so that we refrain from discussing the complications of larger product and factor spaces and the intricacies of existence and uniqueness of equilibria in these settings. Huang et al. (2016) extend the model in Bernard et al. (2007) to a continuum of goods and show that the predictions for an endowment shock are essentially equivalent to the ones we find.

2.3 Firms

Firms operate under increasing returns to scale according to the cost function

$$C_i^k(\varphi) = \left(f_{id} + \frac{q_i}{\varphi} \right) (w_N^k)^{\beta_i} (w_L^k)^{1-\beta_i},$$

where fixed costs f_{id} are industry specific. All costs in our model are paid for in units of the same Cobb-Douglas factor bundle $(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}$. Furthermore, anticipating the equilibrium outcome, increasing returns to scale ensure that any variety is produced only by a single firm.

There is free entry and a perfectly competitive mass of potential entrants can pay a sunk cost $f_{ei}(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}$[16] to draw their productivity parameter φ from a Pareto distribution with shape parameter γ and lower bound 1. As every firm ends up producing a specific variety, we will index varieties by φ. We furthermore assume that there are fixed costs of exporting $f_{ix}(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}$, with $f_{ix} > f_{id}$, which reflects the need for maintenance of a distribution network or marketing expenditure abroad. The ordering of fixed costs furthermore generates the well documented empirical pattern that only the most productive firms export (see Bernard and Jensen, 1995, 1999).

2.4 General Equilibrium and Factor Price Equalization

For reasons of expositional clarity we defer the solution of the model and a statement of the equilibrium conditions to appendices B.1 and B.1.2.

The key explanatory variable in our empirical exercises is the difference in natural gas prices between the US and Europe, so that our theoretical model must allow for factor prices to differ across countries. The first assumption that breaks the factor price equalization theorem that applies in standard neo-classical models is the one of strictly positive trade costs, which entails that the law of one price fails. Secondly, firm heterogeneity and endogenous selection can give rise to Ricardian productivity differences across countries at the industry level and therefore to different (industry weighted) marginal products of both factors.

[16] With this specification of the entry technology we follow Caliendo et al. (2015) just like Bernard et al. (2007) do. This is not without loss of generality, but allows for a much simpler solution of the model.

The next section presents the theoretical predictions regarding an exogenous endowment shock to U.S. natural gas.

3 The Natural Gas Boom: Predictions

We model the shale gas boom in the U.S. as an increase in country k's energy endowment. Figure 1 indicated a tight relationship between a measure of the U.S. natural gas endowment and the price gap of natural gas in the U.S. and OECD Europe. Since it is very difficult to measure endowments, especially across countries, we resort to relative prices as our preferred variable, for which data are more readily available.[17]

Our comparative static exercise is as follows. We explicitly outline the implications of an exogenously driven fall in the relative price of energy in country k that increases the price gap with country l in equilibrium – in other words, we compare equilibria with different factor prices just as in the empirical section below. Implicitly, we think of this effect as caused by an increase in k's endowment with energy. We choose this formulation to present our predictions in a way that is consistent with our data.[18]

The key object in our analysis is k's industry level marginal cost relative to the marginal cost in the same industry in l,

$$\hat{w}_i \equiv \left(\frac{w_N^k}{w_N^l}\right)^{\beta_i} \left(\frac{w_L^k}{w_L^l}\right)^{1-\beta_i}, \qquad i \in \{1,2\}.$$

As we show in our derivations, all endogenous expressions of interest can be written in terms of this ratio. In fact, this is intuitive: in a supply side economy like

[17] It may be argued that the shale gas boom is better conceived of as a technological innovation that made the extraction industry more productive. The implications of the two alternatives, technology or endowments, are virtually the same if we model technological advances in natural gas extraction as an increase in efficiency units. Alternatively, if the extraction industry itself is small compared to the rest of the economy, the general equilibrium effects of a technological advancement on wages, capital rents, and other factors of production will be second order and the results obtained by our modelling choice will be very similar. Finally, international trade in natural gas is prohibitively expensive and therefore our approach may be viewed as more natural.

[18] In order illustrate our results, we have quantified the model as shown in appendix B.3. In these quantitative exercises we linearly increase the U.S. endowment with natural gas, which will be analogous to the empirical results over time, since shale gas extraction capacity has gradually increased over several years.

ours with a relatively mechanical 'inactive' demand side, all shocks are captured by relative factor prices and, hence, marginal costs.

Ahead of our main results below, it will prove useful to first examine the behavior of aggregate industry productivity. We show in appendix B.2 that there is a one-to-one relationship between relative factor prices and relative aggregate productivity at the industry level. What is more, we demonstrate that aggregate productivities move *in tandem* with relative marginal costs in the sense that the effects of shocks that change relative factor prices will be *amplified* by the aggregate productivity response, not dampened.

The corollary of this result is that our economy in fact behaves in a very similar way to a standard neo-classical one, except that all variables will be more responsive to shocks that change relative factor prices in equilibrium. Even more importantly, we can expect that Rybczynski and Heckscher-Ohlin style predictions can be derived.

3.1 The Domestic Economy: Factor Intensity and Output Effects

In this subsection we use our theoretical framework to outline predictions with respect to the domestic economy. For ease of exposition, we start with the predictions for gross output. We can show that the value of gross output at the industry level,

$$R_i^k = \alpha_i R^k \frac{1 - l_i \frac{R^l}{R^k}}{1 - c_i \hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}, \tag{1}$$

where R_k are total revenues,

$$l_i \equiv c_i \frac{\hat{w}_i^{\frac{\sigma\gamma}{\sigma-1}} - c_i}{1 - c_i \hat{w}_i^{\frac{\sigma\gamma}{\sigma-1}}},$$

and $c_i \equiv \tau_i^{-\gamma} (f_{ix}/f_{id})^{\frac{-\gamma+\sigma-1}{\sigma-1}}$.

Using the fact that in the case of a fall in relative energy prices $\hat{w}_i$ will experience a greater fall if an industry is more energy intensive, we can derive our first prediction:

Prediction 1 (Quasi-Rybczynski) *An increase in the price gap between the U.S. and OECD Europe will increase output differentially more in relatively more energy intensive industries.*[19]

The intuition is as follows. First, we condition on industry productivity, i.e. we hold the set of active firms fixed, which leaves us with a standard neoclassical model *at the industry level*, in which the Rybczynski theorem applies and well known mechanisms operate: The shale gas boom lowers the relative price of energy and the industry that uses energy more intensively will attract the lion's share of the natural gas that has become available. As it requires more of the composite input as well, w_L^k is bid up, so that the other industry is willing to release it. In equilibrium, there will be reallocation of resources towards the sector that uses the now more abundant factor more intensively.

As argued above, it turns out that the intra-industry selection effects will *amplify* this movement and hence act as a second driving force behind prediction 1. In particular, lower marginal costs in the energy intensive industry will *ceteris paribus* raise *ex ante* expected profits (for all entrants), so that they become strictly positive net of sunk entry costs. More firms will be encouraged to enter and the industry becomes more competitive, which results in a higher zero profit cut-off productivity. The latter is a sufficient statistic for average productivity in the industry due to our Pareto assumption and therefore reallocation of output towards more productive firms entails higher efficiency in the energy intensive sector. The same mechanism operates in the composite input intensive industry, but here the change in marginal costs is smaller – in fact, marginal costs rise – so that relative productivity in the energy intensive sector is enhanced. Clearly, firm heterogeneity drives all variables in the same direction as the neoclassical forces do, but reinforces this movement.[20]

Our second prediction is tightly linked to the first one:

[19] In our $2 \times 2 \times 2$ framework, we can prove the stronger result that output of the composite factor intensive industry contracts, while the energy intensive one expands. Since our identification strategy will not, however, be able to isolate level effects we resort to the weaker statement.

[20] To get a sense of the quantitative predictions of our model we calibrate the parameters of the model and, using the base year 2006, simulate how an increase in the gas price gap of USD 1 affects output in the energy intensive sector relative to output in the composite intensive one, holding total output and all other prices fixed – a more detailed explanation can be found in appendix B.3. The energy intensive sector is predicted to expand by 3.9 percentage points relative to the composite intensive one.

Prediction 2 (Factor Reallocation) *An increase in the price gap between the US and OECD Europe will reallocate resources more strongly towards more energy intensive industries.*

Formally, with our simple Cobb-Douglas production structure at the industry level, aggregate factor allocations satisfy the expressions

$$\begin{aligned} N_i^k &= \beta_i \frac{R_i^k}{w_N^k} \\ L_i^k &= (1-\beta_i)\frac{R_i^k}{w_L^k} \end{aligned} \tag{2}$$

where N_i^k and L_i^k denote energy and labour allocations to industry i in country k. Invoking the result in prediction 1, it is clear that after the shock, energy is reallocated to the energy intensive sector. In order for it to fully employ this additional factor supply, it needs to attract more of the composite input and we can be assured that the negative price effect of rising composite input prices will be overcompensated by the urge to increase output. The composite input intensive sector will see a loss of resources.

3.2 The Open Economy: International Trade

We are also able to derive a simple expression for exports as function of the relative price gap of energy:

$$X_i^k = M_i^k \bar{r}_{ix}^k = \frac{k_i}{1+k_i} R_i^k, \tag{3}$$

where

$$k_i \equiv c_i \frac{\hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}} - c_i}{1 - c_i \hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}},$$

$\bar{r}_{ix}^k$ are average export sales across firms in industry i and country k, and M_i^k is the number of these exporters. Again using prediction 1, regarding international trade we predict:

Prediction 3 (Quasi-Heckscher-Ohlin) *An increase in the price gap between the U.S. and OECD Europe will increase (decrease) the volume of US exports (imports) differentially more in relatively more energy intensive industries.*

To gain intuition for this result, it is useful to examine the decomposition into the number of firms that export and their average export volume. All else equal, a relative drop in energy prices lowers the fixed costs of exporting, the zero export profit cut-off φ_{ix}^k falls, and a measure of previously purely domestically selling, *inefficient* firms are now able to enter the foreign market. As a result, average exports at the firm level actually shrink. However, at the same time, the extensive margin of exporters adjusts: a larger share of firms exports and the measure of successful entrants in the industry expands. Taken together, as is evident from expression (3), total export volumes at the industry level grow, and differentially more so in the energy intensive industry.[21] In country l, the energy intensive sector faces more competition when exporting to k after the shock, which leads to both a lower number of exporters and lower average revenues abroad. Since we have only two countries, the prediction regarding imports follows.[22]

The simple two country framework we use is highly tractable and allows for interesting analytical results. Unfortunately, however, it lacks the ability to provide predictions for one important margin, the extensive industry margin. This margin is significant in that it provides a means of diversification of demand shocks, potentially allows for stronger and more varied technology spill-overs, and may strengthen diplomatic bonds, among other advantages. We are therefore interested in how the shale gas boom in the U.S. affected the number of industries that trade with a given country.

Instead of extending our model, we briefly describe an extension of the two country version and derive the main prediction from it. An elegant way of tackling the problem of zeros in the trade matrix is provided by assuming that idiosyncratic firm productivity follow a truncated Pareto distribution as described and analysed in Helpman et al. (2008). The distribution of productivity within

[21] Repeating the exercise described in footnote 20 for exports, we predict that, starting in 2006, a widening of the gas price gap would *ceteris paribus* lead to a relative increase of exports of the energy intensive sector by roughly 5.2 percentage points.

[22] We would like to point out that in our model we assume that the same technology is used in both countries, which is a strong assumption and we will come back to this issue in the empirical analyses on imports below.

industries is now capped from above, so that no firm will draw a productivity higher than some threshold $\bar{\varphi}$. In this case, if

$$r_{ix}^k(\bar{\varphi}) < f_{ix}(w_N^k)^{\beta_i}(w_N^k)^{1-\beta_i}$$

there will be no exports from country k to country l in industry i. A sufficient drop in the energy price reverses the inequality and spurs exporting, the likelihood of which is increasing in the energy intensity of the industry, ceteris paribus. Our final prediction is therefore

Prediction 4 (The Extensive Industry Margin) *An increase in the price gap between the U.S. and OECD Europe will increase the extensive industry margin of U.S. exports differentially more in relatively more energy intensive industries.*

We now turn to presenting the data set used for the main empirical analysis.

4 Data

In order to test the main theoretical predictions, we proceed in two steps. First, we present evidence on factor allocation and output effects in the manufacturing sector, and secondly, we present results pertaining to the trade responses. We combine several data sources for this purpose, some details of which are provided here.[23]

4.1 Factor Allocation and Output Effects

In order to measure output and sector allocation effects, we work with sector level GDP data produced by the Bureau of Economic Analysis (BEA). This data comes at an annual resolution for the period 2000-2013, covering the whole of the U.S. across 150 five digit industries, classified according to the North American Industry Classification System (NAICS). We match this data with the five digit sector energy intensities as measured through the 2002 IO tables.

We furthermore want to explore the impact of the shale gas boom on the allocation of two factors of production, capital and labor. We draw on detailed county

[23] A more detailed discussion of the individual data sets and sources used is relegated to Appendix A.

level employment data from the County Business Patterns (CBP). We use the five digit NAICS sector disaggregation to produce an annual balanced panel from 2000 to 2013 and match this to energy intensities constructed at the across 171 five digit NAICS sectors from the 2002 IO tables. The data provides employment during the first week of March in a given year.

As we noted, the focus of this paper is not to explore the distinct local economic effects of the shale gas boom. Rather, we explore the extent to which we see wider spillover effects of the endowment shock, that work through the theoretical mechanisms discussed. Our identifying variation does not exploit spatial variation in natural gas price differences within the U.S. as these are second order; further, since the trade data used is not geographic, in order to be internally consistent, we remove the spatial dimension of the domestic data. To ensure that our results are not capturing the direct economic spillovers due to local extraction, we remove counties from the aggregation sample that are located in the proximity of shale deposits.[24] The main dependent variable will be the log of employment by sector and year.

The third data source we use will allow us to shed light on capital expenditure as a proxy to capture capital allocation. The data we use is proprietary data on manufacturing plant expansion and new plant investments collected by Conway. The data has the most extensive U.S. coverage capturing capital expenditures.[25] For an investment project to be included in the data set, it needs to meet at least one of the following criteria: (1) the project cost should be at least USD 1 million, (2) covering at least 20,000 sq. ft. or (3) create employment for at least 50 people. In total, the data contains information on 26,510 capital expenditures, totalling approximately USD 717 billion in capacity additions. The majority (3 quarters) of the capacity additions are coded at the five digit NAICS resolution; the remaining projects are mapped to the most representative five digit NAICS code. The data is available over the time period from 2003- 2013. We do not observe each event specific to a project ranging from announcement to completion. This introduces

[24] We use the common Energy Information Administration Map of Shale Plays and remove any county, that has a non-empty overlap with any shale play. This removes 24% of all counties across the U.S., a map of the major shale plays is presented in Appendix Figure A4

[25] Some subsets of the data have been used in previous research studying the impact of capital expenditures in the manufacturing sector on local economic structure (see Greenstone et al. (2010), Greenstone and Moretti (2003)).

noise in our dependent variable. To be consistent throughout, we use as time variable the year in which a project was entered into the Conway database, which for the vast majority coincides with the date that the investment was announced. As with the employment data, we remove the explicit spatial component of the data by aggregating overall capital expenditures occurring within a five digit sector within the U.S., after having removed counties that lie above any known shale deposits that may be affected directly by the extraction activities taking place. The result is an annual level national panel at the five digit sector resolution.

