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The General Equilibrium Effects of the Shale Revolution

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Abstract

The shale revolution is gradually transforming the industrial structure of the United States. This paper quantifies these changes in a model in which industries are linked by productivity linkages. In this framework, productivity gains in one industry may spill over to other industries. For 2015 (the most recent data available), we find that the shale revolution raised US relative wages by around 0.84 percent, whereas Mexican and Canadian wages declined by 1.12 and 1.43 percent, respectively. Judging by countries' ability to sell goods to the US, China is the main beneficiary of the shale revolution with increased US exports of more than $14 billion (7 percent) in 2015. At the same time, the US automobile industry lost sales of more than $65 billion (almost 10 percent) because of the shale revolution.

Keywords: Shale revolution, industry linkages, Ricardian trade, oil and gas production, structural change

JEL Classification: F11, O50, L16, Q33

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1 Introduction

When in 1947 the now-dissolved U.S. Bureau of Mines published its first report on the energy trade of the United States, the country ran an energy-trade surplus of more than six percent. At the time, energy was exported mainly in form of coal and lignite, and destined for Europe whose coal industry was still recovering from the war (Routledge, 1968). In the following years, too, the US exported more energy than it imported, but this changed when Venezuela and the Netherland Antilles began shipping crude oil to the US. Starting in 1952, the US consistently imported more energy than it exported, generating an energy-trade deficit that, at its peak in 2008, made up about half the total US deficit. Only eleven years later, this changed when—after almost seven decades—the US again exported more energy than it imported (EIA, 2020).[1]

Several technical developments and their commercialization allowed for this revolution. Rocks, in particular, formations of shale that were once viewed of no commercial value are now supplying the US with large amounts of oil and gas. The shale revolution is gradually reshaping the industrial structure of the US and to a smaller extent that of other countries. The goal of this paper is to quantify these changes.[2]

A productivity-driven growth of an industry typically leads to higher overall wages in the country and, as a consequence, the other industries in the

[1]The energy-trade statistics are now published by the U.S. Energy Information Administration (EIA), a subsidiary of the United States Department of Energy. While imports of crude oil are currently still larger than exports, the US is now exporting considerable amounts of natural gas and petroleum products such as gasoline.

[2]Hughes (2013) uses the term 'shale revolution'; a term we adopt here. For brevity, we may sometimes simply use 'shale'. In the literature, the term fracking revolution is used as well. We provide a formal definition of what we mean by shale revolution in Section 5.

country lose competitiveness and there may be some form of Dutch-disease-type crowding out. But not all industries lose from shale. The industries that build and maintain the oil and gas infrastructure are likely to gain. Other industries benefit from shale because they require cheap energy or because they are able to tap on the physical capital and, especially, the human capital the oil and gas industry has been building up over the past two decades. In the terminology of our model, the tighter an industry is linked to the oil and gas industry, the more likely it is to benefit from shale.

In our framework, industries are linked by productivity linkages so that an industry may benefit from possible productivity spillovers from other industries. The shale revolution is modeled as an increase of the productivity of the oil and gas industry in the US.

There are many possible factors that may link industries. Two industries may be linked because they require similar technologies, because they draw from the same pool of human capital, because one may be a supplier or a buyer in the other industry's production chain, because they require similar infrastructure and similar institutions, or because they have similar climatic, geographic, or geological prerequisites. None of the factors listed are easily observed, nor does it seem possible to identify easily which factor (or factors) cause a link between industries. We can observe, however, the result of such a link in the data. When two industries are linked, they tend to occur in pairs; countries that are productive in one of the industries will tend to be productive in the other as well. On the other hand, when two industries are not linked, their occurrence in the data should mimic random draws.

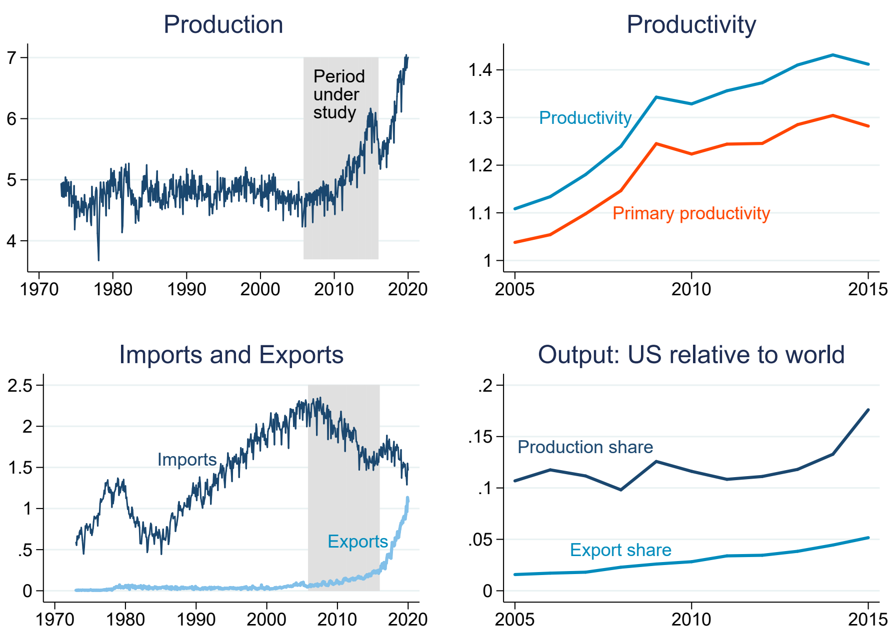

Figure 1: The Shale Revolution

Left hand panels: US oil and gas production (top) and exports and imports (bottom) over time (Source: EIA, in quadrillion BTU). Shaded area: 2005 - 2015, period under study in this paper. Right hand panel top: Estimated US productivity and estimated US primary productivity in the oil and gas industry. Bottom: US production share (US production relative to world production) and export share.

This approach of modeling and estimating industry linkages is a modified version of an approach proposed by Hidalgo, Klinger, Barabási, and Hausmann (2007). The main difference between the two approaches is that we rigorously incorporate the industry linkages into an economic model. This allows us to conduct comparative statics exercises and thus to assess the general equilibrium effects of shale. There is a cost to this more rigorous approach in terms of data requirements. The approach here requires information about countries' internal trade flows, i.e., flows of goods that are produced and consumed in the same country. Unlike the bilateral flows used in Hidalgo et al. (2007), internal flows are available only for relatively coarse industry classes and only for a relatively short period of time, in our case from 2005 to 2015. The data, thus, cover the beginning of the shale revolution and the first decade, but the results we report for 2015 are likely to underestimate the effect one would find with more recent data.[3]

This paper contributes in several ways to the existing literature. First, the paper shows how the type of industry linkages suggested in Hidalgo et al. (2007) can be modeled rigorously in an economic model. Our theoretical framework is a Ricardian model of trade with Eaton and Kortum (2002) technology that we extend to allow for productivity linkages. We are not aware of previous attempts to model industry linkages in this fashion. The recent

[3]While one of the largest producers, the US is still a relatively small exporter of oil and gas. See lower right panel of figure 1. Various factors impede the trade. Until December 2015, for example, the US banned the export of domestically produced crude oil (Clark, 2014). Exporting gas and refined petroleum was possible under the ban. Another important impediment is the missing infrastructure such as pipelines and ports. For an overview of the recent infrastructure developments and infrastructure restrictions see EIA (2015a, 2018, 2019). API (2017) expects the "rapid infrastructure development" currently undergoing, to "continue for a prolonged period of time".

economic literature with industry linkages focuses primarily on input-output linkages. Acemoglu et al. (2012), for example, show in a model with input-output linkages how shocks at the level of the individual industry may lead to aggregate fluctuations.

Productivity linkages and input-output linkages serve different purposes and should be viewed as complements. When studying structural changes over a period of many years, as we do here, input-output linkages themselves respond to the structural change under study. Productivity linkages avoid this endogeneity problem (we continue this discussion in Section 2). The contribution of the paper to this literature is to propose a framework that allows us to study the gradual and long-lasting structural changes we are witnessing with the shale revolution.

Second, by modeling the growth of an industry in a general equilibrium setting, the paper contributes to the literature on the Dutch disease. Corden and Neary (1982), Krugman (1987) and Matsuyama (1992) are important papers in this field.

Finally, the paper contributes to the literature on the shale revolution. Muehlenbachs et al. (2015) study the effect of shale gas development on local housing markets. Using a spatial equilibrium model, Bartik et al. (2019) estimate the local welfare effects of shale and report an average willingness to pay for allowing fracking of $2,500 per household annually. Feyrer et al. (2017) estimate the effect of shale production on income and find that within 100 miles of a well, one million dollars of new oil and gas production generates $257,000 in wages and $286,000 in royalty and business income (see also James and Smith, 2020; Feyrer et al., 2020). Our contribution to this literature is to show how the shale revolution gradually reshapes the economic structure of the US. Doing so, we extend the work of Arezki et al. (2017) who study the effect of shale gas on the US manufacturing sector. Moreover, our setting allows us to assess the effect of shale on the economic structure in countries other than the US.

In line with our expectations, US wages increase with the productivity growth of the oil and gas industry. In our baseline comparative statics exercise, we find that US wages in 2015 increased by 0.84 percent relative to the average wage in our sample because of the shale revolution. Wages in Mexico and Canada, the two main trading partners of the US, decreased by 1.12 and 1.43 percent. These decreases are most likely driven by the fact that both countries are themselves large oil and gas producers. For 2015, we find that the Canadian oil and gas industry lost more than a third of its output (almost $100 billion) because of shale. The Mexican oil and gas industry lost 40 percent (almost $25 billion).[4]

Within the US, only few other industries benefit directly from the shale revolution. The main beneficiary is refined petroleum whose output in 2015 is increased by more than 10 percent because of shale. A large part of the US vehicle production (almost 10 percent, or $65 billion) is replaced by imports from abroad (mainly from Canada, Japan and Germany). In fact, the industry that gains most from shale (after the fossil-energy industries in the US) is the

[4]These numbers are calculated in a comparative statics exercise in which only a single parameter differs from the original equilibrium. All other 120,000 parameters of the model, including the other primary productivities, trade costs, consumption shares are kept unchanged.

Canadian vehicle industry. Judging by countries' ability to sell goods to the US, China is the main beneficiary of shale with increased exports to the US of more than $14 billion (7 percent) in 2015. Other large beneficiaries are Germany and Japan. Saudi Arabia and Russia, on the other hand, see their US exports drop by 48 and 33 percent respectively.

The paper is organized as follows. The next section (Section 2) motivates our choice to use productivity linkages and discusses why using input-output linkages would not be appropriate. Section 3 presents the theoretical framework. Section 4 describes the empirical framework, the data, and discusses the estimation results. Section 5 presents the results of the comparative statics exercises and a summary in Section 6 concludes. An online appendix gives additional information about the data and the estimation procedure, and provides tables for the robustness analysis.

2 Industry Linkages in the Short and in the Long-Run

The shale revolution is transforming the US economy over a period of many years, and the term evolution, rather than revolution, may be more adequate to describe the slow, incremental technical advances over the past decades (Alexander et al., 2011). Studying how the shale revolution transforms the US economy requires what one may call *long-run* industry linkages. The industry linkages should reflect technical characteristics that should themselves be unaffected by the structural change. This rules out the use of input-output linkages. In this section, we explain this position and motivate the approach taken in this paper.

