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London School of Economics and Political Science

Essays in International Trade and Organisational Economics

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Thesis submitted to the Department of Economics of the London School of Economics for the degree of Doctor of Philosophy, London, 9 October 2017.

Declaration

I certify that the thesis I have presented for examination for the PhD degree of the London School of Economics and Political Science is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

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Statement of Conjoint Work

I confirm that Chapter 1 was jointly co-authored with Giuseppe Berlingieri and Claudia Steinwender and I contributed a minimum of 40 percent of this work. I confirm that Chapter 3 was jointly co-authored with Rabah Arezki and Thiemo Fetzer and I contributed a minimum of 30 percent of this work.

Abstract

This thesis contains three chapters that examine various facets of how the market and technological environment shapes firms – and how firms shape their environments.

The first chapter studies how multinational manufacturing firms organise production in parallel processing supply chains. Using confidential data on international sourcing of French manufacturing firms and an instrumental variables strategy based on self-constructed input-output tables, the chapter shows that inputs that account for a high cost share – i.e. that are more important for technological reasons – are more likely to be produced by a multinational for itself, while unimportant ones are outsourced to third parties. It provides additional empirical evidence that this main finding is consistent with a property rights model of the boundary of the firm.

The second chapter produces empirical facts on how exogenous changes in tariffs on intermediate goods have affected vertical integration patterns in France over the period 1996-2006 and evaluates them in light of the current literature. Using a long differences approach and detailed information on supply relationships, it shows that more protectionist policies by other countries and by the EU discouraged integrated relationships from shifting towards outsourcing and that initial market structure mattered for the impact of trade policy.

The third chapter provides rare causal evidence for the relevance of endowment driven comparative advantage. It uses the fracking boom in the US following 2006 as a source of exogenous variation in the endowment of natural gas – and therefore in energy: fracking made energy considerably cheaper in the US compared to the rest of the world. The chapter studies factor, output, and international trade responses across sectors. It finds that energy intensive sectors expand along all dimensions and, most importantly, export more, which validates one of the most important neo-classical theories of why countries trade with each other.

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My life, however, revolves around my own family. My son David has improved this thesis – and its author – beyond compare and without my wife, her love, her friendship, and her help, none of thesis would exist. You two are my rock and my purpose.

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Chapter 1

Organizing Supply Chains: Input Cost Shares and Vertical Integration

1.1 Introduction

Many characteristics shape how firms organize the activities required for producing a certain good or service. One of the most important choices is the firm boundary – whether to perform an activity in-house or procure from a third party – and economists have developed a profound understanding of some of the determinants behind such integration decisions. Financial and contracting institutions[1], the degree to which agents are locked into a business relationship[2], or the relative contributions of different parties to final output[3] have been analyzed formally and shown to affect "make-or-buy" patterns[4]. These insights are crucial: organizational choices influence incentives and help overcome frictions, thereby fuelling productivity in an economy.

Spurred by the rapid emergence of increasingly complex and global value chains, recent interest both on the part of researchers and policy makers has turned to understanding how *technological* features of such supply chains affect integration decisions.[5] Antras and

[1]Prominent works include Acemoglu et al. (2009), Macchiavello (2012), Carluccio and Fally (2012), and recently Eppinger and Kukharskyy (2017), as well as Nunn (2007).

[2]Relationship specificity is at the heart of incomplete contracting explanations of the firm, see Klein et al. (1978), Williamson (1985). Review articles by Lafontaine and Slade (2007), Bresnahan and Levin (2012), and Legros and Newman (2014) provide a good overview of theoretical and empirical work.

[3]See the original contributions by Grossman and Hart (1986) and Hart and Moore (1990). In the international context, see for example Antras (2003).

[4]A body of empirical work in organizational economics based on within industry or firm studies has made points along similar lines, for example Monteverde and Teece (1982), Joskow (1985), Baker and Hubbard (2003), or Forbes and Lederman (2009).

[5]Antras and Helpman (2004) and Irarrazabal et al. (2013) examine the role of geography in internationally fragmented value chains, while Ornelas and Turner (2011), Diez (2014), and, indirectly, Alfaro et al. (2016) study tariffs.

Chor (2013) and Alfaro et al. (2015) point out that many (sections of) supply chains are inherently *sequential* – so that, in a particular order, one activity has to be completed before the next one can begin. This technological feature fundamentally shapes the incentives for firms located downstream of such a sequential supply chain to vertically integrate backwards into the chain. Baldwin and Venables (2013) christened such supply chains "snakes".

Many (sections of) supply chains, however, involve *parallel* processing. Here, activities are performed approximately simultaneously and in no particular order. For instance, let the observational unit be a car factory. A modern automobile consists of about 500 components,[6] which are delivered to a factory and then combined in what is effectively a single production step.[7] Clearly, the sequence of activities is no longer a feature that can affect integration incentives – a "snake" has become a "spider".

Instead of relative upstreamness, such a parallel production technology has an inherently different defining *technological* characteristic: the relative contribution of the individual activities towards downstream output and for simplicity we call it the "technological significance" of an input.[8] Technologically significant inputs are those whose quality, quantity, or specification determines the value of output more than that of other inputs; they are "key" inputs. In view of the ubiquity of such (sections of) supply chains – at the very least all assembly stages are parallel – how does technological significance affect a downstream firm's incentives to vertically integrate its suppliers? Conditional on the "snakes" that produce components, how do firms organize "spiders"?

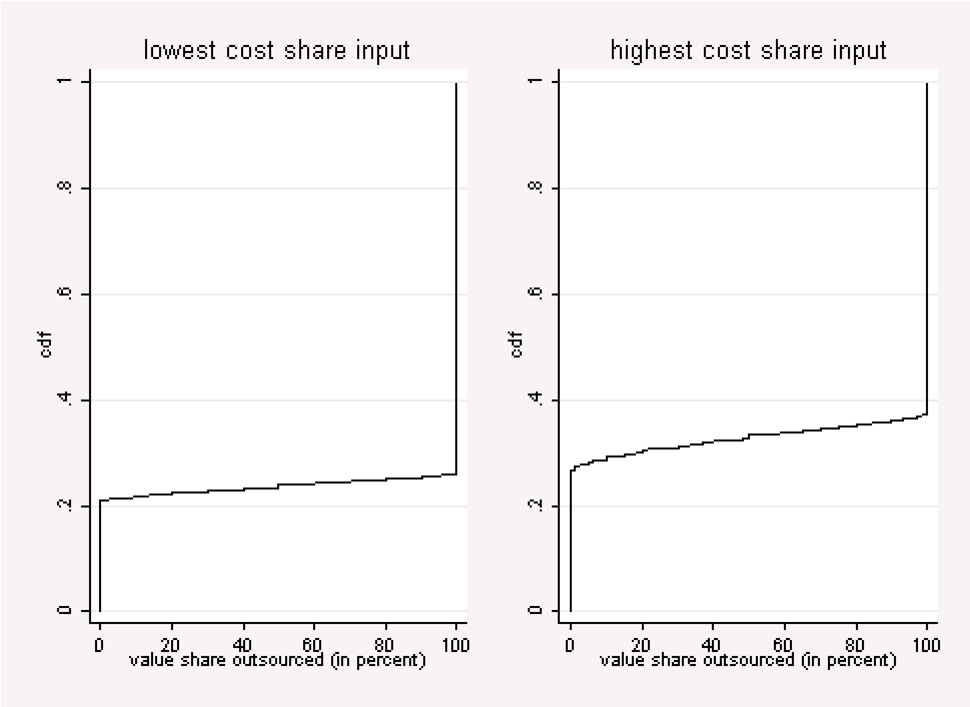
This paper gives an empirical answer to our research question. We use confidential micro data from France to observe the choice between outsourcing and vertical integration in import data that contain intra-firm shipment information (EIIG) for over 3000 firms, more than a hundred origin countries, and, crucially, for more than 1100 detailed inputs. We proxy technological importance by an input's cost share in total – domestic plus foreign – intermediate expenditure. The vast majority of production functions that capture a "spider" setting like ours produce a positive correlation between cost shares and the impact of upstream investments on final output, i.e. technological significance – at least conditional on input prices. We compare inputs with different cost shares sourced by the same firm to each other and relate this margin of heterogeneity to observed integration choices. As an illustration using just our raw data, in figure 1.1 we plot the empirical firm

[6]The Wikipedia list of "auto parts" contains a rough enumeration of the different components of an automobile and it has around 500 entries.

[7]Of course, *within* the factory, there is, again, a defined sequence of tasks. When we refer to an economically *parallel* supply chain, we address a production step that is, for all intents and purposes, too costly to be "unbundled" any further and hence internal sequence is not relevant for make-or-buy decisions.

[8]More precisely, relative technological significance is equivalent to the relative elasticity of output with respect to different inputs. We will be more specific below.

Figure 1.1: The Role of Cost Shares for Vertical Integration



Source: Manufacturing firm in EIIG, cross section in 1999.

level cdf's as a function of the propensity to outsource, focusing only on the least and most important input by cost share on the left and right, respectively. While outsourcing is the prevalent sourcing mode overall, significantly more firms produce the most significant input at least partially in-house.

We employ an instrumental variables approach to show that this positive relationship between vertical integration and technological significance is in fact causal. Input cost shares are endogenous since (multinational) firms skew their sourcing towards their affiliates, price inputs at non-market value to avoid taxes on trade or profits, and exhibit substantial variation of procurement volumes from year to year, causing errors in variables in our cost shares.[9] In order to address these concerns, we use self-constructed input-output (IO) coefficients at the industry level as a source of exogenous variation. IO tables capture technological relationships between industries that are stable over time and similar in many countries. We argue that these features allow us to identify the impact of technological significance on vertical integration.

Unfortunately, official IO tables for France, and in fact for most other countries, are only available at a very coarse, aggregate level, so that we would not be able to compare similar inputs to each other with this type of exogenous variation. Moreover, the official French IO tables are calculated on the basis of international trade flows connected to

[9]From a conceptual point of view, cost shares are only rough proxies of the underlying technological features of supply chains, which is a further margin for errors in variables.

the firms in our sample, which creates concerns about reverse causality. Consequently, we construct our own (import) IO tables from the universe of customs data for France and from industry information about the near universe of French firms participating in international trade. We can produce such micro IO tables for any feasible level of disaggregation and remove our EIIG firms.[10]

The main result of our work, and indeed of this paper, is a highly significant positive relationship between vertical integration and technological significance in the data. This estimate is surprisingly robust to the inclusion of highly demanding fixed effects that address, among other confounders, the concern that our pattern may be driven by sequentiality within establishments. The role of technological significance is economically important: comparing an input that is at the mean of the cost share distribution to one that is wholly insignificant for production we find that the former is 6 percentage points more likely to be integrated, for an overall baseline share of vertical integration of 27 percent.

Next, using the same approach, we explore effect heterogeneity in cost shares on vertical integration with respect to headquarters intensity and the contracting environment. We want to stress that this exercise provides an empirical refinement of our key result that sheds light on the role of vertical linkages for multinational companies, making our findings highly relevant for policy makers. Using various proxies for headquarters intensity like capital, skill, and downstream service intensity, we show that significant inputs are almost twice as likely to be produced in-house in supply relationships with high headquarters intensity than those where instead the upstream suppliers hold the key to success. Moreover, technological significance pushes firms towards vertical integration particularly strongly if the upstream supplier resides in a country with capable contracting enforcement or if the inputs are easy to contract upon. These empirical findings are very much in line with the predictions of our stylized property rights model.[11]

We next examine what mechanisms may explain these empirical findings. In the past two decades, the property rights theory (PRT) of the firm has become the workhorse model for researchers in international trade that study the role of multinational firms.[12] It is therefore a natural point of departure and we ask: what does a suitably generalized PRT framework predict about the vertical integration decision in a parallel processing setting?

[10]We intend to make these IO tables available on our web sites and recommend our approach to other researchers, since the data required are nowadays accessible in many countries of the world.

[11]We also find strong evidence that larger downstream firms more readily integrate significant upstream suppliers and that cost shares predict vertical integration for inputs subject to high import tariffs (which give more scope for transfer pricing). As anticipated in section 1.5.2, we find inconclusive evidence regarding the role of relationship specificity.

[12]Examples include Antras (2003), Diez (2014), Ornelas and Turner (2011) and many more. An exception is the work by Costinot et al. (2011), who use a transaction cost economics model of adaptation to rationalize their findings.

We analyze a stylized property rights model of the boundary of the firm with incomplete contracts in which a downstream firm decides whether or not to in-source any one of a number of upstream inputs it requires for production of a final good.[13] Crucially, the inputs differ in how their quality impacts on the value of the final good; this is how we capture the concept of technological significance. We show that the make-or-buy decision weighs two different forces against each other. First, vertical integration distorts the upstream suppliers' incentives to invest in quality under incomplete contracting, which has more adverse consequences for final output in the case of technologically significant inputs (the "investment distortion effect"). This force pushes for outsourcing important suppliers and integrating marginal ones. However, suppliers of technologically significant inputs command higher bargaining power since falling out with them during *ex post* bargaining is very costly for the downstream firm (the "bargaining power effect"). This force pushes towards integration of important suppliers. Our model's prediction regarding make-or-buy is consistent with our empirical analysis iff the bargaining power effect dominates.[14]

Finally, we show that our stylized model delivers predictions that are highly consistent with our additional findings with respect to headquarters intensity and the quality of contracting institutions. First, the relationship between technological significance and vertical integration is particularly strong if the downstream firm has to make an important investment contribution to final output, since investment distortions even of key inputs are less of a concern. Moreover, if the upstream part of the supply relationship is located in a country with better contracting institutions or supplies inputs that are easy to contract upon, we expect a more positive effect of technological significance on integration, again because upstream investment distortions matter less.[15]

Our research is not only related to the substantial body of theoretical and empirical work that explores determinants of the make-or-buy decision in both organizational and international economics – where we directly contribute to a recent research effort to understand how supply chain characteristics shape organizational choice. We furthermore make progress regarding the anatomy of intra-firm trade. In particular, we draw attention to the fact that there is not only a skewed distribution of intra-firm sourcing *across* firms,[16] but also *within*: multinationals produce only the technologically most significant inputs in-house. Moreover, we complement the findings of Alfaro and Charlton (2009), who show that a large share of FDI is undertaken in vertical supply relationships.

[13] In line with our research question, we omit the individual supply chains (potentially "snakes") that lead up to these inputs.

[14] Our model is a natural reduced form generalization of the model by Antras (2003) and most property rights models would feature the same forces.

[15] We also discuss informally how scale differences up- and downstream, relationship specificity, and transfer pricing considerations affect our relationship of interest, see section 1.5.2.

[16] See Ramondo et al. (2016).

We are, in fact, not the first to notice that cost shares have a role to play in the context of vertical integration: Acemoglu et al. (2010) use direct requirements as measures for relative importance of upstream to downstream investment and show that they amplify the effect of RnD intensity on vertical integration in the UK. Their estimates of the *level* effect of the direct requirement is consistent with our finding, but the focus of their research is on the interaction. Alfaro et al. (2015), using worldwide data on firms, include total requirements as a control in their regressions and also find a positive estimate of the coefficient. They focus, however, on the impact of relative upstreamness rather than cost shares. The fact that the broad idea behind our main finding appears to be relevant even in data sets from countries other than France (UK, worldwide) lends further support to our results.

We explain our empirical strategy in section 1.2, describe our data in section 1.3, and discuss our results in section 1.4. We then outline our conceptual framework and derive the predictions in section 1.5. We conclude with section 1.6.

1.2 Empirical Strategy

We compare the integration decisions of different inputs within a firm and therefore our regressions are all at the firm by input level. Our inputs are classified at the HS 4 digit level (roughly 1100 categories).

For a given HS 4 digit input p we relate the share of imports that a firm i that operates in industry j acquires from its (international) related parties in overall imports of that input from country c, $intrashare_{ijpc}$, to this input's cost share across all intermediate inputs $inputshare_{jp}$.[17][18] We use the latter to capture the concept of technological significance and while cost shares are certainly imperfect measures, we argue that they are good proxies that embody relative technological significance across inputs in a robust way for a wide range of production functions (conditional on input prices).

The baseline structural equation we estimate is

[17] We have checked that the results are fully robust to using various other dependent variables. In particular, we define three binary variables. First, we define an integrated (as opposed to outsourced) flow as $intrashare_{ijpc} \geq 0.5$. Second, we follow Corcos et al. (2013) in that a flow is within firm iff $intrashare_{ijpc} \geq 0.8$ and outside iff $intrashare_{ijpc} \leq 0.2$. Finally, we count as fully integrated only observations that have $intrashare_{ijpc} = 1$, while observations with $intrashare_{ijpc} = 0$ count as outsourced. It is not surprising to find very similar results with all these dummy variables, since few products at a highly disaggregated level are sourced with a mix of outsourcing and integration. This is in itself an interesting feature of the data: make-AND-buy strategies appear to be more prevalent at the firm, rather than at the product level in the cross section, see Loertscher and Riordan (2016) for a theoretical treatment of make-and-buy.

[18] We believe that the *share* of intra-firm trade is the correct dependent variable, because our theoretical mechanism operates at the finest input level and hence predicts organizational mix at, say, the more aggregate HS 4 digit level.

$$intrashare_{ijpc} = \beta_1 \; inputshare_{ip} + \alpha_c + \gamma_i + \phi_p + \varepsilon_{ijpc} \tag{1.1}$$

We include downstream firm i, input p, and sourcing country c fixed effects in our main specification. These specific intercepts ensure that we do not mistake any other input, country, or downstream firm specific characteristics that increase the likelihood of intrafirm sourcing for the effect of the significance of inputs in a firm's production function. In particular, we control for headquarters intensity of the downstream firm's industry (in the literature often captured by capital or skill intensity) and the relationship specificity associated with, and the codifiability of, tasks required for the production of a particular input. Moreover, we address all concerns about country specific gravity factors that influence the patterns of FDI, like distance, market size, multilateral resistance etc. The parameter of interest is β_1.

The key challenge to identification of β_1 is that input cost shares are econometrically endogenous for at least four reasons. First, the denominator (the intrafirm trade share) of the dependent variable enters the numerator of the explanatory variable (the cost shares) and this may create mechanical correlation. Second, firms may substitute towards inputs produced by their foreign affiliates, for example to trigger increasing returns for them and maximize global profits, or because information frictions are less severe. Secondly, multinational firms frequently engage in transfer pricing,[19] which distorts input cost shares selectively in integrated relationships. In our setting, firms in relatively high tax France may charge inflated prices for inputs produced by foreign affiliates in order to artificially reduce their taxable income. Alternatively, transfer pricing is a way of alleviating the burden of tariffs. Finally, it is very likely that we measure input cost shares with considerable error in the sense that the values recorded in our data do not reflect the actual cost structures of our firms. Inventories may fluctuate significantly as a consequence of demand or supply shocks and as we estimate our regressions in a single cross section, inventory states distort input cost shares. Moreover, (international) trade is a relatively lumpy business due to fixed costs of ordering.[20] Consequently, the cost shares we calculate from international trade data are subject to variation due to shipments arriving early or late with respect to a given accounting year. Finally, cost shares reflect technological input-output relationship only to some extent and depend on many other characteristics as well. In other words, cost shares are proxies for the concept we are interested in and consequently further attenuation over and above actual errors in variables is likely.

[19]There is a substantial body of research that explores the nature and consequences of transfer pricing. For recent examples see Davies et al. (2017), Flaaen (2017), and the citations therein.

[20]See Alessandria et al. (2010).

To address these challenges, we employ an instrumental variables strategy. In particular, we use information from self constructed IO tables – which are closely related to industry level input cost shares – to instrument for the firm level cost shares. The details of how we construct them are given below in section 1.3. Industry level IO information needs to be excluded for identification, i.e. IO relationships affect organizational choice only through their effects on input cost shares. We argue that this assumption is likely to hold, since IO tables capture broad features of the underlying production technology and are, in particular, not affected by individual (French) firms.

We estimate equation (1.1) with two stage least squares (2SLS) and allow the error term to be correlated across all observations belonging to the same downstream industry and across all observations belonging to the same upstream input category (HS4).

We explore the robustness of our 2SLS results – and therefore the exclusion restriction – and consecutively introduce

- origin country by downstream industry cj fixed effects to rule out any effects that stem from the interaction between financial development of the origin country and financial constraints.[21]
- origin country by input cp fixed effects to clean our estimates of country-specific input price related factors that drive integration decisions.[22]
- highly disaggregated upstream by downstream industry interacted fixed effects[23] in order to address concerns about
  - relative upstreamness, so that we do not mistake sequential for parallel supply chains
  - vertical spill-overs.

This changes the structural equation to

$$intrashare_{ijpc} = \beta_1 \; inputshare_{ip} + \alpha_{jc} + \gamma_{jp'} + \phi_{pc} + \varepsilon_{ijpc}, \tag{1.2}$$

where p' indicates inputs classified by more aggregate classifications than HS4.[24]

[21] See Acemoglu et al. (2009) and Eppinger and Kukharskyy (2017).

[22] See Alfaro et al. (2016).

[23] Note that we choose the resolution of these interacted fixed effects such that there is still some variation left in the instrument.

[24] There may be concerns about some of the imported inputs in our data not being strictly vertical in the sense that they are used for further processing by the importer. In other words, we may be mistaking horizontal for vertical trade flows. As a robustness check, we therefore re-estimate the baseline 2SLS and 2SLS fixed effects models using a sample of observations where the upstream inputs are produced by industries that are not the same as the sourcing firm's downstream industry. All our results are highly robust to this check and we report the results in Appendix 1.B.

The interacted upstream by downstream industry fixed effects merit some more detailed discussion. Suppose we fix a particular downstream firm and compare the cost shares and integration decisions for HS4 inputs sourced by that firm. If we compare inputs that are produced by the same 4 digit ISIC industry upstream, we ensure that relative upstreamness across the inputs is virtually identical with respect to the downstream firm or production stage. Even in a case where there are small differences left, we can still interpret the change in our estimate as indicative: if the coefficients remain unchanged, it is unlikely that sequentiality plays an important role.

We next investigate key aspects of supply chains that provide additional empirical evidence a) as to which parts of supply chains are most susceptible to a strong influence of technological significance on make-or-buy decisions (a more descriptive point) and b) about which model of the boundary of the firm could potentially explain the relationship between cost shares and vertical integration. To do so, we interact our variable of interest, *inputshare*, with proxies for the determinants we are interested in, generically denoted by $characteristic_{ijpc}$. The structural equation for these exercises is

$$intrashare_{ijpc} = \beta_1 \; inputshare_{ip} + \beta_2 \; inputshare_{ip} \times characteristic_{ijpc} + \alpha_c + \gamma_i + \phi_p + \varepsilon_{ijpc}. \quad (1.3)$$

We study five different groups of determinants and give more detail in the data section 1.3 below. Most importantly we study the impact of headquarters intensity – assuming that the downstream firm makes relationship specific investments that affect output – and the role of the quality of contracting institutions. Moreover, we are interested in fixed cost explanations for the relationships we find and study proxies for downstream firm scale. Finally, we investigate relationship specificity and transfer pricing.

At this point, we also want to highlight that all measures vary, alternatively, at the firm, downstream industry, upstream industry, origin country, or origin country by product level. Consequently, we can capture the main effects $characteristic_{ijpc}$ by appropriate fixed effects and omit them in equation (1.2). In all specifications we instrument both the main effect of *inputshare* and its interaction with the supply chain characteristic. Finally, $characteristic_{ijpc}$ is always an indicator variable that takes the value one iff the respective variable is above the median within an appropriate category. For example, the dummy for a downstream firm characteristic is based on the within NAF industry median across firms. We therefore estimate the impact of a characteristic semi-parametrically by comparing the effect of input cost shares at low and at high values of that characteristic.

1.3 Data

In this section we introduce the data that we use to estimate our empirical models. We proceed by giving details on the main data sets we use and showing a range of summary statistics. We then turn to our instrumental variable and the construction of our own import IO tables.

1.3.1 Data Sets and Summary Statistics

First, we use the Enquete Echanges Internationaux Intragroupe (EIIG) (a single cross section in 1999) to obtain information about intra-firm trade of French firms.[25] The targeted survey population included every French firm whose annual trade volume is at least one million Euros and who is owned by a manufacturing group that controls at least 50% of a foreign firm. Out of this target population (8,236 businesses) roughly half of all firms responded. These 4,305 firms account for about 80% of French trade conducted by French multinational entities.

Corcos et al. (2013) point to the fact that the EIIG survey suffered slightly from non-response. They also show that this poses a significant problem since their results change meaningfully when they apply a selection correction. Fortunately, our estimates are unaffected by this concern because we use within firm variation.

For each responding firm, the EIIG has information about the value share of imports from related parties for each HS 4 digit product that the firm imports, by country of origin. In our final sample we focus on imports by the EIIG manufacturing firms (ISIC Rev. 3 codes 15 to 37).[26]

We supplement these trade data with information from the Enquete annuelle d'Entreprise (EAE), which provides us with balance sheet data on all French firms with more than 20 employees and a random sample of smaller firms. We use these data to obtain total expenditure on intermediate inputs and to construct empirical measures of supply chain characteristics.

Table 2.1 reports summary statistics for the firms in our data. There are about 3,000 firms in the final sample. The first row reports the unweighted import share from affiliated parties across all products and destinations: The average firm in our sample carries out 27% of its transactions across products and destinations inside the boundary of the firm.

[25] Other work that uses this data set includes, notably, Carluccio and Fally (2012), Corcos et al. (2013), Defever and Toubal (2013), and Carluccio and Bas (2015).

[26] The EIIG survey data were amended with official international trade data by the administrators of the survey at the French statistics institute INSEE. The details of this process is described in the official documentation (which is available from the authors after removal from web sources), but for the sake of brevity and since our results are perfectly robust to excluding the affected sourcing flows, we choose to not deal with this issue at any more depth in this paper.

However, the distribution of intra-firm trade is rather skewed towards few, large companies reporting a larger share of intra-firm transactions: The median firm imports only 9% of its transactions from affiliated parties.[27] Moreover, it can be seen that the typical firm will contribute to our estimates since it sources a significant number of different inputs.

Finally, consistent with the target population of the EIIG, our firms are relatively big. Selection of only the biggest, most productive companies into multinational activity is a well known fact. In this paper we use firm fixed effects throughout to address sample selection bias that may arise. Given the data we use, our results have to be interpreted as conditional on international sourcing and internalization decisions: since we only observe trade flows associated with firms that are already multinational companies, our findings are silent about the extensive margin of FDI and, indeed, domestic sourcing behavior. At the same time, multinationals account for a vastly disproportionate amount of economic activity, including international trade, and therefore we are convinced that this research is an important contribution.

An ANOVA shows that the overall variation in intra-firm trade shares is largely explained by across firm differences (48 % of partial sum of squares), while the product (3 %) and country (1 %) margins do not contribute very much. The residual is consequently relatively large and even with our baseline fixed effects, we are hopeful to obtain precise and widely applicable estimates.