4.2 International Trade

The trade data are from Schott (2004). We use concordances provided by Peter Schott and the BEA to match IO tables data to the foreign trade harmonized codes. The resulting dataset used in our main analysis of U.S. imports and exports is a balanced panel at the five digit sector.

We map the trade data to 158 manufacturing sector codes at the five digit level from the 2002 IO tables. There are 218 destination countries or territories and 16 years of data from 1997-2012.[26] Not all observations have positive trade, in which case a zero is reported. That allows us to study the extensive margin of trade as well, i.e. trade occurring for new good and country pairs.[27]

4.3 Energy Intensity

To construct energy intensity, we use the 2002 BEA IO tables – i.e. the ones that prevail before the shale boom – at the five digit NAICS industry classification level. Later IO tables could also be used, in particular the 2007 version. However, this is problematic given the fact that technology coefficients derived from later IO tables are endogenous and would thus potentially bias our regression estimates (see e.g. Morrow and Trefler, 2014 for a discussion; we have shown

[26] We drop 1996 as the NAICS classification was first introduced with the 1997 census. The raw data contains 240 distinct destinations. We further remove 22 countries or territories which either did not continuously exist over the sample period (for example Serbia, Montenegro and Serbia and Montenegro are coded as three distinct countries), or with which the U.S. did not trade at all in any of the 158 sectors over the 16 years.

[27] See Appendix A.3 for details. The trade data can be matched with the 7 digit NAICS industry classification level; however, the best concordance between the six digit IO tables and the trade data is achieved at the 5 digit NAICS sector level.

evidence for this in Figure 2).[28] In total, the IO tables differentiate between 171 five digit manufacturing sectors. There is meaningful variation in the measured energy intensities across these sectors. We distinguish between energy consumed from all sources (in particular electricity and natural gas) and natural gas exclusively, as an alternative. We point out that the latter is difficult to measure, since the Oil and Gas extraction sector in the IO table is not further disaggregated. In both cases, energy can be consumed directly and indirectly, through intermediate goods consumption. Using overall energy intensity allows us to account for potential substitution effects between natural gas and other energy sources. This help allay some of the concerns that arise because we use IO tables related to pre-shale boom era for a specific year implicitly assuming that the production technology is fixed. Using only natural gas consumption allows us to get closer to the source of the comparative advantage. Table 1 provides an overview of energy intensities by their IO table direct and total input cost shares at the three digit sector level; in addition, the size of sectors relative to the overall economy is reported as measured by their overall input cost share. The most energy intensive sectors are, not surprisingly, Petroleum and Coal Products Manufacturing, Primary Metal Manufacturing, Non-metallic Mineral Product Manufacturing and Chemical Manufacturing.

In the next section, we present the empirical specifications and discuss the underlying identifying assumptions in detail.

5 Empirical Specification

We now outline the empirical specifications that we estimate to explore the effect of the U.S. natural gas endowment shock on manufacturing sector output, the allocation of factors of production and, finally, on international trade.

5.1 Factor Allocation and Output Effects

In the first set of exercises, we present evidence supporting the first two theoretical prediction, suggesting that the shale gas boom induced an expansion of the manufacturing sectors of the economy that use more energy.

[28] The details of the construction are discussed in appendix A.4.

In order to do so, we estimate variants of the following two empirical specifications. First,

$$y_{jt} = \alpha_{ij} + d_{j't} + l_{j_q t} + \gamma \times E_j \times \Delta P_t + \epsilon_{jt} \tag{4}$$

As dependent variable we study national outcome measures y_{jt}, gross output, employment or capital investment, specific to a set of five digit sectors j at time t.

Our coefficient of interest is the estimate γ, which captures the differential effect of the increase in the natural gas price gap P_t between the U.S. and OECD Europe across sectors j that have a different degree of energy usage in their production process, captured by the energy intensity measure E_j. As such, the variation that we exploit is across industries and over time and not spatial by nature.[29] The estimated coefficient γ can be interpreted as a semi-elasticity that captures the proportional change in the outcome variable y_{jt} for every dollar increase in the price gap for a hypothetical sector that uses only energy as an input.

A natural concern is that prices themselves are an equilibrium outcome. This affects the interpretation of our results. As discussed in the theoretical section, we explore the effects of a quasi exogenous shift of the general equilibrium and as such, we estimate the equilibrium response as our parameter of interest. Hence, we interpret our estimates as capturing a comparative static rather than measuring a partial effect.

We employ three sets of fixed effects to address concerns about omitted variables, in particular, of unobserved trends. The first fixed effect, α_j, absorbs time-invariant confounders that are specific to a sector j, and thus remove a lot of the time-invariant industry specific fundamentals.

Five digit NAICS sectors j are nested into meaningful coarser sector classifications j', where $j' \subset j$.[30] We make our time fixed effects $d_{j't}$ specific to sub-sectors j', which allows us to rule out time varying shocks that may affect similar sectors jj' equally, such as regulatory changes or demand shocks. Throughout the paper, we will make the non-linear time effects specific to the two digit sector level.

[29] While there exists spatial variation in natural gas prices in the U.S., as for example pointed out in Fetzer (2014), this variation is second order in comparison to the natural gas price differentials across countries. We explore within country price differences for the main trade regressions in Appendix C; unsurprisingly the results are very similar.

[30] Just to give an example, NAICS code 31 captures mostly non-durable consumption goods, such as 311 Food Processing or 315 Apparel Manufacturing.

The third fixed effect $l_{j_q t}$ aims to reduce concerns about linkages of individual sectors to the oil and gas extraction sectors. As such, these sectors may be directly affected by oil and gas extraction activities through downstream IO linkages. We compute direct input requirements of the oil and gas extraction sectors drawing on inputs from five digit manufacturing sectors. We then construct quintiles q that capture the strength of the respective linkage of manufacturing sector j to the oil and gas extraction sectors. In the regression, we control for the linkages flexibly using strength of linkage by year fixed effects, which allows sectors with different strength of linkages to the mining sector to evolve differently over time.

The second main empirical exercise is a non-parametric version that, rather than exploiting the time-variation captured in the natural gas price gap P_t, asks the data to reveal the dynamics of the evolution of the dependent variable y_{ct} that is correlated with the energy intensity E_j. The empirical specification is

$$y_{jt} = \alpha_j + d_{j't} + l_{j_q t} + \sum_t \gamma_t \times E_j + \epsilon_{jt} \tag{5}$$

Inspecting the plotted estimates γ_t will allow us to explore the extent to which sectors, of different energy intensity, where evolving similarly prior to the dramatic divergence in natural gas prices between the U.S. and the rest of the world.

The next section presents the empirical strategy for the analysis of the trade data.

5.2 International Trade

The exposition of the empirical strategy for international trade only differs in two aspects from the previous ones. First, our dependent variable y_{djt} will now capture a trade outcome, such as the log value of exports from sector j to a destination d at time t or the log value of imports coming from origin d and classified as belonging to sector j. Secondly, the fixed effects will be slightly different. The main specification is as follows:

$$y_{djt} = \alpha_{dj} + l_{j_q t} + b_{dj't} + \gamma \times E_j \times \Delta P_t + \epsilon_{djt} \tag{6}$$

We control for five digit sector code j by destination d fixed effects b_{dj}. These would capture any time-invariant factors that affect, say, demand from China for

U.S. energy intensive goods. These fixed effects also capture, for instance, bilateral distance and other time-invariant sector specific trade frictions. Similarly, we also flexibly control for linkages with the oil and gas extraction sectors, $l_{j_q t}$, which may affect trade directly through the imports or reduced exports of inputs required for oil and gas extraction.

The trade-pair specific time fixed effects $\alpha_{dj't}$ control for time varying shocks that are specific to a trade-pair. Some examples of variables that would be captured with this are demand shifters, such as annual GDP, population, trade agreements, general *time varying trade costs* and exchange rates. Even more so, we make these fixed effects specific to a coarser sector level j'; throughout, we will allow these trade pair specific non-linear time trends to be heterogenous at the two digit sector level. As mentioned, the two digit sector level captures broad distinctions between durable and non-durable manufacturing outputs and we de facto control for sector specific time varying trade costs and demand shocks.

The identifying variation is coming from the variation in energy intensity measured by E_j across sector codes *within* a set of sectors that are quite similar, as they all belong both to the same two digit sector main codes. Since we are mainly using logged trade measures, the coefficient of interest, γ, is a semi-elasticity that captures the proportional change in trade for every dollar increase in the price gap for a hypothetical sector that uses only energy as an input.

The fixed effects allow for a relaxed identification assumption: all that is required for the estimates γ to capture the causal effect of the shale gas boom, is that industries within the same two digit industry classification would have followed parallel trends in the respective outcome variables, if the shale gas boom had not occurred. As in the factor-reallocation and output exercise, we can present evidence in favor of this identification assumption by exploring the evolution of the coefficients γ_t over time; positive coefficients would indicate that exports of energy intensive products is growing stronger, relative to non-energy intensive sectors. We estimate the following specification:

$$y_{djt} = \alpha_{dj't} + b_{dj} + l_{j_q t} + \sum_t \gamma_t \times E_j + \epsilon_{djt} \tag{7}$$

The results from the non-parametric exercise are presented graphically, thus highlighting the evolution of trade volumes accounting for the energy intensity of

the respective goods. In the main tables, we focus on US exports to all countries and work off the natural gas price gap as measured between the U.S. and OECD Europe or between the U.S. and individual OECD member countries, whenever such price data is available. In the appendix, we also explore other price differences and the results are very similar throughout, which is not too surprising, as the variation in the price gaps that is relevant is not driven by prices changing elsewhere in the world, but rather by U.S. prices dropping dramatically.[31]

We now turn to presenting the results from our empirical exercise, along with some robustness checks.

6 Results

We present our results in the same sequence as before, first exploring domestic factor allocation and output effects, then turning to the trade results.

6.1 Factor Allocation and Output Effects

The results on the effect of the shale gas boom on gross output, employment, and capital investment are depicted in table 2. Panel A presents the effect of the shale gas boom on gross output across sectors. The estimated effect is positive throughout and significant, suggesting that energy intensive sectors of the economy expand differentially as natural gas prices drop. The coefficient implies that, in the case of Chemical Manufacturing, which has a total energy cost share of 8.33 %, output expands by $8.33\% \times 19.1\% = 1.59\%$ for every dollar that the price gap increases. Note that, even though the mining linkage year effects control to some extent for the direct effects of shale gas extraction, since we use national level output data the estimated effect may be considered an upper bound.

Panel B presents the results for employment. Throughout again, the coefficient is positive and significant, suggesting that employment in energy intensive manufacturing sector in counties far away from the shale extraction sites expands significantly. The coefficients imply that employment in Chemical Manufacturing

[31]The results are presented in Appendix Tables A2 and A3). As noted, the original data trade also provides a further spatial component in form of the U.S. customs district, where the export data was recorded. Appendix C shows that we obtain very similar results when accounting for the customs origin district on an unbalanced panel to exploit within U.S. natural gas price differences.

expands by $8.33\% \times 7.4\% = 0.6\%$ for every dollar that the price gap increases. We can perform another back of the envelope calculation to scale the effect. Given that the average industry has an energy cost share around 5%, we estimate that employment increased, on average, by 3.6% up to the year 2012, when the natural gas price gap stood near USD 10. Using the average sector level employment, we can arrive at an overall estimate of the employment gains: total manufacturing sector employment in counties not located above or near shale deposits increased by around 356,000 jobs in the year 2012 after the shale gas boom. This is around 0.2% of the overall size of the labor force in 2012. Note that this estimate captures the indirect employment effects due to the shale gas boom, rather than the direct economic stimulation due to extraction activity as we focus on energy intensive employment in places far away from shale gas extraction. We can relate this estimate to the findings in the existing literature on local economic effects. Fetzer (2014) finds local employment gains of around 600,000 jobs, while Feyrer et al. (2015) find slightly larger estimates of around 750,000; this suggests that the indirect employment gains in the manufacturing sector range from 0.47 to 0.59 for every job created due to extraction activity and its directly associated spillovers. Exploring overall employment levels, there is some evidence suggesting a reversal of a trend in manufacturing sector employment, which the shale gas boom has contributed to. Over our sample period, manufacturing sector employment shrank from around 16.7 million jobs in the year 2000, to a low of 11.1 million in 2010. This trend has been widely associated with increased Chinese import competition and has been studied, for example, in Autor et al. (2013). Since 2010 however, the aggregate trend in our data has reversed with employment having recovered by around 400,000 to 11.5 million in 2013. Similarly studying our aggregated data suggests that the most energy intensive manufacturing sectors with NAICS codes 324-331 have added around 140,000 jobs alone.

Panel C presents the result for capital expenditure in counties located far from shale deposits. Again, and consistent with the theory, the coefficient is positive and large in magnitude, albeit estimated imprecisely. The p-values range from 0.14 to 0.19. It is unsurprising that the coefficient estimates come with limited confidence, as the dependent variable is measured with a lot of noise. The coefficients suggest that investment in a hypothetical sector that uses only energy as input would expand by close to 40% for every dollar increase in the price gap.

For Chemical Manufacturing again, the (noisily) estimated capital expenditure increase is $8.33\% \times 39.4\% = 3.3\%$ for every dollar that the price gap increases. For the average industry with an energy cost share around 5%, capital investment increased by 20% for the year 2012, when the price gap stood near USD 10. Since the average annual investment in non-shale counties is around USD 300 million by sector and year, simply scaling the coefficient implies increased investment due the shale gas boom by an order of magnitude or by around USD 10 billion for 2012.[32]

Next, we present the results from estimating the non-parametric specification (5), which allows the energy intensity E_j to affect outcomes flexibly over time. Thus we assess the extent to which the dynamics move in a similar way as the price gap and speak to the common trends assumption inherent to this research design.

The results for our three outcome measures are presented in Figure 4. Panel A presents the result for gross output. For the years 2000 to 2003, the coefficient is close to zero, but it becomes positive and significant from 2004 onwards. This is not surprising as our national aggregate measures are likely to be affected by the direct economic effects of shale oil and gas extraction, since for lack of spatially disaggregated sector level data, we are not able to remove data coming from places that are directly affected due to the extraction activity. When we introduce the results for employment and capital investment below, where we can explicitly remove data coming from places that see a lot of economic activity due to shale extraction, this early pick up is not present.

Panel B presents the employment results. Throughout the period from 2000 to 2006, the coefficient estimates suggest that manufacturing sector employment did not grow at differential rates in a way that is correlated with the energy intensity. From 2007 onwards, the employment starts to increase significantly. This suggests a slight lag, since global natural gas markets already decoupled in 2006. A slightly lagged effect is not surprising, since it takes time for new jobs to be created, even more so as some require auxiliary capital investment. Additionally, the employment data is measured in the first quarter of the respective year, which mechanically contributes to a lagged effect.

[32] Overall, the estimated effects on factor reallocation are also in line with the quantitative predictions derived in Appendix B.3.

In panel C we present the results for capital investment. The data is only available from 2003 onwards, but, reassuringly, the estimated coefficients on the interaction are flat for 2004 and 2005 and only become positive from 2006 onwards, which coincides with the price gap, which significantly widens. Afterwards, the estimated coefficient is positive throughout, albeit volatile, which can be traced back to the volatile nature of capital investments. In sum, the results suggest that sectors with different energy consumption were evolving on similar trends prior to the shale gas boom.