Imagine, for the moment, a situation in which the US bans the production of (crude) oil and gas in the country and suppose that the ban is permanent and unexpected. What would be the consequences of such a decision?

The US input-output tables give good indications of the immediate consequences of the ban. The oil and gas industry itself does not supply many other industries with its products, but it is the main supplier of petroleum refineries, whose output is used in virtually any other industry in form of gasoline, diesel or heating oil (see also the discussion in Section 4). The reduced supply of these products directly affects all other industries in the US and given the current dependence on domestically produced oil and gas, the immediate economic impact of the ban would be severe.

As time goes by, the economy will adapt. Imports of oil and gas from abroad will increase and will make up for parts of the lost domestic production. Some firms will try to find alternatives to oil and gas, and other will develop energy-saving production processes. Since these adaption change the flows of intermediate goods between the industries, they will necessarily alter the input-output linkages.

In addition to the diversion of input-output flows, the closure of the domestic oil and gas industry will have other, more indirect consequences. The most obvious of these is probably the productive knowledge and know-how that is lost when the industry's workers move on to other professions, and universities stop offering petroleum engineering and related courses. These indirect effects, too, may have an impact on other industries.

The question that remains to be answered in this thought experiment is, then, how we may assess the long-run impact of the ban. Is the presence of a domestic oil and gas industry essential for some of the other industries? Does the absence of an oil and gas industry systematically weaken (or strengthen) other industries? One possible way to answer these question is to study industry patterns in other countries, and, in the way specified by the theoretical model, this is the approach taken in this paper.

In our theoretical framework, industry linkages are productivity linkages and we assume that the linkages equation is log-linear with constant coefficients,

$$\log A_{i,t}^{k} = \sum_{l=1, l\neq k}^{K} \beta^{lk} \log A_{i,t}^{l} + \log \alpha_{i,t}^{k}. \tag{1}$$

Country i's productivity in industry k at time t, $A_{i,t}^{k}$, is a function of the productivities of the country's other industries at the same point in time. Productivity gains in one industry may spill over to other industries but we rule out spillovers from other countries or other points in time. The industry coefficients, β^{lk}, show the (direct) link between two industries l and k. In line with our assumption that the coefficients reflect technical relationships between industries, we assume that they are constant across countries and vary only slowly over time. For the quantitative analysis in Section 4, the industry coefficients are estimated using data from 60 countries over a period of 11 years. Since productivity is not observable, we estimate the industry coefficients using the industry-exporter-time fixed-effects from the regression of a standard gravity equation. Section 4 discusses the estimation procedure.

Finally, the primary productivities, $\alpha_{i,t}^k$, capture the part of a country's productivity that is not already picked up by any possible spillovers from other industries. The primary productivities reflect a country's endowment with the productivity factors that are necessary in the production of industry k's output (e.g., knowledge, know-how, or climatic and geographic factors). In this framework, the shale revolution is modeled as an increase of the US primary cabability in the oil and gas industry (see Section 5).

Solving equation (1), we find

$$\log A_{i,t}^k = \sum_{l=1}^{K} \lambda^{lk} \log \alpha_{i,t}^k \tag{2}$$

where the industry linkages, λ^{lk}, are the entries of the linkages matrix Λ that can be calculated using

$$\Lambda = (I - B)^{-1}, \tag{3}$$

where B is the matrix of industry coefficients (with zeros on the diagonal) and I is the identity matrix. Equation (3) reveals some formal similarities between the model here and the input-output model. The industry coefficients, β^{lk}, correspond to the entries of the direct requirement matrix, the productivity linkages, λ^{lk}, correspond to the entries of the total requirement matrix, and the right hand side of equation (3) corresponds to the Leontief inverse. Given the functional form assumption in (1) where productivity enters both the left and the right hand side, this similarity was expected.

3 Theoretical Framework

The variant of the Eaton and Kortum (2002) model we use here is a simplified version of the original model and has been discussed before in Donaldson (2018), Costinot et al. (2011), Levchenko and Zhang (2016), and others. We extend this model to allow industries to be linked so that an industry's productivity may benefit from spillovers from other industries. From the point of view of the individual firm, the linkages are external and do not affect the firm's optimization problem so that the main properties of the original model are preserved. In particular, Walras' law continues to hold and the model is homogeneous of degree zero in wages. The original model is nested in our model as a special case when industries are presumed independent.

Industry linkages are productivity linkages, but since productivity is not directly observable, we will define industry linkages as capability linkages. Capability linkages and productivity linkages are equivalent in this setting because of the homogeneity property. A country's (export) capability is defined as

$$\kappa_i^k = \frac{A_i^k}{w_i},$$

where A_i^k is country i's productivity in industry k relative to the country's wage rate. This ratio of productivity over wages is sometimes called competitiveness in the literature.[5]

Consider a static world economy with $i = 1, ..., I$ countries. The world is

[5]Capabilities, too, are not observable but they are observable in relative terms, i.e., country i's capability relative to some other country's capability. This relative observability will be sufficient to estimate the industry linkages.

Ricardian with each country endowed with a single factor of production (labor) and trade is driven by productivity differences. In each country, there are $k = 1, ..., K$ industries (sectors) and in each industry, there are infinitely many competitive firms. Each firm produces one of infinitely many varieties $\omega \in \Omega$ of an industry's output. Labor can move freely across firms and industries, but not across countries. Let L_i denote country i's labor endowment and w_i its wage rate. We drop time-subscripts in this section, to keep the notation simpler.

Preferences Preferences are given by a utility function of the form

$$U_i = \prod_{k=1}^{K} \left(Q_i^k\right)^{\mu_i^k} \tag{4}$$

where Q_i^k is a basket of the varieties of the good produced by industry k. We assume that $\sum_{k=1}^{K} \mu_i^k = 1$ so that μ_i^k indicates the fraction of income that households spend on industry k goods. The varieties are aggregated symmetrically by a Dixit-Stiglitz-Spence aggregator

$$Q_i^k = \left(\int_{\Omega} q_i^k\left(\omega\right)^{\frac{\sigma-1}{\sigma}} d\omega\right)^{\frac{\sigma}{\sigma-1}} \tag{5}$$

where $q_i^k\left(\omega\right)$ is the quantity of variety ω of industry k consumed in i. Households maximize (4) subject to their budget constraint, $w_i L_i = \sum_{k=1}^{K} P_i^k Q_i^k$, where P_i^k is the CES price of the Dixit-Stiglitz-Spence aggregator.

Technology Markets are competitive and firms set prices equal to marginal costs $\left(w_i/z_i^k(\omega)\right)$ where $z_i^k(\omega)$ is the firm's labor productivity drawn randomly from a Fréchet distribution with a cumulative distribution function of the form

$$F_i^k = \exp\left\{-\left(\frac{z}{A_i^k}\right)^{-\theta}\right\}.$$

Here, A_i^k is a scale parameter; the larger A_i^k, the larger the probability that a country draws a high productivity (the mean of the Fréchet distribution is linear in A_i^k). We refer to A_i^k as country i's productivity in industry k. In the original Eaton & Kortum model, A_i^k is exogenous. When we introduce industry linkages below, A_i^k becomes an endogenous variable. The second parameter of the Fréchet distribution, θ, is a shape parameter that affects the spread of the distribution. The smaller θ, the larger the "overlap" of the distributions in the different countries and the more trade takes place within the same industry. As θ gets larger, the countries will tend to specialize in distinct industries (see footnote 7 for more).

The productivity draws are independent across countries. Once a productivity is drawn, anyone in the country is free to produce the variety and every producer of that variety in the country has access to the same production technology. No producer has market power and all prices will be set equal to marginal costs. Trade is subject to iceberg costs, that is, the cost of delivering one unit of a variety from i to j is $d_{ij}^k \geq 1$ and we assume that

$$d_{ij}^k \leq d_{ij'}^k d_{j'j}^k \text{ for all } i, j, j'.$$

Given the assumptions above, the price of variety ω in sector k in country j purchased from country i is given by

$$p_{ij}^{k}(\omega) = p_{ii}^{k}(\omega)\, d_{ij}^{k}.$$

This price is a potential (or hypothetical) price because j will only purchase ω from i if i happens to be the least expensive source. The actual price paid in j is given by the lowest of all hypothetical prices, that is

$$p_{j}^{k}(\omega) = \min_{i\in I}\left\{p_{ij}^{k}(\omega)\right\} = \min\left\{\frac{w_i}{z_i^k(\omega)} d_{ij}^{k}\right\}.$$

Under the assumption that productivities are drawn from a Fréchet distribution, the hypothetical prices, $p_{ij}^{k}(\omega)$, are distributed exponentially. Since the minimum of a set of exponentially distributed variables is as well distributed exponentially, $p_{j}^{k}(\omega)$ is distributed as well exponentially. The probability that i is the least cost producer of variety ω to destination j is then given by

$$\pi_{ij}^{k} = \Pr\left\{p_{ij}^{k}(\omega) \leq \min_{s\in I\setminus i} p_{sj}^{k}(\omega)\right\} = \frac{\left(\frac{A_i^k}{w_i d_{ij}^k}\right)^{\theta}}{\sum_{s\in I}\left(\frac{A_s^k}{w_s d_{sj}^k}\right)^{\theta}}. \tag{6}$$

Where we used the fact that both expressions in the curly braces are exponentially distributed.[6] Since there are infinitely many varieties in each industry, this probability is also the fraction of k-varieties that country j buys from

[6]Let $X_1, ..., X_n$ be independent and exponentially distributed random variables with parameters $\lambda_1, ..., \lambda_n$, then $\min\{X_1, ..., X_n\}$ is also exponentially distributed with parameter $\lambda = \lambda_1 + ... + \lambda_n$. If x and y are independent and exponentially distributed, i.e., $x \sim \exp(\lambda)$ and $y \sim \exp(\mu)$, then $\Pr\{x \leq y\} = \frac{\lambda}{\lambda+\mu}$.

country i.[7]

Industry linkages take the form of capability linkages. The particular functional form assumption is log-linear with constant coefficients,

$$\log \kappa_i^k = \sum_{l=1, l\neq k}^{K} \beta^{lk} \log \kappa_i^l + \log \rho_i^k, \tag{7}$$

where ρ_i^k is the primary capability of country i in industry k and β^{lk} are called industry coefficients. Given the functional form assumption, a country's capability originates from two sources. First, an industry's capability may be influenced by the capabilities of the other industries in the country. The sum on the right hand side of equation (7) aggregates the contributions of the other industries (of the network of industries). The second source is a country's primary capability ρ_i^k. This is a form of remainder that includes everything not already captured by the contribution of the network. We rule out spillovers from other countries. Solving equation (7) we find

$$\log \kappa_i^k = \sum_{l=1}^{K} \lambda^{lk} \log \rho_i^l \tag{8}$$

[7] With X_{ij}^k denoting sector k trade flows from country i to country j, this share can be written as $\pi_{ij}^k = X_{ij}^k / X_j^k$ where X_j^k is country j's consumption of sector k goods, i.e., $X_j^k = \sum_s X_{sj}^k$. The share π_{ij}^k approaches either 0 or 1 as we increase the shape parameter θ of the Fréchet distribution since

$$\lim_{\theta\to\infty} \pi_{ij}^k = \lim_{\theta\to\infty} \left(\frac{A_i^k}{w_i d_{ij}^k}\right)^\theta / \min_{s\in I} \left\{ \left(\frac{A_s^k}{w_s d_{sj}^k}\right)^\theta \right\}$$

which equals 1 for $i = s$ and 0 otherwise. In words, as θ increases, the countries tend to specialize in distinct industries and no intra-industry trade takes place. In some sense, our model includes the model of Dornbusch et al. (1977) as a special case when $I = 2$.

where the industry linkages, λ^{lk}, are the entries of the linkages matrix Λ which can be found using equation (3). Homogeneity of degree zero in wages implies that the linkages equation must be independent of wages and can, therefore, be written as

$$\log A_i^k = \sum_{l=1}^{K} \lambda^{lk} \log \alpha_i^k \tag{9}$$

where α_i^k is country i's primary productivity in industry k. The relationship between α_i^k and ρ_i^k is then given by

$$\log \rho_i^k = \log \alpha_i^k - \log w_i \left(1 - \sum_{l=1}^{K} \beta^{lk}\right). \tag{10}$$

The primary capability is determined by the difference between the primary productivity and a country's wages weighted by the column-sums of $(I - B)$.