Table 1.1: Summary Statistics

	mean	median	sd	count
Average Intra-Firm Trade Share	0.27	0.09	0.34	3157
Average Number of Products	10	7	12	3157
Employment	467	198	1,186	3107
Sales	160.1k	38.8k	1,136.7k	3155
Capital Intensity	900	450	7100	3103
Intangible Cap. Int.	105.7	17.5	1020.7	2971
Skill Intensity	184.8	171.9	71.4	3103
TFP Wooldridge (ln)	1.53	1.24	1.16	3003

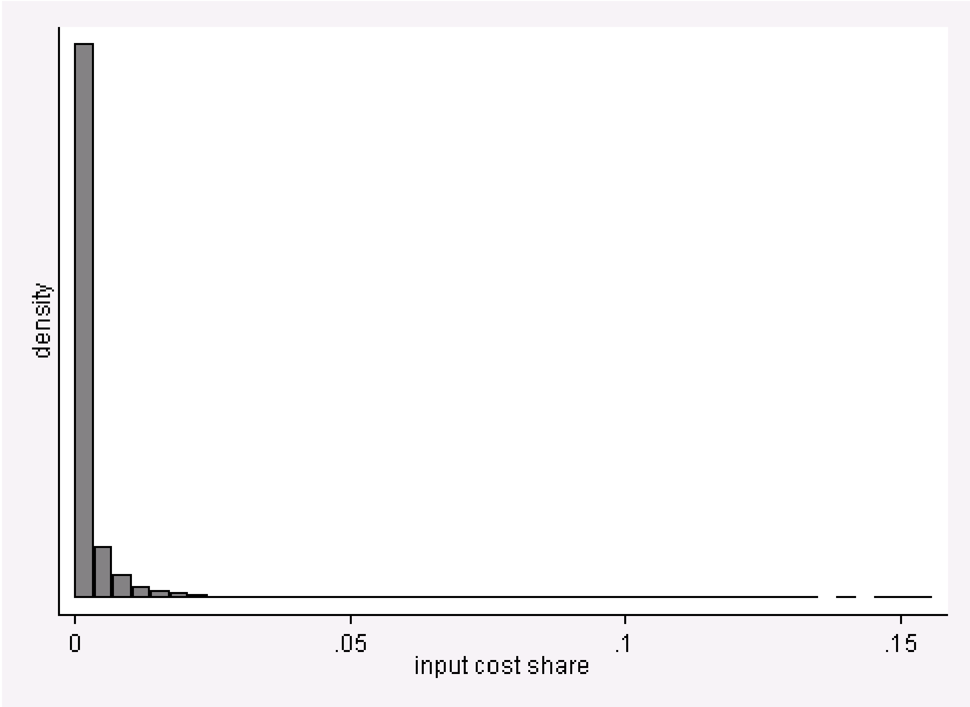
The second key ingredient of this paper is a proxy for technological significance and we have chosen to use intermediate input cost shares. More important inputs are therefore those on which a firm spends more. We calculate $inputcostshare_{ip}$ as

$$inputshare_{ip} = \frac{\sum_c imports_{ipc}}{totcost_i}$$

where $imports_{ipc}$ is the total value of all imports by firm i of input p from country c and $totcost_i$ is total expenditure on intermediate goods by firm i taken from the EAE. Figure

[27] A similar skewness has also been noted by Ramondo et al. (2016).

Figure 1.2: Empirical Density of Input Cost Shares



1.2 shows the empirical density of the input cost shares at the firm-by-input level.

For this main regressor, an ANOVA shows that about 29 % of the total sum of squares can be attributed to firm differences, while only 14 % can be traced to across product differences.

One may be worried that our results suffer from the fact that we use a selection of sourcing transactions, namely those from international trade partners. The ramifications could either be loss of external validity or genuine bias. To address these concerns we use several different normalizations for our input cost share that take account of different import propensities of firm-input pairs. We check that our results are fully robust to using either spending on foreign sourced intermediates or total costs (value added plus intermediate spending) instead of total intermediate costs in the calculation of the input cost shares. Moreover, we argue that, even if our results apply only to international sourcing, we still capture interesting patterns for multinational firms (as well as FDI and intra-firm trade flows).

1.3.2 Instrument: Input-Output Tables

We construct a valid instrument for input cost shares using various IO tables, including self-constructed ones. The two requirements we face are that we need relatively disaggregated information in order to achieve a strong first stage and that we need to remove our EIIG firms' trade flows from the IO data – otherwise we have no hope to satisfy both relevance and exogeneity.

In principle, IO tables are readily available for most countries and France is no exception. However, arguably the most commonly used and familiar one, the official 2 digit ISIC Rev. 3 domestic French table for the year 1999 satisfies neither of our requirements. For the purpose of this paper, "domestic" refers to an IO table that contains domestic transactions alongside international trade. It is therefore the standard IO table most researchers use and we call it "domestic" in order to differentiate it from those tables that contain only (import) trade flows. Clearly, the domestic IO table captures mostly domestic transactions and, together with a high level of aggregation, makes for a weak(er) first stage. Unfortunately, there are no disaggregate tables available for France (unlike for the U.S.).

We therefore construct our own IO tables for the year 1999 from transaction level import data for the whole of France.[28] For 4 digit NAF 1993[29] industry codes of all trading firms we rely on the FICUS database, which contains balance sheet and administrative information for the near universe of French enterprises. The customs data are matched to this firm information with a success rate of 91%. Finally, we use balance sheet information to obtain gross output by NAF industry and compute the import direct requirements at the NAF - HS 4 digit level.[30, 31] Since these tables are constructed directly from micro data, we name them "micro" tables.

We perform two additional modifications to improve our instrument further. First, when computing the industry level intermediate costs, we leave out a firm's own trade flows, effectively creating firm specific IO tables.[32] Second, we compute the table for 1996: to the extent that import IO tables capture mostly the underlying technological substitution patterns across inputs (and hence their technological significance), the 1996 direct requirements are good predictors of 1999 input cost shares, while arguably being less suspicious of causing reverse causality or other problems.

Figure 1.3 illustrates the variation in four of our IO tables. The upper left graph is well known: at the 2 digit level, by far most of the transaction volume takes place on the main diagonal, while only few, usually proximate sectors are connected off the main diagonal. Our 2 digit table constructed from micro data replicates this pattern very well – an observation we interpret as validation for our approach. As expected, we do find a few differences between the first two tables, which relate to the fact that we do not make

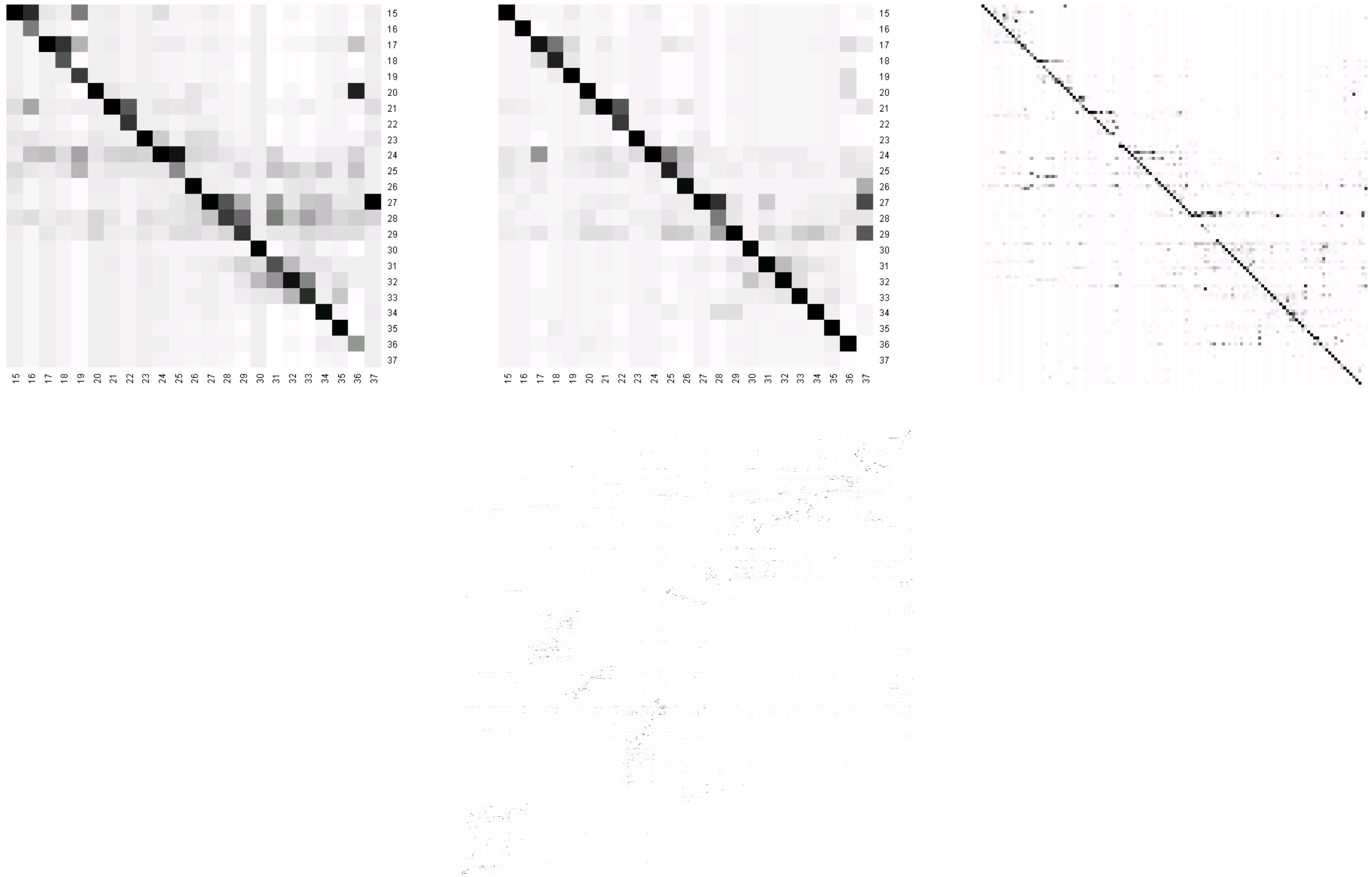
[28]We plan to make our French import IO tables available on our websites for the future use of researchers.
[29]NAF is the French industry classification and slightly more disaggregate than ISIC or NACE.
[30]More detailed information can be found in Appendix 1.A.
[31]For robustness we also use domestic 2002 benchmark IO tables from the US, which we convert from 6 digit US IO classification to 4 digit ISIC. Such a conversion has certain limitations and hence we only use them sparingly.
[32]For further robustness, we later remove trade flows of all our EIIG firms from our international trade data when we construct the import IO table.

any strong assumptions regarding tradability and simply let the actual trade transactions speak.

Constructing the tables at a more disaggregate level has two effects. First, the diagonal becomes relatively "thinner". Secondly, the elements off the diagonal exhibit more "contrast". In other words, the cells now have clear borders and stand out properly from the background. Econometrically, we reduce measurement error and bring the relevant variation to the fore.

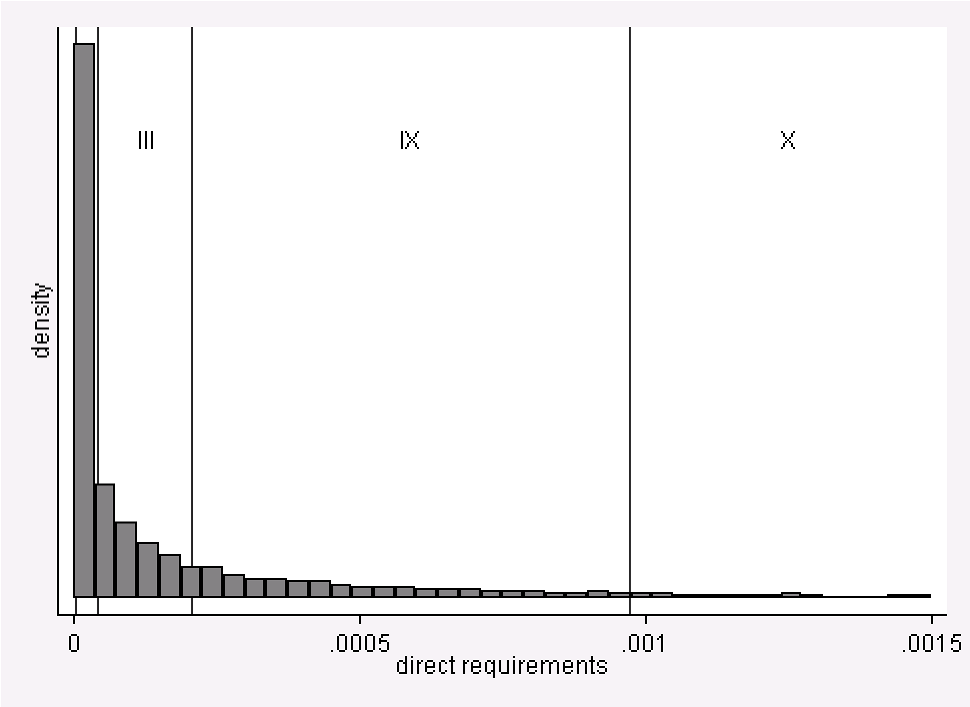
The asymmetric IO table at the finest level of disaggregation – our preferred level – exhibits a soft "diagonal", which stems from the fact that product and industry classifications follow a similar ordering. Industry codes are usually assigned on the basis of the product they produce (and vice versa).

Figure 1.3: IO Tables



In reading pattern starting with upper left: Official 2 digit domestic, 2 digit self-constructed, 4 digit symmetric self-constructed, 4 digit asymmetric self-constructed.

Figure 1.4: Empirical Density of Direct Requirements



The actual instrument we use below is not the direct requirement itself, but a categorical variable indicating quantiles of the direct requirement distribution. Figure 1.4 shows the empirical density of our self constructed import requirements. It is very skewed to the left and even the median is relatively small (remember that we normalize by gross output). The vertical lines indicate quintiles and our preferred instrument is a variable that takes the value 5 whenever the direct requirement of downstream industry j with respect to upstream input p falls into the segment V, value 4 if it falls into IV, and so on. In this way we semi-parametrically capture the skewed distribution of the requirements and make the instrument more robust to both measurement error and endogeneity concerns.

When assessing the variation in the instrument, a large part (about 22 %) is explained by input differences, while only a small part comes from downstream industry ones (about 5 %).

1.4 Results

1.4.1 Main Specifications

We start by estimating equation (1.1) in Table 2.3 with OLS. As we move along the columns, we add, one by one, the country, firm, and input fixed effects. The coefficient of interest, β_1, is always estimated as positive and highly significant. Taking the estimate in column (4), we calculate that an input at the median of the input cost share distribution is about 0.2 percent more likely to be integrated than a wholly insignificant input. This difference grows to 43 percent for the most crucial input, always over a baseline probability of 27 percent.

Table 1.2: Baseline Correlations

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share	(5) intra-firm share
inputshare	3.730***	3.865***	2.973***	4.174***	2.771***
	(0.494)	(0.501)	(0.351)	(0.468)	(0.312)
Country FE		YES			YES
Firm FE			YES		YES
HS4 product FE				YES	YES
Observations	84,643	84,643	84,643	84,643	84,643
R-squared	0.017	0.036	0.542	0.096	0.580

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressor is the firm by input level cost share in total expenditure on intermediates. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

As discussed above, however, these estimates suffer from endogeneity and we proceed by instrumenting the input cost share with our quintile instrument. Table 1.3 reports the 2SLS results and the first stage table 1.10 can be found in Appendix 1.B.[33] To illustrate the rationale for our instrument, we start by instrumenting the input cost share with a quintile variable based on the official 2 digit import IO tables for France in 1999 – the corresponding result is reported in column (1). We then use our self constructed IO table in column (2), the same table for 1996 in column (3), and the 1996 self-constructed table without any EIIG trade flows in column (4). Finally, in column (5), we report the 2SLS estimate with an instrument for which we first predict our self-constructed 1999 French IO table with the 2002 domestic U.S. benchmark IO tables provided by the BEA and then calculate the quintile variable.

The key result from these regressions – and indeed of this paper – is that, irrespective of the IO table and hence variation used, we obtain almost identical 2SLS estimates that are highly significant and positive. Our (weakly) preferred instrument is the one used in column (3), since it provides a good balance between a strong first stage and plausibly exogenous variation for identification of β_1. Using this preferred specification and comparing a wholly insignificant input to one that lies at the median of the cost share distribution we find that the latter is roughly half a percentage point more likely to be produced in-house, while the most important input overall is a staggering 141 percent

[33] The baseline 2SLS results when we exclude observations where the downstream industry potentially produces the input sourced can be found in table 1.11 in Appendix 1.B.

Table 1.3: Baseline 2SLS

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share	(5) intra-firm share
inputshare	8.664***	8.696***	9.087***	9.236***	8.832***
	(1.914)	(1.144)	(1.254)	(1.183)	(1.573)
Country FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES
Instrument	Official import 2dig	Micro 1999 excl own firm	Micro 1996 excl own firm	Micro 1996 excl EIIG	Micro 1996 U.S. predicted
Observations	78,237	78,237	78,237	78,237	78,237
R-squared	0.561	0.560	0.558	0.557	0.560
F-stat 1st stage	67.53	253	219.9	149.1	92.07

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressor is the firm by input level cost share in total expenditure on intermediates. The instrument is a categorical variable that indexes quintile bins of the direct requirements distribution of the respective IO table. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

more likely to be integrated.[34]

We next show that these estimates are highly robust to a range of very demanding fixed effects by estimating specification (1.2). We are particularly interested in the stability of $\hat{\beta}_1$, because it gives an insight as to a) the variation used for estimation and b) the exclusion restriction. Using different kinds of variation to estimate β_1 sheds light on the generality of our findings, while accounting for more and more unobserved factors through flexible fixed effects regressions, we test whether there are immediate concerns regarding the exclusion restriction in the benchmark specification.

Table 1.4 reports the results.[35] Column (1) repeats the baseline regression for a common sample across columns (1) to (3), while column (2) contains the results when we add the interacted downstream industry by country and upstream input by country effects. Columns (3) and (4) are the most demanding baseline specifications we run. First, we fix a particular HS 4 digit input and compare its cost shares and integration choices

[34] We implement one further robustness check on these baseline results: we estimate the baseline specification with Logit IV, rather than the linear probability model, to take into account that our dependent variable is largely a binary variable. The results are remarkably robust. Moreover, we either drop final goods according to the UN classification based on BEC or remove firms that report more than 5 percent of their total sales in the "wholesale" industry category according to the EAE. In both cases, we find slightly stronger results, which alleviates concerns regarding mere importing of final goods and carry-along trade. Finally, one may be worried that ownership decisions have been made according to the total requirement of an upstream product for downstream production and that the sourcing decisions we observe reflect these, rather than cost shares. To alleviate this concern, we include total requirements directly in our regressions as a control. The point estimates are slightly smaller throughout, but not significantly so, and the first stages become somewhat weaker.

[35] Tables 1.12, 1.14, and 1.13 in Appendix 1.B show the first stages, the OLS estimates with the same fixed effects, and the exercise where we exclude observations where the upstream industry producing an input is the same as the one of the downstream firm.

across firms in the same NAF downstream industry. Secondly, we fix a particular firm and compare cost shares and integration patterns across all inputs produced by a particular 4 digit ISIC industry. Remarkably, the estimates in columns (2), (3), and (4) are virtually indistinguishable from our preferred baseline result, even if we restrict the identifying variation to be within highly detailed input-output relationships. Most notably, conditioning on roughly equivalent relative upstreamness of the inputs relative to the downstream industry leaves the results unchanged and hence addresses concerns that our pattern may be caused by sequentiality rather than technological significance in parallel processing settings.

Table 1.4: Robustness 2SLS, Fixed Effects

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share
inputshare	11.191*** (1.336)	12.754*** (1.389)	8.376*** (2.893)	8.260*** (2.593)
Country FE	YES			
Firm FE	YES	YES	YES	
HS4 product FE	YES			
Country*HS4 product FE		YES	YES	YES
Country*Ind 4dig FE		YES	YES	YES
Firm*Up Ind 4 dig				YES
Ind 4dig * HS4 product FE			YES	
Instrument	Micro 1996 excl own firm	Micro 1996 excl own firm	Micro 1996 excl own firm	Micro 1996 excl own firm
Observations	71,999	71,999	71,999	67,002
R-squared	0.553	0.642	0.740	0.821
F-stat 1st stage	210.6	233	49.55	51.01

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressor is the firm by input level cost share in total expenditure on intermediates. The instrument is a categorical variable that indexes quintile bins of the direct requirements distribution of our self constructed 1996 import IO table. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

To summarize, these empirical analyses shed light on our research question: firms tend to integrate into supply chains that are relatively important in terms of cost shares and, by virtue of our instrumental variables approach, in terms of technology. Technological features of supply networks are consequently not only crucial in sequential processes as shown by Alfaro et al. (2015), but also in parallel settings: we argue that multinational firms integrate input production whenever these intermediates play an important role.

1.4.2 The Role of other Supply Chain Characteristics

We now turn to analyzing empirically how five characteristics of supply chains affect the relationship between technological significance and vertical integration. We ask: in which supply chains do we expect our mechanism to be strongest? What model of the firm is likely to be consistent with empirical firm behavior?

In doing so, we emphasize our results on headquarters intensity and the contracting environment, since these are particularly germane to distinguishing between mechanisms related to property rights models and since they play an important role in the global supply chains of multinational firms.

Headquarters Intensity

We implement an empirical test by estimating equation (1.3). As is common in the literature, we proxy headquarters intensity alternatively by physical or intangible capital intensity, skill intensity, or service intensity at the downstream firm, which we directly call HQ intensity for short. The details of how we construct these variables can be found in the data Appendix 1.A. Since all measures are at the firm level, we compute the median dummies within NAF industries.

The results are reported in table 1.5.[36] All interactions are significant and positive.[37] Consequently, we argue that supply relationships where the downstream party contributes a lot to output are those where high cost shares more strongly increase the likelihood of intra-firm sourcing. These typically include bottleneck industries as well as those that manufacture components from raw materials.

As in all our exercises in this subsection we use a dummy for whether a given downstream firm's characteristic is above or below the median in an appropriate category, in the case of table 1.5 a four digit industry. In addition to making the estimates more robust to functional form mis-specification, this addresses concerns of reverse causality. We have conducted two robustness exercises. First, one may still be concerned about endogeneity and we have repeated the exercise at the industry level with co-variates from 1996, i.e. with dummies equal to one if a four digit industry's characteristic was above the within 2 digit industry median in 1996. The results are less strong due to the loss in variation, but remain at least weakly significant throughout. Moreover, one may be concerned that our proxies for headquarters intensity may reflect productivity or firm size rather than headquarters intensity. To alleviate this worry we have included (and instrumented) an

[36]The first stage results, a table including the main effects of the supply chain characteristics, and the OLS estimates can be found in Appendix 1.B. The same applies to the contracting environment results below. Complementary tables for the remaining three exercises are available upon request.

[37]HQ intensity is highly significant if we interact it directly with our cost shares.

Table 1.5: Headquarters Intensity

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share	(5) intra-firm share
inputshare	8.198***	8.140***	7.966***	8.389***	4.970***
	(1.271)	(1.372)	(1.108)	(1.143)	(1.485)
$\times$ $\mathbb{1}$(Capital Intensity)$_i$	2.523*				2.126
	(1.442)				(1.428)
$\times$ $\mathbb{1}$(Intangible Cap. Int.)$_i$		3.345**			2.900*
		(1.597)			(1.614)
$\times$ $\mathbb{1}$(Skill Intensity)$_i$			3.228**		2.097
			(1.608)		(1.591)
$\times$ $\mathbb{1}$(Service Intensity)$_i$				2.289	2.026
				(1.453)	(1.439)
Country FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES
Observations	79,995	79,995	79,995	79,995	79,995
R-squared	0.550	0.550	0.549	0.551	0.549
KP-stat 1st stage	132.7	133.6	106.5	133.7	34.94
Instruments	Micro 1996 excl own firm and interactions				

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median. The instruments are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

interaction of a median employment dummy as a measure of firm size with the cost share variable. Again, the results are slightly weaker, but remain strongly positive and at least significant.

Contract Intensity

Multinational firms maintain extensive supply chains across the whole globe. Nowadays, the vast majority of countries participates at least in some part of such global value chains and they differ with respect to many aspects that shape production networks. One such factor is their institutional ability to enforce contracts. Moreover, certain activities are inherently difficult to enforceably write into a contract. Non-standard, highly customized specifications or highly complex tasks would require infinitely rich descriptions and therefore it is often economical to intentionally leave contracts incomplete. Consequently, supply chains of different firms or industries are sometimes more, sometimes less severely affected by contract incompleteness or contract intensity. Clearly, understanding how these patterns affect how technological significance impacts on make-or-buy decisions is important.

We again work with the empirical model in equation (1.3) and choose two country level variables, a rule of law index and an index of intellectual property rights protection. Moreover, we compute a measure of contract intensity at the downstream firm level and two such measures at the downstream industry level, the former of which is similar to the firm level one, while the latter is routineness of the tasks performed upstream to produce the input. All details can be found in the data Appendix 1.A. We highlight that these variables capture different sources of contract incompleteness and that, if all have similar effects, these results are particularly convincing.

Table 1.6 reports our estimates. It is noteworthy that all effects are positive and strongly statistically significant. Moreover, these impacts are big: a high quality of contracting institutions or low contract intensity almost doubles the effect of input cost shares.

Table 1.6: Contracting Environment

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share	(5) intra-firm share	(6) intra-firm share
inputshare	5.608***	5.143**	7.868***	7.699***	7.067***	-1.470
	(1.831)	(2.075)	(1.177)	(1.491)	(1.561)	(2.523)
$\times$ $\mathbb{1}$(Rule of Law)$_c$	4.318**					2.057
	(1.884)					(2.142)
$\times$ $\mathbb{1}$(IPR Protect.)$_c$		4.886**				2.889
		(2.138)				(2.488)
$\times$ $\mathbb{1}$(Contr. Int. Firm)$_i$			3.794**			3.601**
			(1.609)			(1.611)
$\times$ $\mathbb{1}$(Contr. Int. Industry)$_j$				5.175**		5.285**
				(2.133)		(2.152)
$\times$ $\mathbb{1}$(Upstr. Routineness)$_p$					4.349**	4.288**
					(2.089)	(2.051)
Country FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES	YES
Observations	82,950	82,950	82,950	82,950	82,950	82,950
R-squared	0.552	0.552	0.550	0.551	0.549	0.547
KP-Stat 1st stage	139.7	141.2	118.7	144.9	105.4	32.58
Instruments	Micro 1996 excl own firm and interactions					

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median. The instruments are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Fixed Costs, Relationship Specificity, Transfer Pricing

If vertical integration carries low fixed costs or, equivalently, downstream firms tend to be relatively large or productive and can therefore incur such fixed costs, vertical integration is more likely. Unfortunately, to our knowledge there is no empirical measure at the country level that allows for comparing the set-up costs of affiliates to the costs of outsourcing in the same country. However, our data readily supply us with firm size measures, namely productivity, employment, and total revenues, so that we can gauge how they interact with technological significance.

The results from estimating (1.3) with these measures are reported in table 1.7. While the relationship between technological significance and vertical integration is statistically significantly stronger for large firms, column (4) suggests that even among relatively smaller and less productive firms still manage to maintain subsidiaries in other countries to produce inputs by themselves. In the light of the sample we use this may not come as a surprise, since we condition on multinational firms, which have already selected into both trading and FDI. Consequently, the difference between fixed costs of outsourcing and integration is likely to be manageable even by relatively smaller firms.

Table 1.7: Scale

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share
inputshare	8.182***	6.519***	6.781***	5.527***
	(1.294)	(1.118)	(1.137)	(1.238)
$\times\ \mathbb{1}(\text{Wooldridge TFP})_i$	3.026**			1.967
	(1.482)			(1.560)
$\times\ \mathbb{1}(\text{Employment})_i$		4.978***		3.664*
		(1.476)		(1.913)
$\times\ \mathbb{1}(\text{Sales})_i$			4.408***	1.227
			(1.471)	(1.885)
Country FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES
Observations	82,950	82,950	82,950	82,950
R-squared	0.551	0.552	0.551	0.552
KP-stat 1st stage	115.4	132.6	132.5	56.23
Instruments	Micro 1996 excl own firm and interactions			

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of scale is above the within NAF industry median. The instruments are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of scale is above the within NAF industry median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

We now turn to variables that relate to the outside options of the two parties of a supply relationship. First, we use an indicator variable for whether an input p is differentiated or traded on an exchange. Second, we use the share of differentiated inputs produced by the upstream industry. Third, we argue that more complex products are more customizable and intricate and thereby less valuable in other relationships – we include a measure of input complexity.

Table 1.8 reports the results from estimating (1.3) with the slight deviation that we do not compute above or below median indicators for the input specific measure of relationship specificity; it is already a dummy variable. While all point estimates are slightly positive, none of them are significant due to relatively large standard errors.[38] The explanation may partially be that the relationship specificity variables based on the Rauch measure are highly skewed towards differentiated products, so that there is little variation on the right hand side.