Overall, the evidence presented so far suggests that output and factors of production move in the way theoretically predicted and, for the variables where we can vastly reduce concerns about the effects being spuriously driven by the direct extraction activities, we can offer reassuring empirical support for the parallel trends assumption. We now turn to the main focus of the paper, exploring the effect on U.S. energy intensive exports.

6.2 Trade

The significant price gaps that are a result of the dramatic expansion of production and inability to trade shale gas directly, give U.S. manufacturing a cost advantage, in particular, for energy intensive goods. In this section, we present our empirical evidence for a dramatic expansion in energy intensive manufacturing sector exports due to the emergence of the natural gas price gap.

Our main results are presented in Table 3. Panel A shows effects estimated on the unbalanced panel of log value of trade. The results suggest that, for Chemical Manufacturing, exports increase by $8.33\% \times 39.4\% = 1.6\%$ for every dollar increase in the natural gas price gap. This effect is similar in magnitude to the output effect.[33]

If we scale up the point estimate, given that the price gap has widened to USD 10 per cubic foot of natural gas in 2012, we find that the average manufacturing sector exports (with an energy intensity of around 5%) have expanded by 10 %. Overall, the results suggest an expansion of manufacturing sector exports by USD 101 billion for 2012 due to the shale gas boom. This amounts to roughly 4.4% of

[33]They are also roughly in line with what we expected given the quantitative predictions of our stylized model.

the overall value of exports of goods and services from the U.S. in 2012. It is interesting to relate this figure with a crude estimate of the trade collapse and general trade volumes. Over the sample period from 1997 to 2012, the value of all manufacturing goods exported more than doubled, increasing from USD 502 billion to 1,070 billion. The trade collapse in the wake of the financial crisis is not far away from our estimate for the energy intensive manufacturing export expansion: from 2008 to 2009, manufacturing exports shrank by USD 185 billion, dropping from USD 916 billion to 731 billion. The above results suggest that the cost advantage due to the shale gas boom may have helped the U.S. economy recover significantly faster.

In panel B we explore import effects, imposing the U.S. energy coefficients. We see no differential change. This is at odds with the theoretical results, which would suggest a reduction of energy intensive imports – in fact, this is not fully unanticipated. As Leontief (1953) conjectured in his seminal paper and as Trefler (1995) and Davis and Weinstein (2001) later on confirmed, the assumption of symmetric technologies across countries is add odds with the data in a way that obfuscates patterns consistent with endowment driven theories of comparative advantage. A second complication is afforded by IO linkages that prevent imports from dropping dramatically, if the production of energy intensive goods makes use of imported intermediary goods that also require a significant amount of energy inputs. We will address this 'import puzzle' in the next section.

Panel C and D present the results for the extensive margin of exports and imports, estimated on the full balanced panel. The coefficients are small and not always precisely estimated. However, they present a consistent picture, suggesting that it is more likely that the U.S. start to export energy intensive manufacturing goods and is less likely to start importing them. The effects are, however, small compared to the overall sample mean of the dependent variable. This suggests that the bulk of the expansion in trade is coming from countries that the U.S. has been trading with in the past.[34]

We now turn to showing that our key empirical result, which documents an expansion of energy intensive manufacturing exports, is robust to a number of

[34]In Appendix Table A7 we zoom in on the pairs with which the U.S. had consistently had positive trade throughout the 16 year period of our sample. The point estimates are slightly larger, suggesting again that the bulk of the effect is coming from the intensive margin of trade.

possible concerns.

Robustness and Ruling Out Alternative Explanations There are two main threats to our empirical strategy. First, we are concerned about the extent to which the common trends assumption is satisfied, and secondly, there are concerns that our measure of energy intensity is spuriously related to some other industry specific cost share measure. In this part of the paper, we also try to address the puzzling finding on the import response.

We begin by presenting evidence in support of the identification assumption of common trends, inspecting the evolution of trade outcomes of energy intensive manufacturing sectors relative to less energy intensive ones. The results are presented graphically in Figure 5. The dynamic of the estimated coefficient follows broadly the pattern of the price gap. The estimated coefficients hover around zero before 2006, and pick up in dynamics only from the mid 2000s onwards, which is consistent with the timing of the endowment shock. The average of the estimates prior to 2006 is insignificant and close to zero, while it is positive and significant for the period from 2006 onwards. The point estimate suggests an increase in exports close to 2 log points for a hypothetical sector that uses only energy as input, relative to the year 1997.

Regarding our measure of energy intensity E_j, there are two aspects: first, the measure may be a noisy estimate, which introduces attenuation bias. Second, there could be concerns that this measure is capturing some other sector specific trend that is picked up by the estimate. We address these in turn.

First, we explore the extent to which our results are due to the choice of energy intensity measure E_j. Rather than imposing a noisy estimate E_j, we can estimate separate effects γ_j for each sector j. For example, we can explore heterogeneous effects across three digit sectors by estimating:

$$y_{djt} = \alpha_{dj't} + b_{dj} + l_{j_q t} + \sum_{j' \in \text{NAICS3}} \gamma_{j'} \times \Delta P_t + \epsilon_{djt} \tag{8}$$

The results from this analysis are presented in Table 5. The omitted sector j' is "Computer and Electronic Product Manufacturing", which is the least energy intensive sector at the three digit level. The estimated effect is positive for most sectors, and, in particular, positively correlated with the energy intensity mea-

sure. Unsurprisingly, the largest effects are estimated for the most energy intensive manufacturing sectors, such as Chemical Manufacturing, Petroleum Products Manufacturing and Primary Metal Manufacturing. In the table, we also report the overall share of manufacturing sector exports over the sample periods. From 1997 to 2012, manufacturing sector exports more than doubled. This expansion is not homogeneous across manufacturing sectors: Chemical manufacturing, a sector that benefits widely from cheap energy, expanded its share of exports by around 1/3 from 13.4% prior to 2006 to around 18.4% over the period from 2006 to 2012.

Secondly, the energy intensity measure interacted with the price gap may capture some other industry specific non-linear trend in exports or imports that is wrongly attributed to the shale gas boom. There could, for example, be a secular trend away from exporting labor intensive manufacturing sector output. Since factor cost shares are mechanically related, we may wrongly attribute the trend towards energy intensive exports as a trend away from capital or labor intensive exports. Another concern is the tight oil boom that accompanied the shale gas boom. While in the main table, we highlight that we obtain similar results when our energy intensity measure zooms in on natural gas input requirements, there are still concerns that we capture the effect of the shale oil endowment shock, which has also caused the emergence of small price gaps in crude oil prices in 2011 and 2012, as shown in Appendix Figure A3.

In Table 6 we present results accounting for other industry level characteristics interacted with the price gap and control for highly demanding trends to alleviate these concerns. Column (1) presents the baseline results for exports. In column (2) we add further interactions, allowing the natural gas price gap to affect capital and labor intensive sectors differentially. Importantly, the coefficient on exports remains strongly positively associated with exports. In column (3) we control for linear trends that are specific to a five digit sector by trading partner level. This is an extremely saturated model as evidenced by an overall R^2 of 92%. The linear trends account, for example, for trends in exporting of capital versus labor intensive goods. The point estimate becomes smaller, but remains highly statistically significant.

Columns (4) - (6) explore the extent to which the crude oil price difference carries significant signal. Using the crude oil price difference instead of the natural gas price difference in column (4), we see that energy intensive exports increase

the cheaper crude oil in the U.S. is relative to Europe. In column (5) we see that this effect completely disappears when we include both crude oil price differences and the natural gas price gap, which indicates that the signal is coming from the natural gas as non-tradable factor of production. In column (6) we again include the highly demanding linear trends and see that the results are broadly similar.

Measurement Error in Import Energy Intensity A central challenge in the literature testing the Heckscher-Ohlin prediction of comparative advantage and relative factor abundance is measurement of production technology. While we are confident that we capture the energy requirements adequately for the U.S., imposing that the production technology – in this case the energy intensity for an output – is the same across countries is a strong assumption. The puzzling finding of no negative effect on imports is suggestive that we may simply be mis-measuring the factor intensity for the foreign countries. One way to address this is to turn to country specific IO tables and to estimate energy intensities for different countries. We use the World Input Output Tables (WIOT) to arrive at estimates of energy intensity of sectors at a coarse three digit sector resolution. Unfortunately, that data is only available for 40 countries and there is no meaningful extensive margin, since the 40 countries account for the bulk of all U.S. trade. We can use energy intensities at the three digit sector level to re-estimate the export and import regressions.

The results are presented in Table 4. Columns (1) and (2) use the U.S. three digit WIOT technology coefficients. In Panel A we present the results on exports, while Panel B explores imports. The export coefficient is positive as expected, while the import coefficient is now negative, but small in magnitude and imprecisely estimated. In Columns (3) and (4) we use the respective trading country's technology coefficient. The point estimate for U.S. exports is similar in magnitude to the point estimate we obtained when using the "correct" U.S. technology coefficients, while the import coefficients are again negative but insignificant. This exercise suggests that at a coarse resolution, U.S. and non U.S. technology coefficients may be fairly similar, irrespective of what measure is used. While not statistically significant, we find consistently negative coefficients on the import coefficients and, using geographically refined natural gas price differences, these become just marginally statistically insignificant (see appendix table A8 for re-

gional natural gas price differences).

Further Concerns Our estimates of the impact of the shale gas boom on manufacturing sector trade may be underestimated for two further reasons. First, bordering countries such as Canada and Mexico may directly benefit from exports of U.S. shale gas. This spillover effect would induce us to underestimate the true effect of the shale gas boom. We can address this by removing Canada and Mexico from the estimating sample, the results are widely unaffected as indicated in Appendix table A4. The second concern is that of fuel displacement: shale gas and regulatory action is displacing U.S. produced coal for power generation as documented in Knittel et al. (2015). This may depress coal prices on world markets and induce fuel substitution towards coal, which depresses natural gas prices. Indeed, U.S. coal exports increased dramatically between 2006 and 2012. Yet, even in the peak year, U.S. coal exports only account for 1.48% of a growing world coal demand and thus we expect that fuel substitution towards coal only has a second order effect on natural gas prices.

7 Conclusion

This paper provides empirical evidence of the effects of a plausibly exogenous change in relative factor prices – the price of natural gas – on production and, importantly, international trade. We use differences in endowment of natural gas to contribute to a long standing literature testing the implications of relative factor abundance on specialization and trade outcomes. In line with our theoretical predictions, we showed that the shale gas boom has induced an relative expansion of energy intensive manufacturing in the U.S., which consequently led to factor reallocation, in particular of capital and labor. We then turned to studying manufacturing sector exports and found that U.S. manufacturing exports have grown by about 10 percent on account of their energy intensity since the onset of the shale revolution.

Our findings and identification strategy constitute a novel way to empirically test the heirloom prediction by Heckscher and Ohlin that countries export their abundant factors, and more generally the neo-classical predictions regarding the

effects of changes in factor prices. In doing so, our work abstracts from IO linkages, leaving the intricacies of trade in value added largely untouched. In a world dominated by global supply chains, further research could help deepen our understanding of shocks to factor supply.

Looking forward, the recent removal of restrictions on crude oil exports from the U.S. would be more consequential than for natural gas in increasing domestic prices and in reducing international crude oil prices, considering the much higher degree of tradability of oil. Indeed, liquefaction and transportation costs would make exporting liquefied natural gas economical only at relatively high prices prevailing in other markets. The price differential between the U.S. compared to Asia and Europe is thus likely to persist in turn helping to lift U.S. manufacturing.

References

Acemoglu, D. and V. Guerrieri (2006). Capital deepening and non-balanced economic growth. *NBER Working Paper 12475*.

Allcott, H. and D. Keniston (2013). Dutch Disease or Agglomeration ? The Local Economic Effects of Natural Resource Booms in Modern America.

Aragón, F. and J. Rud (2013). Natural resources and local communities: evidence from a Peruvian gold mine. *American Economic Journal: Economic Policy*, 1–31.

Autor, D. H., D. Dorn, and G. H. Hanson (2013). The China Syndrome: Local labor market impacts of import Competition in the United States. *American Economic Review 103*(6), 2121–2168.

Baldwin, R. E. (2008, June). *The Development and Testing of Heckscher-Ohlin Trade Models: A Review*, Volume 1 of *MIT Press Books*. The MIT Press.

Bernard, A. B. and J. B. Jensen (1995). Exporters, jobs, and wages in u.s. manufacturing: 1976-1987. *Brookings Papers on Economic Activity: Microeconomics*.

Bernard, A. B. and J. B. Jensen (1999). Exceptional exporter performance: cause, effect, or both? *Journal of International Economics 47*(1), 1 – 25.

Bernard, A. B., S. J. Redding, and P. K. Schott (2007). Comparative advantage and heterogeneous firms. *Review of Economic Studies 74*(1), 31–66.

Bernstein, J. and D. Weinstein (2002). Do endowments predict the location of production?: Evidence from national and international data. *Journal of International Economics 56*, 55–76.

Caliendo, L., R. C. Feenstra, J. Romalis, and A. M. Taylor (2015). Tariff reduction, entry, and welfare: theory and evidence for the last two decades. *NBER Working Paper*.

Celasun, O., G. D. Bella, T. Mahedy, and C. Papageorgiou (2014). The U.S. Manufacturing Recovery: Uptick or Renaissance ? *IMF Working Paper*.

Choi, Y.-S. and P. Krishna (2004, August). The Factor Content of Bilateral Trade: An Empirical Test. *Journal of Political Economy 112*(4), 887–914.

Davis, D. R. and D. E. Weinstein (2001). An Account of Global Factor Trade. *American Economic Review 91*(5), 1423–1453.

Debaere, P. (2014). The Global Economics of Water: Is Water a Source of Comparative Advantage? . *American Economic Journal: Applied Economics 6*(2), 32–48.

Feenstra, R. C. (2015). *Advanced International Trade: Theory and Evidence Second Edition*, Volume 1 of *Economics Books*. Princeton University Press.

Fetzer, T. (2014). Fracking Growth. *CEP Discussion Paper*.

Feyrer, J., E. T. Mansur, and B. Sacerdote (2015). Geographic Dispersion of Economic Shocks: Evidence from the Fracking Revolution. *NBER Working Paper Series* (21624).

Greenstone, M., R. Hornbeck, and E. Moretti (2010). Identifying Agglomeration Spillovers: Evidence from Million-Dollar Plants. *Journal of Political Economy 118*(3), 536–598.

Greenstone, M. and E. Moretti (2003). Bidding for Industrial Plants : Does Winning a Million Dollar Plant Increase Welfare ?

Harrigan, J. (1995, aug). Factor endowments and the international location of production: Econometric evidence for the OECD, 1970-1985. *Journal of International Economics 39*(1-2), 123–141.

Harrigan, J. (1997). Cross-country comparisons of industry total factor productivity: theory and evidence. *Federal Reserve Bank of New York Research Paper*.

Harrison, A. E. and M. S. McMillan (2006). Outsourcing Jobs?Multinationals and US Employment. *NBER Working Paper 12372*.

Hausman, C. and R. Kellogg (2015). Welfare and Distributional Implications of Shale Gas.