Equilibrium Assuming balanced trade, consumption in i must equal production in i,

$$\sum_{k=1}^{K} Q_i^k P_i^k = \sum_{j=1}^{I} \sum_{k=1}^{K} Q_j^k P_j^k \pi_{ij}^k$$

and with expenditure matching income in equilibrium, the condition can be written as

$$w_i L_i = \sum_{j=1}^{I} \sum_{k=1}^{K} \pi_{ij}^k \mu_j^k w_j L_j \tag{11}$$

where $w_i L_i$ on the left hand side of equation (11) is country i's wage income and the expression on the right hand side indicates the sources of these payments. The product $\mu_j^k w_j L_j$ is the size of the market for sector k goods in country j, and country i supplies a share of π_{ij}^k to this market. Summing over sectors and countries then gives total payments reveived by firms in i.

Equation (11) closes the model and determines the wage vector. The model has three sets of endogenous variables, wages (equation 11), market shares (equation 6) and productivities (equation 8, with $\kappa_i^k = A_i^k/w_i$). The wage of one country will serve as the numéraire.

4 Estimation Framework, Data and Results

The comparative statics exercises require a number of parameters whose estimation we describe in this section. Our first step will be to estimate the export capabilities that form the basis for the industry linkages and the productivities. Then, with the capabilities at hand, we can estimate the industry linkages.

For the entire empirical part, we will stay within the framework outlined in section 3; both regression equations are derived from theoretical relationships discussed before. With the exception of the gravity control variables (e.g., distance between countries), population (L_i), and the trade elasticity (θ), all parameters are derived from a single data set on trade flows. What we do here is, in some sense, to split the information contained in these flows into endogenous components and into parameters that—for the exercises studied here—one may reasonably consider exogenous.

4.1 Empirical Framework

Dividing equation (6) by the same expression for another exporter and replacing π_{ij}^k by X_{ij}^k/X_j^k and A_i^k/w_i by κ_i^k, gives a gravity equation of the form

$$\left(\frac{X_{ij}^k}{X_{i'j}^k}\right) = \left(\frac{\kappa_i^k}{\kappa_{i'}^k}\right)^{\theta} \left(\frac{d_{ij}^k}{d_{i'j}^k}\right)^{-\theta}. \tag{12}$$

In this Ricardian model, sector k trade flows from i to j (relative to the same flows from another exporter) are larger, the larger i's export capability relative to the export capability of i'. Similarly, trade flows are larger, the lower the trade costs between two countries, again, in relative terms.

We follow the literature and estimate the gravity equation with ppml (Poisson pseudo maximum likelihood). See Santos Silva and Tenreyro (2006) and Mayer and Head (2002) for a discussion. In order to derive an estimation equation from equation (12), we first take logs and add an importer-industry fixed effect to take care of the difference over exporters. Then we replace $\theta \log \kappa_i^k$ by an exporter-industry fixed effect and $-\theta \log d_{ij}^k$ by $\delta_{ij}^k D_{ij}$, where D_{ij} is a vector of gravity control variables that we use to measure the cost of trading between countries. D_{ij} includes an intra-fixed effect that indicates when importer and exporter are the same country. Finally, adding time-subscripts and a disturbance term gives the estimation equation

$$X_{ij,t}^k = \exp\left(\delta_{i,t}^k + \delta_{j,t}^k + \delta_{ij,t}^k D_{ij,t}\right) + \eta_{ij,t}^k. \tag{13}$$

The data for the gravity control variables are from Head et al. (2010) and include, for example, a measure of distance between i and j and indicators of a common language or a common currency. Appendix A.1 gives more information. The control variables are not industry-specific but since we estimate equation (13) for each industry separately, the coefficients may vary over industries.

Equation (13) identifies only relative exporter-industry fixed effects ($\delta^k_{i,t} - \delta^k_{i',t}$) and therefore only relative capabilities ($\log \kappa^k_{i,t} - \log \kappa^k_{i',t}$). This will be important for the comparative statics exercises because it restricts the type of question we may ask there. Calculating prices, for example, requires information about the level of capabilites and the relative capabilities we can identify here are not sufficient. The comparative statics exercises are, therefore, mute with respect to prices and in particular with respect to welfare. We return to this point again in the next section.

We denote the log-difference over exporters with a tilde as in

$$\tilde{\kappa}^k_{i,t} = \frac{\kappa^k_{i,t}}{\kappa^k_{i',t}}. \tag{14}$$

Other relative variables such as $\tilde{d}^k_{ij,t}$ or $\tilde{\rho}^k_{i,t}$ are defined accordingly. In order to avoid choosing a reference country, we use the geometric mean over all exporters as our normalization factor so that $\tilde{\kappa}^k_{i,t} = \kappa^k_{i,t} / \prod_s \left(\kappa^k_{s,t}\right)^{\frac{1}{I}}$.

In the second regression, we estimate the industry linkages. In Section 3, we specified the linkages equation in levels (equation 7), but relative capabilities are sufficient to identify the linkages. Dividing equation (7) by the same expression for another exporter gives our estimation equation for the industry coefficients

$$\log \tilde{\kappa}_{i,t}^{k} = \sum_{l=1}^{K} \beta^{lk} \log \tilde{\kappa}_{i,t}^{l} + \delta_i^k + \eta_{i,t}^{k}, \tag{15}$$

where we already replaced the relative primary capability, $\tilde{\rho}_{i,t}^{k}$, with an exporter-industry fixed effect, δ_i^k, and a residual, $\eta_{i,t}^k$, that we minimize. We treat the residual as an integral part of countries' primary capability. The industry coefficients (β^{lk}) do not carry a time-index nor an exporter-index, in line with our assumption that the coefficients identify technical relationships between industries that are constant across countries and vary only slowly over time. For the 11 years in our sample, we assume that the coefficients are constant. The industry-coefficients are, therefore, estimated using capability estimates from 60 countries over a period of 11 years.

Estimation is by OLS. Given the log-linear form of the linkages equation, we can estimate equation (15) without the need to specify the trade elasticity θ by using $(\delta_{i,t}^k - \delta_{i',t}^k)$ rather than $\log \tilde{\kappa}_{i,t}^k$. The difference $(\delta_{i,t}^k - \delta_{i',t}^k)$ corresponds to the convolution $\theta \log \tilde{\kappa}_{i,t}^k$. Specifying θ will be necessary in Section 5, when we calculate the equilibrium.

4.2 Constructing the Internal and Bilateral Trade Flows

Our main data are sector-specific trade flows (bilateral and internal) that we construct from the OECD inter-country input-output data set (OECD, 2018). Summing the rows of the input-output tables, gives the trade flows required for our exercises. The original data contain flows for the years 2005 to 2015 for 65 countries and 37 industries and are classified according to ISIC Revision 4.

The OECD data covers the entire world economy and contains all economic activities ranging from agriculture via manufacturing to the services industries, so that summing the flows over industries and importers ($\sum_s \sum_m X_{is}^m$) gives a country's gross production. The OECD data set includes a position for the rest of the world (ROW) that subsumes all flows of the countries that do not appear explicitly.

Some industries and some countries require special attention because of poor coverage. We move five countries (Costa Rica, Cyprus, Iceland, Cambodia, and Malta) to the rest of the world because of many missing data, leaving us with $59 + 1$ countries. The 59 countries that appear explicitly in the data set cover more than 90 percent of world economic output and of total trade flows.

The original OECD data set aggregates industries 05 (coal) with 06 (oil and gas) into an aggregate called $05T06$. We split this aggregate into its two constituents using UN Comtrade data for the bilateral flows ($X_{ij,t}^k$) and EIA data for countries' internal flows ($X_{ii,t}^k$). The EIA data (EIA, 2019) are published in quantity units that we convert into monetary units by using the ratio of imports reported by Comtrade relative to the imports reported by the EIA to evaluate the internal trade flows. Appendix A.1 provides detailed information and a discussion. Finally, we merge five of the original 37 industries with neighboring classes because of missing data. Our data set then has 33 industries, 60 countries (exporters and importers) and covers the eleven years from 2005 to 2015.

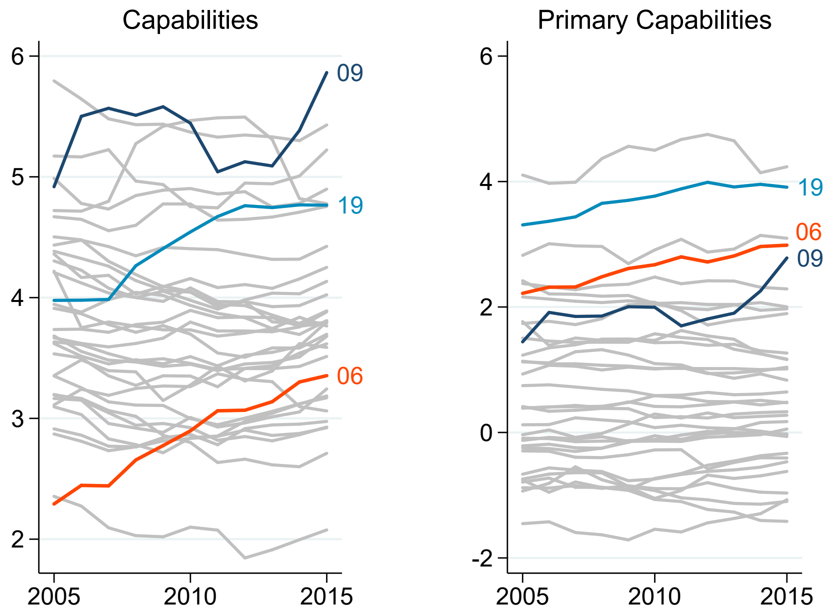

Figure 2: US Export Capabilities Over Time

US relative export capabilities (left) and relative primary export capabilities (right) over time. The capabilities are scaled by θ and shown are the convolutions $\theta \log \tilde{\kappa}^k_{i,t}$ and $\theta \log \tilde{\rho}^k_{i,t}$. Industries: 06 (Oil and gas), 09 (Mining support service activities), and 19 (Refined petroleum).

4.3 Results and Discussion: Capabilities

Figure 2 shows how relative US capabilities evolve during our sample period. The left hand panel shows capabilities, the right hand panel shows primary capabilities (both in logarithms and scaled by θ). In 2005, industry 06 (crude oil and gas) was the least competitive industry in the US, but experienced a steep increase during the sample period. In 2015, industry 06 still belongs to the less competitive US industries and even at the current pace, it will take some time until its export capabilities reach the level of many other industries in the US. In line with the steep increase in 06's export capabilities, the US experienced a sharp increase in the primary capability of 06 (right hand panel).