Table 1.8: Relationship Specificity

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share
inputshare	9.475***	9.044***	8.351***
	(1.526)	(1.993)	(1.749)
$\times$ $\mathbb{1}$(Rauch Differentiated)$_p$	0.399		
	(1.875)		
$\times$ $\mathbb{1}$(Upstr. Rel. Specificity)$_p$		0.961	
		(2.250)	
$\times$ $\mathbb{1}$(Harvard Complexity)$_p$			1.869
			(2.072)
Country FE	YES	YES	YES
Firm FE	YES	YES	YES
HS4 product FE	YES	YES	YES
Observations	82,950	82,950	82,950
R-squared	0.551	0.552	0.551
KP-stat 1st stage	70.39	49.01	117.8
Instruments	Micro 1996 excl own firm and interactions		

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of relationship specificity is above the across downstream NAF industry or across upstream ISIC industry median (note: the Rauch measure is already a dummy). The instruments are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of relationship specificity is above the across downstream NAF industry or across upstream ISIC industry median (note: the Rauch measure is already a dummy). Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Finally, we are interested in the role of input cost shares in the face of tariffs and hence the potential to price intra-firm transactions at non-market values. This wide-spread practice is relevant for global supply chains in that tariffs are obvious choice variables for governments if they want to attract – or repulse – multinational companies.

[38] Complexity is an exception, since we do find a statistically significant and positive effect with a simple interaction term of cost shares with the complexity index. We choose not to rely on these results since they are clearly not very robust and in order to remain consistent in our empirical approach.

We use effectively applied ad valorem import tariffs imposed by the European Union whose customs union France is a member country of. Effectively applied tariffs are MFN tariffs towards WTO member countries unless preferential agreements stipulate a lower rate towards a given country. Table 1.9 contains the estimates from equation (1.3), where we rely on both the maximum tariff charged within an HS code and a simple average over several tariff lines across all lines in a given HS code. We aggregate up to the 4 digit level using French import data from 1996. The estimates are at least marginally statistically significant and positive.

Table 1.9: Transfer Pricing

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share
inputshare	9.802***	9.920***	9.642***
	(1.532)	(1.677)	(1.663)
$\times$ $\mathbb{1}$(Eff. Appl. Tariff (Max))$_{cp}$	3.876*		2.830
	(2.066)		(3.192)
$\times$ $\mathbb{1}$(Eff. Appl. Tariff (Average))$_{cp}$		3.555	1.319
		(2.199)	(3.426)
Country*HS4 product FE	YES	YES	YES
Country*Ind 4dig FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	76,359	76,359	76,359
R-squared	0.632	0.632	0.632
KP-stat 1st stage	145.9	146	101.9
Instruments	Micro 1996 excl own firm and interactions		

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure transfer pricing potential is above the across country by input median. The instruments are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure transfer pricing potential is above the across country by input median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Summary of the Empirical Findings

Our empirical findings suggest that there is a robust, and economically large, positive relationship between cost shares of an input and the probability that this input is made as opposed to bought. In other words, in parallel processing supply chain segments, (multinational) firms integrate vertically those inputs that contribute a lot to output – in other words, the technologically important ones – and tends to outsource production of marginal inputs.

Moreover, we find that this strong pattern is amplified whenever the downstream firm plays an important role, the contracting environment is good, the downstream firm is big, and whenever EU import tariffs are high. There is no convincing evidence that relationship specificity plays a role.

1.5 Theoretical Framework

Having outlined the main contribution of this paper, we want to go one step further and explore what mechanisms may be behind, or consistent with, our findings. Any candidate framework will have to be able to replicate the empirical patterns we have provided in the previous sections. We can conceive of at least three candidate models of the boundary of the firm – a transaction cost model of supply assurance, a more general transaction cost framework with fixed costs, and a property rights model. As discussed in the introduction, there is a substantial body of empirical research belonging to the international trade literature on multinational firms that provides evidence at least consistent with, but most likely supportive of, the property rights framework. Consequently, it is natural to start with such a model and see if its predictions are consistent with our findings. This is the task we undertake in this section.

We want to stress that we do not attempt to *test* different models of the firm against each other. This is by itself very difficult and the standard set by the organizational economics literature for such tests is very high indeed (see Whinston (2001)). Instead, we content ourselves with assessing whether a version of the workhorse model of multinational firm behavior delivers predictions consistent with the empirical evidence available to us.

1.5.1 Baseline Model

Technology

A downstream firm produces a quantity y of a final good for which it requires a discrete number I of upstream inputs. In a slight abuse of notation, we use I to address both the number and the finite and countable set of inputs. Final goods are produced by combining a bundle of these intermediate inputs in the following way:

$$y = \sum_{i}^{I} m(i)^{\delta(i)},$$

where $m(k) > 0$ denotes the quality of input k. All inputs are always delivered with quantity one, but their productive contribution depends on their quality. Moreover, inputs may have different elasticities with respect to final output (δ).[39] It is this parameter $\delta(i)$ that corresponds one-to-one to the cost shares in our empirical section and it is what we refer to as technological significance. We assume that inputs are ordered in such a way that a higher index refers to more important inputs: $\delta(i) : I \mapsto (0,1)$ is strictly increasing. Note that all inputs matter for production and that we assume decreasing returns to scale for any given input, implying that we have decreasing returns overall. Moreover, the production function is fully additive in the input terms, so that there are no technical complementarities between inputs.

The suppliers can invest into quality and their costs of producing a unit of input i with quality $m(i)$ is c_M; production upstream is subject to constant returns to quality investments.

Downstream preferences

There is perfect competition between downstream good producers and hence each firm takes the price as given. Two implications follow: first, revenues are proportional to output and we can normalize the price of the final output good $p_y \equiv 1$. Secondly, due to the fact that the demand curve is fully inelastic, we have shut down interactions between inputs arising from the demand side.

Further Assumptions, Contracting and Timing

There is a continuum of homogeneous suppliers that can potentially produce any given input k, but none of them can produce more than one variety. Contracts are – for now – fully incomplete in the sense that only property rights can be contractually specified and enforced at any point in the game. Crucially, investments are non-contractible. The timing of the game is as follows:

1. Contract written that includes arrangements regarding ownership
2. Supplier makes the investment into quality and ships inputs
3. Output sold and revenues are split in bilateral bargaining

We follow Antras and Chor (2013) and do not specify the nature of the bargaining game in more detail. Instead, we capture the key insights of the property rights theory of the firm by assuming that ownership conveys a bargaining advantage. The downstream firm will be able to capture a share $\beta(i) \in [0,1]$ of the surplus with any individual supplier,

[39] We could generalize this production function to include heterogeneous weights in the basket of inputs. What matters, however, for the make-or-buy decision is elasticity of output with respect to inputs (see Grossman and Hart (1986)). Consequently, we omit these weights from the outset to avoid confusion.

while the latter obtain a share $1-\beta(i)$. $\beta(k)$ may be viewed as the ownership share of downstream firm in supplier k's assets and it is the downstream firm's choice variable on stage 1.[40]

The inputs sport different characteristics in relation to final output and therefore it would be very strong to assume that the impact of ownership on bargaining power is uniform. We therefore generalize our model in this dimension a little more, albeit in a reduced form way. In particular, we assume that the share of the surplus that accrues to the downstream firm is $\gamma(i)\beta(i)$, where $\gamma(i)>0$ $\forall i$ is a set of parameters – $\gamma(i)$ is continuous and monotonic in i – and $\beta(i)\in[0,\gamma(i)^{-1}]$. Note that we do not make an assumption regarding how bargaining power varies with technological significance of an input, i.e. $\gamma(i)'$, at this point. Intuitively, $\gamma(i)$ acts as a short-hand for how the two parties' outside options respond to changes in technological significance.

What could be a microfoundation for $\gamma(i)'<0$? A more significant supplier may have a better threat-point under vertical integration (i.e. the downstream firm's outside option is worse), since any given loss in quality due to appropriation/firing by the downstream firm in case of disagreement on the bargaining stage has a more negative impact on output. Consequently, the downstream firm has to choose a higher ownership share to make up for this loss. A microfoundation of $\gamma(i)'>0$, on the other hand, may rely on the supplier's outside option under outsourcing. If selling outside the relationship entails a (proportional) loss of quality – for example due to adaptation to the new customers' specifications – other downstream firms are increasingly unwilling to pay a high price for important inputs, since they sacrifice an ever larger amount of value on their product. Less important inputs may suffer less in case of a break-up.

Solution

We solve the game by backward induction. The surplus generated by adding an input k of quality $m(k)$ to the final product is equal to $\alpha(k)m(k)^{\delta(i)}$, of which the supplier gets a share $1-\gamma(k)\beta(k)$. Consequently, supplier k optimally chooses to invest ($*$ denotes optimal choices)

$$m(k)^* = \left(\frac{\delta(i)}{c_M}\right)^{\frac{1}{1-\delta(i)}} \left[\alpha(k)[1-\gamma(k)\beta(k)]\right]^{\frac{1}{1-\delta(i)}}.$$

More important inputs in terms of $\alpha(i)$ and $\delta(i)$ receive more investment in quality, and, crucially, the distortions in case of downstream ownership are stronger.

[40]For precision throughout this theory section, when we write $\beta(i)$, we mean the function $\beta:[0,1]\mapsto[0,1]$, while $\beta(k)$ refers to a particular input k. The same applies to all other functions.

The downstream firm on the first stage chooses $\{\beta(i)\}_I$ to maximize its total profits. A simple way to derive predictions regarding the function $\alpha(i)$ is to consider what Antras and Chor (2013) call the unconstrained problem, i.e. choosing the value of $\beta(k)$ freely from $\mathbb{R}$. Total profits are

$$\left(\frac{\delta(i)}{c_M}\right)^{\frac{\delta(i)}{1-\delta(i)}} \sum_{i}^{I} \alpha(i)^{\frac{1}{1-\delta(i)}} \gamma(i)\beta(i)(1-\gamma(i)\beta(i))^{\frac{\delta(i)}{1-\delta(i)}}$$

and the optimal choice of $\beta(k)$ is

$$\beta(k)^* = \frac{1-\delta(k)}{\gamma(k)}.$$

Holding $\gamma(i)$ constant for now, suppliers of more important inputs are more likely to be stand-alone firms. As $\delta(i)$ increases, suppliers will up their investments due to a higher marginal return. Now, while the downstream firm's marginal benefit from more ownership increases slightly as investment grows, the marginal costs increase relatively strongly since the distortions limit investment severely. We call this effect the "investment distortion effect".

Moreover, focusing on changes in $\gamma(i)$ – what we call the "bargaining power effect" – more important inputs may be more likely to be integrated if the downstream firm's bargaining power decreases sufficiently as it deals with ever more important inputs. By contrast, if downstream bargaining power increases with technological significance, the downstream firm will produce only unimportant inputs in-house. We would argue that, while even small suppliers can cause severe disruptions in supply chains and hence command considerable bargaining power, it is more likely that strong vertical linkages will improve a supplier's bargaining position, at least on an everyday basis, so that $\gamma(i)' < 0$.

Taken together, the degree of vertical integration increases with technological significance iff

$$-\varepsilon_{\gamma(i),i} > \varepsilon_{\delta(i),i},$$

where $\epsilon_{w,t}$ denotes the elasticity of w with respect to t. Consequently, the property rights model of the firm predicts a pattern consistent with our empirical findings – namely that more important inputs are more likely to be integrated – if the bargaining power effect is stronger than the investment distortion effect.

A final comment regarding ex ante transfers – for example due to ex ante market power of the downstream firm and ensuing take-it-or-leave-it offers – is in order. Allowing for these implies that the downstream firm maximizes the *joint* ex ante surplus of the relationship by picking $\beta(i)$. Since it can appropriate all profits through the transfer, there is no incentive to increase its ownership and hence all inputs are outsourced. Clearly, there is no heterogeneity across inputs. This result relies, however, on our assumption that there are no relationship specific investments to be made downstream.

1.5.2 Extensions

Headquarters intensity

We first explore how one of the most important determinants of vertical integration in the property rights model interacts with technological significance, namely headquarters intensity. If the downstream firm has an investment choice, too, the more important it is vis-a-vis the upstream supplier's the more likely vertical integration becomes. The reason is that total surplus of the relationship is maximized if the party with the higher marginal return on investment faces less of a distortion in their decision due to low profit participation.

Assume for this subsection that the downstream firm has a number I of investment decisions to make, one for each input. We denote them by $h(i)$ and they could capture adaptation required for inputs i to fit together properly; processing of the individual inputs in some other way; or quality control. For simplicity, we choose a simple Cobb-Douglas aggregator for the investment decisions, so that output is now

$$y = \sum_{i}^{I} h(i)^{\eta} \left[m(i)^{\delta(i)} \right]^{1-\eta}.$$

η is common across inputs and captures headquarters intensity. There are constant returns for the downstream investments and the costs are c_H

Following the same reasoning as before, the ex post surplus of the supply relationship with the supplier of input k is

$$h(k)^{\eta} \left[m(k)^{\delta(k)} \right]^{1-\eta},$$

since there are still no complementarities across inputs. The optimal investment choices are

$$h(k)^{*} = \left[\frac{\eta}{c_H} \right]^{\frac{1-\delta(k)(1-\eta)}{(1-\eta)(1-\delta(k))}} \left[\frac{(1-\eta)\delta(k)}{c_M} \right]^{\frac{\delta(k)}{1-\delta(k)}} \left[\gamma(k)\beta(k) \right]^{\frac{1-\delta(k)(1-\eta)}{(1-\eta)(1-\delta(k))}} \left[1-\gamma(k)\beta(k) \right]^{\frac{\delta(k)}{1-\delta(k)}},$$

and

$$m(k)^* = \left[\frac{\eta}{c_H}\right]^{\frac{\eta}{(1-\eta)(1-\delta(k))}} \left[\frac{(1-\eta)\delta(k)}{c_M}\right]^{\frac{1}{1-\delta(k)}} [\gamma(k)\beta(k)]^{\frac{\eta}{(1-\eta)(1-\delta(k))}} [1-\gamma(k)\beta(k)]^{\frac{1}{1-\delta(k)}}.$$

We take note of two observations about investment decisions. First, it is clear that headquarters intensity does not affect the supplier's investment distortion due to lower revenue participation under vertical integration, which is captured by the final terms. Secondly, the fact that the headquarters' investment renders upstream investment more valuable for output incentivizes the supplier – and more so the more important the downstream investment is. This is captured by the penultimate terms.

Computing total ex ante profits for the downstream firm and maximizing these with respect to $\beta(i)$ as before, we find that

$$\beta(i)^* = \frac{1}{\gamma(i)} \frac{\eta + (1-\delta(i))(1-\eta)}{1+\eta}.$$

If $\eta = 0$, the expression collapses to the solution in the baseline model. The condition for an increasing relationship between significance and the probability of integration is now

$$-\varepsilon_{\gamma(i),i} > \frac{(1-\eta)\delta(i)}{\eta + (1-\delta(i))(1-\eta)} \varepsilon_{\delta(i),i}.$$

In words, if the downstream firm's bargaining power falls more vis-a-vis more important suppliers compared to those suppliers' increasingly significant contribution to output, integration becomes more likely. This is equivalent to what we found in the benchmark model. If $\delta(i) > \frac{1}{2}(1-\eta)$, this condition is somewhat stricter than the one implied by the benchmark model.

The cross derivative $(\beta(i)^*)^2/\partial i \partial \eta$ is positive iff

$$-\varepsilon_{\gamma(i),i} \frac{1-2\delta(i)}{2\delta(i)} < \varepsilon_{\delta(i),i}$$

This expression is satisfied for significant inputs, i.e. those with $\delta(i) > 0.5$. For $\delta(i) < 0.5$ it a matter of parametrization.

With rising headquarters intensity, the upstream investment distortion has a less and less severe impact and hence the negative effect on total surplus created by increasing downstream ownership is alleviated. On the other hand, it is ambiguous whether the costs of ownership in terms of bargaining power vis-a-vis more important suppliers go up or down. Especially for important inputs the model's prediction is very much in line with our empirical findings, namely that headquarters intensity acts as an amplifier for the relationship between technological significance and vertical integration.[41]

Contracting Environment

We now turn to examining how the effect of technological significance depends on the contracting environment. Antras (2015), Acemoglu et al. (2009), and Eppinger and Kukharskyy (2017) examine the effect of better contracting institutions and (or) less contract intensity of a an industry's output and overall find that vertical integration is a complement to complete contracts.

We analyze our baseline model, but introduce the following generalizations. First, suppliers no longer choose a single investment under fully incomplete contracts, but now each make a continuum of investment choices $x_i(j),\ j \in [0,1]$, which translate into quality through $m(i) = exp[\int_0^1 ln\ x_i(j)\mathrm{d}j]$. We assume that all investments $j < \mu$ with $\mu \in [0,1]$ are fully contractible and are chosen by the downstream firm after ownership has been allocated, but before the supplier has made her investment choices. All investments with $j > \mu$ are fully non-contractible ex ante. Consequently, μ will serve as a parameter indicating the quality of contracting institutions or the inverse of contract intensity. Costs of investing are $c_M x_i(j)$.

The analysis of the equilibrium proceeds as before. For all non-contractible investments – indexed by n – the supplier now chooses

$$x_k^{n,*}(j) = x_i^{n,*} = \left(\frac{\delta(k)}{c_M}\right)[1-\gamma(k)\beta(k)]m^*(k)^{\delta(k)}$$

where

$$m^*(k) = \left\{exp\left[\int_0^{\mu} ln\ x_i^c(j)\mathrm{d}j\right]\right\}^{\frac{1}{1-\delta(k)(1-\mu)}} \left(\frac{\delta(k)}{c_M}\right)^{\frac{1-\mu}{1-\delta(k)(1-\mu)}} [1-\gamma(k)\beta(k)]^{\frac{1-\mu}{1-\delta(k)(1-\mu)}}$$

and x_i^c are contractible investments. This expression is similar to the baseline case, but the quality investment is less distorted by potential hold-up the more contractible it is, i.e. the higher μ. This is very intuitive given that complete contracts eradicate all danger of hold-up and hence underinvestment.

Going further, the downstream firm chooses all contractible investments one stage

[41] Transaction cost motives for vertical integration are typically considered independent of the relative importance of an upstream vs. downstream investment, while the hallmark prediction of the property rights theory of the firm is that ownership should be allocated to the party with a higher marginal contribution to the relationshipâs output. Consequently, our empirical results may imply that property rights forces do play a role.

earlier and then goes on to pick ownership. In particular it maximizes

$$[\gamma(k)\beta(k)]^{\frac{1-\delta(k)(1-\mu)}{1-\delta(k)}}[1-\gamma(k)\beta(k)]^{\frac{\delta(k)(1-\mu)}{1-\delta(k)}}\left(\frac{1}{1-\delta(k)(1-\mu)}\right)^{\frac{\delta(k)\mu}{1-\delta(k)}}\left(\frac{\delta(k)}{c_M}\right)^{\frac{\delta(k)(1-\mu)}{1-\delta(k)}}$$

with respect to ownership $\beta(k)$. The solution is

$$\beta(k)^* = \frac{1-\delta(k)(1-\mu)}{\gamma(k)},$$

which collapses to the baseline solution if there are no contractible investments, i.e. $\mu = 0$.

First, the condition for a positive relationship between technological significance and vertical integration becomes

$$-\varepsilon_{\gamma(i),i} > \frac{\delta(i)(1-\mu)}{1-\delta(i)(1-\mu)}\varepsilon_{\delta(i),i}$$

and this condition is more likely to hold if contracts are more complete.

Secondly, it is easy to calculate that the cross derivative $[\partial\beta(i)]^2/\partial i\partial\mu$ is always positive.

The intuition behind this result is the following. The increasingly distortive effect of downstream ownership for more important inputs is alleviated in a better contracting environment, since a higher fraction of such investments is fully contractible ex ante and the hold-up problem becomes less severe. This pushes towards more vertical integration for technologically important inputs.

Clearly, this prediction is fully consistent with our empirical results above.[42]

Fixed costs, relationship specificity, transfer pricing

It is easy to see that an additional (fixed) cost of integration ($f \times \beta(k)$) will lower the optimal ownership share of the downstream firm, or, alternatively, render integration less attractive. If we also introduce productive heterogeneity at the level of the downstream firm, we obtain the standard sorting pattern of larger and more productive firms sorting into vertical integration.[43] The interaction with technological significance is positive: if a firm intends to produce an input in-house it will only be able to do so if it is productive enough to overcome f and if the acquisition target produces an input that is important enough. The empirical patterns we find strongly support this prediction.

The role of relationship specificity is less clear and depends on the assumptions regard-

[42] Please note that the forces highlighted by transaction cost theories of the boundary of the firm would push for the opposite pattern. Ex ante inefficiencies are likely to be at play in our setting.

[43] This is consistent with a body of empirical work, notably Kohler and Smolka (2009), Antras (2015), and Defever and Toubal (2013).

ing the suppliers' outside options one is willing to make. First, let us assume that any amount of relationship specificity of upstream investments renders a supplier's intermediate useless for other downstream firms, either due to temporal constraints or technological incompatibilities. In this case, as long as the downstream firm continues to obtain the same outside option as before – and there is no reason to assume differently – we do not expect a systematic pattern of co-variation between the effect of technological significance and relationship specificity.

Secondly, suppose that a higher degree of relationship specificity involves an increasingly dire outside option for a supplier, irrespective of its significance for the downstream firm. The difference in outside options – and hence bargaining power – between producers of more and less technologically significant inputs is smaller with high relationship specificity, which corresponds to $(0 >)\gamma(i)'_{high} > \gamma(i)'_{low}$ and therefore to $\partial\beta(i)/\partial i|_{high} > \beta(i)/\partial i|_{low}$, i.e. a positive interaction term.

Our empirical evidence is strictly speaking consistent with full relationship specificity in the sense that we find no statistically significant interaction of cost shares with measures of relationship specificity. They are weakly positive, however, which is not inconsistent with the second conceptual view of how to incorporate partial relationship specificity into the model.

Finally, we turn to tariffs as a determinant of vertical integration.[44] In our stylized model, inputs of higher quality carry higher compensation for the supplier, i.e. higher prices, and technological significant inputs command greater investments into quality – as a corollary, more significant inputs, which are more likely to be integrated if $\gamma(i)' < 0$ and sufficiently steep, will also be subject to high ad valorem tariffs. Suppose that integration carries the additional advantage that the price of an input can be manipulated vis-a-vis the customs authorities in a way such that lower payments are to be made. In this case, inputs shipped from high tariff locations are more likely to be produced in-house by the multinational, integrated firm and even more so for more technologically significant inputs. This prediction is again consistent with our findings.

In sum, the property rights model of the firm delivers predictions that are overwhelmingly supported by our empirical evidence. While this observation certainly does not rule out other explanations or theories, it is difficult to see how they can be reconciled with our empirical results regarding headquarters intensity and the contracting environment in a straightforward way.

[44]The impact of tariffs on vertical integration have been analyzed by Ornelas and Turner (2008), Ornelas and Turner (2011), Diez (2014), Antras (2015), and Alfaro et al. (2016). For an overview of the transfer pricing literature see Davies et al. (2017) and Flaaen (2017) and the reviews therein.

1.6 Conclusion

In this paper we give an empirical answer to the questions: which inputs or components that are processed *simultaneously* do multinational firms choose to produce in-house and which do they outsource? How do firms organize "spiders"? By exploiting information about French intra-firm trade and using exogenous variation coupled with demanding fixed effects, we provide robust empirical evidence that input with higher cost shares – technologically more significant inputs – are produced in-house, while the ones with low cost shares are outsourced. Furthermore, we show that this pattern is stronger if the downstream firms contribute a lot to final output and if contracting institutions are good or contract intensity low.

Antras and Chor (2013), Alfaro et al. (2015) have investigated how firms organize "snakes", while we show how they organize "spiders". In order to develop an even more refined understanding of how characteristics of supply chains shape the organizational choices made by firms, we argue that three issues require further attention. First, supply chains are neither "spiders" nor "snakes" – they are input-output networks. A promising next step is a conceptual exploration of vertical integration when there are heterogeneous components with their own sequential supply chains: do these technological features interact in a meaningful way? Second, we urge researchers to conceive of empirical measures that capture the degree of sequentiality versus parallelity of supply chains directly, so that it becomes possible to tell in which parts of the economy the organizational choices of multinational firms are better modelled as the outcome of decision making like the body of a "spider" or as the head of a "snake".[45] Third, policy makers are highly interested in how characteristics of countries and industries interact with the forces of supply chains that shape FDI, since these characteristics are their choice variables or key limitations. To provide significant inputs for the political process, however, the empirical interaction between the technological characteristics of modern supply chains and organizational set-up must be much better understood.

[45] Existing measures that capture other technological aspects are measures of upstreamness as developed by The et al. (2015) and Alfaro et al. (2015) to measure the distance of industries to final demand or the distance between two industries along the values chain. Fan and Lang (2000) and Boehm et al. (2017) construct similarity measures that capture the proximity between two industries in input and/or output space.

Appendix

1.A Data Appendix

In this section we give more details on how we constructed our variables for the empirical analysis.

- Capital Intensity (EAE): The ratio of the physical capital stock to total employment, where the capital stock is measured as the total of tangible capital assets at end of year (EAE item I150) and total employment is the total number of full time equivalent employees (EAE item E101).

- Intangible Capital Intensity: Same as capital intensity, but uses only the total stock of intangible capital assets at end of year

- Skill Intensity (S/L): Is defined as average wage, i.e., the ratio between total wage expenses and the employment of the firms, as in Corcos et al. (2013).

- ln(TFP): is computed using the revised Levinsohn and Petrin (2003) methodology proposed by Wooldridge (2009). The coefficient of a Cobb-Douglas value-added production function are estimated at the 3 digit NACE industry level using intermediate inputs (EAE items R210 and R212) as the proxy for the productivity shock. Real value added is obtained by double-deflation using deflators for output, intermediates, and capital from the OECD STAN database. TFP at the firm level is then calculated as a residual between the actual and predicted value added using the estimated coefficient.

- Scale: either average number of employees over the year (EAE item E101) or total revenues in the end of the year as reported in the EIIG data set.

- Firm level contract intensity: the variable is constructed using the information about firms' imports. The firm-level contract intensity is an import value weighted average of the contract intensity of its inputs, where the measure of contract intensity is a dummy equal to one if an input is (liberally) classified as differentiated in Rauch

(1999). It is therefore similar to the measure used in in Nunn (2007) and Corcos et al. (2013), except that we weight by import value.

- Industry level contract intensity: same as firm level contract intensity, but weighting by total downstream industry (NAF) imports.

- Headquarters intensity measured by service intensity: ratio of workers employed in branches that produce services (Nace codes from 50 to 93) to total employment.

- Rule of Law: We use the Rule of Law index for 1998 provided in the World Governance Indicators, see Kaufmann et al. (2011).

- IPR Protection: We use the IPR protection index provided by Park (2008).

- Routine Task Intensity: We concord the indices (average routineness content of tasks) provided in Costinot et al. (2011) to our NAF industry classification.

- Relationship Specificity: We use the classification in Rauch (1999) and recode every HS 4 input to "relationship specific" if it is differentiated, while it is "not relationship specific" if it is traded on exchanges or reference priced. Therefore, our variable is a simple indicator at the product level.

- Upstream Relationship Specificity: This measure is similar to the indicator, but we weight by upstream exports for the whole of France, so that the measure is at the level of the upstream (ISIC Rev. 3) industry.

- Complexity: We concord the indices in the Harvard Complexity Atlas (Center for International Development at Harvard University (n.d.)) to our HS 4 inputs.