Helpman, E., M. Melitz, and Y. Rubinstein (2008). Estimating Trade Flows: Trading Partners and Trading Volumes. *The Quarterly Journal of Economics 123*(2), 441–487.

Huang, H., J. Ju, and V. Z. Yue (2016). A Unified Model of Structural Adjustments and International Trade : Theory and Evidence from China. *mimeo*.

Knittel, C. R., K. Metaxoglou, and A. Trindade (2015). Natural Gas Prices and Coal Displacement: Evidence from Electricity Markets. *NBER Working Paper*.

Leontief, W. (1953). Domestic Production and Foreign Trade: The American Capital Position Re-Examined. *Proceedings of the American philosophical Society 97*(4), 332–349.

Melick, W. R. (2014). The Energy Boom and Manufacturing in the United States The Energy Boom and Manufacturing in the United States *. *mimeo*.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica 71*(6), 1695–1725.

Melitz, M. J. and S. J. Redding (2014). *Heterogeneous Firms and Trade*, Volume 4, pp. 1–54. Elsevier.

Morrow, P. M. and D. Trefler (2014). HOV and the Factor Bias of Technology. *mimeo*.

Pierce, J. and P. Schott (2012a). A concordance between ten-digit US Harmonized System Codes and SIC/NAICS product classes and industries. *Journal of Economic and Social Measurement* (301).

Pierce, J. R. and P. K. Schott (2012b). The Surprisingly Swift Decline of U.S. Manufacturing Employment. *NBER Working Paper 18655*.

Sachs, J. and A. Warner (1995). Natural resource abundance and economic growth. *European Economic Review 3*.

Schott, P. K. (2004). Across-Product Versus Within-Product Specialization in International Trade. *The Quarterly Journal of Economics 119*(2), 647–678.

Schott, P. K. (2008). The relative sophistication of Chinese exports. In *Economic Policy*, Volume 23, pp. 5–49.

Trefler, D. (1995). The Case of the Missing Trade and Other Mysteries. *American Economic Review 85*(5), 1029–1046.

van Wijnbergen, S. (1984). The Dutch Disease: A Disease After All? *The Economic Journal 94*(373), 41–55.

Wegrzyn, J., W. Litzke, and M. Gurevich (1998). Liquid Natural Gas Heavy Vehicle Program. (724).

Tables and Figures for Main Text

Table 1: Energy Intensity and Relative Sector Size of Exporting NAICS3 Sectors according to 2002 IO Table

Industry	NAICS	Sector Size	Energy Cost		Natural Gas Cost		Labour Cost	
			Total	Direct	Total	Direct	Total	Direct
Food Manufacturing	311	2.36%	4.08%	2.02%	1.87%	0.85%	26.76%	13.59%
Beverage and Tobacco	312	0.62%	2.26%	0.85%	0.94%	0.27%	17.94%	7.54%
Textile Mills	313	0.23%	5.83%	3.26%	2.14%	0.85%	38.18%	21.96%
Textile Product Mill	314	0.16%	3.46%	1.25%	1.34%	0.47%	33.40%	18.68%
Apparel Manufacturin	315	0.21%	3.06%	1.31%	1.72%	0.75%	39.09%	20.54%
Leather and Allied P	316	0.03%	2.62%	1.20%	1.25%	0.52%	37.71%	22.89%
Wood Product Manufac	321	0.46%	3.31%	1.77%	1.23%	0.41%	37.97%	22.91%
Paper Manufacturing	322	0.79%	7.65%	3.82%	4.33%	1.75%	32.68%	18.80%
Printing and Related	323	0.51%	3.00%	1.28%	1.24%	0.29%	47.78%	33.17%
Petroleum and Coal P	324	1.10%	78.21%	66.09%	76.24%	65.31%	12.74%	3.55%
Chemical Manufacturi	325	2.30%	8.33%	3.11%	5.90%	1.63%	28.33%	12.45%
Plastics and Rubber	326	0.88%	4.33%	2.22%	1.56%	0.39%	38.76%	24.85%
Nonmetallic Mineral	327	0.48%	8.38%	4.28%	4.60%	2.06%	40.59%	25.21%
Primary Metal Manufa	331	0.72%	9.15%	4.86%	3.57%	1.55%	36.55%	21.76%
Fabricated Metal Pro	332	1.25%	3.57%	1.56%	1.44%	0.49%	45.85%	29.97%
Machinery Manufactur	333	1.23%	2.27%	0.81%	0.82%	0.19%	44.75%	25.95%
Computer and Electro	334	1.79%	1.73%	0.74%	0.46%	0.13%	42.45%	22.00%
Electrical Equipment	335	0.51%	2.36%	0.97%	0.78%	0.23%	39.41%	23.55%
Transportation Equip	336	3.25%	1.85%	0.63%	0.63%	0.19%	37.99%	18.19%
Furniture and Relate	337	0.38%	2.38%	0.93%	0.77%	0.22%	44.90%	29.23%
Miscellaneous Manufa	339	0.64%	1.80%	0.71%	0.57%	0.15%	41.46%	27.39%

Table 2: Effect of natural gas price gap on energy intensive gross manufacturing output, employment and capital expenditure between 2000 and 2013.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Gross Output				
Energy Intensity	0.181***	0.191***	0.183***	0.194***
× Price Gap	(0.036)	(0.034)	(0.038)	(0.040)
Sectors	150	150	150	150
Observations	2100	2100	2100	2100
R-squared	.963	.964	.963	.964
Panel B: Employment				
Energy Intensity	0.066***	0.074***	0.061***	0.071***
× Price Gap	(0.020)	(0.019)	(0.014)	(0.017)
Sectors	171	171	171	171
Observations	2386	2386	2386	2386
R-squared	.969	.969	.969	.969
Panel C: Capital Expenditures				
Energy Intensity	0.370	0.394	0.316	0.382
× Price Gap	(0.275)	(0.261)	(0.246)	(0.272)
Sectors	171	171	171	171
Observations	1881	1881	1881	1881
R-squared	.639	.639	.638	.639
Mining Linkage x Year FE	X	X	X	X
5 Digit Industry FE	X	X	X	X
2 Digit Industry x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between an OECD average natural gas price and the US industrial use natural gas price. The dependent variable in Panel A is the log of gross output in a given sector. The dependent variable in Panel B is the log(employment) by five digit sector aggregated across counties not located above or near shale deposits. The dependent variable in Panel C is a log(capital expenditures), again aggregated excluding counties located above or near shale deposits. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the four digit sector level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3: Effect of natural gas price gap on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.205***	0.193***	0.210***	0.200***
× Price Gap	(0.022)	(0.018)	(0.022)	(0.019)
Clusters	218	218	218	218
Observations	358603	358603	358603	358603
R-squared	.893	.893	.893	.893
Panel B: Overall Import Value				
Energy Intensity	-0.006	0.024	0.001	0.028
× Price Gap	(0.032)	(0.027)	(0.031)	(0.027)
Clusters	216	216	216	216
Observations	207471	207471	207471	207471
R-squared	.906	.906	.906	.906
Panel C: Any Export				
Energy Intensity	0.002	0.004**	0.000	0.003
× Price Gap	(0.002)	(0.002)	(0.002)	(0.002)
Mean of DV	.655	.655	.655	.655
Clusters	218	218	218	218
Observations	551104	551104	551104	551104
R-squared	.713	.713	.713	.713
Panel D: Any Import				
Energy Intensity	-0.006**	-0.005**	-0.004	-0.003
× Price Gap	(0.002)	(0.002)	(0.002)	(0.002)
Mean of DV	.384	.384	.384	.384
Clusters	218	218	218	218
Observations	551104	551104	551104	551104
R-squared	.754	.754	.754	.754
All specifications include				
Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between an OECD average industrial use natural gas price and the US industrial use natural gas price. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4: World-IO Table Energy Intensity Measures: Effect of natural gas price gap on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	US WIOT Requirements		Trading Country WIOT Requirements	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.151***	0.131***	0.155***	0.125***
× Price Gap	(0.027)	(0.021)	(0.020)	(0.017)
Clusters	39	39	39	39
Observations	96554	96554	96554	96554
R-squared	.919	.919	.919	.919
Panel B: Overall Import Value				
Energy Intensity	-0.039	-0.012	-0.029	-0.015
× Price Gap	(0.046)	(0.035)	(0.037)	(0.027)
Clusters	39	39	39	39
Observations	88098	88098	88098	88098
R-squared	.913	.913	.913	.913
All specifications include				
5 Digit Industry FE	X	X	X	X
2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between an OECD average natural gas price and the US industrial use natural gas price. The sample is restricted to the set of countries for which IO table requirement coefficients could be computed from the WIOT. The dependent variable in Panel A and B are the logged values of exports and imports respectively. All regressions include five digit sector by destination/origin FE and two digit sector by destination/origin by year FE. The Energy Intensity measures used throughout varies across 14 three digit sectors constructed from the WIOT tables. Columns (1) and (2) focus on U.S. WIOT direct and total energy consumption, while columns (3) and (4) use the relevant energy intensity measures for the trading country. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5: Effect of Natural Gas Price Gap on Manufacturing Sector Exports: Heterogenous Effect by three digit NAICS sectors

NAICS 3	Label	Estimate	p	Energy Intensity	Share pre 2006	Share post 2006
311	Food Manufacturing	0.0710	0.00	4.08%	4.3%	5.3%
312	Beverage and Tobacco Product Manufacturing	0.0487	0.00	2.26%	0.9%	0.6%
313	Textile Mills	-0.0228	0.01	5.83%	1.2%	0.9%
314	Textile Product Mills	0.0279	0.00	3.46%	0.4%	0.3%
315	Apparel Manufacturing	0.0082	0.43	3.06%	1.1%	0.3%
316	Leather and Allied Product Manufacturing	0.0367	0.00	2.62%	0.4%	0.3%
321	Wood Product Manufacturing	0.0180	0.01	3.31%	0.8%	0.6%
322	Paper Manufacturing	0.0384	0.00	7.65%	2.5%	2.4%
323	Printing and Related Support Activities	0.0031	0.63	3.00%	0.8%	0.7%
324	Petroleum and Coal Products Manufacturing	0.1504	0.00	78.21%	1.5%	6.6%
325	Chemical Manufacturing	0.0889	0.00	8.33%	13.4%	18.4%
326	Plastics and Rubber Products Manufacturing	0.0683	0.00	4.33%	2.6%	2.7%
327	Nonmetallic Mineral Product Manufacturing	0.0428	0.00	8.38%	1.1%	1.0%
331	Primary Metal Manufacturing	0.0794	0.00	9.15%	3.4%	5.9%
332	Fabricated Metal Product Manufacturing	0.0838	0.00	3.57%	3.4%	3.7%
333	Machinery Manufacturing	0.0733	0.00	2.27%	14.2%	15.1%
334	Computer and Electronic Product Manufacturing	0.0000	.	1.73%	22.0%	14.4%
335	Electrical Equipment Appliance	0.0548	0.00	2.36%	3.8%	3.7%
336	Transportation Equipment Manufacturing	0.0601	0.00	1.85%	18.5%	12.4%
337	Furniture and Related Product Manufacturing	0.0516	0.00	2.38%	0.4%	0.4%
339	Miscellaneous Manufacturing	0.0666	0.00	1.80%	3.4%	4.4%

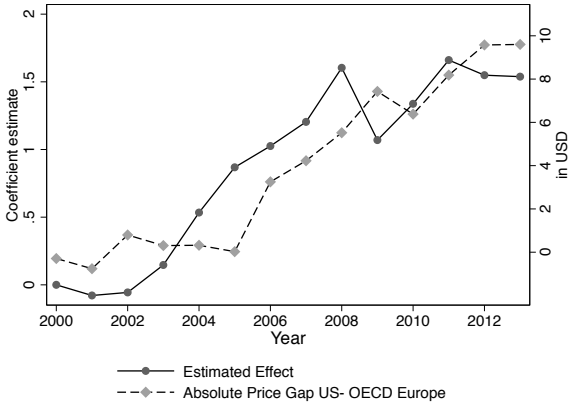
Notes: Table presents results from an exercise estimating the effect of the natural gas price gap on manufacturing sector exports. The Estimated Effect columns presents the coefficient on an interaction between a three digit sector dummy and the price gap, measured as the difference between an OECD average natural gas price and the US industrial use natural gas price. The regression controls for five digit industry by country fixed effect and country by year fixed effects. The omitted three digit sector is sector 334, which is, according to the IO tables the least energy intensive. Standard errors are clustered by destination country.

Table 6: Robustness of Export Effect: Controlling for other sector cost shares, trends and accounting for oil price gaps

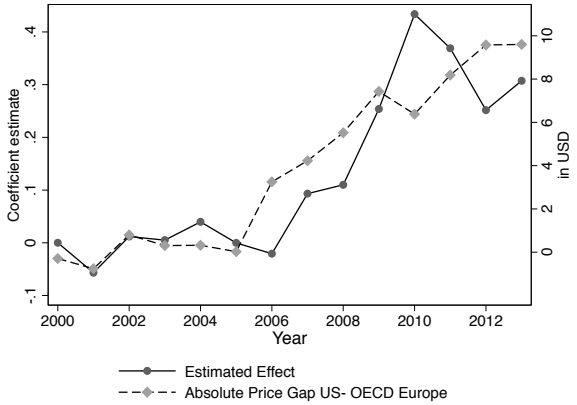
	Other Controls			Oil Prices		
	(1)	(2)	(3)	(4)	(5)	(6)
Energy Intensity x Price Gap	0.132***	0.098***	0.061***		0.126***	0.050***
	(0.014)	(0.014)	(0.018)		(0.017)	(0.018)
Capital Intensity x		-0.053***	0.019			
Price Gap		(0.007)	(0.012)			
Labor Intensity		-0.089***	-0.009			
$\times$ Price Gap		(0.009)	(0.014)			
Energy Intensity x				0.125***	0.011	0.016
(Brent - WTI) Crude Price				(0.013)	(0.011)	(0.012)
Country x 5 Digit Industry FE	X	X	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X	X	X
Country x 5 Digit Industry FE Trend			X			X
Clusters	218	218	218	218	218	218
Observations	358603	358603	358603	358603	358603	358603
R-squared	.893	.893	.924	.893	.893	.924

Notes: Table presents some robustness checks on the export results. Columns (1) - (3) includes further controls and interactions, while columns (4)-(6) include various oil prices and their interactions with the energy intensity. Standard errors are clustered by destination country with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Panel A: Gross Output



Panel B: Employment



Panel C: Capital Expenditures

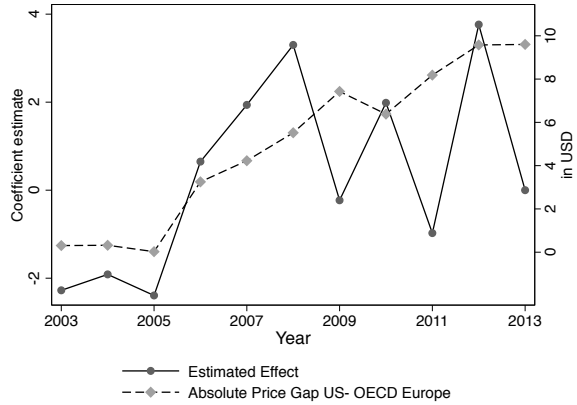


Figure 4: Figures present results from a non-parametric regression interacting the direct energy cost share with a set of year fixed effects on balanced, five digit sector level national balanced panel, controlling for five digit sector fixed effects and two digit sector by year time effects and mining linkage quantile by year fixed effects. Panel A presents the results for the sector level national output in logs. Panel B and C present national outcomes, after having removed counties that are in proximity or above shale deposits. Panel B explores the log of sector level employment, while Panel C presents the log of capital expenditures.