Two other industries (09 and 19) are highlighted in figure 2; both will turn up at various points in the discussion. Industry 09 is a service called mining support service activities and may (jointly with industry 06) reflect what we called the shale revolution in the introduction. We return to this point again in Section 5, when we discuss how to model the shale revolution in the comparative statics exercises. The third industry highlighted, industry 19, is refined petroleum and thus from an input-output point of view down-stream relative to 06. Similarly to industries 06 and 09, industry 19 experienced a significant increase during our sample period.

The noticeable growth in competitiveness of the oil and gas industry in the US becomes even more apparent when we look at deviations from 2005 as shown in figure 3. The capabilities of industry 06 increased by more than any of the other industries in the US. Industries 09 and 19 come second and third. Industry 09 is fairly volatile with a pronounced decline at around 2010. A similar picture emerges when we look at primary capabilities. Here, industry 09 comes first, followed by industry 06 and 19.

4.4 Results and Discussion: Productivity Linkages

There are 1089 (33×33) linkages with a mean of 0.37 and a standard deviation of 0.49. 16.9 percent of the linkages are negative. The distribution is right skewed with a maximum of 3.05 and a minimum of -1.03. Figure 4 shows a heat-plot of the linkages matrix Λ with larger values in dark and smaller values

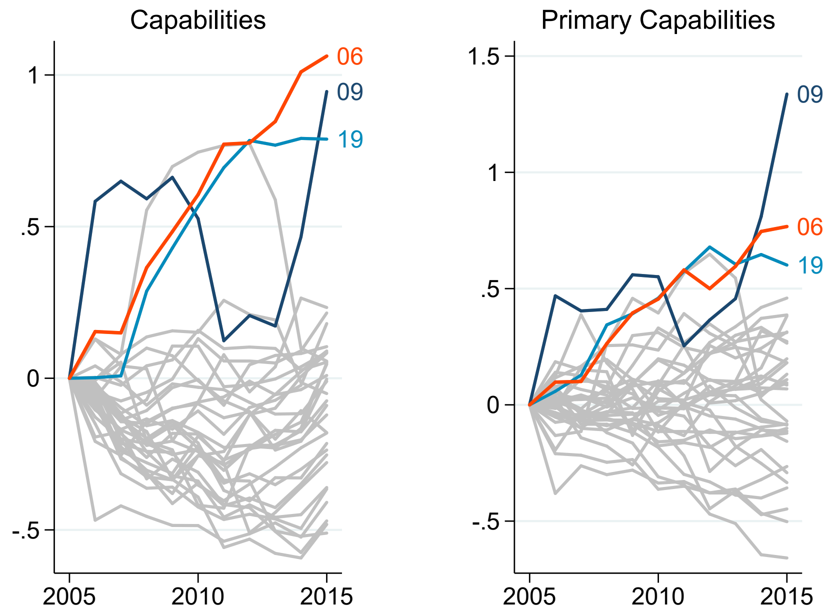

Figure 3: US Export Capabilities Over Time (Levels Relative to their Level in 2005)

US export capabilities over time relative to their 2005 level. Shown are the convolutions $\theta(\log \tilde{\kappa}_{i,t}^{k} - \log \tilde{\kappa}_{i,2005}^{k})$ and $\theta(\log \tilde{\rho}_{i,t}^{k} - \log \tilde{\rho}_{i,2005}^{k})$. Industries: 06 (Oil and gas), 09 (Mining support service activities), and 19 (Refined petroleum).

in bright shading. The diagonal is prominently showing which indicates that, typically, the principal link is between an industry's capability and its own primary capability. There are some larger off-diagonal entries as well but most often, the largest link is situated on the diagonal. The in-strengths (the column-sums of Λ) and the out-strengths (the row-sums of Λ) vary significantly from industry to industry. Table 6 in the Appendix shows the in-strengths and the out-strengths of all industries.

Since most of the links in the linkages matrix are fairly weak, a network representation is appropriate (here we follow Hidalgo et al., 2007). A network

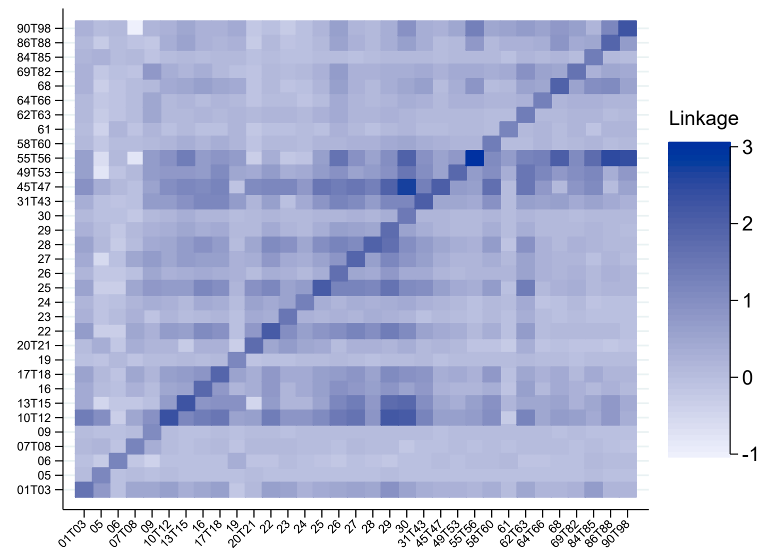

Figure 4: A Heat-Plot of the Industry Linkages

A heat-plot of the linkages matrix (Λ) with larger values in dark and smaller values in bright shading.

representation often helps in providing intuition about the structure of a network by simplifying the network by dropping the weaker linkages. In order to assure that the network remains connected, we first generate the maximum spanning tree. This is a tree (a network without cycles) that connects all industries and that maximizes the sum of the linkages (not including the diagonal of Λ). The maximum spanning tree is unique for weighted graphs when all weights are distinct (as we have here). We then add the 60 largest links to yield an average degree of around 3.

In the network representation in figure 5, each node represents an industry and nodes are linked either because they are linked by the maximum spanning tree or because they belong to the stronger links in original matrix. We lay out the network using a force-spring algorithm where the nodes are represented

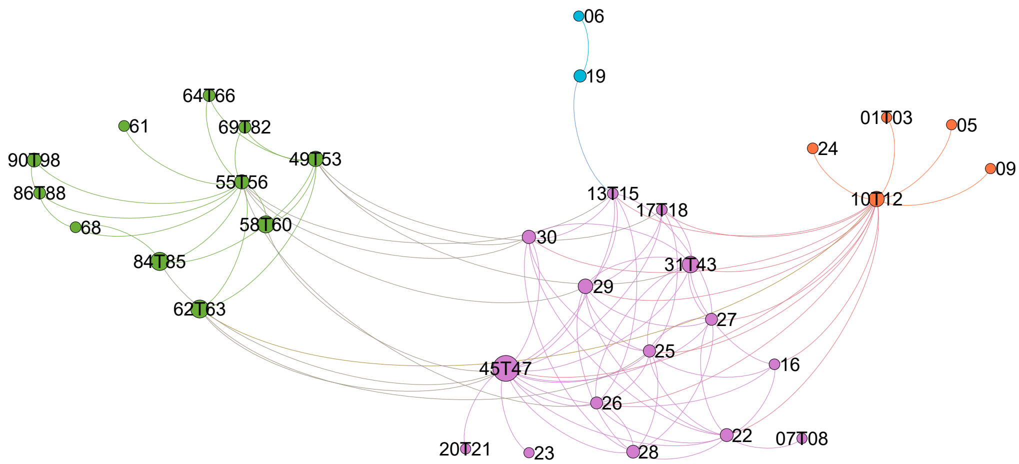

Figure 5: The Industry Network

A network representation of the industry linkages. The node size is proportional to an industry's degree. The layout and the coloring reflect the four communities in the network. The figure is drawn with the software package Gephi.

as equally charged particles and the edges are assumed to be springs (the algorithm we use is described in Blondel et al., 2008). The layout is then determined by the relaxed positions of the particles (the nodes). We retouched the layout manually to avoid overlapping links and untangle dense clusters. The figure is drawn using the software package Gephi.

The node size is proportional to the industry's degree in the binary network and the coloring corresponds to the communities in the network. Using Gephi's default algorithm to calculate the network's modularity, we find four communities. The communities detected here, roughly correspond to the structure of the ISIC classification system. Typical entries of the cluster on the right belong to the first entries of the industry classification system followed by the large community in the bottom center whose industries belong to the middle part of the classification. The community on the left typically contains services that appear in the last part of the classification. Industries 06 and 19 form a separate community with industry $13T15$ (Textiles, including synthetic fibers) serving as a bridge to the rest of the network.

From the point of view of someone who looks for patterns in the productivity data, the weak link of industry 06 with the rest of the industries reflects the fact that industry 06 typically does not pair often with other industries, except for an occasional pairing with 19. Similarly, industry 19 does not seem to pair with many other industries, except industries 06 and $13T15$.

From the point of view of our model and its underlying assumptions, the weak link of industry 06 with the rest of the industries indicates that the factors (the technologies, the human capital, etc.) required to produce oil and gas are rather industry-specific and do not seem to transfer easily to other industries. The industry that is most closely related to the oil and gas industry is the refined petroleum industry.

The fact that industries 06 and 19 form an independent cluster largely separate from the rest of the industries, will drive many of the results in the comparative statics exercises and it is useful to compare our network with two other industry networks in the literature. First, consider the network discussed in Hidalgo et al. (2007). While their measure differs from ours, the underlying data are as well trade flows (though not internal flows). In their network, too, the oil and gas industry is rather isolated. Given that their network has almost 800 industries shows that our result is unlikely to be driven by the smaller number of nodes (industries) in our data set.

Second, consider the network discussed in Carvalho (2014) which is formed by input-output flows for 417 industries in the US. In this network, too, the oil and gas industry is rather isolated and, just as we observe here, its strongest link is with petroleum refineries. But unlike in our network, petroleum refineries is one of the best connected industries in the economy with links to almost any other industry in the country. The connectedness of refined petroleum reflects the fact that its output (gasoline, diesel, heating oil) are important inputs in almost any economic activity.

The different connectedness of the 06/19-cluster reflects the different scopes of the two types of industry linkages. In the short run, refined petroleum and crude oil and gas (via refined petroleum) have strong links to almost all other industries and a disruption in any of these two industries will have noticeable repercussions in the entire US economy. However, in the longer run, the links of these industries with the rest of the economy are significantly weaker. In fact, many countries, especially many of the more advanced countries, do not have very developed industries 06 and 19 and, instead, import gas and petroleum products from abroad.[8]

[8] In 2014, only four countries produced oil or gas from shale commercially (EIA, 2015b). The United States is by far the dominant producer, producing almost 90 percent of world output. The other countries are Canada, Argentina, and China. Shale resources, however, are abundant (EIA, 2013). EIA (2015c) currently lists 46 countries with technically recoverable shale oil and shale gas resources. Most of these countries are included in our data set.

5 Equilibrium and Comparative Statics

In this section, we conduct the comparative statics exercises that allow us to assess, how the shale revolution changes the industrial structure of the US and that of other countries. In the comparative statics exercises, we compare two equilibria: The original equilibrium (the equilibrium we observe in the data) and a hypothetical equilibrium that differs from the original because we change one or more exogenous parameters. In our baseline exercise, we keep the primary productivity of the US in industry 06 (crude oil and gas) constant at its 2005 level. The hypothetical equilibrium thus describes a situation in which the productivity gains made in the industry after 2005 have not taken place. Comparing the two equilibria then allows us to quantify the effect of the shale revolution.