1.B Complementary Tables

Table 1.10: Baseline 2SLS, First Stage

VARIABLES	(1) inputshare	(2) inputshare	(3) inputshare	(4) inputshare	(5) inputshare
Official import 2dig	0.003***				
	(0.000)				
Micro 1999 excl. own firm		0.002***			
		(0.000)			
Micro 1996 excl. own firm			0.002***		
			(0.000)		
Micro 1996 excl. EIIG				0.002***	
				(0.000)	
Micro 1996 U.S. predicted					0.002***
					(0.000)
Country FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES
Observations	78,237	78,237	78,237	78,237	78,237
R-squared	0.541	0.546	0.547	0.544	0.544

The dependent variable is the firm by input level cost share in total expenditure on intermediates. The regressor is a categorical variable that indexes quintile bins of the direct requirements distribution of the respective IO table. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.11: Baseline 2SLS, Dropping Inputs Produced By Downstream Industry

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share	(5) intra-firm share
inputshare	8.195	6.140***	6.777***	7.350***	10.530*
	(5.829)	(1.833)	(2.068)	(2.233)	(5.819)
Country FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES
Instrument	Official import 2dig	Micro 1999 excl own firm	Micro 1996 excl own firm	Micro 1996 excl EIIG	Micro 1996 U.S. predicted
Observations	57,057	57,057	57,057	57,057	57,057
R-squared	0.603	0.608	0.607	0.605	0.595
F-stat 1st stage	34.12	221.9	178.3	119.1	34.14

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressor is the firm by input level cost share in total expenditure on intermediates. The instrument is a categorical variable that indexes quintile bins of the direct requirements distribution of the respective IO table. All HS products that are produced by the downstream firm's 4 digit ISIC industry are excluded from the estimation sample. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.12: Robustness 2SLS, Fixed Effects, First Stage

VARIABLES	(1) inputshare	(2) inputshare	(3) inputshare	(4) inputshare
Micro 1996 excl own firm	0.002***	0.002***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Country FE	YES			
Firm FE	YES	YES	YES	
HS4 product FE	YES			
Country*HS4 product FE		YES	YES	YES
Country*Ind 4dig FE		YES	YES	YES
Firm*Up Ind 4 dig				YES
Ind 4dig * HS4 product FE			YES	
Observations	71,999	71,999	71,999	67,002
R-squared	0.536	0.607	0.738	0.871

The dependent variable is the firm by input level cost share in total expenditure on intermediates. The regressor is a categorical variable that indexes quintile bins of the direct requirements distribution of our self constructed 1996 import IO table. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.13: Robustness 2SLS, Fixed Effects, Dropping Inputs Produced By Downstream Industry

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share
inputshare	9.815***	12.646***	9.694**	7.220**
	(2.445)	(2.598)	(4.062)	(2.978)
Country FE	YES			
Firm FE	YES	YES	YES	
HS4 product FE	YES			
Country*HS4 product FE		YES	YES	YES
Country*Ind 4dig FE		YES	YES	YES
Firm*Up Ind 4 dig				YES
Ind 4dig * HS4 product FE			YES	
Instrument	Micro 1996 excl own firm	Micro 1996 excl own firm	Micro 1996 excl own firm	Micro 1996 excl own firm
Observations	51,783	51,783	51,783	47,036
R-squared	0.610	0.698	0.775	0.847
F-stat 1st stage	160.9	166.5	39.42	69.34

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressor is the firm by input level cost share in total expenditure on intermediates. The instrument is a categorical variable that indexes quintile bins of the direct requirements distribution of our self constructed 1996 import IO table. All HS products that are produced by the downstream firm's 4 digit ISIC industry are excluded from the estimation sample. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.14: Robustness 2SLS, Fixed Effects, OLS

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share
inputshare	2.866***	2.917***	1.968***	1.503***
	(0.318)	(0.324)	(0.333)	(0.490)
Country FE	YES			
Firm FE	YES	YES	YES	
HS4 product FE	YES			
Country*HS4 product FE		YES	YES	YES
Country*Ind 4dig FE		YES	YES	YES
Firm*Up Ind 4 dig				YES
Ind 4dig * HS4 product FE			YES	
Observations	71,999	71,999	71,999	67,002
R-squared	0.591	0.688	0.753	0.828

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressor is the firm by input level cost share in total expenditure on intermediates. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.15: Headquarters Intensity, First Stages (1)

VARIABLES	(1) inputshare	(2) interaction	(3) inputshare	(4) interaction	(5) inputshare	(6) interaction	(7) inputshare	(8) interaction
Micro 4dig asym, 1996	0.002***	-0.000***	0.002***	-0.000***	0.002***	-0.000***	0.002***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
× 𝟙(Capital Intensity)	-0.000	0.002***						
	(0.000)	(0.000)						
× 𝟙(Intangible Cap. Int.)			-0.001***	0.002***				
			(0.000)	(0.000)				
× 𝟙(Skill Intensity)					-0.000**	0.002***		
					(0.000)	(0.000)		
× 𝟙(Service Intensity)							-0.000	0.002***
							(0.000)	(0.000)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	79,995	79,995	79,995	79,995	79,995	79,995	79,995	79,995
R-squared	0.536	0.530	0.536	0.543	0.536	0.539	0.536	0.521

The dependent variables are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median. The regressors are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.16: Headquarters Intensity, First Stages (2)

VARIABLES	(1) inputshare	(2) interaction 1	(3) interaction 2	(4) interaction 3	(5) interaction 4
Micro 4dig asym, 1996	0.003***	0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\times$ $\mathbb{1}$(Capital Intensity)	0.000	0.003***	-0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\times$ $\mathbb{1}$(Intangible Cap. Int.)	-0.001***	-0.001***	0.002***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\times$ $\mathbb{1}$(Skill Intensity)	-0.000	-0.000	-0.000	0.002***	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\times$ $\mathbb{1}$(Service Intensity)	-0.000	-0.000	-0.000	-0.000	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Country FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES
Observations	79,995	79,995	79,995	79,995	79,995
R-squared	0.537	0.531	0.544	0.539	0.522

The dependent variables are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median. The regressors are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.17: Headquarters Intensity, Main Effects

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share	(5) intra-firm share	(6) intra-firm share	(7) intra-firm share	(8) intra-firm share
inputshare	4.095***	6.289***	3.826***	6.173***	3.800***	3.875**	3.554***	5.121***
	(0.510)	(1.874)	(0.487)	(1.792)	(0.450)	(1.696)	(0.420)	(1.670)
$\mathbb{1}$(Capital Intensity)	0.040**	0.038						
	(0.019)	(0.024)						
× $\mathbb{1}$(Capital Intensity)	-0.499	0.089						
	(0.600)	(2.351)						
$\mathbb{1}$(Intangible Cap. Int.)			0.012	0.015				
			(0.020)	(0.025)				
× $\mathbb{1}$(Intangible Cap. Int.)			0.040	0.141				
			(0.591)	(2.492)				
$\mathbb{1}$(Skill Intensity)					0.110***	0.080***		
					(0.017)	(0.025)		
× $\mathbb{1}$(Skill Intensity)					0.260	4.709**		
					(0.535)	(2.314)		
$\mathbb{1}$(Service Intensity)							0.096***	0.084***
							(0.018)	(0.023)
× $\mathbb{1}$(Service Intensity)							0.697	2.658
							(0.455)	(1.984)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
ISIC 4dig Ind FE	YES	YES	YES	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	81,668	80,152	81,668	80,152	81,668	80,152	81,668	80,152
R-squared	0.173	0.168	0.171	0.167	0.186	0.176	0.183	0.177
KP-stat 1st stage		150.7		162.4		160.3		144.4

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the interaction of the firm by input level cost share in total expenditure on intermediates with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median, and the two main terms of the interaction. The instruments are the interaction of a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table with an indicator equal to one if the respective measure of headquarters intensity is above the within NAF industry median, and the two main terms of the interaction. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.18: Contracting Environment, First Stages

VARIABLES	(1) inputshare	(2) interaction 1	(3) inputshare	(4) interaction 2	(5) inputshare	(6) interaction 3	(7) inputshare	(8) interaction 4
Micro 4dig asym, 1996	0.003***	-0.001**	0.003***	-0.001**	0.002***	-0.000***	0.002***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
× 𝟙(Rule of Law)	-0.001***	0.003***						
	(0.000)	(0.000)						
× 𝟙(IPR Protect.)			-0.001***	0.003***				
			(0.000)	(0.000)				
× 𝟙(Contr. Int. Firm)					-0.001***	0.002***		
					(0.000)	(0.000)		
× 𝟙(Contr. Int. Ind)							-0.000	0.002***
							(0.000)	(0.000)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	82,950	82,950	82,950	82,950	82,950	82,950	82,950	82,950
R-squared	0.541	0.506	0.541	0.502	0.541	0.567	0.541	0.636

The dependent variables are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median. The regressors are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.19: Contracting Environment, First Stages

VARIABLES	(1) inputshare	(2) interaction 1	(3) inputshare	(4) interaction 2	(5) inputshare	(6) interaction 3	(7) inputshare	(8) interaction 4
Micro 4dig asym, 1996	0.003***	0.000	0.003***	-0.000	0.000	0.001*	0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
× $\mathbb{1}$(Rule of Law)			-0.000	0.003***	-0.000*	-0.000	-0.000*	0.000
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
× $\mathbb{1}$(IPR Protect.)			-0.001***	-0.001***	0.003***	-0.000***	-0.000	-0.000**
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
× $\mathbb{1}$(Contr. Int. Firm)			-0.001***	-0.001***	-0.001***	0.002***	0.000	-0.000***
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
× $\mathbb{1}$(Contr. Int. Ind)			-0.000	-0.000	-0.000	0.000*	0.002***	-0.000
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
× $\mathbb{1}$(Upstr. Routineness)	-0.000	0.002***	-0.000	-0.000	-0.000	-0.000	-0.000	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
HS4 product FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	82,950	82,950	82,950	82,950	82,950	82,950	82,950	82,950
R-squared	0.541	0.534	0.541	0.507	0.503	0.567	0.636	0.534

The dependent variables are the firm by input level cost share in total expenditure on intermediates and its interaction with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median. The regressors are a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table and its interaction with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.20: Contracting Environment, Main Effects

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share	(5) intra-firm share	(6) intra-firm share
inputshare	1.303**	5.530***	1.542***	4.226*	3.803***	6.708***
	(0.523)	(1.852)	(0.478)	(2.165)	(0.497)	(1.477)
$\mathbb{1}$(Rule of Law)	0.014	-0.002				
	(0.015)	(0.024)				
× $\mathbb{1}$(Rule of Law)	1.550***	3.879**				
	(0.476)	(1.884)				
$\mathbb{1}$(IPR Protect.)			0.019	-0.016		
			(0.015)	(0.031)		
× $\mathbb{1}$(IPR Protect.)			1.353***	5.403**		
			(0.445)	(2.190)		
$\mathbb{1}$(Contr. Int. Firm)					-0.041*	-0.038
					(0.023)	(0.024)
× $\mathbb{1}$(Contr. Int. Firm)					-0.076	0.043
					(0.697)	(2.103)
Firm FE	YES	YES	YES	YES		
HS4 product FE	YES	YES	YES	YES	YES	YES
Country FE					YES	YES
Ind 4dig					YES	YES
Ind 2dig						
Upstr Ind FE						
Observations	84,542	82,970	84,542	82,970	84,695	83,118
R-squared	0.571	0.546	0.571	0.545	0.206	0.198
KP-stat		138.5		138.9		104.7

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the interaction of the firm by input level cost share in total expenditure on intermediates with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median, and the two main terms of the interaction. The instruments are the interaction of a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median, and the two main terms of the interaction. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 1.21: Contracting Environment, Main Effects

VARIABLES	(1) intra-firm share	(2) intra-firm share	(3) intra-firm share	(4) intra-firm share
inputshare	3.861***	3.840*	2.622***	5.870***
	(0.567)	(2.191)	(0.366)	(1.430)
$\mathbb{1}$(Contr. Int. Industry)	-0.007	-0.051		
	(0.028)	(0.038)		
× $\mathbb{1}$(Contr. Int. Industry)	0.796	6.998**		
	(0.747)	(3.171)		
$\mathbb{1}$(Upstr. Routineness)			0.004	-0.016
			(0.008)	(0.011)
× $\mathbb{1}$(Upstr. Routineness)			0.382	3.574*
			(0.596)	(1.991)
Firm FE			YES	YES
HS4 product FE	YES	YES		
Country FE	YES	YES	YES	YES
Ind 4dig				
Ind 2dig	YES	YES		
Upstr Ind FE			YES	YES
Observations	84,697	83,119	84,567	82,986
R-squared	0.124	0.111	0.558	0.536
KP-stat		68.12		114.5

The dependent variable is the input by firm level share of intra-firm import value in total import value. The regressors are the interaction of the firm by input level cost share in total expenditure on intermediates with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median, and the two main terms of the interaction. The instruments are the interaction of a categorical variable that indexes quintile bins of the direct requirements distribution of our 1996 micro import IO table with an indicator equal to one if the respective measure of contracting institutions or contract intensity is above the country, within NAF industry, or across NAF industry median, and the two main terms of the interaction. Standard errors in parentheses are two-way clustered at the downstream NAF industry and at the upstream HS input level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Chapter 2

Trade Policy and Vertical Integration: Empirical Evidence on Intermediate Goods

2.1 Introduction

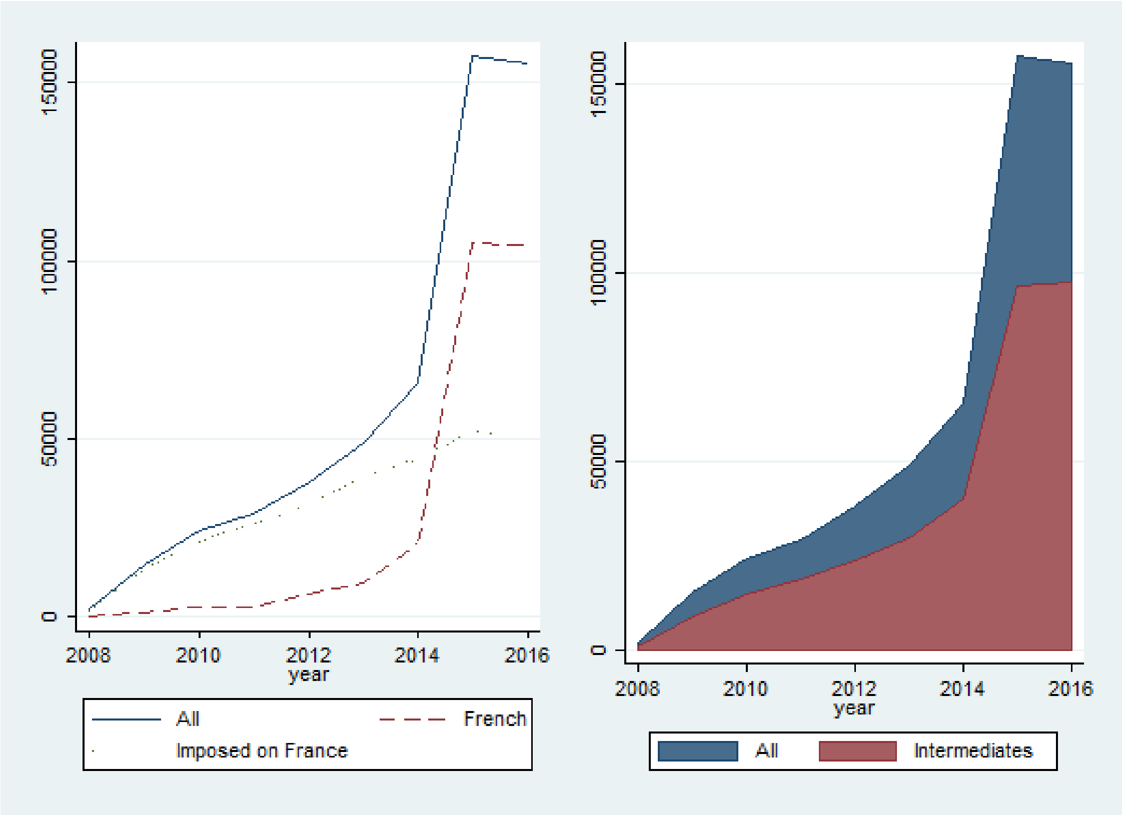
One of the main objectives for research on international trade today is to develop an understanding of the channels through which international trade policy affects welfare in a world of *complex supply relationships*. This important agenda can be motivated by at least two recent empirical observations.

First, while tariffs and other barriers to international trade reached historical lows a few years ago, protectionist sentiments[1] have experienced an unwelcome survival, especially after the Great Recession. Figure 2.1 illustrates this point using the example of France, a large and relatively open economy – as well as the country of interest in this study. The left hand side graph depicts the total number of restrictions (both tariff and non-tariff) imposed by France on imports of foreign goods and by other countries on French exports at the 6 digit HS product level for the period following the Great Recession until 2016. The data for figure 2.1 were collected by Global Trade Alert and cover virtually all newly implemented measures since the crisis.[2] In 2015, the average HS product code was subject to roughly 32 different new protectionist trade policy measures. Both the European Union,

[1] Referring to NAFTA, Donald Trump tweeted "The United States made some of the worst Trade Deals in world history.Why should we continue these deals with countries that do not help us?" (12:14 PM - Jul 5, 2017). At the time of writing, the United Kingdom is set to leave the biggest free trade market in the world. Parties interested (in their version of) free trade have been forced to issue warnings: "Trade protectionism is shortsighted and narrow-minded, and it cannot fundamentally address the problems of unemployment and economic growth worldwide", Mr Wan Jifei, president of the China Council for the Promotion of International Trade.

[2] The most frequent types of interventions are "Import Tariffs" (about 60%), followed by "Public procurement localisation" (11%), and "Tax based export incentive" (7%) as well as "Trade Finance" (3%).

Figure 2.1: Number of Active Restrictions (HS 6 digit Classification)



who conducts trade policy for its member states, and other countries participated in this surge in protectionism, emphasizing that this is a widespread phenomenon. Relating this back to the initial statement, the need for analyzing the effects of trade policy is alive and well.

The second, relatively recent observation is that production has become highly fragmented across countries. As a consequence, international trade in intermediate goods along increasingly global value chains accounts for as much as two thirds of total world trade (Johnson and Noguera (2012)) and has increased in importance over time. Unsurprisingly perhaps, the majority of protectionist measures is also targeted at intermediate inputs, as the right hand side panel of figure 2.1 makes clear – intermediates are the target of political trade restrictions in nearly two thirds of all protectionist events. In sum, any contemporary analysis of trade policy must respect the reality of complex supply relationships and the prevalence of intermediate goods transactions.

This chapter provides *empirical* evidence on one potential channel through which trade restrictions for intermediates bear on an economy's welfare: (re-)allocation of ownership over productive assets in vertical supply relationships.

Why do changes in vertical integration patterns, a dimension of organizational choice, constitute a natural candidate channel for gains or losses from trade? Intermediate inputs are often highly differentiated.[3] They are typically tailored towards a particular buyer that participates in a supply relationship, so that they have little value for other downstream firms. It is often difficult to write effective contracts that govern these transactions and specify adaptation or investments in an enforceable way. Together, these features create the danger of unilateral hold-up or coordination failure, and provide incentives for other inefficient behavior in terms of, for example, ex ante investments. Ownership allocation constitutes one way of mitigating such inefficiencies by addressing them directly by means of control (say, in employment contracts under vertical integration), through affecting outside options in order to re-instate incentives, or by other means. In other words, different organizational choices in terms of 'integration versus outsourcing' have consequences for productivity.

Mitigating inefficiencies created by incomplete contracts and lock-in is, however, not the only consideration that drives ownership allocation decisions within a supply relationship between an input producer and a downstream buyer. Outside options, i.e. alternative customers or suppliers, may be widely available or scarce, which affects the probability of finding an attractive partner in case an existing relationship breaks down.[4] Market structure therefore affords disciplining "threat points". Moreover, the size of the surplus generated by a relationship can improve coordination between the two parties[5] or simply render organizational choices infeasible in the presence of fixed costs.[6] Since, at least potentially, tariffs, quotas, red tape, and other barriers to trade impact on these considerations, they are capable of driving re-organization and thus affect efficiency and welfare.

These conceptual insights are of course not new. Most prominently, Ornelas and Turner (2011)[7] argue that tariffs can change a downstream firm's outside option in an existing domestic supply relationship by making foreign suppliers more or less attractive. Furthermore, in relationships that involve firms from different countries, trade barriers affect marginal returns on investments made by the partners and therefore influence incentives to make specific investments into a relationship in the first place. The authors show how these insights weigh on the potential welfare effects from protectionist policies. In another study of vertical firm boundaries in a global economy, Antras and Helpman (2004) show that, in the presence of fixed organizational and offshoring costs, tariffs can

[3] Antras and Staiger (2012) report that about a quarter of world trade in goods with "parts" or "components" in their classification title (a highly conservative measure of intermediate status) was differentiated in 2000 according to the Rauch (1999) classification. Nunn (2007) estimates that all final goods industries in the US make use of differentiated inputs, while a substantial fraction uses differentiated inputs predominantly. This pattern has been found for firms in other countries as well.

[4] E.g. McLaren (2000) or Grossman and Helpman (2002).

[5] E.g. Hart and Holmstrom (2010).

[6] E.g. Antras and Helpman (2004).

[7] See also their earlier work, Ornelas and Turner (2008).

wield power through selection of firms with heterogeneous core productivities. In the face of rising trade barriers, companies with foreign suppliers may find them less attractive and resort to producing themselves domestically.[8] Unfortunately, to date there is – to the best of my knowledge – no *empirical* evidence regarding the role of tariffs on intermediate goods for ownership allocation in vertical supply relationships that could shed light on the importance and validity of these mechanisms.

To start filling this gap, I study French manufacturing firms over the period 1996 - 2006. By means of confidential data I am able to observe in which four digit industry a firm or its affiliates are active and sell to a relevant market. Following the methodology in Fan and Lang (2000) I code the supply relationship between a firm's primary industry and its secondary industries (or the main industries of its affiliates) as "vertically integrated"; at least in principle these firms are able to produce the inputs they need from their secondary industries themselves. To obtain information on outsourcing I make use of the 2002 benchmark IO tables for the US and assume that if a firm or its affiliates are not active in one of the 50 most important upstream industries ranked by the US direct requirement, the firm outsources production of those inputs.[9] This coding scheme leaves me with 624,000 bilateral supply relationships that are either integrated or outsourced. Importantly, only about 6 out of a thousand relationships are integrated.

To understand the relationship between these choices and trade policy I collect information on effectively applied import tariffs imposed by France and other countries, which I aggregate from the product to the industry level by means of appropriate French trade flows in 1996 as weights. In the case of France, tariffs are unlikely to be the outcome of vertical integration decisions and are hence much less subject to endogeneity concerns than they would be, for example, in the U.S.. The reason is that they are either set in multinational negotiations within the EU or by trading partners who use the EU as their counterparty in negotiations. Moreover, France, Germany, the United Kingdom, Italy, and Spain are all large, highly developed members of the EU and produce in very similar industries, so that it is unlikely that individual French firms will be able to influence trade policy.

My empirical strategy relies on co-variation between vertical integration patterns and industry level tariffs *over time*,[10] which mostly comes from various bigger and smaller

[8]These important conceptual contributions will be discussed at length below.

[9]Focussing on the 50 most important upstream industries reduces the dimensionality of the problem and excludes supply relationships that are unlikely to be integrated for the purpose of procurement, namely those with very small contribution to output.

[10]The fact that my estimates are identified by time variation further alleviates reverse causality concerns regarding tariffs since substantial changes in trade policy measures over time are typically part of wider liberalization efforts, see footnote 11.

trade liberalization episodes like accessions to the EU.[11, 12]

Based on these data and using linear regression models with fixed effects I produce a set of stylized facts about how changes in import and export tariffs (import tariffs of other countries vis-a-vis France) on intermediate goods affect vertical integration. The goal of this chapter is twofold. First, it is intended to provide empirical evidence to assess which of the predictions made in previous conceptual work hold up against the experience of one important and large economy. I discuss this literature in great detail in the next section. Secondly, the chapter is intended to show new margins of organizational behavior of firms that may motivate both further conceptual and empirical work. Importantly, this chapter addresses neither the issue of which organizational form is the most efficient in different contexts, nor how the welfare effects of protectionism change due to endogenous re-organization.[13]

The first empirical fact I establish pertains to overall changes in the patterns of vertical integration and is a negative result.

Fact 1 *Trade policy in the intermediates market has had no economically relevant effect on vertical integration in the aggregate.*

None of my baseline estimates, where I relate the probability of integration for a given supply relationship to import and export tariffs on the intermediate input produced upstream, suggests that industrial restructuring and trade policy in terms of import or export tariffs were linked *in the aggregate*. This is a quantitative statement: if we look at the economy before and after changes in tariffs, the overall patterns of vertical integration remained very similar. Relying exclusively on time variation in tariffs alleviates concerns that the estimates reflect other time invariant industry features correlated with tariffs. Even though this methodology is very demanding on the data. Notwithstanding, it produces very tight confidence bands around the point estimates that do not allow for any uncertainty regarding the first empirical fact.

This does, of course, *not* imply, however, that tariffs have had no impact on organizational choice and the second empirical fact reflects this important point.

[11]Accession candidates to the EU enacted agreements with the EU ten years before their anticipated accession dates, which stipulated a gradual phasing out of tariffs, so that a lot of variation in tariffs vis-a-vis the EU is generated years before the actual accession events.

[12]The fact that a lot of variation comes from these accession events implies that the *changes* in tariffs in my data are pre-determined by the *levels* of tariffs present ex ante. This observation is another argument against reverse causality between firm level decisions and tariffs.

[13]There is considerable disagreement/ambiguity in the literature concerning the efficiency properties of vertical integration and outsourcing. Grossman and Hart (1986) type models of firm boundaries predict that vertical integration is efficient if and only if the headquarters' contribution to output is more important than the supplier's. Transaction cost theories typically imply that vertical integration is always more efficient at the margin (for empirical evidence see Forbes and Lederman (2009) or Hortaçsu and Syverson (2007)). On the other hand, historical evidence suggests that, by revealed preference, outsourcing can be more efficient, typically driven by economies of scale (Stigler (1951)).

Fact 2 *Both higher import and export tariffs have had a) no economically relevant impact on outsourced relationships and b) increased the probability that integrated relationships remained integrated.*

To produce fact 2, I condition the effects of tariffs on firms' organizational states in 1996 and find strong heterogeneity as described. I find that import and export tariffs have *the same* qualitative effect on vertical integration, contrary perhaps to what may be expected. The most important implication of fact 2 is that a theory which produces predictions that are independent of the initial organizational state will remain incomplete in explaining integration patterns.[14]

To shed first empirical light on the potential mechanisms through which tariffs on intermediates affect integration decisions, I explore two sets of candidates, aspects of market structure and firm level adjustments. These choices are motivated by a number of conceptual contributions that explore the role played by the availability of alternative trading partners outside a given supply relationship for integration decisions.[15] To operationalize this task, I first interact import and export tariffs with 1996 – i.e. time invariant – measures of the number of firms active in an industry and of sales concentration. I do the same for the ratios of these variables in the seller and buyer industries.

Fact 3 *A favourable market for the buyer side of a relationship amplifies the effect of import tariffs, while the effect of export tariffs is independent of market structure.*

Finally, I include time variant variables directly in the regression and study how the coefficient estimates for import and export tariffs change. If the latter affect the probability of integration in a supply relationship through any of these time varying regressors, this correlation will not be reflected in the coefficients on tariffs any more. The types of variables I include are the aforementioned market structure measures and firm level information, most importantly firm size and productivity.

Fact 4 *The empirical evidence is consistent with firm level adjustments accounting for the effects of import and export tariffs, while changes in market structure do not seem to have played a role.*

[14]As a further contribution, I show that tariffs had heterogeneous effects depending on *where* an integrated production facility was located, i.e. whether it was in France or outside of the EU. It should be noted that they are consistent with the literature that highlights the interaction between locational and organizational choice, see for example Antras and Helpman (2004), Ramondo and Rodriguez-Clare (2013), or Arkolakis et al. (2017).

[15]I discuss the contributions of McLaren (2000) and Conconi et al. (2012) in great detail in section 2.2. Grossman and Helpman (2002) is closely related to McLaren (2000), but not intended to be used for the kinds of exercises relevant for this chapter.

These final results should be viewed as interesting correlations, since I do not attempt to identify the channels independently beyond excluding certain sorting patterns via fixed effects. In particular, one may still be worried about reverse causality in the case of firm level variables. This notwithstanding, given that data sets with a coverage and quality required to perform such exercises are rare and often difficult to obtain, I believe there is considerable merit in reporting interesting correlations to spur future work.