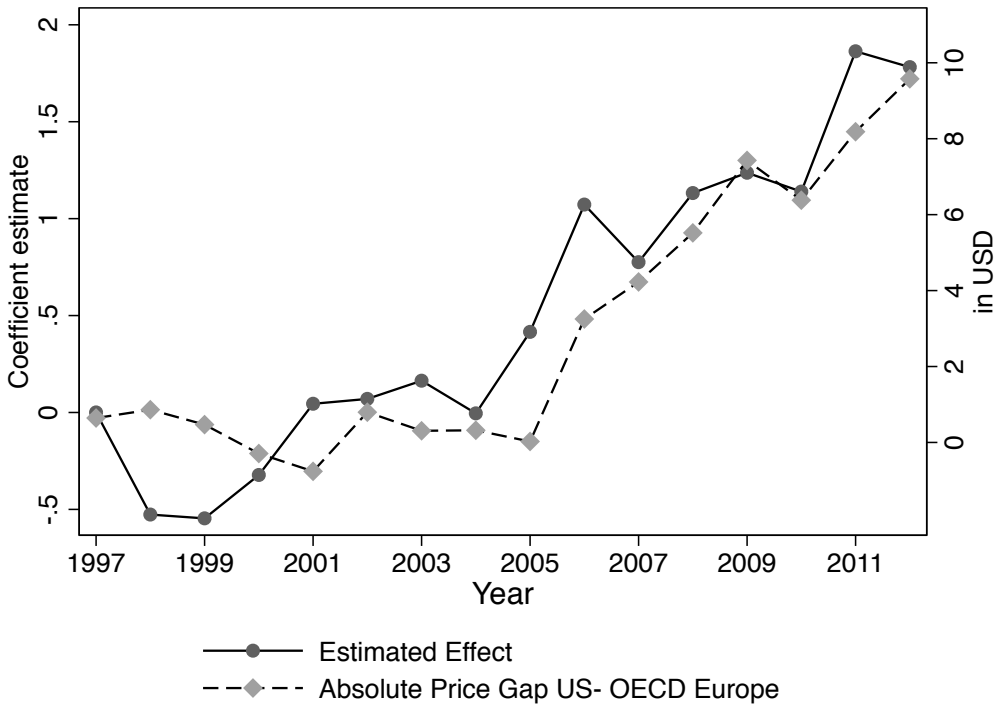


Figure 5: Evolution of natural gas price gap and exports. Figure present results from a non-parametric regression interacting the direct energy cost share with a set of year fixed effects on the logged value of exports at the five digit sector level, controlling for five digit sector by destination fixed effects, as well as three digit sector by destination and year fixed effects.

A Data Appendix

This section provides further details on the physics of natural gas shipping. It furthermore discusses and provides more details about the underlying data used in the empirical exercises.

A.1 The Physics of Natural Gas Transportation

Differences in regional natural gas prices are fundamentally determined by the laws of physics through the bearing the latter have on both transformation and transportation costs. For pipeline transportation, the cost relates to the frictions that arise as natural gas travels through pipelines. Natural gas transportation via pipelines between the U.S. and other major markets such as Europe and Asia is however not a viable option, due to the long distance natural gas would need to travel. This requires re-compression along the way due to the natural friction, which is not possible beneath the sea surface given existing technology. To be traded, U.S. natural gas would thus need to be shipped and that requires liquefaction. For liquefaction of natural gas, the costs arise due to the work required to compress and cool down natural gas to achieve a phase change from gas to liquid. This occurs at temperatures of around -160 degrees celsius (-256 degrees Fahrenheit). The gas is then compressed to only 1/600th its original volume. Natural gas has a heating value of around $Q = 890kJ/mole$. The minimum energy required to liquefy natural gas is implied by the first law of thermodynamics. This minimum energy requirement has two components. First, there is an energy requirement in order to cool down natural gas. The amount of energy required for that is dictated by the specific heat of natural gas. The specific heat of substance measures how thermally insensitive it is to the addition of energy. A larger value for the specific heat means that more energy must be added for any given mass in order to achieve a change in temperature. For natural gas that constant is given by $c_p = 2.098\frac{J}{g^\circ}$, meaning that 2.098 Joules of energy are required to achieve a 1 degree change per gram of natural gas at constant pressure. The second component of the energy requirement is the energy required to achieve a phase change. A phase change consists in the change in physical properties from gaseous to liquid and then to solid. A phase change does not involve a change in temperature

but rather a change in the internal energy of the substance. The amount of energy required to achieve a phase change from gaseous to liquid is given by the substances latent heat of vaporization, for natural gas that is $\Delta H_v = 502 J/g$.

From the above, we can compute the implied minimal energy required to cool down natural gas and achieve a phase change as follows:

$$Q_{l,min} = W_{l,min} = c_p \Delta T + \Delta H_v$$

The minimal energy required to liquefy natural gas from 20 degrees to -160 degrees is 14.1 kJ/mole. This does not seem that significant in relation to the heat content of 890 kJ/mole, accounting for only 1.6% of the heat content. However, the actual work required is a lot higher since the energy required to cool down and achieve the phase change is obtained from other physical processes involving the burning of fuel. These processes are far from achieving a 100% energy conversion efficiency. The actual work required can be expressed as:

$$W_l = \frac{W_{l,min}}{\epsilon_l \times \epsilon_w}$$

where ϵ_w is the energy conversion efficiency of converting methane to electricity and ϵ_l is the efficiency factor for conversion to liquids. These shares are significantly lower than 1. The Department of Energy estimates that $\epsilon_w = 35\%$, while ϵ_l may range between 15% - 40% (see Wegrzyn et al. (1998)). This suggest that the energy costs for liquefaction can range anywhere between 100kJ - 268 kJ, suggesting energy losses range between 11.2%-30% from the liquefaction process alone.

In addition, there are losses associated with the re-gasification process; furthermore, there are costs for transport, storage, and operating costs along the whole value chain. All these accrue in addition to the conversion costs implied by the laws of physics. A recent analysis of a proposed LNG plant in Cyprus suggests that the minimum liquefaction costs are 1.4 times the cost of the natural gas feedstock.[35]

The inherent costs associated with transforming and transporting natural gas thus suggest that domestic natural gas prices in the U.S. will remain significantly

[35]See Natural Gas Monetization Pathways for Cyprus, MIT Energy Initiative, http://mitei.mit.edu.

lower compared to Europe and Asia in the foreseeable future.

A.2 Domestic Data

National Level Output We work with national level output data obtained from the BEA. The data is made available at the five digit industry resolution as national aggregate by year on http://www.bea.gov/industry/gdpbyind_data.htm.

County Business Patterns Employment Data We draw on detailed county level employment data from the County Business Patterns (CBP). We use the five digit NAICS sector disaggregation to produce an annual balanced panel from 2000 to 2013 and match this to energy intensities constructed at the five digit NAICS sector level from the 2002 IO tables. The CBP data provides employment during the first week of March in a given year, the first quarter payroll and the annual payroll. The fine disaggregation into five digit sector and across counties is helpful to remove data stemming from counties that are directly affected by shale gas extraction and the associated local spillovers. As in many instances there are very few employees in counties, for confidentiality protection the CBP data does not provide the actual number of employees, but rather, provides the number of employees by establishment size group. The establishment size classes are 1-4, 5-9, 10-19, 20-49, 50-99, 100-249, 250-499, 500-999, 1000 and above. In case the data is missing, we infer the number of employees by computing the overall employment as the number of establishments by size class, taking the midpoint employment by size class as an estimate. This should introduce measurement error in our dependent variable, which only affects the estimated standard errors.

In order to ensure that our results are not capturing the direct economic spillovers due to local extraction, we remove counties from the aggregation sample that are located in the proximity of shale deposits.[36] The main dependent variable will be the log of employment by sector and year.

Capital Expenditure Data The data is available at the zip code level and provides the number of jobs created and the size of the capital expenditure as well

[36]We use the common Energy Information Administration Map of Shale Plays and remove any county, that has a non-empty overlap with any shale play. This removes 24% of all counties across the U.S., a map of the major shale plays is presented in Appendix Figure A4

as the NAICS industry classification. For the time variable, we use the respective date when it was entered in the dataset by Conway.

We construct a five digit level national series, providing an aggregation where we remove capital expenditures that occur in locations that may be directly affected by the shale gas boom, i.e. those located on shale plays.

A.3 Trade Data

This part of the appendix describes how the trade data of Schott (2008) was processed to construct two data sets that are used in this paper. The two data sets are: (1) a balanced panel of trade between the US and partner countries at the five digit sector code level and (2) an unbalanced panel of trade between US customs districts and trade partner countries at the five digit sector code level.

In order to arrive at the second data set, some processing of Schott (2008) data is necessary. The data are provided at the harmonised system (HS) product code classification for trade data. The trade data have four panel dimensions: origin or destination US customs district c, product code j, and origin or destination country i in year t.[37] The product codes j data are mapped to 7-digit North American Industry Classification Codes (NAICS) using the routine detailed in Pierce and Schott (2012a). As the IO tables are computed using combined NAICS codes for several sectors, we map the 7 digit NAICS sectors to 5 digit NAICS sectors, by aggregating import- and export flows on the panel identifiers i, c, t and the transformed 5 digit product code j. In total, there are 158 NAICS5 sectors, 16 years of data, 233 of countries with which the US trades and 44 US customs districts.

The main data set used in the analysis removes the US customs district dimension by collapsing the data.

A.4 Energy Intensity from IO Tables

We use the approach discussed in Fetzer (2014) to construct the energy intensity of the five digit industries using the 2002 BEA IO table. The IO use table provide,

[37] We refer to product and sector codes j interchangably here.

for each industry, a break-down of all direct costs by commodity that the industry incurs to achieve its level of output.

The direct energy cost is computed as the sum of the costs that an industry incurs using direct energy commodities. Energy commodities are considered to be those produced by the following following six digit NAICS industries:

NAICS 6	Industry Name
211000	Oil and gas extraction
221100	Electric power generation and distribution
221200	Natural gas distribution
486000	Pipeline transportation
S00101	Federal electric utilities
S00202	State electric utilities

Table A1: IO Table Direct Natural Gas Consumption

Unfortunately, the Oil and gas extraction sector is not further decomposed into natural gas or oil extraction, which adds some noise to the measurement. Nevertheless, the table provides all direct energy consumption and captures the three ways that natural gas can be consumed. The three ways to consume natural gas directly follow from the deregulation of the industry which ultimately separated natural gas extraction from transportation. This was achieved in a lengthy regulatory process, beginning with the Natural Gas Policy Act of 1978, and subsequent Federal Energy Regulatory Commission (FERC) orders No. 436 in 1985 and 636 in 1992. These orders ultimately separate the extraction from the transportation process, mandating open access to pipelines which allows end-consumers or local distribution companies (LDCs) to directly purchase natural gas from the producers.

The three ways natural gas is purchased for consumption are:

1. Direct Purchases from the Oil and Gas Extraction Sector, in addition to costs for Pipeline Transportation (NAICS 211000, 486000).

2. Indirect Purchases Through Natural Gas Distribution Utilities (NAICS 2212000 and 486000).

3. Indirect Purchases Through Electric Utilities using natural gas for power generation (NAICS 2211000, S00101 and S00202).

Now, we can further refine this as natural gas is also indirectly consumed through the value chain in the form of intermediate products. In order to account for this indirect consumption, we perform the above step iteratively. Since we know the energy cost share for each commodity, we can compute the energy cost component of each intermediate input and simply add these costs up. We perform this step iteratively to arrive at the overall cost shares.

We proceed in the same way to compute the labor cost share. In the IO table, each sector reports its labor costs. We simply compute the direct and indirect labor cost share using the same method.

Last, but not least, we compute the capital intensity of a sector. We follow the approach in Acemoglu and Guerrieri (2006), who construct capital intensity of a sector as:

$$K_j = \frac{VA_j - W_j}{VA_j}$$

where VA_j is nominal value added in sector j and W_j is the wage bill of that sector. The three components of value added are (1) compensation of employees, (2) taxes on production and imports less subsidies, and (3) gross operating surplus.

The resulting time invariant measures are merged with the trade data. For some sectors, we have to compute the energy intensity at a four digit level, as the NAICS codes in the IO tables combine several sector codes or are only available at the four digit sector level.

B Theory and Simulation

In this appendix we first show how our theoretical framework is solved, present the set of equations that need to hold in equilibrium, and then conduct a series of quantitative exercises.

B.1 Model Solution

B.1.1 Optimal Behavior and Market Clearing

The industry level first order condition of the cost minimization problem equates the marginal rate of technical substitution between the two inputs with the input price ratio:

$$\frac{\beta_i}{1-\beta_i}\frac{L_i^k}{N_i^k} = \frac{w_N^k}{w_L^k}. \tag{9}$$

Here, N_i^k and L_i^k denote the respective energy and labour input allocations. Moreover, the solution to the firm level price setting problem is the usual CES constant mark-up rule for both the domestic and export market, $p_{ix} = \tau_i p_{id}(\varphi) = \tau_i (w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}/\rho\varphi$, where subscript d indicates domestic variables, while subscript x denotes exporting related prices.

Profits from domestic activity, π_{id}^k, and from exporting, π_{id}^k, can be written as

$$\pi_{im}^k(\varphi) = \frac{r_{im}(\varphi)}{\sigma} - f_{im}(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}, \quad m \in \{d, x\},$$

where $r_i(\varphi) = r_{id}(\varphi) + r_{ix}(\varphi)$ are revenues of a firm with productivity φ, the sum of domestic sales and sales abroad (which are zero for non-exporters). The existence of fixed costs of producing together with free entry implies that there is a unique zero profit cutoff φ_i^{*k} in every country and industry implicitly defined by

$$r_i(\varphi_i^{*k}) = f_{id}(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}, \tag{10}$$

so that all firms that draw $\varphi < \varphi_i^{*k}$ exit the market and all firms with $\varphi > \varphi_i^{*k}$ survive. Similarly, fixed costs of exporting imply that only the most productive firms among the survivors will export, i.e. every firm with productivity $\varphi > \varphi_{ix}^{*k}$. This selection mechanism is our key intra-industry concern as described above.