5.1 Equilibrium

Our first step is to calculate the original equilibrium (the original wage vector) for each of the 11 years of the sample. Equation (11) determines wages as a function of market shares ($\pi^k_{ij,t}$), consumption shares ($\mu^k_{j,t}$), and population ($L_{i,t}$). We use data from the World Bank for countries' population (see table 7 in the Appendix). Market shares and consumption shares can be calculated from our data set on trade flows using

$$\pi^k_{ij,t} = \frac{X^k_{ij,t}}{X^k_{j,t}} \text{ and } \mu^k_{j,t} = \frac{X^k_{j,t}}{X_{j,t}},$$

where $X^k_{j,t} = \sum_s X^k_{s,t}$ and $X_{j,t} = \sum_s X^s_{j,t}$. With 60 countries in our sample, the system has 59 wage equations that need to be solved simultaneously. The wage of one of the countries serves as the numéraire. Table 7 in the Appendix shows the equilibrium wages in all 60 countries for 2015. As with capabilities and productivities, we normalize wages using the geometric mean across all countries. Table 7 also shows countries' per capita income. Given that wages in our model are a measure of a country's overall productivity, the high correlation between both variables is expected.

With wages at hand, we can calculate the productivities using equation (3) and the primary productivities using equation (10). At this point, we have to choose a value for the trade elasticity θ. Our baseline value is $\theta = 6$; Section 5.3 discusses how this choice affects the results. A plot of US productivities and primary productivities over time is almost identical to the plot with capabilities in figures (2) and (3) above, and therefore not shown. The main difference between both figures is a different scaling due to θ.

5.2 Comparative Statics

We define the shale revolution as the technological advances of the US oil and gas industry that affect the industry's output *after* 2005. In the baseline comparative statics exercise, the primary productivity of industry 06 (crude oil and gas) in the US serves as a proxy for the factors we want to capture. In Section 5.3, we discuss this choice and the result of two additional exercises.

In the baseline comparative statics exercise, we replace $\tilde{\alpha}^{06}_{US,t}$ by $\tilde{\alpha}^{06}_{US,2005}$ in all years and leave all other primary productivities unchanged. Since equation

Table 1: The Impact of Shale on Relative Wages

Gains			**Losses**		
Country	Impact of shale	Energy reliance*	Country	Impact of shale	Energy reliance*
USA	0.84	2.46	Greece	-0.19	3.20
Ireland	0.37	0.12	Norway	-0.31	13.46
Luxembourg	0.30	0.05	Russia	-0.37	12.63
Japan	0.30	0.35	Kazakhstan	-0.40	8.58
Switzerland	0.27	0.21	ROW	-0.73	11.84
Germany	0.24	0.42	Brunei	-0.79	37.02
Czech Republic	0.24	0.81	Colombia	-0.86	5.04
Philippines	0.23	0.26	Saudi Arabia	-0.94	21.95
Korea	0.23	1.43	Mexico	-1.12	5.01
Hong Kong	0.22	0.11	Canada	-1.43	5.95

Notes: The impact of shale on relative wages in 2015 in percent (relative to the geometric mean of all countries). Largest and smallest 10 effects by impact. Impact is the percentage difference between observed wages and wages predicted in the baseline comparative statics exercise. * Energy reliance is the share of energy-related production (ISIC Rev. 4 classes 05, 06, 19) in total production.

(9) holds in relative terms,

$$\log \tilde{A}_{i,t}^{k} = \sum_{l=1}^{K} \lambda^{lk} \log \tilde{\alpha}_{i,t}^{k},$$

we can use it to calculate relative productivities and in turn, use these with equation (6) and (11) to solve for wages. Solving for the comparative statics equilibrium we have, as above, 59 wage equations with the wage of one of the countries serving as numéraire.

Table 1 shows how shale changes relative wages in the 20 most affected countries (10 largest increases, 10 largest decreases) in 2015. Table 7 in the Appendix shows the effect in all countries. According to the model, shale raised relative wages in the US by around 0.84 percent in 2015. In Mexico and Canada, America's two main trading partners, shale lowered relative wages by 1.12 and 1.43 percent, respectively. Mexico and Canada are both large oil and gas producers themselves which probably explains the drop in wages. In fact, all countries for which the model predicts a large, negative impact on wages are typically large producers of energy products (oil, gas, coal). On the other hand, countries for which the model predicts a positive effect of shale on wages are typically only small producers of these items. All western European countries, for example, are predicted to have slightly higher wages, with the exception of Norway and Greece, two countries with fairly large energy industries.

Figure (6) shows the impact of shale on US market shares in Mexico, Canada, and in the US itself over time. The impact is measured as the difference between the original market shares and the market shares we find in the comparative statics exercise ($\Delta\pi^k_{ij,t} = \pi^{(orig)k}_{ij,t} - \pi^{(cs)k}_{ij,t}$). The two market shares coincide in 2005 by assumption. A positive difference indicates that in the original data, we observe a higher market share than in the hypothetical situation where we turn off the productivity gains in the oil and gas industry. The market shares of industry 06 (crude oil and gas) increase in all three countries. The market shares of almost all other industries decrease with only few exceptions, of which industry 19 (refined petroleum) is the most important one. US market shares of industry 19 are higher in all three countries. The network representation of the industry linkages (figure 5) already indicated a close relationship between industries 06 and 19 with both industries forming an independent cluster, that is almost unconnected to the other industries.

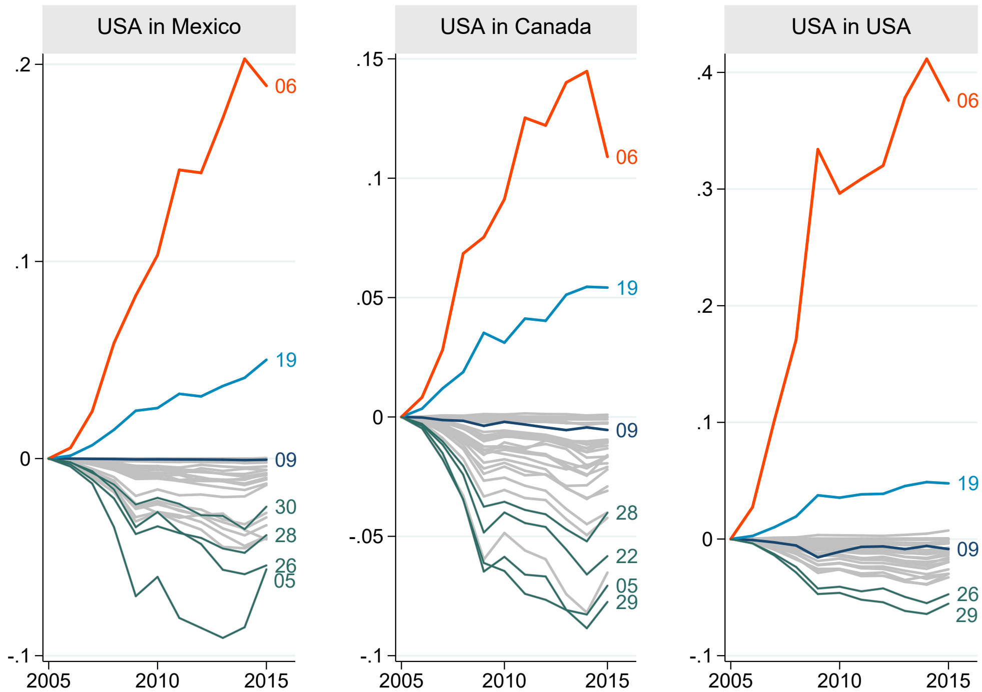

Figure 6: The Impact of Shale on Market Shares

The impact of shale on US market shares ($\pi_{ij,t}^k$) in Mexico, Canada, and the US over time. Positive values indicate higher market share due to shale. By assumption, the impact is zero in 2005.

Tables 2 to 4 report the impact of shale on trade flows and on industry output. The model does not allow us to predict the level of the flows, only flows relative to another exporter, but we may approximate the levels assuming that the impact on wages is small, relative to the impact on flows. Consider the following equation that shows how trade flows depend on the parameters and the variables of the model.

$$X_{ij}^k = \pi_{ij}^k \mu_j^k w_j L_j$$

Table 2: The Impact of Shale on Trade Flows

Exporter	Importer	Industry	Description	Trade flows		Impact of shale	
Gains				observed*	predicted*	by value*	percent
USA	USA	06	Crude oil and gas	670.07	347.67	322.40	92.73
USA	USA	19	Refined petroleum	404.00	382.11	21.89	5.73
USA	Canada	06	Crude oil and gas	16.93	3.74	13.18	351.99
Canada	USA	29	Vehicles, trailers	38.12	28.54	9.58	33.58
Japan	USA	29	Vehicles, trailers	39.78	33.07	6.71	20.28
Germany	USA	29	Vehicles, trailers	38.56	31.93	6.63	20.77
USA	Mexico	06	Crude oil and gas	7.66	1.83	5.83	318.93
USA	Taiwan	06	Crude oil and gas	6.80	1.30	5.51	424.89
Canada	Canada	29	Vehicles, trailers	36.52	31.13	5.39	17.33
Canada	Canada	45T47	Wholesale trade	204.03	199.1	4.93	2.48
Losses				observed*	predicted*	by value*	percent
USA	USA	62T63	IT	548.15	558.87	-10.72	-1.92
Canada	Canada	06	Crude oil and gas	93.22	104.46	-11.24	-10.76
USA	USA	28	Machinery, nec	284.82	297.76	-12.94	-4.35
USA	USA	26	Computers	304.15	322.55	-18.40	-5.71
Saudi Arabia	USA	06	Crude oil and gas	11.05	29.94	-18.89	-63.09
Russia	USA	06	Crude oil and gas	11.03	30.88	-19.86	-64.30
USA	USA	20T21	Chemicals	646.70	667.77	-21.07	-3.16
Mexico	USA	06	Crude oil and gas	13.39	35.85	-22.46	-62.66
USA	USA	29	Vehicles, trailers	560.55	604.63	-44.09	-7.29
Canada	USA	06	Crude oil and gas	51.30	134.82	-83.51	-61.95

Notes: The impact of shale on trade flows (largest and smallest 10 by value in 2015, excluding flows from rest of the world aggregate ROW). Predicted flows from baseline comparative statics exercise. * Billion US $.

Here, μ_j^k and L_j are known parameters and we have comparative statics predictions for π_{ij}^k, but we do not have comparative statics predictions for countries' wages. We may use, however, the wages we found in the original equilibrium (see Section 5.1) as an approximation. When the US is importer (exporter), we slightly underestimate (overestimate) the flows. For the other countries, the bias is reversed.

Table 2 shows the effect of shale on the 20 most affected trade flows for

2015. By far the largest effect (as measured by value) is observed by the internal flows of crude oil and gas in the US where the model predicts almost a doubling of the flows. The flows from the US to its main trading partners Canada and Mexico are predicted to triple, whereas the flows in the opposite direction decrease by more than 60 percent. A large part of the internal trade of vehicles (industry 29) in the US is replaced by imports from abroad (in particular from Canada, Japan, Germany).