To summarize the last two facts, I find that, while market structure adjustments may be relevant for the transmission of intermediates trade policy to organizational choice, firm specific adjustments appear to explain a great deal more and are in this sense more promising candidates for future work. This highlights a new avenue for research since previous conceptual work has either studied changes in market tightness as a mechanism or *conditioned* on firm characteristics, as opposed to endogenizing them.[16]

The main contribution of this paper – providing empirical evidence on the role of tariffs on intermediates for vertical integration decisions – is entirely novel to my best knowledge (I discuss the relationship with Breinlich (2008) in the next paragraph). There exist, however, two bodies of directly related work, the first of which explores the relationship of interest in this chapter conceptually rather than with data and the second of which focuses on tariffs on final goods. The first strand is of course immediately significant for this chapter, and I consider my research as a contribution to our understanding of how supply networks are organized, so that the chapter stands next to the second strand of literature.

Before I comment on these in turn, it is important to highlight the contribution of Breinlich (2008) who uses the CUSFTA agreement between Canada and the US in 1989 as a trade policy shock and shows that larger reductions in tariffs led to more M&A activity, which implied the reallocation of resources from less to more productive firms. However, the focus in Breinlich (2008) is not vertical integration, but ownership reallocation generally, and he distinguishes neither between intermediate and final goods producing industries nor between import and export tariffs.[17]

As mentioned earlier in this introduction, both Ornelas and Turner (2011) and Antras and Helpman (2004) build theoretical models with incomplete contracts and examine, directly or by extension, the impact of tariff on intermediates. Since these are key inputs for giving structural meaning to my empirical results, I discuss them in great detail in

[16]The former is exemplified by McLaren (2000) and the latter by Antras and Helpman (2004).

[17]Feenstra and Hanson (2005) study ownership allocation and regulatory regimes for export processing in the case of China. In contrast to my chapter, their work holds the trade policy environment fixed.

section 2.2 below.[18]

A coherent strand of both conceptual and empirical research on the role of *final* goods tariffs for organization is Alfaro et al. (2010), Conconi et al. (2012), Legros and Newman (2013), and Alfaro et al. (2016). Their common denominator is the underlying idea of the boundary of the firm as determined by efficiency considerations. They are broadly based on a Hart and Holmstrom (2010) multi-tasking framework in which vertical integration facilitates coordination when there are managerial incentives to follow contradicting private incentives.[19] If final goods prices increase due to, say, higher tariffs, there are stronger incentives for coordinated, more efficient decision making and hence (vertical) integration.[20] The theoretical predictions are tested with international ownership data in Alfaro et al. (2010) and Alfaro et al. (2016). A different approach is presented by Diez (2014), who uses U.S. data on intra-firm trade to examine how tariffs on final goods impact on make-or-buy decisions. He also modifies the selection framework set up in Antras and Helpman (2004) to give structural meaning to his estimates.

On a higher level, my work is related to the broader area of optimal trade policy in the face of various organizational phenomena. Antras and Staiger (2012), for example, study the implications of off-shoring and associated contractual difficulties for optimal trade policy.[21] In the same vein, Blanchard (2010) and Blanchard and Matschke (2014), focus on the role of financial dependencies – including FDI – across countries, while Blanchard et al. (2017) develop a conceptual framework and provide supportive empirical evidence to show that production fragmentation across countries affects incentives to set tariffs along global value chains.

It should not go un-noted that my research contributes to the substantial literature in organizational economics that uncovers the determinants of vertical integration patterns. Excellent surveys include Perry (1989), Gibbons (2005), Helpman (2006), Lafontaine and Slade (2007), Hubbard (2008), Hubbard (2010), Bresnahan and Levin (2012), and Antras and Rossi-Hansberg (2009).

This paper proceeds as follows. In section 2.2 I review the current literature with an emphasis on theoretical predictions regarding the effects of intermediate goods tariffs. I

[18]McLaren (2000) and Conconi et al. (2012) do not explicitly analyze the effects of trade policy in the upstream market (they focus on full factor mobility and shocks to market structure.), I discuss these contributions in section 2.2, too, where I deal with the role of market structure.

[19]Alfaro et al. (2016) present a more reduced form version, which broadly nests the model described. It highlights that the key underlying mechanism in efficiency theories of the boundary of the firm is an underlying complementarity: "the efficiency gains generated by integration are more valuable when the price of output is higher, so integration incentives are greater at higher prices."

[20]Conconi et al. (2012) show that this rationale in fact depends on the conditions of the upstream market, which I will discuss in detail below.

[21]Ornelas and Turner (2008) and Ornelas and Turner (2011) also examine welfare implications of trade policy under contract incompleteness.

then go on and outline the empirical strategy in section 2.3, introduce the data set I use for my estimations in section 2.4, and finally discuss the results and their relationship to the current literature in section 2.5. Section 2.6 concludes.

2.2 Literature and Predictions

In this section I summarize the current state of the literature about trade policy for intermediate inputs and (vertical) integration, i.e. organizational choice as it relates to firm boundaries.

2.2.1 Tariffs on Intermediates and Vertical Integration

Antras and Helpman (2004) construct a North-South model of joint organizational and locational choice to study the role of several firm and industry characteristics. Headquarters firms with heterogeneous productivity in the North provide services and suppliers in either the North or the South manufacture intermediate inputs. Investments into either contribution to final output are non-contractible and hence their costs are sunk when firms bargain over the bilateral surplus of the relationship *ex post*. There are two organizational forms, outsourcing (in which case productive assets remain with either party) and backward vertical integration (in which case the downstream firm owns them). Bargaining power is higher if a party can use their assets in an alternative way outside of the relationship and via appropriating a larger share of total surplus, this party obtains a higher return on investment – which in turn spurs investment *ex ante*. If headquarters services are more important for total surplus, ownership should be allocated to the headquarters in order to achieve optimal efficiency in a second best sense. Vertical integration, however, carries higher fixed costs. The headquarters can deal with suppliers in the North or South; in the latter case fixed costs are higher, but variable costs are lower due to a wage differential with the North. Import tariffs on intermediate goods imposed by the North play a fully analogous role to wages. The equilibrium in this model exhibits sorting of firms across different sourcing modes in the following order by increasing productivity of the firm or relationship: first domestic outsourcing, then domestic vertical integration; even more productive firms outsource in the South and the most productive ones engage in vertical FDI.

The initial state of organization determined by productivity shapes how a firm responds to changes in tariffs. Assume that headquarters intensity is high enough so that vertical integration is attractive in the first place. When the North imposes an import tariff on an intermediate, initially domestically outsourced relationships do not respond, since they could never afford the high fixed cost of integration and within country trade becomes no less expensive. Initially vertically integrated relationships in the North should become more stable, since foreign outsourcing has become less attractive due to the tariff. Initially offshore-outsourced relationships should become less likely and FDI more so. This last prediction stems from the fact that the increase in tariffs disproportionally hurts outsourced relationships, which are less productive due to high headquarters intensity. This model, while delivering a rich set of predictions for import tariff changes, is silent on the effect of export tariffs on intermediates, since there is no input trade from North to South.

To my knowledge there is no empirical evidence that tests any of these predictions. Diez (2014) manipulates the model of Antras and Helpman (2004) in order to study the impact of tariffs on final goods with intra-firm trade data. Nunn and Trefler (2013), while providing an empirical effort at verifying implications from Antras and Helpman (2004), focus on non-contractibility and productivity dispersion, but do not deal with tariffs.

Ornelas and Turner (2011) study import tariffs in a model of intermediate goods trade and firm boundaries. In particular, they assume that a downstream producer of a final good uses two types of an input, a customized one and a generic one that needs to be imported and is always subject to an import tariff. The customized one can either be imported from a dedicated foreign supplier or sourced from a dedicated domestic supplier, all of which have heterogeneous productivities. The latter make non-contractible cost reducing investments, as does the downstream firm. If a bilateral pair decides to remain at arm's length, they make investment choices independently, while if they vertically integrate at a constant fixed cost, decision rights are centralized and there is no hold-up – clearly, the trade-off between organizational choices is governed by a fixed cost, variable cost trade-off. The relative attractiveness of different organizational choices is affected by tariffs due to the fact that the share of generic, imported inputs is endogenous and hence cost reducing investments for customized inputs are differentially useful under various trade policy stances. When the import tariff increases under protectionism, offshoring of customized inputs becomes generally less attractive, while foreign integration is more attractive relative to foreign outsourcing: if foreign sourcing is still chosen under protectionism, it must be that the remaining active suppliers are highly productive. Since vertical integration eliminates the hold-up problem, it is complementary to the supplier's idiosynchratic efficiency and is therefore more likely to be chosen. Moreover, since the share of generic inputs falls with higher tariffs and a higher quantity of customized inputs is needed, cost reducing investments become more important/ have a higher return. Again, since vertical integration offers an advantage in terms of enforcement of *ex ante* investment decisions, domestic outsourcing becomes less attractive relative to domestic vertical integration.

2.2.2 Market Structure

McLaren (2000) constructs a model in which upstream suppliers and downstream firms exchange an input in an incomplete contracting environment. The latter causes a hold-up problem in the sense that the supplier's relationship specific investment is sunk *ex post* and the downstream firm is able to appropriate a large share of the quasi-rents generated by the relationship. How severe the hold-up is depends on the supplier's ability to find an alternative customer and the probability of successful search is higher if there are other downstream firms in the market that look for inputs. Alternatively, the two firms can vertically integrate, which comes at a fixed cost. Whether firms outsource or vertically integrate is therefore a matter of market thickness: if a sufficient number of pairs are not vertically integrated, the hold-up problem under outsourcing is small and a pervasive arm's-length equilibrium can exist. If, on the other hand, too many firms are vertically integrated and too few stand-alone suppliers or customers exist, a pervasive integration equilibrium ensues. Opening up to trade can thicken the market in the sense that more buyers and suppliers are available and hence the unsegmented economy may shift to an outsourcing equilibrium.

While this idea is important, it gives no consideration to the fact that tariffs are directional and it instead focuses on "openness", i.e. bi- or multi-lateral liberalization of intermediate input markets. The paper's prediction that trade liberalizations lead to disintegration is not unconditionally true in that lower import tariffs increase the number of upstream suppliers, which, however, is of no use to the existing (domestic) suppliers with respect to the hold-up problem – on the contrary. In sum, this contribution is silent on the separate effects of import and export tariffs, but highlights the important fact that the prevailing market structure in terms of market thickness *before* a change in trade policy may be an important determinant of the qualitative impact of tariffs.

Two pieces of work study the prediction from McLaren (2000) empirically. Hyun and Hur (2014) use survey data on a sample of 800 Korean firms and their organizational outcomes. They present correlations that link trade openness at the 2 digit industry level to an increase in outsourcing. Chongvilaivan and Hur (2012) use the share of inter-plant, within firm transactions in total sales for US manufacturing firms in disaggregated industries as a proxy for integration and relate them to openness measures, finding evidence consistent with the prediction in McLaren (2000). Neither attempt to understand if these relationships are causal, neither distinguish between final and intermediates goods, and, perhaps most importantly, neither focus on trade policy.

Conconi et al. (2012) also study the effect of market structure (relative number of buyers and sellers) in the intermediates market as an additional determinant of integration. Suppose that import tariffs reduce the effective number of upstream suppliers relative to the number of downstream firms. The resulting increase in the suppliers' share in the bilateral surplus induces them to coordinate better with the downstream firms under outsourcing. Under vertical integration, decision making is centralized and unaffected by changes in surplus shares obtained by individual managers. Whether ensuing re-organization favors outsourcing or integration depends on the *initial* market structure. If there were few suppliers to begin with and hence upstream firm managers already obtained a large share of bilateral surplus, the tiny additional incentives for suppliers to coordinate are weak, while downstream firm managers are increasingly strongly incentivized to focus on their private objectives (this is a result of the concavity of the joint production function). Consequently, overall worse coordination makes outsourcing unproductive relative to vertical integration and the latter becomes more prevalent. If suppliers are the long side of the market, the prediction is reversed. Moreover, the model implies that import and export tariffs should have opposite effects, since the former reduces the relative number of upstream suppliers, while export tariffs increase it by lowering the effective number of downstream firms.[22]

2.2.3 Summary

To summarize the findings and discussions to date, the current theoretical literature makes no unambiguous predictions, although most of them imply that trade liberalizations are most likely to lead to more outsourcing. At the same time, there is typically either no distinction between import and export tariffs being made or the latter are not discussed at all. It is therefore for all intents and purposes unclear whether and how import tariffs on intermediates *imposed by other countries* affect organizational choice. Some contributions highlight the fact that the initial state of integration or outsourcing may be significant for the impact of trade policy, an empirical test of which is conducted in this chapter. Finally, with very few exceptions, the literature focuses on market thickness or tightness (or, more generally aspects of market structure) as the key channel through which trade policy impacts on firms.

[22] A similar point related to the impact of market tightness on vertical integration patterns is made by Grossman and Helpman (2002). Their model is not designed to analyze exogeneous changes in trade costs and hence I refrain from discussing this paper in detail.

2.3 Empirical Strategy

To show Fact 1 I use a simple linear model. The dependent variable is a binary variable called $integ_{ijpt}$, which indicates if firm i, whose main business is in industry j, has a production facility in industry p (that provides inputs for j) in year t. This plant can either be part of the legal entity i or of a financially affiliated firm in the same business group.[23] I relate this variable to a measure of import tariffs τ_{jt}^{IM} and to a measure of export tariffs τ_{pt}^{EX}, both levied on the output of industry p that is used as an intermediate in buyer industry j.

$$integ_{ijpt} = \beta_1 \ \tau_{pt}^{EX} + \beta_2 \ \tau_{jt}^{IM} + \boldsymbol{\delta}' \ \mathbf{X}_{jpt} + \gamma_{ip} + \gamma_t + \varepsilon_{ijpt}. \tag{2.1}$$

Organizational decisions are typically sluggish and often take considerable time to be implemented. Moreover, changes in trade policy measures are occasionally accompanied by considerable uncertainty regarding how long they will remain in place in their current form. In these circumstances CEOs may be slow to implement deep adjustments like restructuring firm boundaries. Therefore, all specifications in this paper are of the long difference type. To implement them, I use data sets with only two years (generally 1996 and 2006), focus on buyer firms i that never switch industry j, and include firm by seller industry fixed effects. If the periods are long enough and the error terms are only weakly correlated over time, this regression is more efficient than first differencing. In sum, I use time variation in tariffs and organizational choice to uncover their relationship.[24]

$\mathbf{X}_{jpt}$ in my regressions for fact 1 includes both time varying import tariffs on the inputs used by the seller industry and the export tariffs on the output of the buyer industry in order to address potential omitted variable bias.

While there are many different instruments of trade policy as seen, for example, in the introduction, very few have been recorded for a wide range of countries and for many years. Therefore, my choice of capturing trade policy by means of tariffs is borne out of necessity rather than being a statement that other instruments are not important. Most importantly perhaps, I would be happy to include measures of red tape trade barriers, which have become highly prevalent especially for WTO countries. Like many other measures, however, records of these do not go back in time as far as 1996. To the extent that tariffs capture broad trade policy stances and are positively correlated with other measures, my proxies lead to an overestimate. Since very often, however, non-tariff barriers

[23] My data are at the firm level, unlike the data used in, for example, Alfaro et al. (2015) and Alfaro et al. (2016).

[24] The advantage of using data from one country, like France, is that panel data is both consistent over time and was recorded during periods of active trade policy by means of tariff measures.

are used as substitutes for tariffs, it is likely that my findings are conservative with respect to the impact of the latter.

Import tariffs as they apply to French firms' international trade are set by the European Union and are therefore the outcome of an, often lengthy, multinational bargaining game. It seems very unlikely that a single French firm will be able to influence import tariffs on its intermediate inputs by its integration decisions. Export tariffs, i.e. import tariffs imposed by other countries, are even less likely to be subject to concerns of reverse causality, as other countries levy taxes on goods from the European Union as a whole and not against those from a single member state like France. I allow the error terms to be correlated across supply relationships governed by all firms in the same buyer industry in a given year, as well as across supply relationships that include the same seller industry in a given year. Consequently, I cluster standard errors by buyer industry by year as well as seller industry by year. These clusters correspond to the variation in my right hand side tariffs and all results are robust to allowing for correlation within industry but across time periods.

Finally, note that export tariffs vary by seller industry p and import tariffs by buyer industry j. The reason for this asymmetry is that tariffs are specified at a very detailed level so that aggregation becomes necessary. As is perhaps most intuitive, I weight export tariffs by seller industry export value to those countries that impose a particular duty. Consequently, export tariffs vary by seller industry. Similarly, import tariffs are weighted by buyer industry import values of the taxed input and therefore vary by buyer industry. I will give more details on the exact weighting schemes in the Data section 2.4 below. Crucially, all tariffs used in regressions are in logs.[25]

Fact 2 is a statement about the differential experiences of initially outsourced and initially integrated supply relationships. I show this fact in a lagged dependent variable (LDV) model by interacting the tariff measures τ_{pt}^{EX} and τ_{jt}^{IM} with the initial value $integ_{ijpt_0}$ (generally $t_0 = 1996$).

$$\begin{aligned} integ_{ijpt} = \beta_1\ \tau_{pt}^{EX} + \beta_2\ \tau_{pt}^{EX} \times integ_{ijpt_0} + \beta_3\ \tau_{jt}^{IM} + \\ \beta_4\ \tau_{jt}^{IM} \times integ_{ijpt_0} + \boldsymbol{\delta}'\ \mathbf{X}_{ijpt} + \gamma_{ip} + \gamma_t + \varepsilon_{ijpt}. \end{aligned} \tag{2.2}$$

Three aspects of this specification are noteworthy. First, since I restrict to a sample where buyer firms never switch industry, the set of fixed effects γ_{ip} absorb the main effect of the interactions $integ_{ijpt_0}$. Consequently, the full transition matrix for the states

[25] Zero tariffs are almost no concern at the aggregate industry level.

outsourcing and integration cannot be identified with this approach.

Secondly, in this LDV specification one may be concerned about a) the correlation between contemporaneous[26] and future tariffs as well as b) auto-correlation in the error terms as sources of bias. I address these concerns in three ways. First, the fact that I estimate the coefficients in a very long difference of 11 years suggests that auto-correlation is weak. Secondly, this model uses *interacted* LDVs rather than main effects, so that weak correlations with tariffs are of second order importance. Finally, I estimate regressions with the LDV as dependent variable and contemporaneous and future tariffs as well as appropriate fixed effects as regressors. I then go on and correlate the residuals from this regression with the residuals obtained from regression 2.2. If all relevant correlations are close to zero, this this evidence in favour of 2.2 not being affected by the typical issues in LDV models.

Thirdly, in this specification I include a rich set of controls $\mathbf{X}_{ijpt}$, which, in order to make this exposition clearer, I specify in more detail when I discuss the results.

I will show empirical evidence for fact 3 using a similar framework with interacted and pre-determined variables. In particular, I use a measure of market structure for both the seller and the buyer industry and interact them with the tariff variables:

$$\begin{aligned} integ_{ijpt} &= \beta_1\ \tau^{EX}_{pt} + \beta_2\ \tau^{EX}_{pt} \times marketstr_{jt_0} + \beta_3\ \tau^{EX}_{pt} \times marketstr_{pt_0} + \\ &\beta_4\ \tau^{IM}_{jt} + \beta_5\ \tau^{IM}_{jt} \times marketstr_{jt_0} + \beta_6\ \tau^{IM}_{jt} \times marketstr_{jt_0} + \boldsymbol{\delta}\ \mathbf{X}_{ijpt} + \gamma_{ip} + \gamma_t + \varepsilon_{ijpt}. \end{aligned} \tag{2.3}$$

Finally, to provide suggestive evidence on the possible mechanisms through which tariffs affect organizational choice, I re-estimate specification (2.2) and include *time-varying* measures of market structure and firm characteristics like size and performance. This strategy exploits the "bad control problem" in the sense that the model features variables that could just as well be on the left hand side, i.e. interesting outcomes of variation in trade policy. To the extent that these variables are intermediaries for organizational change, I use them to gauge the mechanisms through which tariffs affect vertical integration. It must be clear, however, that this is at best weak evidence, since all estimates are subject to omitted variable bias and, in the case of firm level characteristics, reverse causality. Nevertheless, since prior conceptual work on the present topic has not suggested any other confounders or explanations, it is useful to study these conditional correlations.

[26]Indeed, if tariffs are permanently important determinants of integration decisions – which is what this and other research work argues – one would in fact *expect* a cross sectional correlation between vertical integration and tariffs if these variables exhibit some persistence.

2.4 Data

2.4.1 Data Sources and Variables

I make use of two data sets to measure vertical integration decisions. First, the Enquête annuelle d'Entreprise (EAE), which provides balance sheet data on all French firms with more than 20 employees and a random sample of smaller firms. Crucially, it records several variables by primary and secondary activity, which makes it possible to observe in which 4 digit ISIC Rev. 3 industries a firm operates. To be precise, the survey allows me to observe all industries in which a firm sells to the market – if a firm creates inputs for itself without selling them outside the firm (say, cafeteria services), I will not be able to see these integrated activities. It is an open question to what extent this shortcoming affects my (and other researchers') empirical results, but it seems likely that full scale self-sufficient provision especially of important inputs merits substantial production facilities that make at least some selling to the market a sensible strategy.[27] In line with the practice in previous research (e.g. Acemoglu et al. (2010)), I take the primary activity of a firm as its buyer industry and the secondary industries as the seller industries in which it can potentially produce inputs for the downstream activity – in other words, the firm may source inputs from its secondary industries in-house. This information is the basis for my measure of "full" integration.

My second data source is the Enquête sur les liaisons financières entre sociétés (LiFi), which records all financial connections between firms in France and between a French firm and its foreign affiliates. To be precise, LiFi only records information on foreign affiliates that are directly linked to any French firm, so that affiliates of foreign headquarters are only recorded if they are either in France or directly related to a French firm. There are several additional firm level thresholds that limit the scope of the survey to relatively large firms, for which, however, LiFi is exhaustive.[28] This survey crucially provides information about the ISIC Rev. 3 industry of the affiliate of a LiFi firm, which allows me to identify vertical integration at the business group level both within French and multinational groups. To assign affiliates to firms, I identify every EAE firm's headquarters (at least 50% "control share" – voting rights – in the respective firm) and through them I relate affiliates to firms. Thus I obtain information about which inputs a downstream firm can potentially source from within the boundary of the (multinational) firm or group, which is a looser measure of integration.

[27] Below I will restrict the sample to the 50 most important input-output relationships measured by direct requirements in the IO table. This should further alleviate the concern of mis-classification error.

[28] All details can be found at `https://www.insee.fr/fr/metadonnees/source/s1249`. Accessed on 27/09/2017.

Joining information about both vertical integration within the same firm as a legal entity as well as through financial linkages across entities, I am able to portray a richer picture of integration decisions than previous research and examine organizational heterogeneity.

I complement this data with input-output information from the US benchmark input-output (IO) table from 2002 published by the BEA – and concorded to the ISIC Rev. 3 classification – to measure outsourced relationships between a downstream firm and its upstream suppliers. First, I restrict the IO table to the 50[29] most important seller industries for any given buyer industry, measured by the direct requirement. For every firm I code its relationship with a seller industry as "integrated" if it has either a fully integrated establishment (from the EAE data) or a financially linked firm (from the LiFi data) in that seller industry, and as "outsourced" if not. In one of the exercises below I will also differentiate between the different modes of vertical integration, i.e. if it is "full", "within France" etc.

French IO tables are relatively aggregate (2 digit industry level) and in order to answer my empirical questions I require information with high resolution – otherwise there is little hope to find any variation in my main outcome, integration. After concording the US IO table to ISIC Rev. 3 I am left with IO information at the 4 digit industry level, corresponding to 288 different industries. The main drawback of using US tables is that technology probably differs across countries and I introduce errors in variables into the analysis. To the extent, however, that IO tables capture broad relationships between upstream and downstream industries, these errors should be of second order importance (see Acemoglu et al. (2009)).

To give an example for the coding scheme of the integration variable, consider a car manufacturer that, according to the IO tables, requires two inputs for a car, a chassis and tires, among other things. It therefore reports primary industry code 3410, "Manufacture of motor vehicles", and requires inputs from codes 3420, "Manufacture of bodies (coachwork) for motor vehicles", and 2511, "Manufacture of rubber tires and tubes". If it reports the single secondary activity 3420 (or an affiliate that mainly operates in 3420), I assume that it sources chassis in-house – produces them by itself – and outsources production of tires.

Information on effectively applied *ad valorem* tariffs for all WTO member countries comes from UN TRAINS.[30] As explained above, to concord the HS classified tariffs to ISIC Rev. 3 I use the universe of customs data from France as weights. In particular, I

[29] All results are robust to using either 10 or 25 upstream industries.

[30] Effectively applied tariffs are equal to MFN tariffs unless there is a preferential trade agreement between the EU and a partner country, in which case the preferential rates are applied.

use French import shares of HS products as weights for import tariffs and collapse them to the 4 digit ISIC Rev. 3 industry level. For export tariffs the procedure is similar except that French export shares are used as weights.

I make use of time invariant weights for both imports and exports, namely the 1996 trade values, which are fully pre-determined.[31] Finally, TRAINS provides information about three different summary measures for tariffs for the HS classified goods, which typically contain several tariff lines. I use the maximum tariff within an HS code, but all results are qualitatively robust to using the simple average or even the minimum rate.

I obtain information on market structure from FICUS, which contains administrative balance sheet data for the near universe of French firms. To measure concentration both in the seller and buyer industry, I rely on the market share of the four biggest firms in any 4 digit industry, which is referred to as the "Big4" concentration measure. It is more robust to the fact that there is a large number of small, niche firms in almost all industries that do not compete for large shares of a market in the same way the four biggest competitors normally do. I also compute a standard Hirschman-Herfindahl index for the sales distribution and the number of active firms. Moreover, I analyze the seller-buyer industry ratio of these variables, which is a proxy for market tightness. A drawback of using FICUS is that it only covers domestic firms, but it is unclear if this introduces a bias in my results.[32]

Finally, the EAE provides me with the firm level measures sales, employment, physical and intangible capital intensity, skill intensity, and TFP and labour productivity, which have all been linked to organizational choice and which I employ both as controls and to investigate mechanisms below.

2.4.2 Sample

The objective in this paper is to understand the impact of changes in trade policy – which in the case of tariffs pertains to physical goods – on organizational decisions. It is therefore natural to restrict the analysis to manufacturing industries (ISIC Rev. 3 codes 15** to 37**). Moreover, due to data constraints, I rely on the earliest year available to me, 1996, and the latest year, 2006. The exact years have no significant impact on my results in the sense that other years that are similarly far apart from each other qualitatively produce

[31] I also use a set of weights derived from the trade-weighted average over the entire sample period 1996-2006. The 1996 weights have the advantage of being "cleaner", i.e. less subject to reverse causality concerns, while they have the disadvantage of giving very little weight to the spectacular role played by China, especially after 2001. The average weights address this issue, but at the cost of not being fully pre-determined, albeit still time-invariant. The main patterns documented in the paper are highly robust to the choice of weights, but there are occasional differences in the size of some estimates.

[32] For robustness I include imports by country and industry as additional firms with the respective market shares in the computation of my market structure measures, but the results are unaffected.

the same results.

As stated above, I limit the sample to firms that report a single primary industry throughout their lifetime in my sample, since over the course of the years, a subset of firms classified into different primary industries, either because a secondary activity achieves higher sales or because the firm adjusts its scope intentionally. These artefacts may very well be related to trade policy and add variation that is not immediately meaningful for my purpose. I also exclude all buyer firm by seller industry observations in which a firm's industry is the same as the seller industry (before selecting the 50 most important seller industries). By definition a firm cannot outsource its primary industry and hence these observations are inherently different from the rest.