Firms, when making the decision to enter the market or not, compare their expected discounted profit from entering with entry costs. Since we assume an infinite number of potential entrants, it must be that, in equilibrium, the expected discounted profit (which is conditional on survival, i.e. a productivity draw above φ_i^{*k}) is equal to the sunk cost of entry. We follow the model of Melitz (2003) and

posit that firms are infinitely lived once they have successfully entered, but face an exogenous probability of exit δ that they use to discount. Using the relationships $r_{id}^k(\varphi) = (\frac{\varphi}{\varphi_i^{*k}})^{\sigma-1} r_{id}^k(\varphi_i^{*k})$ and $r_{ix}^k(\varphi) = (\frac{\varphi}{\varphi_{ix}^{*k}})^{\sigma-1} r_{ix}^k(\varphi_{ix}^{*k})$ together with (10), we can write the free entry condition as

$$\frac{f_{id}}{\delta} \int_{\varphi_i^{*k}}^{\infty} \left[\left(\frac{\varphi}{\varphi_i^{*k}} \right)^{\sigma-1} - 1 \right] (-\gamma \varphi^{-\gamma-1}) \mathrm{d}\varphi + \frac{f_{ix}}{\delta} \int_{\varphi_{ix}^{*k}}^{\infty} \left[\left(\frac{\varphi}{\varphi_{ix}^{*k}} \right)^{\sigma-1} - 1 \right] (-\gamma \varphi^{-\gamma-1}) \mathrm{d}\varphi = f_{ei} \quad (11)$$

Moreover, given zero expected profits in all markets *ex ante*, total revenues will be paid out to factors in full[38] and so total country revenues (which are equal to total expenditure) in equilibrium are

$$R^k = w_N^k (N_i^k + N_j^k) + w_L^k (L_i^k + L_j^k). \quad (12)$$

Finally, in equilibrium we require both factor markets and goods markets to clear:

$$\begin{aligned} N_1^k + N_2^k &= \bar{N}^k \\ L_1^k + L_2^k &= \bar{L}^k \end{aligned} \quad (13)$$

and

$$R_i^k = \alpha_i R^k M_i^k \left(\frac{p_{id}^k(\tilde{\varphi}_i^k)}{P_i^k} \right)^{1-\sigma} + \alpha_i R^l \chi_i^k M_i^k \left(\frac{\tau_i p_{id}^k(\tilde{\varphi}_{ix}^k)}{P_i^l} \right)^{1-\sigma}. \quad (14)$$

$\tilde{\varphi}_z^k$ with $z \in \{i, ix\}$ are the average productivities of active firms and exporters, respectively, defined as

$$(\tilde{\varphi}_z^k)^{\sigma-1} = (\varphi_i^{*k})^{\gamma} \int_{\varphi_i^{*k}}^{\infty} \varphi^{\sigma-1} (\gamma \varphi^{-\gamma-1}) \mathrm{d}\varphi.$$

R_i^k are aggregate revenues in industry i, $M_i^k = R_i^k / r_i(\tilde{\varphi}_i^k)$ is the number of active

[38] To see this result more clearly, note that variable, fixed, entry, and potentially fixed exporting costs are all paid in terms of the same composite Cobb-Douglas input bundle.

firms in industry i and χ_i^k is the *ex ante* probability of exporting conditional on survival, which, by the law of large numbers, equals the share of exporters when there is a continuum of firms:

$$\chi_i^k = \left(\frac{\varphi_{ix}^{*k}}{\varphi_i^{*k}} \right)^{-\gamma}.$$

An equilibrium is a collection of quantities $\{R^k, N_i^k, L_i^k\}$, cut-offs $\{\varphi_i^{*k}\}$, and prices $\{P_i^k, w_N^k, w_L^k\}$, that satisfies equations (9), (12), (11), (13), (14), and the price index definitions for both countries and industries. Altogether there are 22 variables in 22 equations and we choose energy in l as our numéraire, $w_N^l = 1$. The full set of equations after all substitutions is reported below. Bernard et al. (2007) prove that there is a unique solution to this system of equations and we will not reiterate it in this paper.

B.1.2 Collection of general equilibrium conditions with a Pareto parametrization

The equilibrium satisfies

$$\begin{aligned} N_1^k + N_2^k &= \bar{N}^k \\ L_1^k + L_2^k &= \bar{L}^k \end{aligned} \tag{15}$$

(Labor market clearing conditions)

$$\frac{\beta_i}{1-\beta_i} \frac{L_i^k}{N_i^k} = \frac{w_N^k}{w_L^k} \tag{16}$$

(cost minimization)

$$R^k = w_N^k (N_i^k + N_j^k) + w_L^k (L_i^k + L_j^k) \tag{17}$$

(Aggregate Revenues)

$$\frac{f_{id}(\sigma-1)}{\delta(\gamma+1-\sigma)} (\varphi_i^{*k})^{-\gamma} \left[1 + \tau_i^{-\gamma} \left(\frac{P_i^k}{P_i^l} \right)^{-\gamma} \left(\frac{R^k}{R^l} \right)^{\frac{-\gamma}{\sigma-1}} \left(\frac{f_{ix}}{f_{id}} \right)^{\frac{-\gamma+\sigma-1}{\sigma-1}} \right] = f_{ei} \tag{18}$$

(free entry conditions)

$$(P_i^k)^{1-\sigma} = \frac{\frac{\rho^{\sigma-1}}{\sigma f_{id}} R_i^k (\varphi_i^{*k})^{\sigma-1}}{\left[(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}\right]^{\sigma}\left[1+\tau_i^{-\gamma}\left(\frac{f_{ix}}{f_{id}}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}\left(\frac{P_i^k}{P_i^l}\right)^{-\gamma}\left(\frac{R^k}{R^l}\right)^{\frac{-\gamma}{\sigma-1}}\right]} + \frac{\frac{\rho^{\sigma-1}}{\sigma f_{id}} R_i^l (\varphi_i^{*l})^{\sigma-1}\ \ \tau_i^{-\gamma}\left(\frac{f_{ix}}{f_{id}}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}\left(\frac{P_i^l}{P_i^k}\right)^{-\gamma+\sigma-1}\left(\frac{R^l}{R^k}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}}{\left[(w_N^l)^{\beta_i}(w_L^l)^{1-\beta_i}\right]^{\sigma}\left[1+\tau_i^{-\gamma}\left(\frac{f_{ix}}{f_{id}}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}\left(\frac{P_i^l}{P_i^k}\right)^{-\gamma}\left(\frac{R^l}{R^k}\right)^{\frac{-\gamma}{\sigma-1}}\right]} \tag{19}$$

(utility maximization)

$$\left[(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}\right]^{\sigma} = \frac{\alpha_i \rho^{\sigma-1}}{\sigma f_{id}} R^k (P_i^k)^{\sigma-1} (\varphi_i^{*k})^{\sigma-1} \tag{20}$$

(goods market clearing)

B.2 Derivations and Proofs

We start with a few definitions. First

$$\hat{x} \equiv \frac{x^k}{x^l}$$

is our notation for a ratio of a variable across countries. Using this notation,

$$\hat{w}_i \equiv \hat{w}_N^{\beta_i} \hat{w}_L^{1-\beta_i} \quad i \in \{1,2\}.$$

Finally, let $\tau_i^{-\gamma}(f_{ix}/f_{id})^{\frac{-\gamma+\sigma-1}{\sigma-1}} \equiv c_i$.

In a first step, we prove a useful lemma:

Lemma 1

$$\left(\frac{R^k}{R^l}\right)^{\frac{-\gamma}{\sigma-1}}\left(\frac{P_i^k}{P_i^l}\right)^{-\gamma} = \frac{\hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}} - c_i}{1 - c_i \hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}$$

Proof. Taking the ratio of goods market clearing conditions across countries yields

$$\hat{w}_i^{\sigma} = \left(\frac{R^k}{R^l}\right)\left(\frac{P_i^k}{P_i^l}\right)^{\sigma-1}(\hat{\varphi}_i{}^*)^{\sigma-1}$$

or

$$\left(\frac{P_i^k}{P_i^l}\right)^{-\gamma}\left(\frac{R^k}{R^l}\right)^{\frac{-\gamma}{\sigma-1}} = \hat{w}^{\frac{-\sigma\gamma}{\sigma-1}}(\hat{\varphi}_i{}^*)^{\gamma} \tag{21}$$

Moreover, taking the same ratio of the free entry conditions and substituting (21) leads to

$$(\hat{\varphi}_i^*)^{-\gamma}\frac{1+c_i\hat{w}^{\frac{-\sigma\gamma}{\sigma-1}}(\hat{\varphi}_i{}^*)^{\gamma}}{1+c_i\hat{w}^{\frac{\sigma\gamma}{\sigma-1}}(\hat{\varphi}_i{}^*)^{-\gamma}} = 1, \tag{22}$$

so that

$$(\hat{\varphi}_i^*)^{\gamma} = \frac{1-c_i\hat{w}_i^{\frac{\sigma\gamma}{\sigma-1}}}{1-c_i\hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}. \tag{23}$$

We combine (21) and (23) to obtain Lemma 1.

■

Now we are in a position to show that there is a one-to-one relationship between relative factor prices (marginal costs) across countries and relative aggregate industry productivities. Moreover, aggregate productivities move *in tandem* with relative marginal costs in the sense that the effect a shock to relative marginal costs will be amplified by an aggregate productivity response.

Proof. Taking the ratio of the free entry conditions across countries, respecting the relationship between the zero profit cut-offs and average industry productivity, and applying Lemma 1 we arrive at

$$(\hat{\tilde{\varphi}})^{\gamma} = \frac{1+k_i}{1+l_i}$$

where

$$k_i \equiv c_i\frac{\hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}} - c_i}{1-c_i\hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}$$

and

$$l_i \equiv c_i \frac{\hat{w}_i^{\frac{\sigma\gamma}{\sigma-1}} - c_i}{1 - c_i \hat{w}_i^{\frac{\sigma\gamma}{\sigma-1}}}.$$

In the same way we can express relative industry productivity *across industries within a country*:

$$\left(\frac{\tilde{\varphi}_i}{\tilde{\varphi}_j}\right)^{\gamma} = \frac{1+k_i}{1+k_j}.$$

All k_i and l_i, $i \in \{1,2\}$ are all strictly monotonic in $\hat{w}_i$, $i \in \{1,2\}$. Moreover, if there is a decrease in the relative across country energy price then energy intensive industries become relatively more productive. ■

The derivation of gross output R_i^k works as follows. We use the goods market clearing condition to substitute wages out of the expressions for the ideal price indices to arrive at

$$\alpha_i R^k = R_i^k \frac{1}{1+k_i} + R_i^l \frac{l_i}{1+l_i}. \tag{24}$$

The equivalence (24) holds for the foreign country, too, and gives us a system of two equations in the two variables of interest, R_i^k and R_i^l. Solving this system and rearranging yields

$$R_i^k = \alpha_i R^k \frac{1 - l_i \frac{R^l}{R^k}}{1 - c_i \hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}. \tag{25}$$

It is easy to see that – holding total incomes constant – gross output is decreasing in the price gap $\hat{w}_N$ and more so for the energy intensive sector, proving prediction 1.

Aggregate exports in sector i are

$$X_i^k = \alpha_i R^l \chi_i^k M_i^k \left(\frac{\tau_i p_{id}^k(\tilde{\varphi}_{ix}^k)}{P_i^l}\right)^{1-\sigma}.$$

Again using Lemma 1, we can write exports as

$$X_i^k = \frac{k_i}{1+k_i} R_i^k, \tag{26}$$

which is also decreasing in $\hat{w}_N$ and more so for the energy intensive sector, proving prediction 3.

B.3 Quantitative Analysis

In this section we outline a calibration/simulation exercise for our simple model to illustrate the key comparative statics. We also provide details on how we derive our quantitative predictions for the first and third comparative statics exercises in the main text.

In the simulations, we use the following parameter values:

Parameter	Value	Origin
σ	3.8	BRS
γ	3.4	BRS
β_1, β_2	0.1091, 0.0073	Own
α_1, α_2	0.53, 0.47	Own
$\bar{L}^k$	15000	Own
$\bar{N}^l, \bar{L}^l$	10000, 15000	Own
f_{e1}, f_{e2}	1, 1	Own
f_1, f_2	0.1, 0.1	Own
f_{1x}, f_{2x}	1.5*f_1, 1.5*f_2	Own
δ	0.025	BRS
τ_1, τ_2	1.4, 1.4	Own

We take Bernard et al. (2007) as guidance and adjust their choices slightly to facilitate finding a numerical solution. Both factor intensities and expenditure shares – key scale parameters as is evident from the analytical solutions in (1) and (3) – however, are calibrated using our data: First, we compute the (sector size weighted) average energy intensity of industries with energy cost shares weakly larger than the median industry (see table 1 for the exact numbers). We conduct the same calculation for weakly below median industries to find the energy intensity of the composite factor intensive industry in the model. The sum of the

relative sector sizes across the two groups (normalized to manufacturing output only) gives us the expenditure shares α_i.

The main results are shown in figure A5, where we linearly increase the relative domestic endowment with energy from 0.5 to 1.5. The first graph plots the model implied development of the energy price gap, defined in such a way that a fall in k's price is captured by an increase in the price gap. The third graph illustrates how output grows in the energy intensive industry relative to the composite input intensive one and, as evidenced by the second graph in the first row, the productivity effect goes in the same direction as the neo-classical Rybczynski effect, amplifying the response rather than dampening, let alone reversing it. Prediction 2 is illustrated in the second row of figure A5, while the third row shows the behavior of exports and imports, illustrating our third prediction. As discussed in the main text, our result for the extensive industry margin of exporting is not directly derived from the literal model we outline in this paper and therefore we do not show any quantitative results for the fourth prediction.

Finally, we examine the size of the output and export response implied by our model. According to expression (1), we need additional data on U.S. and OECD Europe output and producer prices (to proxy for the composite input's price) for 2006, which we obtain from the BEA, Eurostat[39], and the OECD for manufacturing industries. We plug these into (1) together with our parameter values and natural gas price information (indexed to 2010 to match PPI) for 2006. In order to obtain the change in percent, we hold total manufacturing output R as well as the price of the composite good – the PPI – fixed for both countries at the 2006 level and let the natural gas prices evolve as observed for 2007 in the data, giving us the response to a USD 1 increase in the price gap. We repeat the procedure for exports.

C Exploiting Within-U.S. Natural Gas Prices

As highlighted in Fetzer (2014), the shale gas boom has lead to some price discrepancies within the U.S., which are partly due to a lack of physical pipeline

[39] We use information that aggregates 28 member countries of the EU, because PPI data is readily available at that level. Disaggregated price data at the country level is difficult to aggregate and so we choose the lesser evil of extending our scope to non-OECD EU members.

capacity, but also due to high transport costs within pipelines over long distances. These transport costs are, however, very small in comparison to the transport costs when considering shipping natural gas as LNG. Nevertheless, we explore here whether within-U.S. price differences provide dramatically different estimates as compared with the main results in the paper.

We perform the main analysis pertaining to domestic outcomes (employment and capital investment) and trade outcomes, accounting for the spatial price differences within the U.S.. We have to make some strong assumptions with regards to the trade data: we match U.S. customs districts to U.S. states to be able to exploit natural gas price data available at the state level. This means, we implicitly assume that the customs district, where an export transaction is recorded, is sufficiently close to the location of production. The industrial use natural gas price data was obtained from the Energy Information Administration (EIA) and is available at the state level from 1997 onwards.

The empirical analysis is simply adding a further dimension. For the factor allocation exercise, we estimate:

$$y_{jkt} = \alpha_{jk} + d_{j'kt} + l_{j_q t} + \gamma \times E_j \times \Delta P_{kt} + \epsilon_{jkt} \tag{27}$$

The only aspect added is a further index k indicating the county within a state where employment and capital investment occur. The price gap is now measured as the difference between the state level prices and the OECD Europe average. For the capital investment, rather than exploiting levels of investment in a county, we construct a dummy that is equal to 1 in case there was any investment announced in a year-sector-county; for employment, we use the log of Employment +1 in a given sector-year-county.