This pattern is confirmed in table 3 that reports aggregate US imports ($\sum_s X^s_{i,j=USA,2015}$). Imports from China increase by more than \$14 billion because of shale. Germany and Japan, too, see their US exports increase considerably. Countries that observe a decline of their exports to the US are, again, countries with a large energy industry, such as Saudi Arabia, Russia and the countries aggregated in ROW (ROW includes countries like Iraq, Iran, and other Gulf states).

Our last table (table 4) in this section reports industry output ($\sum_s X^k_{i,s,2015}$). Again, we report the 20 most affected industries. The industries that gain most from shale are industries 06 and 19 in the USA. With the exception of vehicles from Germany and Japan, all other industries in the table that gain are Canadian. These gains in Canada are offset by a sizeable decline in Canadian output of crude oil and gas. Seven of the ten industries that lose most are US American. Industry 29 (vehicles and trailers), for example, is predicted to lose almost a tenth, or \$65 billion, of its output because of shale. The exercise also predicts large declines for industries $20T21$ (Chemicals) and 26 (Computers).

Table 3: The Impact of Shale on US Imports

Exporter	US Imports		Impact of shale	
Gains	observed*	predicted*	by value*	percent
China	215.10	200.92	14.18	7.06
Germany	143.71	130.74	12.97	9.92
Japan	118.82	107.85	10.97	10.17
Ireland	51.49	46.27	5.22	11.29
South Korea	75.19	70.20	4.99	7.10
India	75.45	72.08	3.37	4.67
France	64.78	61.46	3.33	5.41
Great Britain	105.39	102.08	3.31	3.24
Switzerland	31.71	28.67	3.05	10.63
Italy	57.79	54.99	2.80	5.09
Losses	observed*	predicted*	by value*	percent
Kazakhstan	3.70	5.49	-1.79	-32.66
Netherlands	31.62	33.60	-1.99	-5.91
Australia	29.87	32.24	-2.37	-7.36
Colombia	7.30	10.38	-3.08	-29.66
Norway	12.32	17.09	-4.76	-27.87
Mexico	76.84	90.05	-13.21	-14.67
Saudi Arabia	19.34	37.55	-18.21	-48.49
Russia	41.23	61.70	-20.48	-33.19
Canada	258.19	311.07	-52.89	-17.00
ROW	235.39	344.09	-108.70	-31.59

Notes: The impact of shale on US imports (largest and smallest 10 by value for 2015). Predicted imports from baseline comparative statics. * Billion US$.

Table 4: The Impact of Shale on Industry Output

Country	Industry	Description	Output		Impact of shale	
Gains			observed*	predicted*	by value*	percent
USA	06	Crude oil and gas	765.18	366.61	398.57	108.72
USA	19	Refined petroleum	482.86	436.67	46.20	10.58
Canada	29	Vehicles, trailers	80.60	65.04	15.56	23.92
Canada	45T47	Wholesale trade	244.93	235.98	8.94	3.79
Germany	29	Vehicles, trailers	408.42	400.88	7.54	1.88
Japan	29	Vehicles, trailers	415.59	408.59	6.99	1.71
Canada	69T82	Technical services	166.76	160.24	6.52	4.07
Canada	10T12	Food products	122.20	117.07	5.14	4.39
Canada	20T21	Chemicals	45.35	40.37	4.97	12.32
Canada	24	Basic metals	49.14	44.47	4.67	10.51
Losses			observed*	predicted*	by value*	percent
USA	45T47	Wholesale trade	2934.14	2954.40	-20.26	-0.69
USA	69T82	Technical services	3342.31	3365.66	-23.35	-0.69
Russia	06	Crude oil and gas	362.42	386.82	-24.39	-6.31
Mexico	06	Crude oil and gas	33.84	58.57	-24.73	-42.22
USA	28	Machinery, nec	362.21	388.79	-26.58	-6.84
USA	64T66	Finance & insurance	2291.04	2322.17	-31.13	-1.34
USA	26	Computers	365.96	404.85	-38.88	-9.60
USA	20T21	Chemicals	771.76	815.54	-43.77	-5.37
USA	29	Vehicles, trailers	637.81	703.11	-65.30	-9.29
Canada	06	Crude oil and gas	164.81	258.83	-94.02	-36.32

Notes: The impact of shale on industry output (largest and smallest 10 by value in 2015, excluding industries from the rest of the world aggregate ROW). Predicted output is output predicted in the baseline comparative statics exercise. * Billion US$.

5.3 Discussion

The impact of the shale revolution resembles the situation described in the models of the Dutch disease. The lower an industry's trade costs, the larger the impact. In the case of services, where trade costs are often considerable, the impact of shale is small or negligible.

In this section, we resume some of the discussions we started before. First, we discuss our choice to model the shale revolution by keeping industry 06 at its 2005 level. Second, we analyze how our choice of setting the trade elasticity, θ, equal to 6 affects our results and we also discuss how the results change when we exclude a number of countries with gaps in the data. Finally, we will discuss the contribution of shale to the structural change in the US relative to the contribution of other US industries.

5.3.1 Industry 09 and Trade Costs

In our baseline exercise, we used the primary productivity of industry 06 (crude oil and gas) as a proxy for the factors that allowed for the shale revolution. There is, however, a second industry (09, mining support service activities) that may as well reflect some of the technological advances we are interested in. Some of the technical operations of the mining industry, "particularly [operations] related to the extraction of hydrocarbons, may also be carried out for third parties by specialized units as an industrial service, which is reflected in [industry] 09" (United Nations, 2008, page 79). In fact, the capabilities and productivities of industry 09 in the US increase just as much as the capabilities and productivities of industry 06 (see figures 2 and 3). We will, therefore, include industry 09 together with 06 in a second comparative statics exercise. In a third exercise, we keep both the primary productivity and the trade costs of industry 06 constant at its level in 2005.

Overall, the results of the second exercise closely resembles the results of the first. Table 8 in the Appendix shows the effect of both exercises on the US market shares in Mexico. For our baseline exercise, the model predicts a reduction of the US market share of industry 06 in Mexico from 24.88 percent to 5.94. For the second exercise, the reduction is slightly smaller to 6.38. The only noticeable difference between both exercises is the prediction of industry 09 that sees an increase in our baseline model (from 0.06 to 0.11) and a decrease in the second exercise (from 0.06 to 0.02). For all other industries, there is almost no difference between the two exercises. A possible explanation for this is that industry 09 is by far the smallest industry in our sample by value. Total world consumption of 09 is almost only half the size of the second smallest industry in the sample.

In the third comparative statics exercise, we keep the primary productivity of industry 06 and the trade costs of industry 06 at their level in 2005. Here, too, the numbers do not differ much from the baseline exercise (see Table 8). During the sample period, US trade costs of 06 decrease but most of the large infrastructure developments take place after 2015. See footnote 3 in the introduction for more information on the infrastructure developments.

5.3.2 Trade Elasticity and Countries with Data Gaps

In all comparative statics exercises, we have set the trade elasticity θ equal to 6. As equation (6) shows, θ influences how changes in productivity carry over to changes in market shares and via the wage equation to changes in wages. Mayer and Head (2002) compare the estimation results from several hundred estimates and classify them according to the methodology used. Their preferred estimate is 5.03, which is somewhat lower than our choice. Table 8 in the appendix shows how θ affects the US market shares in Mexico we find in the baseline exercise. Setting θ equal to 3 gives almost identical results to our baseline choice of 6, but raising the value to 8 increases the predicted impact of shale. Looking, again, at the US share of industry 06, we see that when θ equals 8, the model predicts a reduction from 24.88 to 1.67 whereas when θ equals 6, the reduction is smaller (from 24.88 to 5.94). Overall, a choice of 6 seems more conservative than a value of 8 and reducing θ further only has a small effect on the results so that we may conclude that the results are robust with respect to our choice of θ.

In Appendix A.1, we report that for some countries, the output of oil, gas and coal reported by the EIA differed from the output reported by the OECD. These were mainly smaller countries (such as Hong Kong or Luxembourg) and countries with a dominating energy industry (such as Saudi Arabia). In order to see whether these countries affect the results, we re-calculate the capabilities, wages and productivities and re-run our baseline comparative statics exercise for this smaller set of countries. Table 8 in the appendix reports how this change affects the US market shares in Mexico. Using the smaller set of 53 countries, the predicted impact of shale is smaller. For example, the US market share of industry 06 in Mexico reduces from 24.88 to 8.19 when we exclude these countries rather than from 24.88 to 5.94 in the case of 60 countries. For all other industries, the predicted changes are small or negligible, so that having a larger sample seems preferable and any bias caused by these countries is unlikely to be substantial.

5.3.3 Decomposing the Structural Change in the US

We close this section with a discussion about the contribution of shale to the structural change in the US, relative to the contribution of other US industries. Our measure of an industry's contribution to the country's structural change is the industry's contribution to the country's wage variations. Above, we have seen that shale raised wages in 2015 by about 0.84 percent in the baseline comparative statics exercise. A question this number raises is, whether this impact is large relative to the impact of the other 32 industries.

In order to answer this question, we conduct for each industry a comparative statics exercise in which we keep the industry's primary productivity at the level it had in 2005. Subtracting the resulting wages from the wages of the original equilibrium gives, for each industry, a series of yearly wage differences. The absolute value of these wage differences, relative to the sum of absolute wage differences of all industries is then our measure of an industry's contribution to the economy's structural change.

Figure 7 shows each industry's contribution over time. For 2005, the comparative statics equilibrium coincides with the original equilibrium so that each

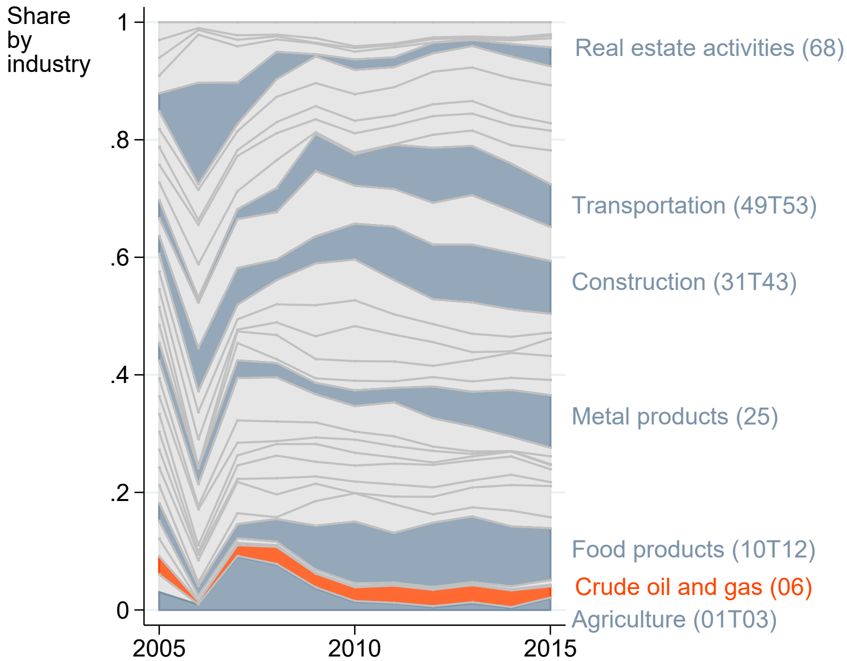

Figure 7: Structural Change in the US (2005 to 2015)

Decomposition of the US overall structural change into parts that can be attributed to each industry. The contribution of each industry to the overall structural change is measured by each industry's contribution to the country's wage variation.

industry's contribution is $1/K = 1/33$. The industries' contributions varies considerably in the following years. At around the financial crisis in 2007, the contribution of industry 68 (real estate activities) is particularly prominent. In recent years, industry $10T12$ (food products) is an important contributor to the US structural change. The contribution of industry 06 (crude oil and gas) is not particularly large but fairly steady over time. Its impact is more gradual and persistent than that of many others. It is possible that the contribution of oil and gas increases, when the recent infrastructure investments in pipelines and export facilities are reflected in the data.