Table 2.1: Summary Statistics

	1996				2006			
	Mean	Median	SD	Obs	Mean	Median	SD	Obs
Panel A: Firm and Relationship Level								
Employment	136	46	493	12,361	140	49	417	12,357
Sales (k Euro)	25,700	5,600	143,500	12,480	41,200	8,400	363,000	12,480
All Integrated Relationships	0.0056	0	0.0740	624,000	0.0058	0	0.0760	624,000
Fully ...	0.0037	0	0.0600	624,000	0.0032	0	0.0560	624,000
Domestic affiliated ...	0.0009	0	0.0300	624,000	0.0012	0	0.0350	624,000
EU affiliated ...	0.0009	0	0.0300	624,000	0.0010	0	0.0310	624,000
Outside EU affiliated ...	0.0007	0	0.0270	624,000	0.0009	0	0.0300	624,000
Panel B: Industry Level								
Export Tariffs	1.0272	1.0141	0.0446	116	1.0195	1.0088	0.0373	115
Import Tariffs	1.0229	1.0112	0.0360	118	1.0155	1.0070	0.0273	118
Buyer Big 4 Concentration	0.38	0.31	0.24	118	0.41	0.36	0.24	118
Seller Big 4 Concentration	0.39	0.31	0.25	117	0.42	0.35	0.25	117

Table 2.2: Summary Statistics cont'd

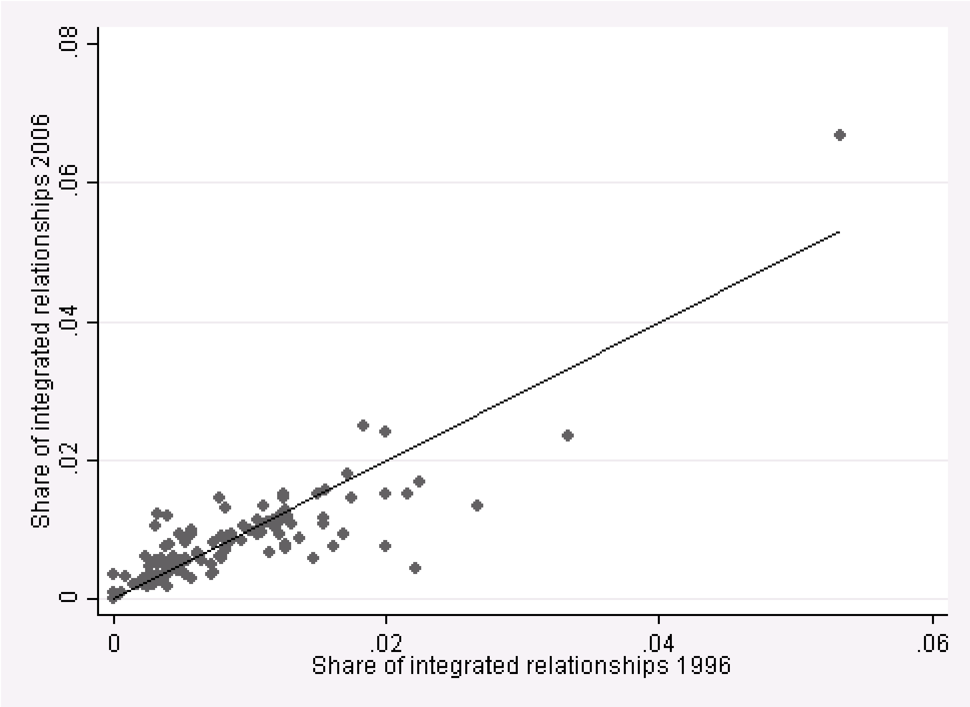
1996

Top 5 Industries			Bottom 5 Industries		
ISIC	Name	Integ	ISIC	Name	Integ
23	coke, refined petroleum, nuclear fuel	0.016	26	Other non-metallic mineral products	0.004
35	Other transport equipment	0.013	30	Office, accounting and computing m.	0.003
24	Chemicals and chemical products	0.012	22	Publishing, printing	0.003
29	Machinery n.e.c.	0.011	19	Tanning and dressing of leather	0.003
31	Electrical machinery	0.011	15	Food products and beverages	0.002

2006

Top 5 Industries			Bottom 5 Industries		
ISIC	Name	Integ	ISIC	Name	Integ
35	Other transport equipment	0.013	28	Â fabr. metal products, excl. mach /equ.	0.005
24	Chemicals and chemical products	0.012	26	Other non-metallic mineral products	0.005
30	Office, accounting and computing m.	0.012	22	Publishing, printing	0.004
31	Electrical machinery	0.012	15	Food products and beverages	0.003
34	Motor vehicles	0.010	19	Tanning and dressing of leather	0.002

Figure 2.2: Integration Variation



Panel A in table 2.1 presents summary statistics for the firms and their relationships in my sample. The firms left after imposing the restrictions mentioned above are a little bigger than the average across the entire manufacturing sector, which is due to the fact that firms with less than 20 employees are under-represented in the EAE survey and due to a survival bias for the 11 year period.

Dependent Variable: Integration

With respect to the main In 1996, roughly 3 in 10 firms had an affiliate in one of its supplier industries and roughly 6 in a thousand supply relationships are vertically integrated, but as seen in the standard deviation, the distribution was highly skewed. The whole distribution shifted slightly towards outsourcing, but the change over time is small. Table 2.2 lists both the 5 industries with the highest and the lowest shares of vertical integration in both 1996 and 2006. These aggregate statistics, however, mask considerable heterogeneity across the 4 digit industries as shown by figure 2.2, which plots the share of integrated supply relationships at the 4 digit industry level in 2006 against the same statistics in 1996. There is no common trend, but widespread movement both towards deeper vertical integration and towards outsourcing.[33]

[33]If any pattern can be made out, it is that industries that originally had a lot of fragmentation saw more integration, while traditionally highly integrated ones saw more outsourcing. In fact, this pattern, while weak, will be linked to tariffs in my main results.

Regressors: Tariffs and Market Structure

Panel B of table 2.1 shows summary statistics at the industry level, namely for tariffs and market concentration. Export tariffs start out at on average 2.7 percentage points (median 1.4 percentage points) and decreased slightly to 2 percentage points (median 0.9 percentage points). During the same period, average import tariffs fell from 2.3 percentage points to 1.6 (median from 1.1 to 0.7). These values are, once again, not representative of all industries' experience.

Instead, figure 2.3 gives an idea of the identifying variation in both import and export tariffs. I plot a particular ad valorem tariff in a given year in a particular 4 digit industry as function of its value in a previous period, so that deviations from the 45 degree line (plotted) show the within industry variation I exploit below. As expected given the time frame of the data, most industries saw a decline in tariffs. In view of the lower bound of zero for tariffs, it is unsurprising that those industries with particularly high 1996 tariffs experienced the largest cuts. The key trade liberalization episodes that provide variation here are the efforts of European Integration.

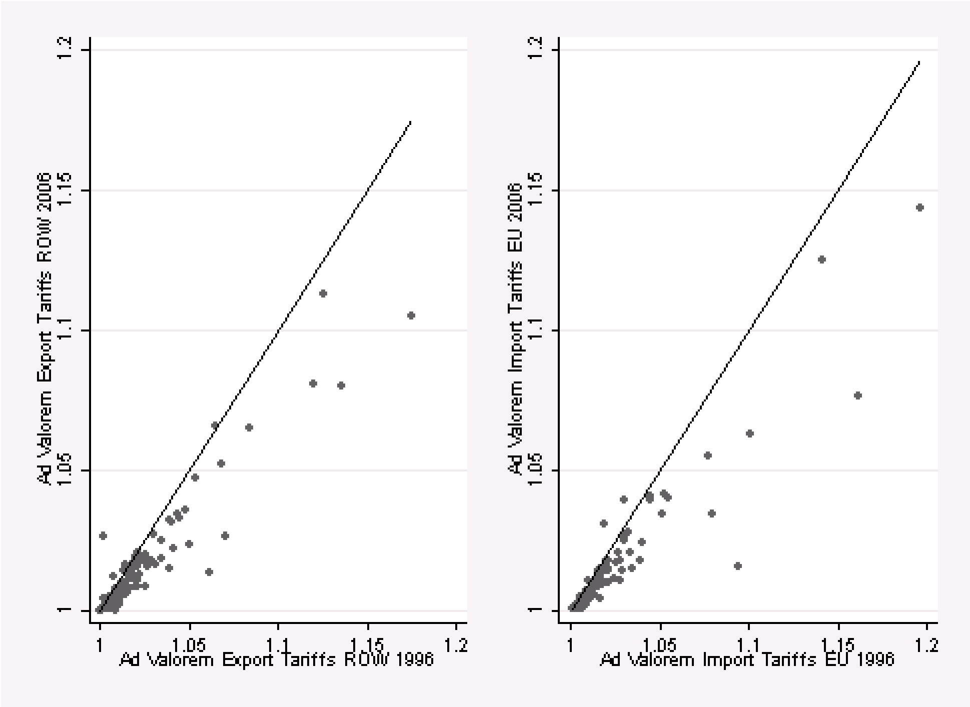
The Eastern European countries that joined the European Union in 2004 began their accession processes already ten years earlier and part of this road to membership was a *gradual* bilateral reduction of trade barriers over time. As a result, the period used in this chapter starts when Eastern European countries like Poland, Hungary, the Czech Republic, Slovakia and Slovenia as well as the Baltics still faced significant EU import tariffs and imposed them on EU/French goods. For example, in 1996 the simple average tariff across all product categories that Poland imposed vis-a-vis France was 1.0725 ad valorem. These were particularly high in agriculture, but manufacturing goods were strongly affected, too. Moreover, the standard deviation of these tariffs was substantial at 0.0908. Similarly, the EU charged an across good average tariff of 1.0140. These fell to zero within the time period I use for estimation and provides identifying variation.

Finally, the market shares of the four biggest firms in each ISIC Rev. 3 digit industry hovered around 39 percent on average, which is considered relatively concentrated. No strong movement towards more concentration is discernable according to the averages, but the median across industries increased quite significantly.

2.5 Results

In what follows I describe the results from my empirical exercises outlined in section 2.3 and connect them to the theoretical predictions discussed above in section 2.2.

Figure 2.3: Tariff (Within) Variation



2.5.1 Aggregate Effects

Table 2.3: Aggregate Effects

VARIABLES	(1) *integ*	(2) *integ*	(3) *integ*	(4) *integ*	(5) *integ*	(6) *integ*	(7) *integ*	(8) *integ*
τ_p^{EX}	-0.010	-0.004	0.006	0.000	0.001		0.000	
	(0.008)	(0.007)	(0.008)	(0.002)	(0.002)		(0.002)	
τ_p^{IM}	-0.023**	0.010***	-0.008***	-0.014		-0.005		-0.003
	(0.010)	(0.003)	(0.001)	(0.012)		(0.011)		(0.009)
τ_{upstr}^{IM}							-0.031	
							(0.031)	
$\tau_{downstr}^{EX}$								0.022***
								(0.006)
Constant	YES							
2 digit Seller Ind * 2 digit Buyer Ind		YES	YES					
Year				YES				
Firm * Seller Ind				YES	YES	YES	YES	YES
Firm * Year					YES		YES	
Seller Ind * Year						YES		YES
Observations	1,242,488	621,244	621,244	1,242,488	1,242,488	1,242,488	1,242,488	1,242,488
R-squared	0.000	0.004	0.004	0.709	0.716	0.710	0.716	0.710

The dependent variable is an indicator that is equal to one if a downstream firm has access to production facilities for intermediates provided by an upstream industry. The main regressors are trade weighted export and import tariffs. Standard errors in parentheses are two-way clustered at the downstream and upstream ISIC Rev. 3 4 digit industry level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Fact 1, which says that changes in tariffs had no impact on the aggregate integration patterns, is supported by the results in table 2.3. Column (1) presents the raw correlations of export and import tariffs in the intermediates market. While there is no discernable correlation between export tariffs and vertical integration, import tariffs display a significantly negative, but almost imperceptibly small correlation. To illustrate this, take the representative downstream industry that experienced the average cut in import tariffs. The probability that a supply relationship for a firm in that industry was integrated changed by X percentage points, over a baseline of 0.58 percent.

Next, I explore the cross-sectional variation by limiting the sample to the year 1996 in column (2) and 2006 in column (3). To address the most immediate concerns about omitted factors while still retaining maximum variation to estimate the coefficients of interest, I include 2 digit upstream and downstream fixed effects.[34] Export tariffs continue to have no significant correlation with the probability of integration, while import tariffs were initially positively, then negatively correlated 11 years later. The latter estimates are very precisely estimated and the effect sizes are, again, diminutive. Comparing firms in two industries that have tariff *levels* two standard deviations apart, exhibit a difference in the probability of integrating a supply relationship equal to 0.09 of a percentage point, over a baseline of 0.0056. Similar comparisons can be made for 2006.

As I convert the specification into a long difference type regression and introduce year effects in column (4), all significant correlations disappear. In columns (5) and (6) I introduce fixed effects that account for all variation in import and export tariffs, respectively, namely buyer firm by year as well as seller industry by year fixed effects. These specifications are the two most demanding on the data, but also those that minimize omitted variable bias concerns. From now on I report results in pairs with these fixed effects throughout.

Finally, in columns (7) and (8) I address concerns that the estimates are confounded by import tariffs on inputs of the seller industry p, τ^{IM}_{upstr}, or by export tariffs on the output of the buyer industry j, $\tau^{EX}_{downstr}$. It should be noted that my buyer firm fixed effects control for any changes in the downstream market for the output of j and hence absorb any incentives related to output prices (Conconi et al. (2012), Legros and Newman (2013), and Alfaro et al. (2016)). It is clear that these do not affect the results in any way.

The main take-away from this table is that there is no change in the prevalence of vertical integration that can be linked to tariffs. In fact, this result is consistent with the small drop in vertically integrated relationships in the summary statistics. While the changes in tariffs over the respective periods have not been especially large (cf. figure

[34]Since tariffs vary at the 4 digit levels, effects at this level of disaggregation are not possible.

2.3), the small standard errors indicate that my methodology is relatively powerful in detecting even slight co-variation. It is more likely that tariffs affect different relationships in different ways, as would be consistent with the insights from Antras and Helpman (2004). Overall, the experience of France between 1996 and 2006 does not suggest that renewed protectionism will have substantial effects on vertical integration patterns, and therefore efficiency, *on the aggregate*.

2.5.2 Integrated vs. Outsourced Relationships

Table 2.4: Integration Status

VARIABLES	(1) *integ*	(2) *integ*	(3) *integ*	(4) *integ*	(5) *integ*	(6) *integ*
τ_p^{EX}	-0.013		0.001		0.038	
	(0.012)		(0.051)		(0.085)	
$\times$ $integ_{t-1}$	11.843**		7.833**	7.892**		
	(5.828)		(3.882)	(3.968)		
$\times$ full $integ_{t-1}$					6.042*	6.121*
					(3.265)	(3.325)
$\times$ domestic $integ_{t-1}$					0.795	0.775
					(2.873)	(2.863)
$\times$ foreign EU $integ_{t-1}$					35.646***	36.372***
					(11.175)	(11.367)
$\times$ foreign non-EU $integ_{t-1}$					22.586***	22.713***
					(5.884)	(5.913)
τ_p^{IM}		-0.103**		0.057		0.058
		(0.045)		(0.112)		(0.098)
$\times$ $integ_{t-1}$		21.908**	13.461*	13.451*		
		(9.835)	(7.839)	(7.853)		
$\times$ full $integ_{t-1}$					9.908*	9.876*
					(5.320)	(5.311)
$\times$ domestic $integ_{t-1}$					17.292	17.197
					(13.512)	(13.556)
$\times$ foreign EU $integ_{t-1}$					-0.963	-0.997
					(3.820)	(3.878)
$\times$ foreign non-EU $integ_{t-1}$					-9.559***	-9.523***
					(2.608)	(2.651)
Controls			YES	YES	YES	YES
Firm * Seller Ind	YES	YES	YES	YES	YES	YES
Firm * Year	YES		YES		YES	
Seller Ind * Year		YES		YES		YES
Observations	1,087,478	1,087,478	1,087,478	1,087,478	1,087,478	1,087,478
R-squared	0.727	0.729	0.751	0.746	0.756	0.752

The dependent variable is an indicator that is equal to one if a downstream firm has access to production facilities for intermediates provided by an upstream industry. The main regressors are trade weighted export and import tariffs, each interacted with the dependent variable in 1996. These lagged dependent variables are also differentiated by type of integration status: fully integrated, domestic affiliate, EU foreign affiliate, and outside EU affiliate. Control variables include (the levels of and) interactions of all four tariffs with firm characteristics (sales, employment, physical and intangible capital intensity, skill intensity, TFP, labor productivity) and market characteristics (Big4 concentration, HHI, number of firms, ratios of these variables up and downstream) pre-determined in 1996 – unless collinear with fixed effects. In addition, (3) includes $\tau^{IM}_{upstr,t}$ and $\tau^{IM}_{upstr,t}$ interacted with $integ_{t-1}$ and $\tau^{EX}_{downstr,t}$ interacted with $integ_{t-1}$; (4) includes $\tau^{IM}_{upstr,t}$ interacted with $integ_{t-1}$ and $\tau^{EX}_{downstr,t}$ and $\tau^{EX}_{downstr,t}$ interacted with $integ_{t-1}$; (5) and (6) includes the variables in (3) and (4), but with $integ_{t-1}$ split into types. Standard errors in parentheses are two-way clustered at the downstream and upstream ISIC Rev. 3 4 digit industry level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Fact 2 is established based on the evidence in table 2.4. Columns (1) and (2) show the effects of export and import tariffs on the intermediate good p separately on initially outsourced and on initially integrated relationships. Starting in columns (3) and (4) I include a large set of controls: First, I add the levels and interactions of all four tariffs (import and export tariffs on the intermediate as well as the import tariffs on inputs further upstream and export tariffs on output of the downstream firm) with the lagged dependent variable $integ_{t-1}$ (terms collinear with the fixed effects are dropped). Furthermore, I interact these tariffs with firm characteristics (sales, employment, physical and intangible capital intensity, skill intensity, TFP, labor productivity) and market characteristics (Big4 concentration, HHI, number of firms, ratios of these variables among sellers and buyers of p). All characteristics are the pre-determined values in 1996. Again, variables collinear with the fixed effects are dropped.

Recall that the dependent variable includes all integrated relationships, regardless of whether they are fully integrated in the same legal entity or whether they implicate a domestic, EU, or non-EU affiliate. In columns (5) and (6) I replace the lagged dependent variable by indicators for whether a relationship was integrated in a particular way (for example, through a domestic affiliate). I include the same controls as before, except for the tariff interactions – tariffs are now all interacted with indicators for the different types of integration as well.

Columns (3) and (4) illustrate that, far from having been ineffectual, tariffs on intermediates have had a powerful effect on the probability that previously integrated relationships remain integrated, but no effect on previously outsourced ones. Based on column (3) and extrapolating using the linear model, restoring the average export tariff from its 2006 level to the one in 1996 implies that integrated relationships become $7.833 * [log(1.0272) - log(1.0195)] = 2.6$ percentage points more likely to remain integrated. Based on column (4), the same exercise for import tariffs implies an increase in the same probability by 4.2 percentage points. Given that trade weighted tariffs were already relatively low in 1996 by historical standards, these effects are economically meaningful. In sharp contrast, there is no statistically or economically significant effect on outsourced relationships, where the transition probability does not change to a first order degree. Of course, the findings in this exercise are in no way a contradiction to Fact 1, since the share of integrated relationships is relatively small as can be seen in the summary statistics.

With respect to import tariffs, this finding is consistent with the predictions of Antras and Helpman (2004). They deduce that, following a tariff increase, the share of vertically integrated relationships increases, since trade costs and integration are complements as the latter is the efficient organizational choice (if it was less efficient, we would counterfactually not observe any integration according to their model). The results are broadly consistent with the predictions in McLaren (2000) if a majority of relationships never reacts to tariff changes and always remains in the outsourcing state, regardless of market conditions. Higher tariffs would shield the market from (effective) entry in upstream and downstream industries, so that outsourcing becomes unattractive; there are few alternative customers or suppliers outside a bilateral relationship, hold-up is severe, and parties choose vertical integration as a means of overcoming this problem. On a more detailed level, however, it remains unclear to what extent the findings support the theoretical predictions from market thickness theories. The fact that import and export tariffs have symmetric impacts conditional on each other cannot be related to them directly. Finally, the fact that the effect of tariffs depends on the the initial organizational state presents a difficulty for all theories without firm heterogeneity.

Columns (5) and (6) decompose the impact of tariffs by location and type of organization. Export tariffs have had their main impact outside France, while there were no (much less) significant and large changes in relationships that were integrated within France. Falling import tariffs led to re-organization: integrated activities that were previously performed at home are now carried out abroad, mostly outside the European Union. The latter finding is highly consistent with the predictions of Antras and Helpman (2004) and Ornelas and Turner (2011).

Since these regressions are performed on lagged dependent variable models, one may be concerned that the results are biased due to initial sorting, anticipation effects, and auto-correlation, as discussed above. In table 2.8 of appendix 2.A I examine these concerns econometrically and find no strong evidence of problematic variation.

2.5.3 Market Structure

I now turn to market structure and start by examining the effects of seller and buyer industry conditions before analyzing how they affect the main estimates in relation to each other.

The market structure measures I use are Big 4 concentration, HHI indices and the number of active firms, all for the seller side of the p market as well as the buyer side. I have used the measures not directly, but rather as indicator variables that take on the value one whenever an industry's measure is above the across industry median and zero otherwise. Column pairs in table 2.5 each report results from using the variables mentioned towards the lower end of each column.

The results indicate that the stabilizing effect of protectionism by other countries on integrated relationships is weaker in industries with more concentration or a lower number

Table 2.5: Market Structure (1)

VARIABLES	(1) integ	(2) integ	(3) integ	(4) integ	(5) integ	(6) integ
τ_p^{EX}	-0.025		0.001		0.000	
	(0.028)		(0.011)		(0.011)	
$\times\ \mathbb{1}(charac_{downstr})$	0.011		0.001		0.019	
	(0.016)		(0.033)		(0.023)	
$\times\ \mathbb{1}(charac_{upstr})$	0.028		-0.583		-0.015	
	(0.031)		(0.382)		(0.100)	
$\times\ integ_{t-1}$	15.167***		14.635**		14.715**	
	(5.717)		(6.512)		(6.674)	
$\times\ integ_{t-1} \times \mathbb{1}(charac_{downstr})$	-6.558**		6.041		-17.492	
	(3.165)		(3.658)		(10.893)	
$\times\ integ_{t-1} \times \mathbb{1}(charac_{upstr})$	-5.020		17.882		-0.318	
	(5.612)		(11.486)		(37.804)	
τ_p^{IM}		0.033		0.026		0.030
		(0.081)		(0.056)		(0.107)
$\times\ \mathbb{1}(charac_{downstr})$		-0.121		-0.043		-0.276**
		(0.003)		(0.005)		(0.005)
$\times\ \mathbb{1}(charac_{upstr})$		0.054		0.099*		0.032
		(0.045)		(0.059)		(0.041)
$\times\ integ_{t-1}$		20.843**		26.190**		24.034**
		(10.554)		(11.602)		(11.139)
$\times\ integ_{t-1} \times \mathbb{1}(charac_{downstr})$		22.254**		-8.807		47.704***
		(8.761)		(10.517)		(11.002)
$\times\ integ_{t-1} \times \mathbb{1}(charac_{upstr})$		-22.575**		-0.186		39.917
		(9.290)		(18.767)		(56.089)
Characteristic	Big4	Big4	HHI	HHI	# Firms	# Firms
Controls	YES	YES	YES	YES	YES	YES
Firm * Up Ind	YES	YES	YES	YES	YES	YES
Firm * Year	YES		YES		YES	
Up Ind * Year		YES		YES		YES
Observations	1,087,478	1,087,478	1,087,478	1,087,478	1,087,478	1,087,478
R-squared	0.768	0.759	0.768	0.755	0.768	0.755

The dependent variable is an indicator that is equal to one if a downstream firm has access to production facilities for intermediates provided by an upstream industry. The main regressors are trade weighted export and import tariffs, each interacted with both the dependent variable in 1996 and a dummy variable that is equal to one if a downstream (or upstream) industry has a market characteristic above the across ISIC Rev.3 4 digit industry median – including the triple interactions. Control variables include (the levels of and) interactions of all four tariffs with firm characteristics (sales, employment, physical and intangible capital intensity, skill intensity, TFP, labor productivity) and market characteristics (Big4 concentration, HHI, number of firms, ratios of these variables up and downstream) pre-determined in 1996 – unless collinear with fixed effects. Interactions of τ_p^{EX} with HHI and # Firms omitted in (1), τ_p^{IM} with HHI and # Firms in (2) and so on. Standard errors in parentheses are two-way clustered at the downstream and upstream ISIC Rev. 3 4 digit industry level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

of firms on the seller side of the intermediates market. This result is consistent with the observation that intermediate production profits are part of a vertically integrated firm's considerations – which is not the case under outsourcing – and higher export tariffs diminish those profits directly, thereby making integration less attractive. In industries with high concentration on the seller side, this profit effect is likely to be more substantial and therefore I find a smaller positive impact of export tariffs in these types of markets.

The effect of import tariffs is amplified if the downstream industry is highly concentrated, while it is mediated by concentration upstream.

Conconi et al. (2012) have highlighted that it may not be the absolute number of firms

Table 2.6: Market Structure (2)

VARIABLES	(1) integ	(2) integ	(3) integ	(4) integ	(5) integ	(6) integ
τ_p^{EX}	0.002		-0.017		-0.002	
	(0.011)		(0.027)		(0.018)	
$\times$ $\mathbb{1}(ratio - charac)$	-0.071		0.018		0.002	
	(0.045)		(0.032)		(0.017)	
$\times$ $integ_{t-1}$	18.363***		13.092		13.070	
	(6.239)		(8.494)		(8.527)	
$\times$ $integ_{t-1} \times \mathbb{1}(ratio - charac)$	-4.332		3.868		3.822	
	(3.615)		(4.317)		(4.345)	
τ_p^{IM}		0.025		-0.093		-0.094
		(0.052)		(0.071)		(0.072)
$\times$ $\mathbb{1}(ratio - charac)$		-0.058		0.120*		0.117*
		(0.063)		(0.064)		(0.064)
$\times$ $integ_{t-1}$		22.147**		25.538**		25.599**
		(10.775)		(11.308)		(11.328)
$\times$ $integ_{t-1} \times \mathbb{1}(ratio - charac)$		4.681		-6.413*		-7.326**
		(3.874)		(3.637)		(3.659)
Characteristic	# Firms	# Firms	Big4	Big4	HHI	HHI
Controls	YES	YES	YES	YES	YES	YES
Firm * Seller Ind	YES	YES	YES	YES	YES	YES
Firm * Year	YES		YES		YES	
Seller Ind * Year		YES		YES		YES
Observations	1,087,478	1,087,478	1,087,478	1,087,478	1,087,478	1,087,478
R-squared	0.768	0.755	0.768	0.755	0.768	0.755

The dependent variable is an indicator that is equal to one if a downstream firm has access to production facilities for intermediates provided by an upstream industry. The main regressors are trade weighted export and import tariffs, each interacted with both the dependent variable in 1996 and a dummy variable that is equal to one if an upstream-downstream industry combination has a market characteristic ratio above the across ISIC Rev.3 4 digit industry combination median – including the triple interactions. Control variables include (the levels of and) interactions of all four tariffs with firm characteristics (sales, employment, physical and intangible capital intensity, skill intensity, TFP, labor productivity) and market characteristics (Big4 concentration, HHI, number of firms) pre-determined in 1996 – unless collinear with fixed effects. Standard errors in parentheses are two-way clustered at the downstream and upstream ISIC Rev. 3 4 digit industry level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

that matters for the relative attractiveness of different organizational forms, but rather the *relative* number. I examine my data to see if there is any evidence for this channel. Table 2.6 repeats the same specifications as before, but with the ratios of the variables mentioned towards the bottom of each column, with the seller market variable in the numerator. In other words, I compute actual measures of market tightness and exploit the heterogeneity in the effects of tariffs. As in table 2.5, here I rely only on semi-parametric measures, i.e. indicator variables that are equal to one whenever a measure is higher than the across industry pair median, since ratios are more readily comparable to each other than direct measures like the absolute number of firms and a semi-parametric approach is more robust to functional form mis-specification.

If the *relative* number of sellers of intermediates is high (or if their relative concentration is low), i.e. there is what is often called a "buyer market", the positive effect of higher import tariffs on vertically integrated relationships is stronger, while the effect of exports does not vary systematically with market tightness. Interestingly, the effects of import tariffs on outsourced relationships, while still economically small, are more positive in buyers' markets.