For the trade exercise, we estimate

$$y_{djkt} = \alpha_{djk} + l_{j_q t} + b_{dj't} + \gamma \times E_j \times \Delta P_{kt} + \epsilon_{djkt} \tag{28}$$

Again, the only difference is that we added the sub-index k accounting for the state. The results for domestic factor allocation are presented in Table A9. The results for trade outcomes are presented in Table A10. Throughout, the results are very similar as in the main analysis.

Figures and Tables for Appendix

Table A2: Effect of natural gas price gap on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.205***	0.189***	0.197***	0.185***
× Price Gap	(0.033)	(0.027)	(0.034)	(0.028)
Clusters	82	82	82	82
Observations	164789	164789	164789	164789
R-squared	.906	.907	.906	.907
Panel B: Overall Import Value				
Energy Intensity	-0.024	-0.008	-0.003	0.012
× Price Gap	(0.038)	(0.033)	(0.037)	(0.033)
Clusters	82	82	82	82
Observations	123076	123076	123076	123076
R-squared	.908	.908	.908	.908
Panel C: Any Export				
Energy Intensity	-0.001	0.002	-0.004	-0.000
× Price Gap	(0.003)	(0.003)	(0.003)	(0.003)
Clusters	82	82	82	82
Observations	215196	215196	215196	215196
R-squared	.716	.716	.716	.716
Panel D: Any Import				
Energy Intensity	-0.007**	-0.005**	-0.004	-0.003
× Price Gap	(0.003)	(0.003)	(0.003)	(0.003)
Clusters	82	82	82	82
Observations	215196	215196	215196	215196
R-squared	.759	.759	.759	.759
All specifications include				
Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between a world region average industrial use natural gas price and the US industrial use natural gas price. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A3: Effect of natural gas price gap on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.206***	0.190***	0.191***	0.179***
× Price Gap	(0.038)	(0.033)	(0.042)	(0.037)
Clusters	27	27	27	27
Observations	53230	53230	53230	53230
R-squared	.931	.931	.931	.931
Panel B: Overall Import Value				
Energy Intensity	-0.020	-0.022	0.025	0.014
× Price Gap	(0.042)	(0.041)	(0.041)	(0.038)
Clusters	27	27	27	27
Observations	51064	51064	51064	51064
R-squared	.919	.919	.919	.919
Panel C: Any Export				
Energy Intensity	0.006**	0.005**	0.005**	0.004**
× Price Gap	(0.003)	(0.002)	(0.002)	(0.002)
Clusters	27	27	27	27
Observations	55932	55932	55932	55932
R-squared	.613	.612	.612	.612
Panel D: Any Import				
Energy Intensity	-0.001	0.003	-0.001	0.003
× Price Gap	(0.004)	(0.004)	(0.003)	(0.003)
Clusters	27	27	27	27
Observations	55932	55932	55932	55932
R-squared	.672	.672	.672	.672
All specifications include				
Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between a country average industrial use natural gas price and the US industrial use natural gas price. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A4: Robustness to removing border countries Canada and Mexico: Effect of natural gas price gap on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.205***	0.192***	0.210***	0.199***
× Price Gap	(0.022)	(0.019)	(0.023)	(0.019)
Clusters	216	216	216	216
Observations	353563	353563	353563	353563
R-squared	.886	.886	.886	.886
Panel B: Overall Import Value				
Energy Intensity	-0.011	0.019	-0.004	0.023
× Price Gap	(0.032)	(0.027)	(0.031)	(0.027)
Clusters	214	214	214	214
Observations	202435	202435	202435	202435
R-squared	.899	.899	.899	.899
Panel C: Any Export				
Energy Intensity	0.002	0.004**	0.000	0.003
× Price Gap	(0.002)	(0.002)	(0.002)	(0.002)
Mean of DV	.652	.652	.652	.652
Clusters	216	216	216	216
Observations	546048	546048	546048	546048
R-squared	.711	.711	.711	.711
Panel D: Any Import				
Energy Intensity	-0.006**	-0.005**	-0.004	-0.003
× Price Gap	(0.002)	(0.002)	(0.002)	(0.002)
Mean of DV	.378	.378	.378	.378
Clusters	216	216	216	216
Observations	546048	546048	546048	546048
R-squared	.75	.75	.75	.75
All specifications include				
Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between a country average industrial use natural gas price and the US industrial use natural gas price. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A5: Estimating the effect of US natural gas endowment proxied by estimated recoverable reserves on energy intensive gross manufacturing output, employment and capital expenditure between 2000 and 2013.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Gross Output				
Energy Intensity x Natural Gas Reserves	1.829***	2.067***	1.911***	2.122***
	(0.467)	(0.421)	(0.492)	(0.490)
Sectors	150	150	150	150
Observations	1950	1950	1950	1950
R-squared	.966	.967	.966	.967
Panel B: Employment				
Energy Intensity x Natural Gas Reserves	0.493**	0.642***	0.498**	0.642***
	(0.245)	(0.242)	(0.208)	(0.232)
Sectors	171	171	171	171
Observations	2219	2219	2219	2219
R-squared	.973	.973	.973	.973
Panel C: Capital Expenditures				
Energy Intensity x Natural Gas Reserves	3.814	4.710	2.417	3.969
	(3.907)	(3.621)	(2.966)	(3.403)
Sectors	171	171	171	171
Observations	1710	1710	1710	1710
R-squared	.648	.649	.648	.649
All specifications include				
5 Digit Industry FE	X	X	X	X
2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Gas Reserves are estimates of the US dry natural gas reserves provided by the EIA. The dependent variable in Panel A is the log of gross output in a given sector. The dependent variable in Panel B is the log(employment) by five digit sector aggregated across counties not located above or near shale deposits. The dependent variable in Panel C is a log(capital expenditures), again aggregated excluding counties located above or near shale deposits. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the four digit sector level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A6: Estimating the effect of US natural gas endowment proxied by estimated recoverable reserves on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	2.156***	2.089***	2.226***	2.171***
× Natural Gas Reserves	(0.234)	(0.197)	(0.237)	(0.202)
Clusters	218	218	218	218
Observations	379635	379635	379635	379635
R-squared	.891	.891	.891	.891
Panel B: Overall Import Value				
Energy Intensity	0.081	0.294	0.219	0.399
× Natural Gas Reserves	(0.342)	(0.292)	(0.335)	(0.289)
Clusters	216	216	216	216
Observations	218961	218961	218961	218961
R-squared	.903	.903	.903	.903
Panel C: Any Export				
Energy Intensity	0.043**	0.066***	0.028	0.054***
× Natural Gas Reserves	(0.022)	(0.019)	(0.020)	(0.018)
Clusters	218	218	218	218
Observations	585548	585548	585548	585548
R-squared	.711	.711	.711	.711
Panel D: Any Import				
Energy Intensity	-0.065**	-0.057***	-0.037	-0.034
× Natural Gas Reserves	(0.026)	(0.022)	(0.026)	(0.021)
Clusters	218	218	218	218
Observations	585548	585548	585548	585548
R-squared	.751	.751	.751	.751
All specifications include				
Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Gas Reserves are estimates of the US dry natural gas reserves provided by the EIA. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A7: Intensive margin effect of natural gas price gap on energy intensive export and import values between 1997 and 2012.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.239***	0.234***	0.238***	0.233***
× Price Gap	(0.023)	(0.019)	(0.024)	(0.020)
Clusters	192	192	192	192
Observations	267220	267220	267220	267220
R-squared	.899	.899	.899	.899
Panel B: Overall Import Value				
Energy Intensity	-0.009	0.022	-0.004	0.024
× Price Gap	(0.034)	(0.029)	(0.033)	(0.028)
Clusters	186	186	186	186
Observations	184715	184715	184715	184715
R-squared	.904	.904	.904	.904
All specifications include				
Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between an OECD average natural gas price and the US industrial use natural gas price. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The sample is restricted to the set of country-sector pairs with which the U.S. has had some non-zero trade across all years from 1997-2012. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A8: World-IO Table Energy Intensity Measures: Effect of natural gas price gap on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	US WIOT Requirements		Trading Country WIOT Requirements	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.123***	0.107***	0.134***	0.111***
× Price Gap	(0.029)	(0.023)	(0.025)	(0.019)
Clusters	35	35	35	35
Observations	85399	85399	85399	85399
R-squared	.919	.919	.919	.919
Panel B: Overall Import Value				
Energy Intensity	-0.052	-0.029	-0.068	-0.049
× Price Gap	(0.044)	(0.033)	(0.043)	(0.031)
Clusters	35	35	35	35
Observations	77321	77321	77321	77321
R-squared	.913	.913	.913	.913
All specifications include				
5 Digit Industry FE	X	X	X	X
2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between a world region average industrial use natural gas price and the US industrial use natural gas price. The sample is restricted to the set of countries for which IO table requirement coefficients could be computed from the WIOT. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout varies across 14 three digit sectors. Columns (1) and (2) focus on U.S. WIOT direct and total energy consumption, while Columns (3) and (4) use the relevant energy intensity measures for the trading country. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A9: Effect of natural gas price gap between U.S. states and the OECD Europe on energy intensive gross employment and capital expenditure between 2000 and 2013.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Employment				
Energy Intensity	0.009***	0.017***	0.007***	0.016***
× Price Gap	(0.002)	(0.003)	(0.002)	(0.002)
Sectors	171	171	171	171
Observations	7093151	7093151	7093151	7093151
R-squared	.871	.871	.871	.871
Panel B: Capital Expenditures				
Energy Intensity	0.001***	0.001***	0.001***	0.001***
× Price Gap	(0.000)	(0.000)	(0.000)	(0.000)
Sectors	171	171	171	171
Observations	5575549	5575549	5575549	5575549
R-squared	.168	.168	.168	.168
All specifications include				
County x 5 Digit Industry FE	X	X	X	X
2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price gap measures the differnce in the OECD Europe industrial use average price and U.S. state level industrial use natural gas prices. The dependent variable in Panel A is the log(employment+1) by five digit sector in counties not located above or near shale deposits. The dependent variable in Panel B is a dummy that is 1 if there was any capital expenditures in a county and year, excluding counties located above or near shale deposits. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the U.S. state level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A10: Effect of natural gas price gap between U.S. states and OECD Europe on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.133***	0.123***	0.136***	0.129***
× Price Gap	(0.031)	(0.026)	(0.032)	(0.027)
Clusters	40	40	40	40
Observations	2299198	2299198	2299198	2299198
R-squared	.768	.768	.768	.768
Panel B: Overall Import Value				
Energy Intensity	0.028	0.053**	0.025	0.048*
× Price Gap	(0.029)	(0.024)	(0.029)	(0.024)
Clusters	40	40	40	40
Observations	1651893	1651893	1651893	1651893
R-squared	.803	.803	.803	.803
Panel C: Any Export				
Energy Intensity	0.002	0.002	0.002**	0.002*
× Price Gap	(0.001)	(0.001)	(0.001)	(0.001)
Clusters	40	40	40	40
Observations	2.21e+07	2.21e+07	2.21e+07	2.21e+07
R-squared	.677	.677	.677	.677
Panel D: Any Import				
Energy Intensity	-0.002**	-0.001	-0.002**	-0.001
× Price Gap	(0.001)	(0.001)	(0.001)	(0.001)
Clusters	40	40	40	40
Observations	2.21e+07	2.21e+07	2.21e+07	2.21e+07
R-squared	.723	.723	.723	.723
All specifications include				
State x Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between the OECD Europe average industrial use gas price and U.S. state level natural gas prices. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are two-way clustered at the U.S. state and destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A11: Effect of natural gas price gap on energy intensive export, import values on the extensive and intensive margin between 1997 and 2012 (including agriculture, mining and other service sector trade captured in the trade data.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Overall Export Value				
Energy Intensity	0.242***	0.223***	0.245***	0.230***
× Price Gap	(0.022)	(0.019)	(0.023)	(0.019)
Clusters	218	218	218	218
Observations	409571	409571	409571	409571
R-squared	.89	.89	.89	.89
Panel B: Overall Import Value				
Energy Intensity	0.025	0.047*	0.028	0.049*
× Price Gap	(0.032)	(0.027)	(0.031)	(0.027)
Clusters	216	216	216	216
Observations	238442	238442	238442	238442
R-squared	.903	.903	.903	.903
Panel C: Any Export				
Energy Intensity	0.003	0.005**	0.002	0.004**
× Price Gap	(0.002)	(0.002)	(0.002)	(0.002)
Clusters	218	218	218	218
Observations	655962	655962	655962	655962
R-squared	.722	.722	.722	.722
Panel D: Any Import				
Energy Intensity	-0.002	-0.002	-0.000	-0.001
× Price Gap	(0.002)	(0.002)	(0.002)	(0.002)
Clusters	218	218	218	218
Observations	655962	655962	655962	655962
R-squared	.755	.755	.755	.755
All specifications include				
Country x 5 Digit Industry FE	X	X	X	X
Country x 2 Digit Industry x Year FE	X	X	X	X
Oil and Gas Linkage x Year FE	X	X	X	X

Notes: Price Gap is measured as the difference between a country average industrial use natural gas price and the US industrial use natural gas price. The dependent variable in Panel A and B are the logged values of exports and imports respectively. The data includes agricultural goods, mining sector and service sector trade included in the trade data and for which a measure of energy intensity could be constructed. The dependent variable in Panel C and Panel D is a dummy that takes the value of 1 in case of non-zero exports (imports) in a sector and year respectively. The Energy Intensity measures used throughout are at the five digit sector level and come from the U.S. IO table. Columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

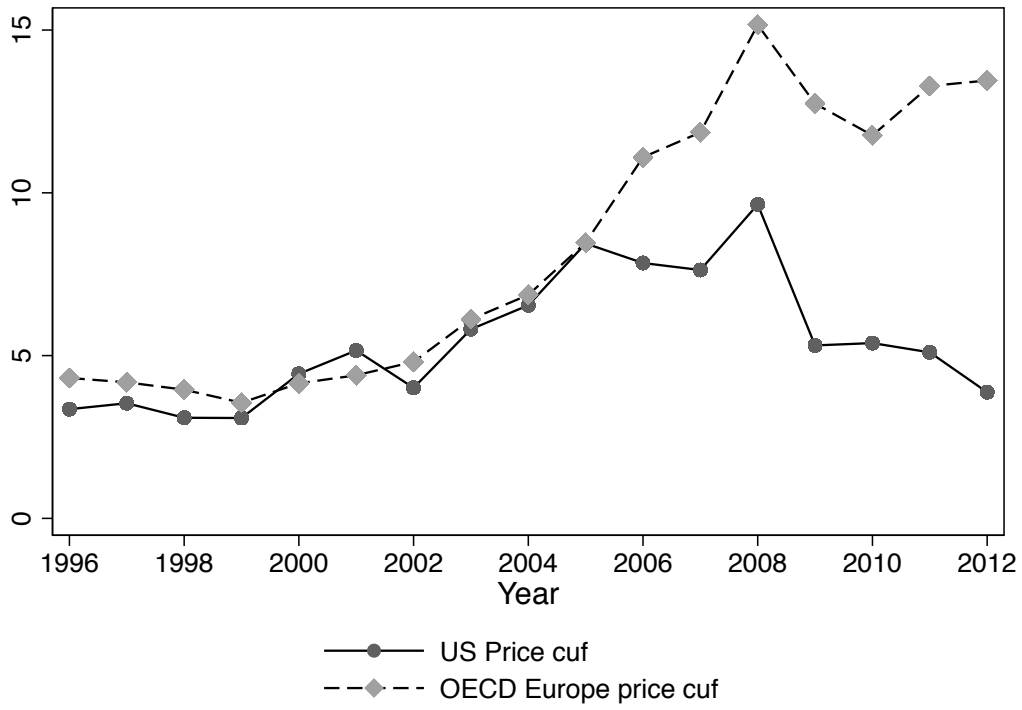


Figure A1: Natural Gas Prices for Industrial use across the OECD Europe and the U.S. over time.