6 Summary

This paper quantifies the general equilibrium effects of the shale revolution in a Ricardian model of trade in which industries are connected by productivity linkages. In this framework, productivity gains in one industry may spill over to other industries. The reason for this modeling choice is that the analysis requires industry linkages that are constant over a longer period and that are themselves unaffected by the structural change we want to analyze. This rules out, for example, the use of input-output linkages. The productivity linkages are external to the firm, so that the model preserves the simple structure of the original Eaton & Kortum model. Modeling industry linkages in this fashion in a general equilibrium model seems to be new in the literature.

We model the shale revolution as an increase of the productivity of the oil and gas industry in the US. These productivity improvements may spill over to other industries and may, in principle, outweigh any negative impact from the higher wage level that is caused by the productivity increases (the Dutch disease).

The industry network implied by the estimated linkages is a modular network in which industries form separate clusters. Industries have tight connections with industries from the same cluster, but weak connection with industries in different clusters. The oil and gas industry forms a separate cluster with petroleum refineries. The productivity improvements in the oil and gas industry will, therefore, spill over to petroleum refineries, but will have only minor effects on the productivities of the other industries in the US.

For 2015 (the most recent data available), the comparative statics exercises predict slightly higher wages in the US (0.84 percent) relative to the average wage in all countries in the sample. In Mexico and Canada, Americas two main trading partners, wages decline. Many industries in the US see their output reduced because of the higher wages, but the impact varies widely from industry to industry. In the case of refined petroleum, the higher wages are outweighed by the productivity spillovers, so that the overall effect is positive. Since services are not easily traded and thus face much less competition from abroad, the higher US wages barely affect their output. The impact of the shale revolution is most pronounced in the case of manufacturing goods (vehicles, chemicals, electronics, or machinery). Goods that the US previously would have produced domestically are now replaced by imports from abroad. China, in particular, is benefiting from this replacement. Given the recent and planned infrastructure developments, such as the building of new ports and pipelines, it seems likely that the structural changes reported in this paper are only the first signs of a more profound structural change of the country in the coming years.

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A Online Appendix

A.1 The Construction of the Data Set

Constructing Trade Flows from international input-output tables We calculate the bilateral trade flows by summing up the rows of the international input-output tables (OECD, 2018). The original data are in million US Dollars which we convert into Dollars. Negative values (130 of the 1673100 values are negative) and zeros are replaced by one. We move the following five countries to the balance position ROW because of many missing data: Costa Rica, Cyprus, Iceland, Cambodia, and Malta. We use MX1 for Mexico and CN1 for China. The following industries are merged because of missing data: 90T96 and 97T98 to 90T98; 84 and 85 to 84T85; 31T33, 35T39, and 41T43 to 31T43. This leaves us with 60 exporters and importers (of which one is ROW) and 32 industries for a period of 11 years (from 2005 to 2015). See table 7 for a list of the countries included in the analysis.

Splitting Industry 05T06 into 05 and 06 Industry 05T06 is split into its two components 05 (Coal and lignite) and 06 (Crude oil and gas) using UN Comtrade data (Harvard Dataverse, 2019) for the bilateral trade flows and EIA (EIA, 2019) data for the internal trade flows.

The UN Comtrade data are classified according to the Harmonized System (HS 1992). Since there is no direct concordance between the HS-products and the industries in ISIC Rev. 4, we use a chain of concordances: from ISIC Rev. 4 to CPC2 to HS (2007) to HS (1992). Following this chain, we assign the following HS 1992 classes to ISIC Rev. 4 class 05: 2701, 2702, 2704, 2705, 2706, 2707, 2708 and the following HS (1992) classes to ISIC Rev. 4 class 06: 2709, 2710, 2711, 2712, 2713. Countries that do not appear explicitly in the OECD Data are allocated to the balance position ROW.

The internal trade of industries 05 and 06 are constructed as the difference between a country's production and its exports as reported by the EIA. The EIA publishes data about several energy sources for more than 160 countries. Four of these sources are relevant for us. The output of industry 05 (coal an lignite) corresponds EIA's total primary coal. The output of industry 06 (crude oil and gas) corresponds to three series in the EIA data: (1) total petroleum and other liquids (nonrefined), (2) natural gas, and (3) liquefied petroleum gases and ethane.

All 59 countries of our data set appear in the EIA data. The remaining countries are aggregated into the balance position Rest of the World. For some countries, the EIA reports zero production and zero exports of liquefied petroleum gases and ethan in the most recent years in the sample. When the corresponding exports reported by the Comtrade data are positive, we assume that these data are missing and project the series using a simple linear forecast. For the US, for example, the EIA reports zero production and zero exports in 2015 whereas the UN Comtrade data report positive export for 2015.

The EIA data are published in quantity units which we convert into monetary units using the ratio of imports as reported by UN Comtrade and imports as reported by the EIA as a proxy for the price. In the case of natural gas (measured in bcf, billion cubic feet), this ratio equals, for example,

$$P_{i,t}\left[\frac{\$}{bcf}\right] = \frac{\text{Country } i\text{'s imports as reported by UN Comtrade } [\$]}{\text{Country } i\text{'s imports as reported by EIA } [bcf]}.$$

The other three price series are constructed in the same fashion. Since the 4-digit HS (1992) classes do not distinguish between natural gas and liquefied gas, we use the 6-digit data in this case. HS classes 271121, 271119, 271129 correspond to natural gas and HS classes 271114, 271113, 271112, 271111 to liquefied gases. Once the series have the same units, we aggregate them. The internal flows of the countries that do not appear explicitly in the OECD data set are merged into the balance position ROW.

For the US, constructing the flows of coal, oil and gas from the EIA data works reasonably well. Total production of 05 and 06 constructed using the EIA data overestimates the original OECD aggregate 05T06 by between 0.08 and 3.56 percent with an average deviation of 1.87 percent. For the other OECD countries, the average deviation is larger but still within reasonable bounds. However, for smaller countries and for countries like Saudi Arabia where the oil and gas sector dominates the domestic economy, the two magnitudes may differ significantly (see table 8). We discuss this point in detail in Section 5.3.

Gravity Controls and Rest of the World Our main source for the gravity control variables is the CEPII gravity dataset (Head et al., 2010), see table 5 for a list of the controls included in the regression. The data on currency unions are from De Sousa (2012), the data on countries' internal distances are

Table 5: Gravity Control Variables

Variable	Description
`distw`	weighted distance (pop-wt, km)
`comlang_off`	1 for common official of primary language
`comcol`	1 for common colonizer post 1945
`colony`	1 for pair ever in colonial relationship
`comcur`	1 for common currency
`contig`	1 for contiguity
`comleg_pretrans`	1 if common legal origins before transition
`comleg_posttrans`	1 if common legal origins after transition

Notes: Gravity control variables used in the regression of the gravity model.

from Mayer and Head (2002).

For the balance position "rest of the world" (ROW) included in the OECD data, we need to impose a number of assumption regarding the gravity control variables. We need, for example, the distance between a country and the rest of the world or whether a country and the rest of the world speak the same language. These assumptions are for the most part arbitrary, but imposing some assumption is necessary if we want to keep the balance position in the data set. Keeping the balance position ROW and imposing assumptions seems preferable than dropping ROW. In addition, changing these assumptions leaves the estimates of the export capabilities and the trade costs of the US and its main trading partners virtually unchanged. The estimation results of more peripheral countries such as Morocco are only slightly affected.

We set the internal distance of ROW equal to the average internal distance of the countries in ROW for which internal distances are available. The bilateral distance between ROW and the other countries is calculated as a weighted distances where the weights are calculated from the trade flows between countries.[9] If a country shares a common border with one of the countries in ROW,

[9] If the rest of the world contains two countries, A and B, then the distance between ROW and country C is calculated as $w_{CA}\overline{CA} + w_{CB}\overline{CB}$, where $\overline{CA}$ is the distance between C and A and the weights correspond to the shares of exports from C to A and B.

we assume that the country shares a common border with ROW. The other control variables are treated in the same fashion.

Table 6: Industry Classes (ISIC Revision 4) Used in the Analysis

Industry	Description	Industry Linkages		Data for USA 2015				
		In-strength	Out-strength	Consumption share	Industry output		Impact of shale	
					observed	predicted	by value	percent
01T03	Agriculture	11.86	14.00	1.41	448.60	456.00	-7.37	-1.62
05	Coal	-1.21	0.99	0.24	80.52	85.20	-4.68	-5.49
06	Crude oil and gas	-0.77	-0.12	2.72	765.2	366.60	398.6	108.72
07T08	Non-energy mining	3.05	2.17	0.21	64.76	68.91	-4.15	-6.02
09	Mining services	10.89	1.47	0.27	87.77	90.83	-3.06	-3.37
10T12	Food products	14.08	32.17	3.02	924.20	943.70	-19.49	-2.07
13T15	Textiles	15.72	20.40	0.66	85.16	92.38	-7.22	-7.81
16	Wood products	16.66	14.26	0.34	98.16	100.20	-2.08	-2.07
17T18	Paper & printing	17.10	17.35	0.82	266.30	273.10	-6.75	-2.47
19	Refined petroleum	7.68	2.15	1.46	482.90	436.70	46.20	10.58
20T21	Chemicals	6.76	5.60	2.56	771.80	815.50	-43.77	-5.37
22	Plastic products	14.97	18.18	0.77	226.30	238.80	-12.55	-5.25
23	Metallic minerals	9.87	5.30	0.42	118.90	117.70	1.24	1.05
24	Basic metals	8.44	7.39	0.80	221.10	229.60	-8.49	-3.70
25	Metal products	14.70	22.82	1.21	361.10	375.10	-13.98	-3.73
26	Computers	21.21	9.89	1.24	366.00	404.80	-38.88	-9.60
27	Electrical equipment	18.78	14.85	0.48	119.74	123.80	-4.06	-3.27
28	Machinery	14.28	19.07	1.25	362.22	388.80	-26.58	-6.84
29	Vehicles, trailers	24.04	9.72	2.52	637.80	703.10	-65.30	-9.29
30	Transport equipment	24.31	5.89	0.83	318.54	329.00	-10.46	-3.18

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Table 6 – *Continued from previous page*

Industry	Description	Industry Linkages		Data for USA 2015				
		In-strength	Out-strength	Consumption share	Industry output		Impact of shale	
					observed	predicted	by value	percent
31T43	Construction	16.36	20.87	6.79	2071.38	2081.00	-10.62	-0.51
45T47	Wholesale trade	9.77	32.53	9.25	2934.00	2951.95	-20.26	-0.69
49T53	Transportation	9.72	23.85	3.53	1107.02	1124.97	-17.95	-1.6
55T56	Accommodation & food	12.12	30.49	2.95	905.70	909.60	-3.91	-0.43
58T60	Publishing	13.96	6.81	1.96	648.20	649.70	-1.46	-0.23
61	Telecommunications	4.16	2.96	1.96	634.70	632.30	2.44	0.39
62T63	IT	18.59	6.14	1.94	576.20	593.30	-17.16	-2.89
64T66	Finance & insurance	10.52	6.19	7.03	2291.00	2322.00	-31.13	-1.34
68	Real estate activities	11.65	12.50	9.53	3000.12	3002.51	-2.39	-0.08
69T82	Technical services	10.37	11.11	10.24	3342.78	3366.13	-23.35	-0.69
84T85	Education and government	11.56	3.79	12.08	3807.31	3809.75	2.44	0.06
86T88	Health and social work	11.73	9.80	6.95	2187.01	2187.17	-0.16	-0.01
90T98	Entertainment	10.65	12.98	2.59	819.70	819.99	-0.29	-0.04

Table 6: Industry classes (ISIC Revision 4) used in the analysis, and additional information. In-strength and out-strength are respectively the row-sum and column-sum of the linkage matrix. Predicted output from baseline comparative statics exercise.