Unfortunately, the predictions in Conconi et al. (2012), which could be used to interpret the finding on upstream market tightness, are not unambiguous and I do not see an operationalizable way of conditioning on the parameters in their model. Consequently, I am not in a position to link these results to their predictions directly. It is noteworthy, however, that export and import tariffs should have opposite effects on vertical integration conditional on initial market tightness according to their model, which is at odds with my findings.

The main take-away from this exercise is, therefore, an empirical pattern that future conceptual work may have to address – or at least which it should not be inconsistent with.

2.5.4 Mechanisms

Table 2.7: Mechanisms

VARIABLES	(1) integ	(2) integ	(3) integ	(4) integ	(5) integ	(6) integ
τ_p^{EX}	-0.008		-0.009		0.006	
	(0.008)		(0.009)		(0.006)	
$\times$ $integ_{t-1}$	7.920**	8.001**	7.685**	7.788**	1.133	1.141
	(3.909)	(4.017)	(3.754)	(3.863)	(1.335)	(1.373)
τ_p^{IM}		-0.063*		-0.081**		-0.012
		(0.037)		(0.035)		(0.021)
$\times$ $integ_{t-1}$	13.235*	13.103*	12.798*	12.658*	0.597	0.584
	(7.743)	(7.703)	(7.651)	(7.585)	(3.361)	(3.316)
Variables	None	None	Only Market Str	Only Market Str	Market Str + Firm	Market Str + Firm
Firm * Up Ind	YES	YES	YES	YES	YES	YES
Firm * Year	YES		YES		YES	
Up Ind * Year		YES		YES		Yes
Observations	1,179,032	1,179,032	1,179,032	1,179,032	1,179,032	1,179,032
R-squared	0.750	0.745	0.752	0.747	0.786	0.782

The dependent variable is an indicator that is equal to one if a downstream firm has access to production facilities for intermediates provided by an upstream industry. The main regressors are trade weighted export and import tariffs, each interacted with the dependent variable in 1996. Market Structure variables include Big4 concentration, HHI, number of firms, and the ratios of these variables up and downstream – plus their interactions with the lagged dependent variable. Firm variables include sales, employment, physical and intangible capital intensity, skill intensity, TFP, labor productivity – plus their interactions with the lagged dependent variable. Standard errors in parentheses are two-way clustered at the downstream and upstream ISIC Rev. 3 4 digit industry level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The final empirical fact I establish – and which has to be viewed as a set of interesting correlations – is that changes in market structure have not acted as a channel through which tariffs affect vertical integration, while firm level adjustments may be potential candidates. In table 2.7 I introduce the market structure and firm level variables – that I have so far employed as pre-determined controls – as time varying and contemporaneous variables. I also include their interactions with initial organizational state.

Columns (1) and (2) repeat the baseline regressions without controls on the common sample in the table. Columns (3) and (4) feature the market structure variables, while columns (5) and (6) include also the firm characteristics. It is clear from the stability of the tariff estimates that market structure variables play a minor role, while firm level adjustments do affect the estimates and can account for almost all of the effect of tariffs. This pattern is also reflected in the fact that none of the market structure variables turn out to be significant while firm size, capital and skill intensity, and labor productivity are highly significant determinants, irrespective of the specification (not shown here for brevity).

This finding suggests that, even though market structure explanations may be part of the picture, more energy should be devoted to understanding how firm level adjustments relay the impact of trade policy to organizational choice. Antras and Helpman (2004) take firm characteristics as exogenous, while Ornelas and Turner (2011) do not consider this margin of heterogeneity at all. While my results are at best indicative correlations, they justify more refined empirical investigations into this issue.

2.6 Conclusion

In this paper, I have produced a set of stylized facts about how changes in import and export tariffs affect vertical integration by studying French firms over the period 1996 - 2006. I provide empirical evidence to assess which of the predictions made in previous conceptual work hold up against the experience of one important and large economy. Secondly, I show new margins of organizational behavior of firms that may motivate both further conceptual and empirical work.

While the four main stylized facts that I establish for France are important, this is obviously only a first step that complements other researchers' work in order to develop a broad understanding of the impact of trade policy as it works through trade. Such a research agenda is all the more urgent as protectionist pressures – which typically originate from populism that incites the alleged losers from globalization – afflict politicians and decision makers. The observations I made from Global Trade Alert data in the Introduction hold for all other countries in the sample.

In addition to investigating observed changes in organizational choice as a response to trade policy, another matter is pressing: we have very little empirical evidence as to which organizational forms are efficient and under what circumstances. The main reasons for an apparent impasse on this issue are that finding plausible and useful exogenous variation across firms and industries is difficult and that, typically, organizational choices co-move, thus making statements about the impact of firm boundaries on productivity near impossible (see Athey and Stern (1998)). An alternative strategy is to approach the problem from a structural point of view and I see considerable merit in following this path. First attempts in this direction in the international trade literature like Ramondo and Rodriguez-Clare (2013) and Arkolakis et al. (2017) have been promising in this respect.

Appendix

2.A Lagged Dependent Variable Concerns

Table 2.8: Bias in LDV Specification

VARIABLES	(1) $integ_{t-1}$	(2) Resid (1)	(3) $integ_{t-1}$	(4) Resid (3)
$\tau^{EX}_{p,t-1}$	-0.004*			
	(0.002)			
$\tau^{EX}_{p,t}$	0.003			
	(0.002)			
Resid main regression		0.000		-0.000
		(0.021)		(0.021)
$\tau^{IM}_{p,t-1}$			-0.004**	
			(0.002)	
τ^{IM}_{pt}			0.002	
			(0.002)	
Buyer Ind * Seller Ind 2d	YES	YES		
Firm * Year	YES	YES		
Buyer Ind 2d * Seller Ind			YES	YES
Up Ind * Year			YES	YES
Observations	623,058	623,058	623,058	623,058
R-squared	0.090	0.000	0.053	0.007

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In table 2.8 I first regress initial organizational states on initial and future tariff levels, see columns (1) and (3), choosing appropriate fixed effects. Contemporaneous correlations are negative and significant, but very small in comparison with the main effects in table 2.4. There is no evidence of anticipation. In columns (2) and (4) I correlate the residuals from the previous regressions with the residuals from estimating the main specification without controls, but with the same fixed effects. Note that this is a conservative test, because much of the variation in the residuals form the main regressions is captured by controls and more demanding fixed effects. The results reveal that there is little cause for concern from auto-correlation. Together with the fact that my LDV models feature

$integ_{t-1}$ only in interaction terms and that the main regressions are long differences over more than ten years, this evidence is highly encouraging.

Chapter 3

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

3.1 Introduction

> 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.[1]
>
> - Hans-Ulrich Engel, BASF North America Chief

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.[2] As exemplified by the quotes above, the shale gas revolution has sparked a policy debate

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

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 therefore 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.[3]

Natural gas markets are much less integrated compared to markets for other fossil fuels.[4] 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 3.1 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.

As indicated in Figure 3.1, 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 3.1 also illustrates that the price differences arising from the shale gas production boom

[3] Appendix 3.A.1 provides more details on the physics of natural gas transportation and the implied transportation costs.

[4] In Appendix Figure 3.7 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.

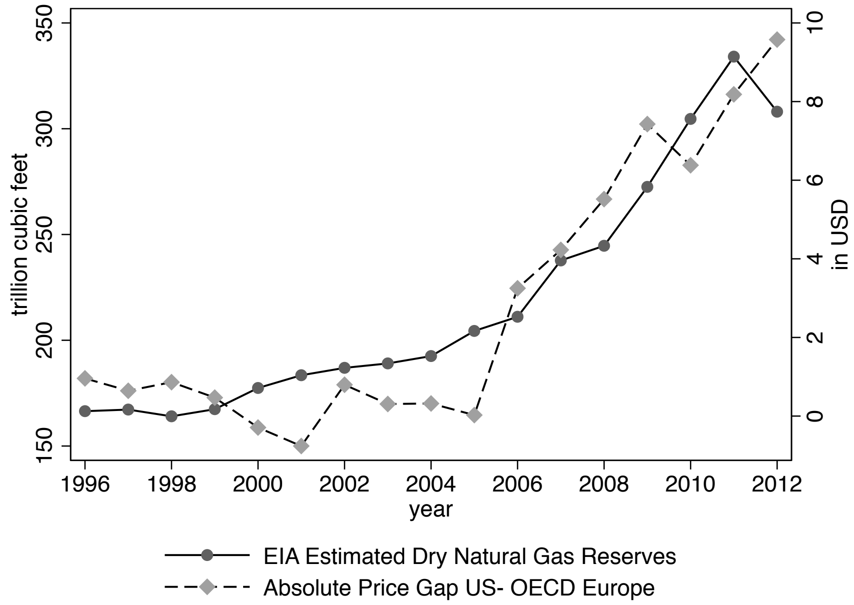


Figure 3.1: Evolution of estimated Natural gas reserves and absolute US-OECD Natural Gas Price Gap

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.

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 in our reduced form empirical analyses, 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.[5] Indeed, shocks that increase competition in an industry lead to exit of the least productive firms and hence boost aggregate productivity in that sector.[6] 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

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

[6] See Melitz (2003).

forces in our model 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 3.2 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.

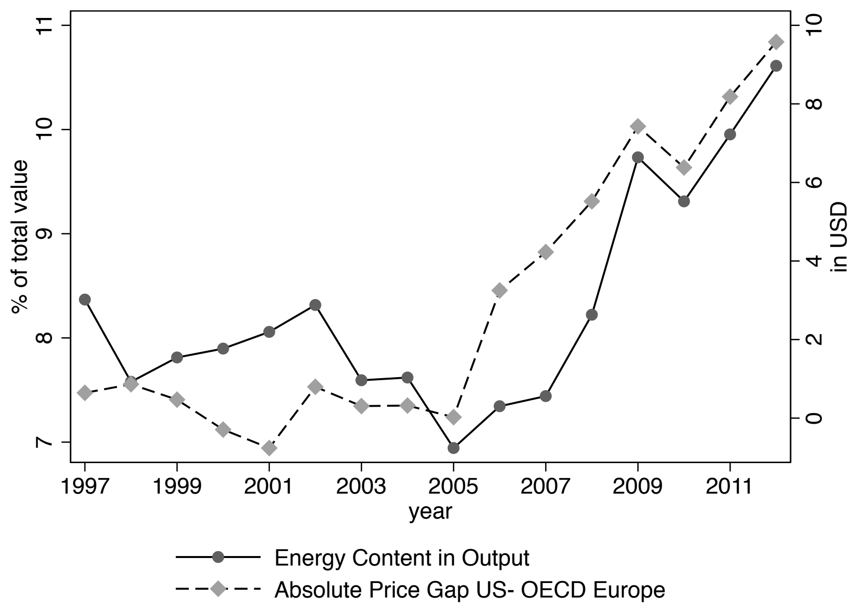


Figure 3.2: Evolution of the energy content of US Exports and absolute US-OECD Natural Gas Price Gap

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.

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 3.3 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 empirical 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 – in terms of input costs and, hence, output shares – 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.

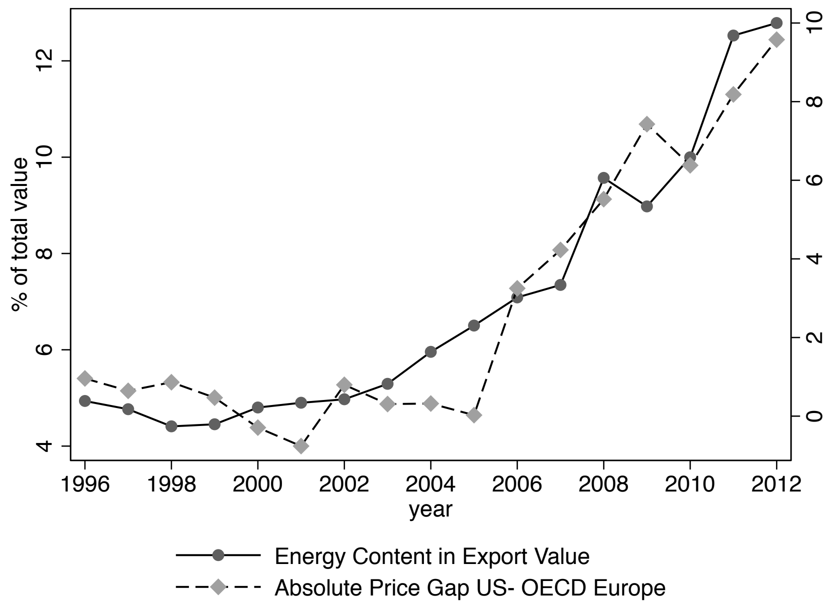


Figure 3.3: Evolution of the energy content of US Exports and absolute US-OECD Natural Gas Price Gap

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 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.[7] 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[8]) appear to obtain in the data; both output and production factors are reallocated towards energy intensive industries 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.[9] 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.[10] 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

[7] For very good reviews of this research see Baldwin (2008) and Feenstra (2015). Seminal contributions include Leontief (1953), Leamer (1984), Bowen et al. (1987), Trefler (1995), Davis and Weinstein (2001), Schott (2003), Schott (2004), 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.

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

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

[10] 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.

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.[11] 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 3.2 discusses the theoretical framework, while Section 3.3 presents the comparative static exercise that we bring to the data. Section 3.4 describes the various datasets used, while Section 3.5 lays out the empirical strategy. Section 3.6 presents the main results and robustness checks. Section 3.7 concludes.

[11] 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, 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.

3.2 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.[12]

3.2.1 Set-up and Industry Technology

There are two countries, indexed by k, l[13] 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 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[14], 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.

[12] In contrast to this paper, Bernard et al. (2007) only discuss the effects of a trade liberalisation. Huang et al. (2015) 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.

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

[14] 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. (2015) 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.

3.2.2 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.

3.2.3 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 $f_{ei}(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}$[15] 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).

3.2.4 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 3.C.1 and 3.C.1.

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

[15] 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.

at the industry level and therefore to different (industry weighted) marginal products of both factors.

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

3.3 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 3.1 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.[16]

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.

In order illustrate our results, we have quantified the model as shown in Appendix 3.C.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.

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 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

[16] 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.

aggregate industry productivity. We show in appendix 3.C.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.

3.3.1 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,

$$R_i^k = \alpha_i R^k \frac{1 - l_i \frac{R^l}{R^k}}{1 - c_i \hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}, \tag{3.1}$$

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.*[17]

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

[17] 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.

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.

To get a rough idea 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 3.C.3. The energy intensive sector is predicted to expand by 3.9 percentage points relative to the composite intensive one.

Our second prediction is tightly linked to the first 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

$$\begin{aligned} N_i^k &= \beta_i \frac{R_i^k}{w_N^k} \\ L_i^k &= (1-\beta_i) \frac{R_i^k}{w_L^k} \end{aligned} \tag{3.2}$$

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.

3.3.2 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:

$$X_i^k = M_i^k \bar{r}_{ix}^k = \frac{k_i}{1+k_i} R_i^k, \tag{3.3}$$

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 (3.3), total export volumes at the industry level grow, and differentially more so in the energy intensive industry.

Repeating the quantitative exercise described above and in Appendix 3.C.3 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.

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.[18]

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 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.*

The stylized model presented here provides us with a good understanding of the mechanisms at work when endowments change and how we can relate allocations to prices in equilibrium. To what extent do these predictions derived from a 2x2x2 model generalize to a real world, empirical setting?

Regarding the country dimension, it is straightforward to constrain empirical work by introducing country fixed effects or by aggregating across countries, treating all countries outside the home country as a single entity. We will adopt the former approach later on.

The theoretical Heckscher-Ohlin literature highlights that indeterminacy issues can arise in worlds of multiple factors and multiple goods, which potentially lead to modifications or even failures of our predictions (Feenstra (2015)). Crucially, the results of our

[18] 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.

empirical work below, even if consistent with our main derivations for the 2x2x2 model, would not constitute a proper test of neoclassical trade theory (or at least of one of the most prominent set of mechanisms).

There are three answers to this challenge. First, as Feenstra (2015) argues, there is (weak) empirical evidence (Kohli, 1993 that the sufficient conditions on the numbers of goods and factors are met (more factors than goods), so that indeterminacy is not a first order concern. Secondly, in the least ambitious interpretation of our theoretical model we would argue that our state-of-the-art theory merely guides our empirical efforts and that we do not provide a strict *test* of the model. Finally, apart from the aforementioned restriction on the cardinality of good and factor sets, there is no reason to suspect any problems in a more general version of our model. The underlying complementarity between factor abundance and factor intensity is unimpaired (cf. Costinot and Rodriguez-Clare, 2014) and, upon inspection, the system of equations shown in Appendix 3.C.1 does not suggest any further complications. Moreover, as Huang et al. (2015) show, it is possible to derive very similar predictions in a Bernard et al. (2007) type model with a continuum of goods.

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

3.4 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.[19]

3.4.1 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). These data come 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 these 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 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 provide 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 are 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.[20] 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 are proprietary data on manufacturing plant expansion and new plant investments collected by Conway. The data have the

[19] A more detailed discussion of the individual data sets and sources used is relegated to Appendix 3.A.

[20] 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 3.9

most extensive U.S. coverage capturing capital expenditures.[21] 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 contain 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 are 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 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.[22]

3.4.2 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.[23] Not all observations have positive trade, in which case a zero

[21]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)).

[22]We have replicated our analyses with information on capital provided by the NBER and the CES. The unconditional correlation between our Conway data and the relevant NBER-CES variable capturing industry investment at the 5 digit NAICS level is 0.59. Qualitatively the results are similar, although the point estimates using the NBER-CES data are larger compared to the ones obtained from our Conway data. However, the latter are estimated with more precision. This is not too surprising as the Conway data captures announcements and not necessarily the exact point that investment expenditures are incurred. We have a preference for the Conway data as they allow us to remove investment happening in counties above or near shale deposits and this information is likely to reflect completely new additions to capacity, whereas the NBER-CES investment data may capture capital replacement. The results are available from the authors upon request.

[23]We drop 1996 as the NAICS classification was first introduced with the 1997 census. The raw data contain 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.

is reported. That allows us to study the extensive margin of trade as well, i.e. trade occurring for new good and country pairs.[24]

3.4.3 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 evidence for this in Figure 3.2).[25] 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 3.1 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.

[24] See Appendix 3.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.

[25] The details of the construction are discussed in appendix 3.A.4.

Table 3.1: 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%

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

3.5 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.

3.5.1 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.

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

$$y_{jt} = \alpha_j + d_{j't} + l_{j_q t} + \gamma \times E_j \times \Delta P_t + \epsilon_{jt} \tag{3.4}$$

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. 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 an 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 $j' \subset j$.[26] 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 $j \subset j'$ 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.

It is important to highlight that oil and gas extraction activities are excluded throughout from the analysis. The focus of this paper is on the indirect effects of the shale gas boom on the manufacturing sector. Nevertheless, some manufacturing sectors may be directly affected by oil and gas extraction activities through downstream IO linkages, whereby manufacturing sectors are expanding as they provide inputs to the oil and gas extraction activities (such as tubes). As such, the expansion in these sectors could be driven by the indirect benefits due to the IO linkages. The third fixed effect l_{j_qt} aims to reduce concerns about such linkages of individual sectors to the oil and gas extraction sectors affecting our estimated coefficients. 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_{jt} that is correlated with the energy intensity E_j. The empirical specification is

$$y_{jt} = \alpha_j + d_{j't} + l_{j_q t} + \sum_t \gamma_t \times E_j + \epsilon_{jt} \tag{3.5}$$

Inspecting the plotted estimates γ_t will allow us to explore the extent to which sectors, of different energy intensity, were 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.

3.5.2 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

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

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:

$$y_{djt} = \alpha_{dj} + l_{j_q t} + b_{dj't} + \gamma \times E_j \times \Delta P_t + \epsilon_{djt} \tag{3.6}$$

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.[27]

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:

[27] We provide an evaluation of U.S. export tariffs in Appendix 3.B, where we argue that the residual variation after controlling for our fixed effects is not problematic.

$$y_{djt} = \alpha_{dj't} + b_{dj} + l_{j_q t} + \sum_t \gamma_t \times E_j + \epsilon_{djt} \tag{3.7}$$

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.[28]

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

3.6 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.

3.6.1 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 3.2. 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 expands by $8.33\% \times 7.4\% = 0.6\%$ for every dollar that the price gap increases. We can perform another back of the

[28]The results are presented in Appendix Tables 3.9 and 3.10). As noted, the original trade data also provide a further spatial component in form of the U.S. customs district, where the export data was recorded. Appendix 3.D 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.

Table 3.2: 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

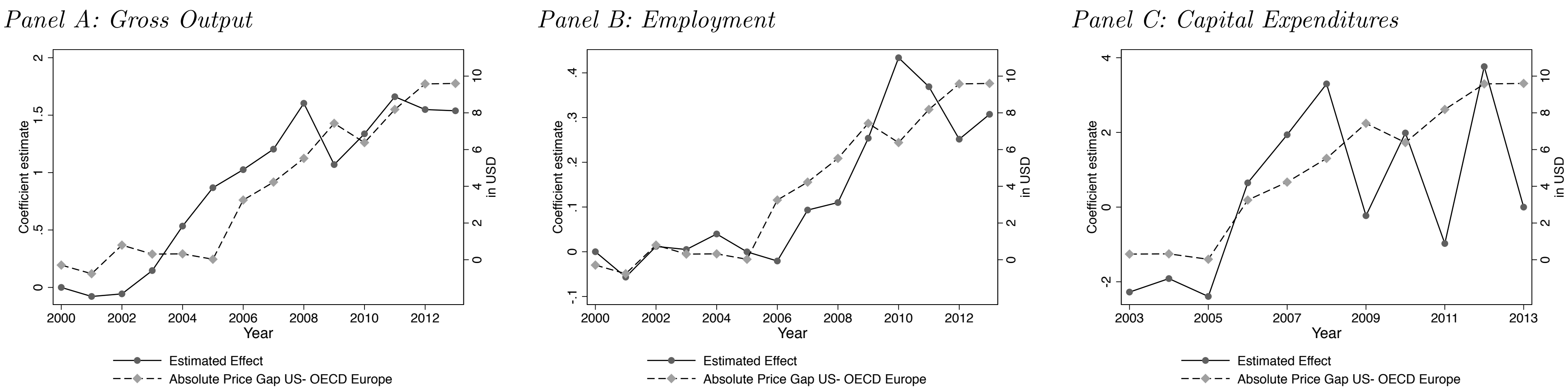
Notes: Price Gap is measured as the difference between an OECD average natural gas price and the US industrial use natural gas price. The dependent variable in Panel A is the log of gross output in a given sector. The dependent variable in Panel B is the log(employment) by five digit sector aggregated 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 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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. Overall, the estimated effects on factor reallocation are also in line with the quantitative predictions of our model.

Next, we present the results from estimating the non-parametric specification (3.5), 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.

Figure 3.4: Non-parametric Regressions for National Outcomes



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.

The results for our three outcome measures are presented in Figure 3.4. 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 are measured in the first quarter of the respective year, which mechanically contributes to a lagged effect.

In panel C we present the results for capital investment. The data are 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.

3.6.2 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.

Table 3.3: 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 × Price Gap	0.205*** (0.022)	0.193*** (0.018)	0.210*** (0.022)	0.200*** (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 × Price Gap	-0.006 (0.032)	0.024 (0.027)	0.001 (0.031)	0.028 (0.027)
Clusters	216	216	216	216
Observations	207471	207471	207471	207471
R-squared	.906	.906	.906	.906
Panel C: Any Export				
Energy Intensity × Price Gap	0.002 (0.002)	0.004** (0.002)	0.000 (0.002)	0.003 (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 × Price Gap	-0.006** (0.002)	-0.005** (0.002)	-0.004 (0.002)	-0.003 (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 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Our main results are presented in Table 3.3. 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.[29]

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 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

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

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.[30]

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 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 3.5. The dynamic of the estimated coefficient follows broadly the pattern of the price

[30]In Appendix Table 3.14 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.

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.

Figure 3.5: Evolution of Natural Gas Price Gap and Exports

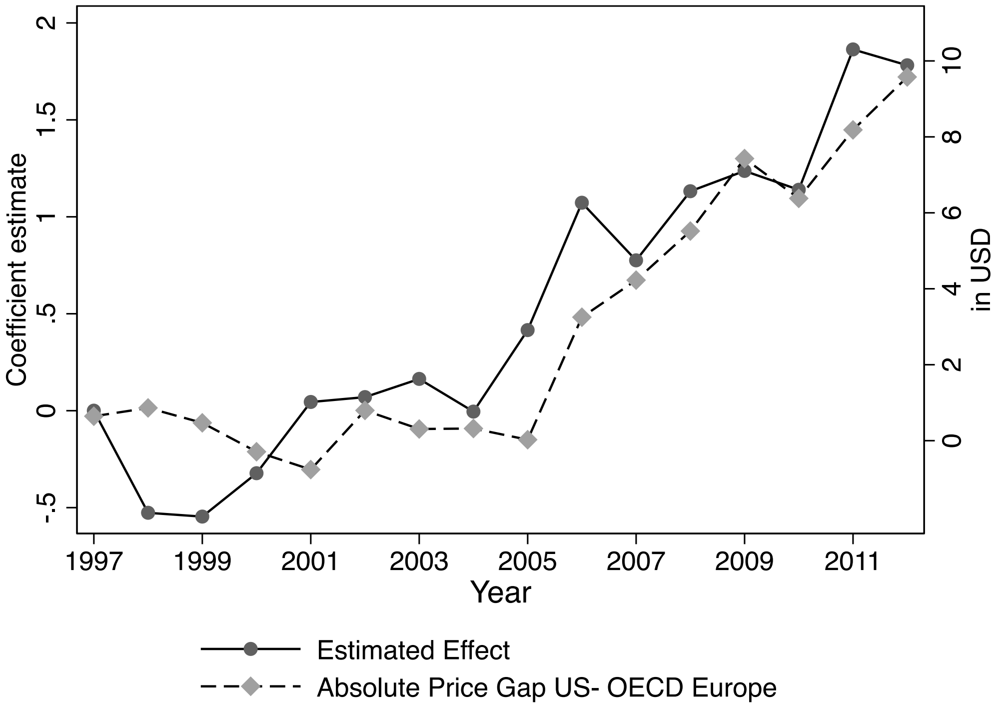


Figure present results from a non-parametric regression interacting the direct energy cost share with a set of year fixed effects on the logged value of exports at the five digit sector level, controlling for five digit sector by destination fixed effects, as well as three digit sector by destination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

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:

$$y_{djt} = \alpha_{dj't} + b_{dj} + l_{j_q t} + \sum_{j' \in \text{NAICS3}} \gamma_{j'} \times \Delta P_t + \epsilon_{djt} \tag{3.8}$$

The results from this analysis are presented in Table 3.4. 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 measure. 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.

Table 3.4: 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.

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 3.8.

Table 3.5: 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			
× 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 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In Table 3.5 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, these data are 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 3.6. 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 3.15 for regional natural gas price differences).

Table 3.6: 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 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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 3.11. 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.

3.7 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.

Appendix

3.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.

3.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.[31]

The inherent costs associated with transforming and transporting natural gas thus suggest that domestic natural gas prices in the U.S. will remain significantly lower compared to Europe and Asia in the foreseeable future.

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

3.A.2 Domestic Data

National Level Output We work with national level output data obtained from the BEA. The data are 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 provide 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 do 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 are 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.[32] The main dependent variable will be the log of employment by sector and year.

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

[32] 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 3.9

3.A.3 Trade Data

This part of the appendix describes how the trade data of Schott (2008) were 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.[33] 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.

3.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, 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 3.7: IO Table Direct Natural Gas Consumption

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

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.

3.B Tariffs

In this section we provide a more detailed discussion of export tariffs that U.S. industries face. U.S. trade policy makers are likely to be mindful of the changes in comparative advantage we identify over our sample period and hence put their considerable weight behind pushing for differential liberalization for energy intensive products. Consequently, omitting tariffs in our regressions may bias our estimates upwards. In the main text, we argue that given our estimation strategy we need to be wary of differential variation of export tariffs *within* two digit sectors over time.