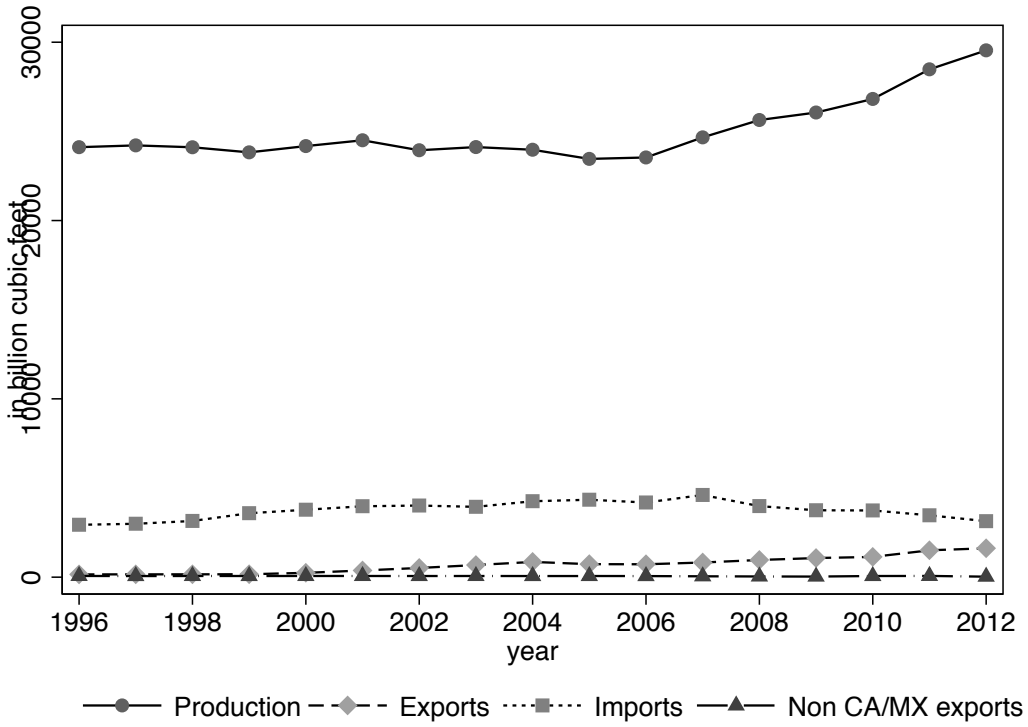


Figure A2: U.S. Natural Gas Production, Imports and Exports.

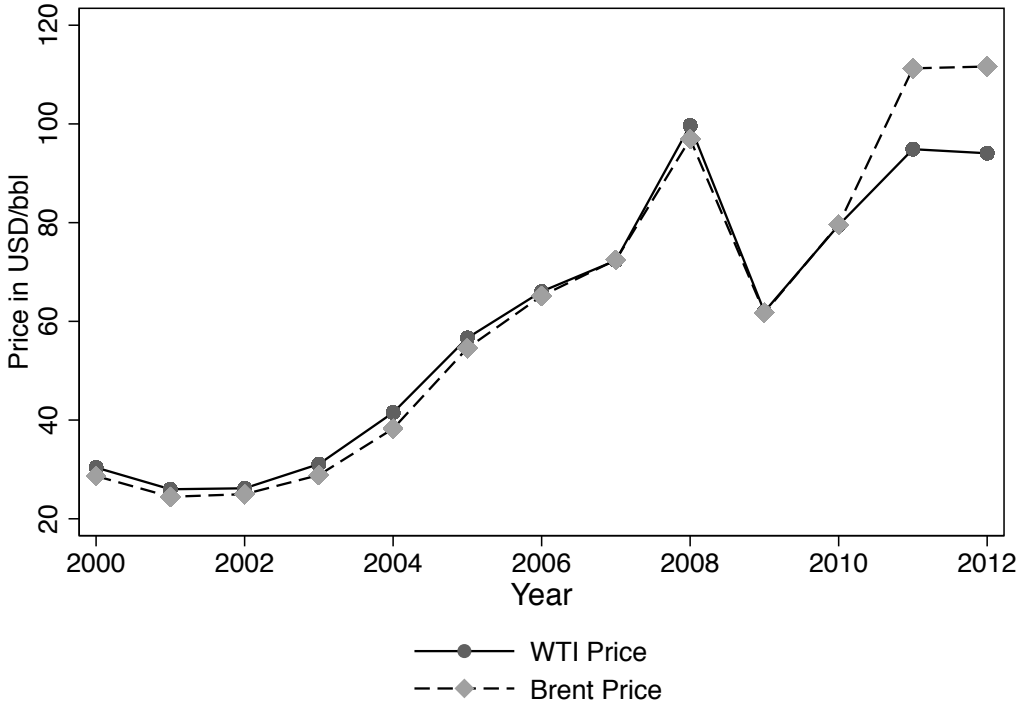


Figure A3: Crude Oil Prices for Brent (Europe) and WTI (US) over time.

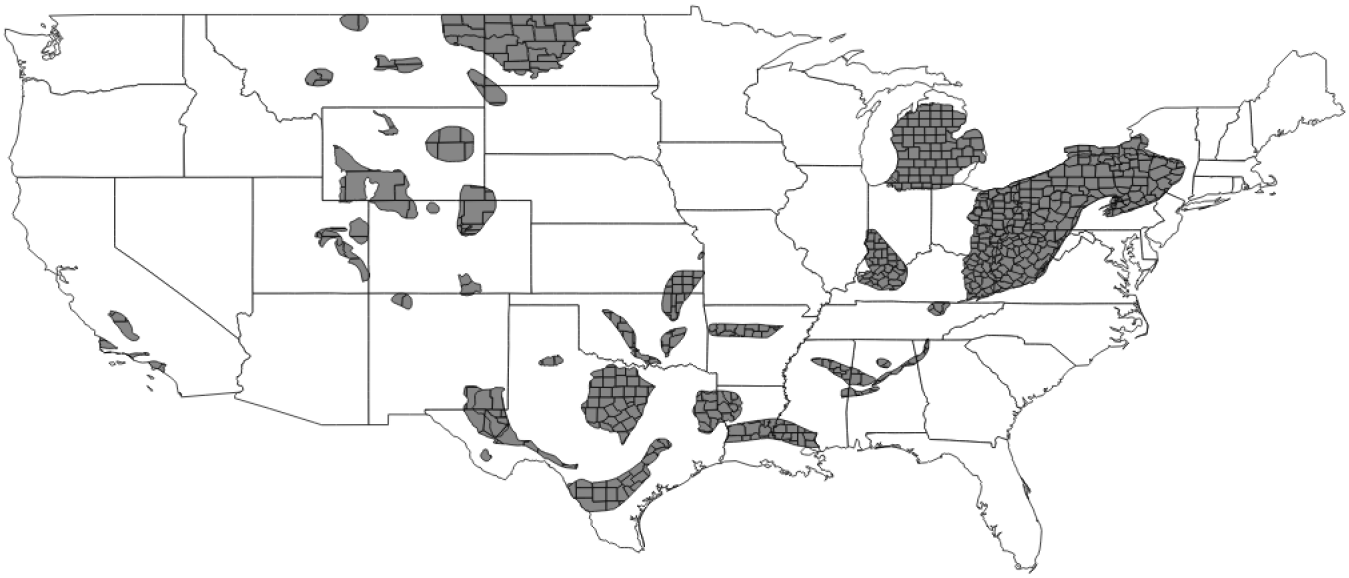


Figure A4: Map of US States and major US Shale Plays: For the U.S. domestic employment and capital expenditure data, we remove data from counties that are located above or near shale plays, before aggregating the data to national five digit sector level figures.

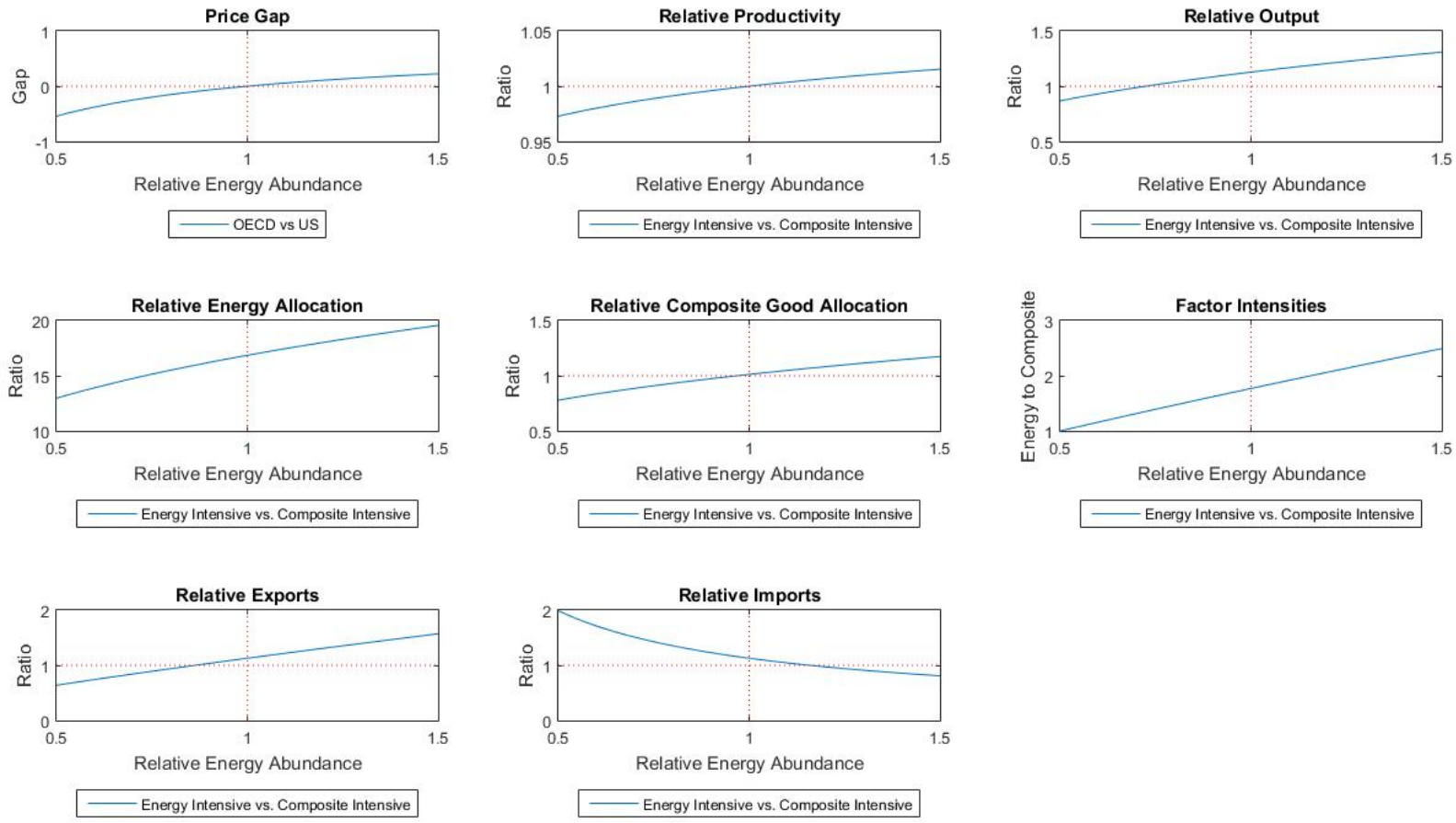


Figure A5: Simulations: Increase in US Energy Endowment. We increase the relative US energy endowment from 0.5 to 1.5 and plot our variables of interest against the ratio $(\bar{N}^{US}/\bar{L}^{US})/(\bar{N}^{OECD}/\bar{L}^{OECD})$.

CENTRE FOR ECONOMIC PERFORMANCE
Recent Discussion Papers

1453	Randolph Bruno Nauro Campos Saul Estrin Meng Tian	Foreign Direct Investment and the Relationship Between the United Kingdom and the European Union
1452	Stephen J. Redding Esteban Rossi-Hansberg	Quantitative Spatial Economics
1451	Elias Einiö	The Loss of Production Work: Evidence from Quasi-Experimental Identification of Labour Demand Functions
1450	Marcus Biermann	Trade and the Size Distribution of Firms: Evidence from the German Empire
1449	Alessandro Gavazza Simon Mongey Giovanni L. Violante	Aggregate Recruiting Intensity
1448	Emmanuel Amissah Spiros Bougheas Fabrice Defever Rod Falvey	Financial System Architecture and the Patterns of International Trade
1447	Christian Fons-Rosen Vincenzo Scrutinio Katalin Szemeredi	Colocation and Knowledge Diffusion: Evidence from Million Dollar Plants
1446	Grace Lordan Jörn-Steffen Pischke	Does Rosie Like Riveting? Male and Female Occupational Choices
1445	Stephen J. Redding David E. Weinstein	A Unified Approach to Estimating Demand and Welfare
1444	Anna Valero John Van Reenen	The Economic Impact of Universities: Evidence from Across the Globe
1443	Marta De Philippis	STEM Graduates and Secondary School Curriculum: Does Early Exposure to Science Matter?

1442	Thierry Mayer Marc J. Melitz Gianmarco I.P. Ottaviano	Product Mix and Firm Productivity Responses to Trade Competition
1441	Paul Dolan Georgios Kavetsos Christian Krekel Dimitris Mavridis Robert Metcalfe Claudia Senik Stefan Szymanski Nicolas R. Ziebarth	The Host with the Most? The Effects of the Olympic Games on Happiness
1440	Jörn-Steffen Pischke	Wage Flexibility and Employment Fluctuations: Evidence from the Housing Sector
1439	Brian Bell John Van Reenen	CEO Pay and the Rise of Relative Performance Contracts: A Question of Governance
1438	Fadi Hassan Paolo Lucchino	Powering Education
1437	Evangelia Leda Pateli	Local and Sectoral Import Spillovers in Sweden
1436	Laura Kudrna Georgios Kavetsos Chloe Foy Paul Dolan	Without My Medal on My Mind: Counterfactual Thinking and Other Determinants of Athlete Emotions
1435	Andrew B. Bernard Andreas Moxnes Yukiko U. Saito	Production Networks, Geography and Firm Performance
1434	Zack Cooper Stephen Gibbons Matthew Skellern	Does Competition from Private Surgical Centres Improve Public Hospitals' Performance? Evidence from the English National Health Service

The Centre for Economic Performance Publications Unit
Tel 020 7955 7673 Fax 020 7404 0612
Email info@cep.lse.ac.uk Web site http://cep.lse.ac.uk