Table 7: List of Countries Included in the Analysis

Exporter	ISO 3	Population (million)	GDP per capita ($1000)	Wage (relative to basket)		Impact of shale	EIA 05T06 Discrepancy
				observed	predicted	percent	percent
Argentina	ARG	43.42	10.50	0.49	0.49	0.15	1.60
Australia	AUS	23.82	55.10	2.73	2.73	-0.01	5.40
Austria	AUT	8.64	47.85	2.95	2.95	0.19	-1.70
Belgium	BEL	11.27	45.16	2.65	2.64	0.08	7.50
Bulgaria	BGR	7.18	7.61	0.40	0.40	0.02	8.20
Brazil	BRA	206	11.35	0.52	0.52	0.01	1.50
Brunei Darussalam*	BRN	0.42	32.66	2.50	2.52	-0.79	-1.60
Canada	CAN	35.83	50.30	2.24	2.27	-1.43	1.00
Switzerland	CHE	8.28	76.55	5.05	5.04	0.27	2.40
Chile	CHL	17.76	14.89	0.76	0.76	0.12	3.40
China	CHN	1371	6.50	0.36	0.36	0.18	1.30
Colombia	COL	48.23	7.46	0.26	0.26	-0.86	8.80
Czech Republic	CZE	10.55	21.38	1.34	1.33	0.24	5.70
Germany	DEU	81.69	45.52	2.96	2.95	0.24	5.70
Denmark	DNK	5.68	60.40	3.69	3.69	0.13	1.40
Spain	ESP	46.44	30.60	1.77	1.77	0.11	9.60
Estonia*	EST	1.32	17.77	1.00	1.00	0.07	—
Finland	FIN	5.48	45.32	2.50	2.49	0.14	9.90
France	FRA	66.59	41.77	2.25	2.25	0.18	10.50
United Kingdom	GBR	65.13	41.76	2.21	2.21	0.18	1.50

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Table 7 – *Continued from previous page*

Exporter	ISO 3	Population (million)	GDP per capita ($1000)	Wage (relative to basket)		Impact of shale	EIA 05T06 Discrepancy
				observed	predicted	percent	percent
Greece	GRC	10.82	22.62	1.19	1.19	-0.19	14.00
Hong Kong*, China	HKG	7.29	36.26	1.42	1.42	0.22	—
Croatia	HRV	4.2	14.11	0.75	0.75	0.06	-4.00
Hungary	HUN	9.84	14.65	0.86	0.86	0.21	14.00
Indonesia	IDN	258.2	3.83	0.20	0.20	0.05	1.80
India	IND	1309	1.75	0.09	0.09	0.11	2.50
Ireland	IRL	4.7	67.72	4.29	4.28	0.37	-2.40
Israel	ISR	8.38	33.18	1.87	1.86	0.19	3.90
Italy	ITA	60.73	33.96	2.05	2.05	0.16	-0.10
Japan	JPN	127.1	47.16	2.35	2.34	0.30	10.60
Kazakhstan	KAZ	17.54	10.62	0.69	0.69	-0.40	5.10
Korea	KOR	51.01	24.87	1.43	1.43	0.23	11.90
Lithuania	LTU	2.9	15.38	0.87	0.87	-0.16	9.70
Luxembourg*	LUX	0.575	107.24	6.70	6.68	0.30	—
Latvia*	LVA	1.98	14.28	0.60	0.60	0.01	—
Morocco	MAR	34.80	3.21	0.12	0.12	0.10	-17.00
Mexico	MEX	125.9	9.72	0.53	0.54	-1.12	-7.20
Malaysia	MYS	30.72	10.75	0.61	0.61	0.06	-0.70
Netherlands	NLD	16.94	51.87	3.15	3.15	0.05	-0.70
Norway	NOR	5.19	90.13	5.75	5.77	-0.31	1.00
New Zealand	NZL	4.606	37.04	1.82	1.82	0.18	0.00

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Table 7 – *Continued from previous page*

Exporter	ISO 3	Population (million)	GDP per capita ($1000)	Wage (relative to basket)		Impact of shale	EIA 05T06 Discrepancy
				observed	predicted	percent	percent
Peru	PER	31.38	5.94	0.27	0.27	-0.10	-0.90
Philippines	PHL	101.70	2.62	0.11	0.11	0.23	6.60
Poland	POL	37.99	14.64	0.88	0.88	0.17	2.70
Portugal	PRT	10.36	22.02	1.20	1.20	0.08	4.90
Romania	ROU	19.82	9.71	0.52	0.52	0.10	6.00
Rest of the World	ROW	2035.00	n.a.	0.10	0.10	-0.73	0.40
Russian Federation	RUS	144.10	11.33	1.08	1.08	-0.37	1.00
Saudi Arabia*	SAU	31.56	21.51	1.22	1.23	-0.94	-36.50
Singapore*	SGP	5.54	52.79	3.14	3.14	0.01	—
Slovak Republic	SVK	5.42	18.74	1.08	1.08	0.20	7.00
Slovenia	SVN	2.06	23.73	1.41	1.41	0.12	11.90
Sweden	SWE	9.80	55.42	3.40	3.39	0.17	1.10
Thailand	THA	68.66	5.74	0.34	0.34	0.16	3.70
Tunisia	TUN	11.27	4.27	0.18	0.18	0.03	1.50
Turkey	TUR	78.27	13.90	0.68	0.68	0.08	1.00
Chinese Taipei	TWN	23.49	46.96	2.08	2.07	0.18	11.30
United States	USA	320.7	52.10	2.35	2.33	0.84	1.90
Viet Nam	VNM	93.57	1.65	0.09	0.09	0.16	-5.00
South Africa	ZAF	55.29	7.58	0.37	0.37	0.04	7.40

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Table 7 – *Continued from previous page*

Exporter	ISO 3	Population (million)	GDP per capita ($1000)	Wage (relative to basket)		Impact of shale	EIA 05T06 Discrepancy
				observed	predicted	percent	percent

Notes: Countries included in the Analysis. Data for population and per capita income are 2015 data from the World Bank. Observed wage is equilibrium wage of the model in 2015. Basket is geometric average wage in all countries (unweighted). Predicted wage is from baseline comparative statics exercise for 2015. Impact of shale is difference between observed and predicted wage, in percent. EIA 05T06 Discrepancy is percentage difference between internal trade as reported by the OECD (in monetary units) and internal trade as reported by the EIA (converted into monetary units using import prices). Discrepancy not reported when either OECD or EIA data is missing. * Countries not included in the smaller sample of 53 countries (see section 5.3.2).

Table 8: Robustness Analysis

Industry	Equilibrium	Comparative Statics							
		Exercise			Trade Elasticity (θ)			Number of Countries	
		06	06 & 09	06 & Cost	3	6	8	60	53
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
01T03	5.62	6.38	6.32	6.38	6.31	6.38	6.86	6.38	5.94
05	10.65	16.27	16.43	16.27	16.10	16.27	21.65	16.27	13.31
06	24.88	5.94	6.38	5.94	5.95	5.94	1.67	5.94	8.19
07T08	0.46	0.66	0.61	0.66	0.66	0.66	0.85	0.66	0.44
09	0.06	0.11	0.02	0.11	0.11	0.11	0.19	0.11	0.10
10T12	3.52	4.26	4.23	4.26	4.21	4.26	4.80	4.26	3.92
13T15	2.13	2.52	2.57	2.52	2.50	2.52	2.8	2.52	2.52
16.00	7.72	8.78	8.91	8.78	8.70	8.78	9.45	8.78	8.00
17T18	16.74	19.51	19.57	19.51	19.33	19.51	21.40	19.51	17.11
19	19.48	14.44	14.55	14.44	14.34	14.44	11.05	14.44	15.45
20T21	14.54	17.54	17.59	17.54	17.39	17.54	19.75	17.54	16.07
22	16	19.94	20.02	19.94	19.77	19.94	22.99	19.94	17.90
23	4.29	4.34	4.45	4.34	4.30	4.34	4.26	4.34	4.28
24	6.13	6.96	6.93	6.96	6.90	6.96	7.49	6.96	6.72
25	18.91	22.29	22.11	22.29	22.12	22.29	24.7	22.29	20.28
26	16.84	22.27	21.42	22.27	22.09	22.27	26.75	22.27	20.75
27	15.01	16.28	15.87	16.28	16.18	16.28	16.97	16.28	15.88
28	25.47	29.35	29.4	29.35	29.2	29.35	32.07	29.35	28.26

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Table 8 – *Continued from previous page*

Industry	Equilibrium	Comparative Statics							
		Exercise			Trade Elasticity (θ)			Number of Countries	
		06	06 & 09	06 & Cost	3	6	8	60	53
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
29	12.38	16.48	16.16	16.48	16.32	16.48	19.93	16.48	15.57
30	25.07	27.54	27.48	27.54	27.35	27.54	28.98	27.54	29.69
31T43	0.85	1.00	0.98	1.00	0.98	1.00	1.10	1.00	0.94
45T47	5.87	6.45	6.49	6.45	6.38	6.45	6.76	6.45	6.68
49T53	8.05	9.02	9.041	9.02	8.94	9.02	9.61	9.02	8.40
55T56	0.31	0.34	0.34	0.34	0.34	0.34	0.36	0.34	0.33
58T60	21.23	22.57	22.65	22.57	22.39	22.57	23.16	22.57	23.32
61	0.41	0.39	0.39	0.39	0.39	0.39	0.37	0.39	0.37
62T63	19.72	23.77	22.38	23.77	23.62	23.77	26.79	23.77	22.13
64T66	2.32	2.89	2.80	2.89	2.86	2.89	3.34	2.89	3.10
68	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
69T82	0.15	0.17	0.17	0.17	0.17	0.17	0.19	0.17	0.17
84T85	1.45	1.42	1.47	1.42	1.41	1.42	1.36	1.42	1.28
86T88	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
90T98	0.82	0.87	0.88	0.87	0.86	0.87	0.89	0.87	0.87

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Table 8 – *Continued from previous page*

Industry	Equilibrium	Comparative Statics							
		Exercise			Trade Elasticity (θ)			Number of Countries	
		06	06 & 09	06 & Cost	3	6	8	60	53
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

Notes: US market shares in Mexico in 2015 in percent. Column 2: Market share observed in the data. Columns 3 to 5: Market shares for three comparative statics exercises. Columns 6 to 8: Market shares for different values of the trade elasticity θ. Columns 9 and 10: Market shares for different sample of countries. Countries excluded in the smaller sample: Saudi Arabia, Brunei, Estonia, Hong Kong, Luxembourg, Latvia, Singapore.