The WTO has created a world of relatively low tariffs for developed countries and hence for the vast majority of international trade flows of manufactured produce. While MFN tariff changes are therefore small by necessity and hence less likely to affect our results considerably (we explore this further below), trade liberalization via free trade agreements (FTAs) is a first order concern. These may be targeted at important markets for relatively energy intensive goods and hence magnify our reduced form estimates.

During our sample period, the U.S. struck free trade agreements with the following countries: Jordan (2001), Australia (2004), Chile (2004), Singapore (2004), Bahrain (2006), Morocco (2006), Oman (2006), Peru (2007), DR-CAFTA, (which includes Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and the Dominican Republic 2005), Panama (2012), Colombia (2012), and South Korea (2012). The Colombia and South Korea agreements could affect our results only in the last three years of our sample period, so that our identification strategy is unimpeached during the crucial periods just after 2006. Among the earlier FTA's, in terms of economic weight in the U.S. export basket, only the ones with three countries may raise concerns: Australia, Chile, and Singapore. These, however, accounted for only 0.9%, 0.7%, and 1.2%, respectively, of total U.S. international trade in 2015. Overall, we therefore conclude that FTAs do not appear to be a major concern for our results.

The U.S. may still have pushed for differential liberalization in the WTO framework and hence we examine the (small) U.S. MFN export tariffs. We merge tariff information from TRAINS to our main data set at the 5 digit sector level. The amount of variation in the tariff rates – minimum, maximum, and average applied MFN tariffs (ad valorem equivalent) – that is explained by our main fixed effects (NAICS5 by country pair and country by NAICS2 x year) ranges between 67% - 91%. This suggests that a lot of the variation in tariffs is controlled for with the fixed effects we employ throughout. Moreover, all our international trade results are robust to making the time fixed effect specific at the three digit NAICS sector level, by destination country by year. In this case, the variation explained with these fixed effects ranges between 79%-94%, highlighting that we effectively control for time varying tariff barriers, but are still able to estimate the effect on energy intensive exports precisely.

A more direct test is to see whether export tariff changes at the five digit NAICS sector by destination country are correlated with the energy intensity of a five digit sector in a way that is correlated with the emergence of the natural gas price gap. The results are presented in Table 3.19. There is no apparent or consistent pattern in the data suggesting that tariffs changed systematically in a way that is correlated with the energy intensity of a sector and the price gap.

Finally, we have re-estimated our main results controlling for country and industry specific export tariffs. As expected given our aforementioned exercises, the results are fully robust and available from the authors upon request.

3.C 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.

3.C.1 Model Solution

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:

$$\frac{\beta_i}{1-\beta_i}\frac{L_i^k}{N_i^k} = \frac{w_N^k}{w_L^k}. \tag{3.9}$$

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

$$r_i(\varphi_i^{*k}) = f_{id}(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}, \tag{3.10}$$

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 (3.10), we can write the free entry condition as

$$\frac{f_{id}}{\delta}\int_{\varphi_i^{*k}}^{\infty}\left[\left(\frac{\varphi}{\varphi_i^{*k}}\right)^{\sigma-1} - 1\right](-\gamma\varphi^{-\gamma-1})\mathrm{d}\varphi + \frac{f_{ix}}{\delta}\int_{\varphi_{ix}^{*k}}^{\infty}\left[\left(\frac{\varphi}{\varphi_{ix}^{*k}}\right)^{\sigma-1} - 1\right](-\gamma\varphi^{-\gamma-1})\mathrm{d}\varphi = f_{ei} \tag{3.11}$$

Moreover, given zero expected profits in all markets *ex ante*, total revenues will be paid out to factors in full[34] and so total country revenues (which are equal to total expenditure) in equilibrium are

$$R^k = w_N^k(N_i^k + N_j^k) + w_L^k(L_i^k + L_j^k). \tag{3.12}$$

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

[34] 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.

$$N_1^k + N_2^k = \bar{N}^k$$
$$L_1^k + L_2^k = \bar{L}^k \tag{3.13}$$

and

$$R_i^k = \alpha_i R^k M_i^k \left(\frac{p_{id}^k(\tilde{\varphi}_i^k)}{P_i^k} \right)^{1-\sigma} + \alpha_i R^l \chi_i^k M_i^k \left(\frac{\tau_i p_{id}^k(\tilde{\varphi}_{ix}^k)}{P_i^l} \right)^{1-\sigma}. \tag{3.14}$$

$\tilde{\varphi}_z^k$ 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 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 (3.9), (3.12), (3.11), (3.13), (3.14), 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.

Collection of general equilibrium conditions with a Pareto parametrization

The equilibrium satisfies

$$N_1^k + N_2^k = \bar{N}^k$$
$$L_1^k + L_2^k = \bar{L}^k \tag{3.15}$$

(Labor market clearing conditions)

$$\frac{\beta_i}{1-\beta_i} \frac{L_i^k}{N_i^k} = \frac{w_N^k}{w_L^k} \tag{3.16}$$

(cost minimization)

$$R^k = w_N^k(N_i^k + N_j^k) + w_L^k(L_i^k + L_j^k) \tag{3.17}$$

(Aggregate Revenues)

$$\frac{f_{id}(\sigma-1)}{\delta(\gamma+1-\sigma)}(\varphi_i^{*k})^{-\gamma}\left[1+\tau_i^{-\gamma}\left(\frac{P_i^k}{P_i^l}\right)^{-\gamma}\left(\frac{R^k}{R^l}\right)^{\frac{-\gamma}{\sigma-1}}\left(\frac{f_{ix}}{f_{id}}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}\right] = f_{ei} \tag{3.18}$$

(free entry conditions)

$$\begin{aligned}(P_i^k)^{1-\sigma} = & \frac{\frac{\rho^{\sigma-1}}{\sigma f_{id}}R_i^k(\varphi_i^{*k})^{\sigma-1}}{\left[(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}\right]^{\sigma}\left[1+\tau_i^{-\gamma}\left(\frac{f_{ix}}{f_{id}}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}\left(\frac{P_i^k}{P_i^l}\right)^{-\gamma}\left(\frac{R^k}{R^l}\right)^{\frac{-\gamma}{\sigma-1}}\right]} + \\ & \frac{\frac{\rho^{\sigma-1}}{\sigma f_{id}}R_i^l(\varphi_i^{*l})^{\sigma-1}\quad \tau_i^{-\gamma}\left(\frac{f_{ix}}{f_{id}}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}\left(\frac{P_i^l}{P_i^k}\right)^{-\gamma+\sigma-1}\left(\frac{R^l}{R^k}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}}{\left[(w_N^l)^{\beta_i}(w_L^l)^{1-\beta_i}\right]^{\sigma}\left[1+\tau_i^{-\gamma}\left(\frac{f_{ix}}{f_{id}}\right)^{\frac{-\gamma+\sigma-1}{\sigma-1}}\left(\frac{P_i^l}{P_i^k}\right)^{-\gamma}\left(\frac{R^l}{R^k}\right)^{\frac{-\gamma}{\sigma-1}}\right]}\end{aligned} \tag{3.19}$$

(utility maximization)

$$[(w_N^k)^{\beta_i}(w_L^k)^{1-\beta_i}]^{\sigma} = \frac{\alpha_i\rho^{\sigma-1}}{\sigma f_{id}}R^k(P_i^k)^{\sigma-1}(\varphi_i^{*k})^{\sigma-1} \tag{3.20}$$

(goods market clearing)

3.C.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 5

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

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

$$\left(\frac{P_i^k}{P_i^l}\right)^{-\gamma}\left(\frac{R^k}{R^l}\right)^{\frac{-\gamma}{\sigma-1}} = \hat{w}^{\frac{-\sigma\gamma}{\sigma-1}}(\hat{\varphi}_i{}^*)^{\gamma} \tag{3.21}$$

Moreover, taking the same ratio of the free entry conditions and substituting (3.21) leads to

$$(\hat{\varphi}_i^*)^{-\gamma}\frac{1 + c_i\hat{w}^{\frac{-\sigma\gamma}{\sigma-1}}(\hat{\varphi}_i{}^*)^{\gamma}}{1 + c_i\hat{w}^{\frac{\sigma\gamma}{\sigma-1}}(\hat{\varphi}_i{}^*)^{-\gamma}} = 1, \tag{3.22}$$

so that

$$(\hat{\varphi}_i^*)^{\gamma} = \frac{1 - c_i\hat{w}_i^{\frac{\sigma\gamma}{\sigma-1}}}{1 - c_i\hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}. \tag{3.23}$$

We combine (3.21) and (3.23) to obtain Lemma 5.

■

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 5 we arrive at

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

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

$$\alpha_i R^k = R_i^k \frac{1}{1+k_i} + R_i^l \frac{l_i}{1+l_i}. \tag{3.24}$$

The equivalence (3.24) 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

$$R_i^k = \alpha_i R^k \frac{1 - l_i \frac{R^l}{R^k}}{1 - c_i \hat{w}_i^{\frac{-\sigma\gamma}{\sigma-1}}}. \tag{3.25}$$

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 5, we can write exports as

$$X_i^k = \frac{k_i}{1+k_i} R_i^k, \tag{3.26}$$

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

3.C.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 (3.1) and (3.3) – 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 3.1 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 3.10, 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 3.10, 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 (3.1), 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[35], and the OECD for manufacturing industries. We plug these into (3.1) 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.

3.D 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 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:

$$y_{jkt} = \alpha_{jk} + d_{j'kt} + l_{j_q t} + \gamma \times E_j \times \Delta P_{kt} + \epsilon_{jkt} \tag{3.27}$$

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.

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

For the trade exercise, we estimate

$$y_{djkt} = \alpha_{djk} + l_{j_q t} + b_{dj't} + \gamma \times E_j \times \Delta P_{kt} + \epsilon_{djkt} \tag{3.28}$$

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 3.16. The results for trade outcomes are presented in Table 3.17. Throughout, the results are very similar as in the main analysis.

Figures and Tables for Appendix

Table 3.8: 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	0.148***	0.167***	0.155***	0.172***
× Price Gap	(0.038)	(0.034)	(0.041)	(0.040)
Sectors	150	150	150	150
Observations	2100	2100	2100	2100
R-squared	.965	.966	.965	.966
Panel B: Employment				
Energy Intensity	0.036*	0.050**	0.037**	0.050***
× Price Gap	(0.020)	(0.020)	(0.017)	(0.019)
Sectors	171	171	171	171
Observations	2386	2386	2386	2386
R-squared	.971	.971	.971	.971
Panel C: Investment NBER-CES				
Energy Intensity	0.144**	0.185***	0.142**	0.181***
× Price Gap	(0.066)	(0.066)	(0.057)	(0.063)
Sectors	153	153	153	153
Observations	1836	1836	1836	1836
R-squared	.934	.935	.934	.935
Panel D: Capital Expenditures				
Energy Intensity	0.354	0.387	0.297	0.371
× Price Gap	(0.284)	(0.275)	(0.254)	(0.283)
Sectors	171	171	171	171
Observations	1881	1881	1881	1881
R-squared	.642	.643	.642	.643
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 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(investment) obtained from the NBER-CES data, while Panel D uses the Conway capital expenditure data transformed in log(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 3.9: 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 × Price Gap	0.205***	0.189***	0.197***	0.185***
	(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 × Price Gap	-0.024	-0.008	-0.003	0.012
	(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 × Price Gap	-0.001	0.002	-0.004	-0.000
	(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 × Price Gap	-0.007**	-0.005**	-0.004	-0.003
	(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 3.10: 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 × Price Gap	0.206*** (0.038)	0.190*** (0.033)	0.191*** (0.042)	0.179*** (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 × Price Gap	-0.020 (0.042)	-0.022 (0.041)	0.025 (0.041)	0.014 (0.038)
Clusters	27	27	27	27
Observations	51064	51064	51064	51064
R-squared	.919	.919	.919	.919
Panel C: Any Export				
Energy Intensity × Price Gap	0.006** (0.003)	0.005** (0.002)	0.005** (0.002)	0.004** (0.002)
Clusters	27	27	27	27
Observations	55932	55932	55932	55932
R-squared	.613	.612	.612	.612
Panel D: Any Import				
Energy Intensity × Price Gap	-0.001 (0.004)	0.003 (0.004)	-0.001 (0.003)	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 3.11: 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 3.12: 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 3.13: 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 × Natural Gas Reserves	2.156***	2.089***	2.226***	2.171***
	(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 × Natural Gas Reserves	0.081	0.294	0.219	0.399
	(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 × Natural Gas Reserves	0.043**	0.066***	0.028	0.054***
	(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 × Natural Gas Reserves	-0.065**	-0.057***	-0.037	-0.034
	(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 3.14: 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 3.15: 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 3.16: 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 × Price Gap	0.009*** (0.002)	0.017*** (0.003)	0.007*** (0.002)	0.016*** (0.002)
Sectors	171	171	171	171
Observations	7093151	7093151	7093151	7093151
R-squared	.871	.871	.871	.871
Panel B: Capital Expenditures				
Energy Intensity × Price Gap	0.001*** (0.000)	0.001*** (0.000)	0.001*** (0.000)	0.001*** (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 3.17: 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 × Price Gap	0.133***	0.123***	0.136***	0.129***
	(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 × Price Gap	0.028	0.053**	0.025	0.048*
	(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 × Price Gap	0.002	0.002	0.002**	0.002*
	(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 × Price Gap	-0.002**	-0.001	-0.002**	-0.001
	(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 3.18: 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 × Price Gap	0.242*** (0.022)	0.223*** (0.019)	0.245*** (0.023)	0.230*** (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 × Price Gap	0.025 (0.032)	0.047* (0.027)	0.028 (0.031)	0.049* (0.027)
Clusters	216	216	216	216
Observations	238442	238442	238442	238442
R-squared	.903	.903	.903	.903
Panel C: Any Export				
Energy Intensity × Price Gap	0.003 (0.002)	0.005** (0.002)	0.002 (0.002)	0.004** (0.002)
Clusters	218	218	218	218
Observations	655962	655962	655962	655962
R-squared	.722	.722	.722	.722
Panel D: Any Import				
Energy Intensity × Price Gap	-0.002 (0.002)	-0.002 (0.002)	-0.000 (0.002)	-0.001 (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 include 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 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3.19: Effect of natural gas price gap on energy intensive export tariffs.

	All Energy Inputs		Natural Gas Input	
	(1) Direct	(2) Direct + Indirect	(3) Direct	(4) Direct + Indirect
Panel A: Minimum Tariff				
Energy Intensity × Price Gap	0.186** (0.084)	0.126 (0.118)	0.159* (0.085)	0.118 (0.113)
Clusters	108	108	108	108
Observations	181555	181555	181555	181555
R-squared	.676	.676	.676	.676
Panel B: Maximum Tariff				
Energy Intensity × Price Gap	-0.597 (0.373)	-0.510 (0.336)	-0.649* (0.372)	-0.541 (0.326)
Clusters	108	108	108	108
Observations	181555	181555	181555	181555
R-squared	.698	.698	.698	.698
Panel C: Average Tariff				
Energy Intensity × Price Gap	-0.002 (0.121)	-0.014 (0.137)	-0.048 (0.118)	-0.041 (0.132)
Mean of DV	13.4	13.4	13.4	13.4
Clusters	108	108	108	108
Observations	181555	181555	181555	181555
R-squared	.696	.696	.696	.696
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

Notes: Price Gap is measured as the difference between an OECD average natural gas price and the US industrial use natural gas price. 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 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

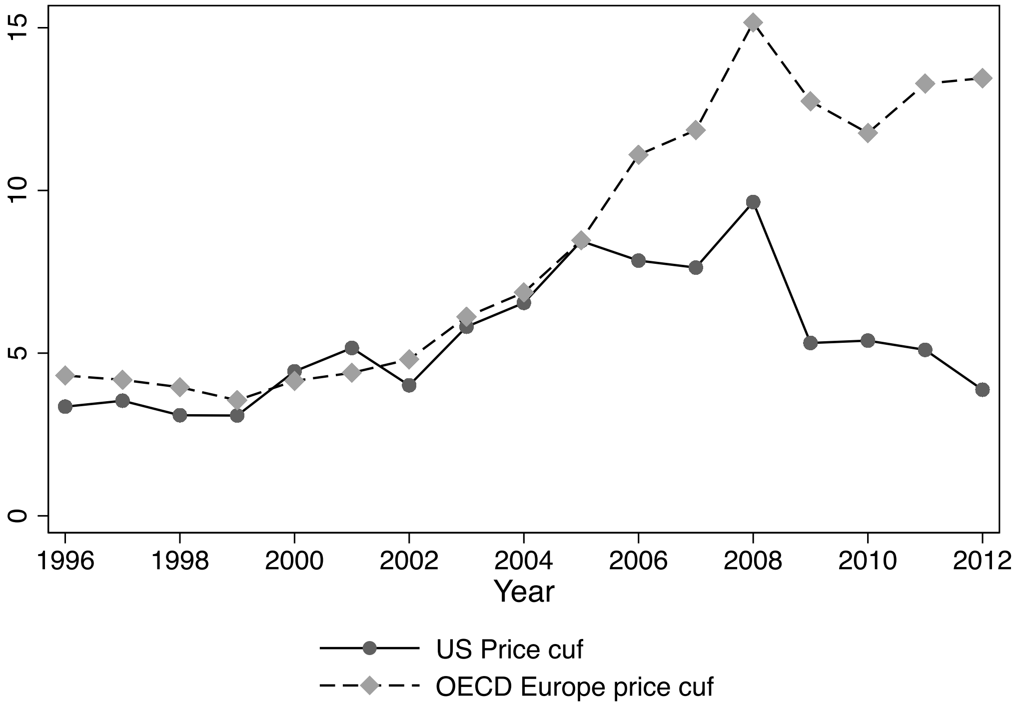


Figure 3.6: Natural Gas Prices for Industrial use across the OECD Europe and the U.S. over time.

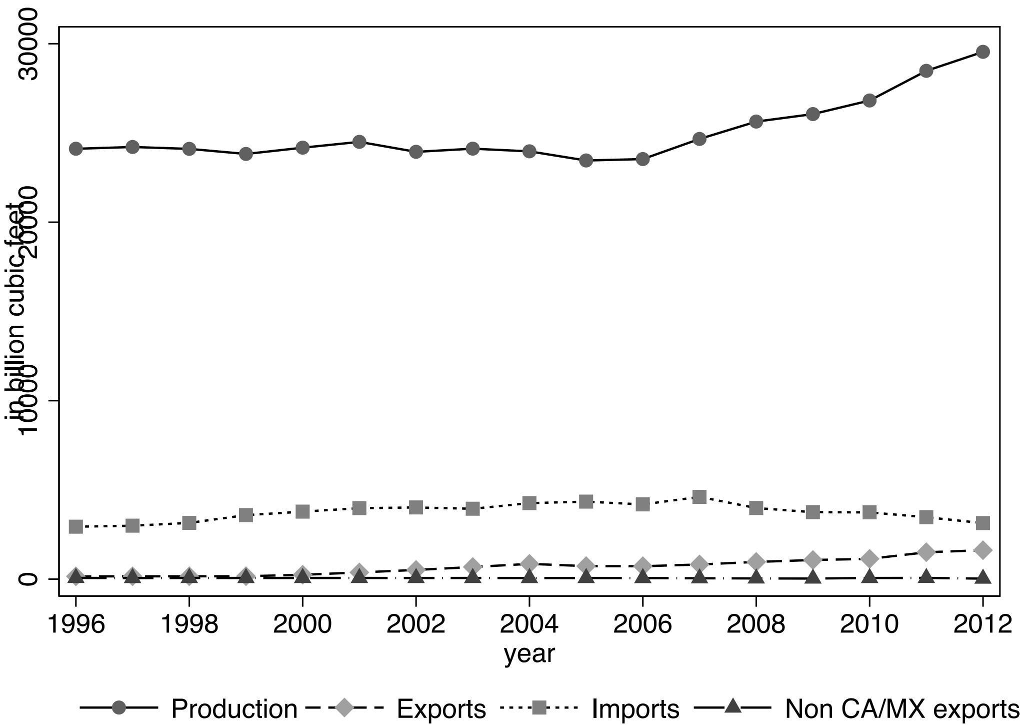


Figure 3.7: U.S. Natural Gas Production, Imports and Exports.

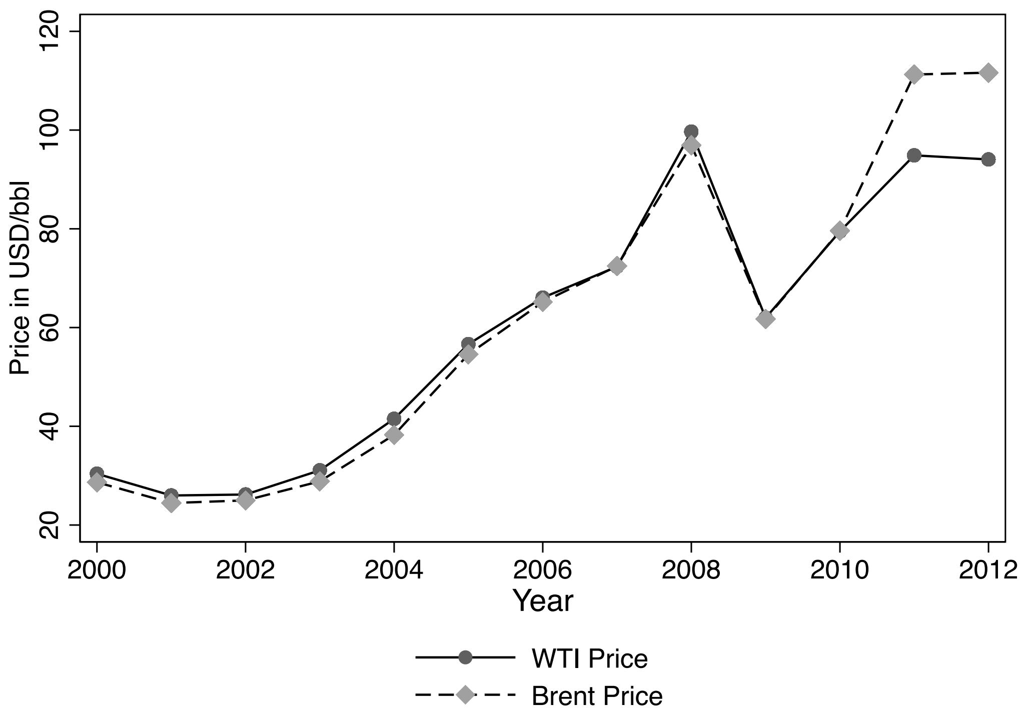
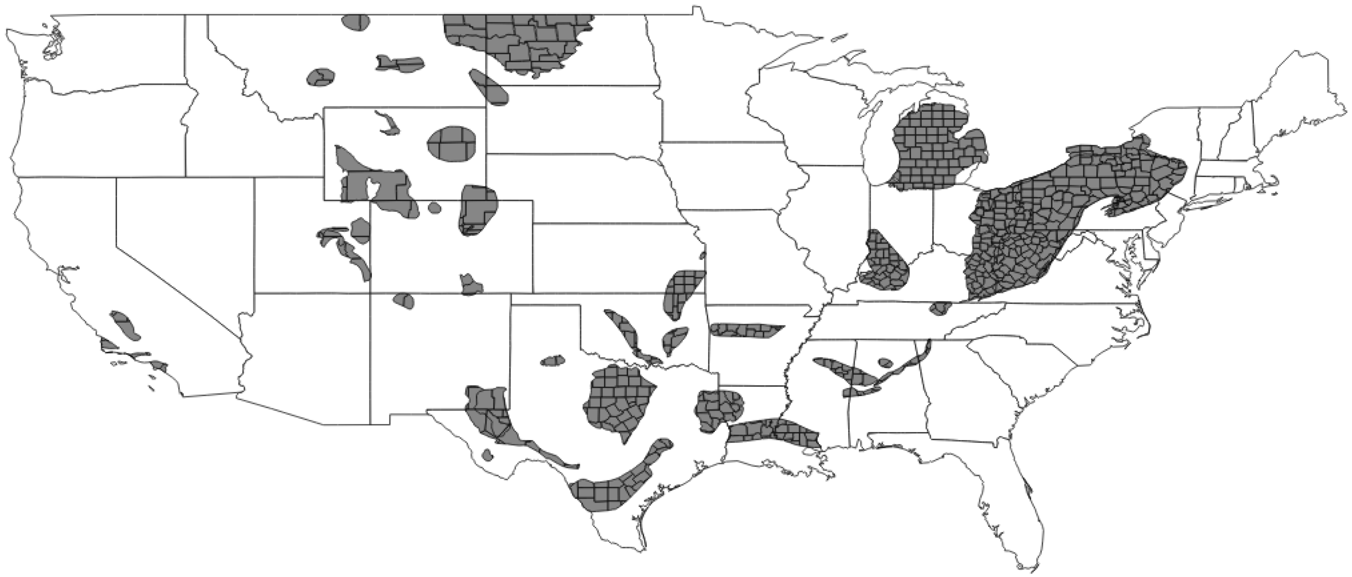


Figure 3.8: Crude Oil Prices for Brent (Europe) and WTI (US) over time.

Figure 3.9: 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 3.10: Simulations: Increase in US Energy Endowment

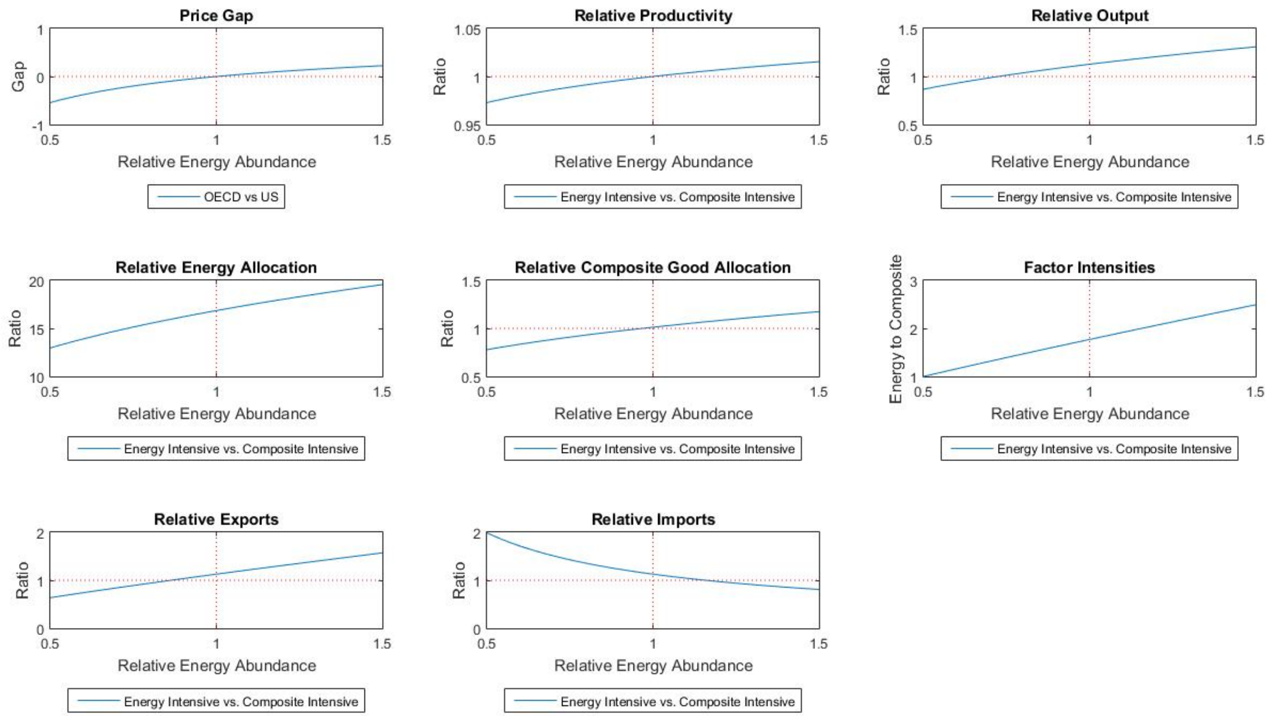
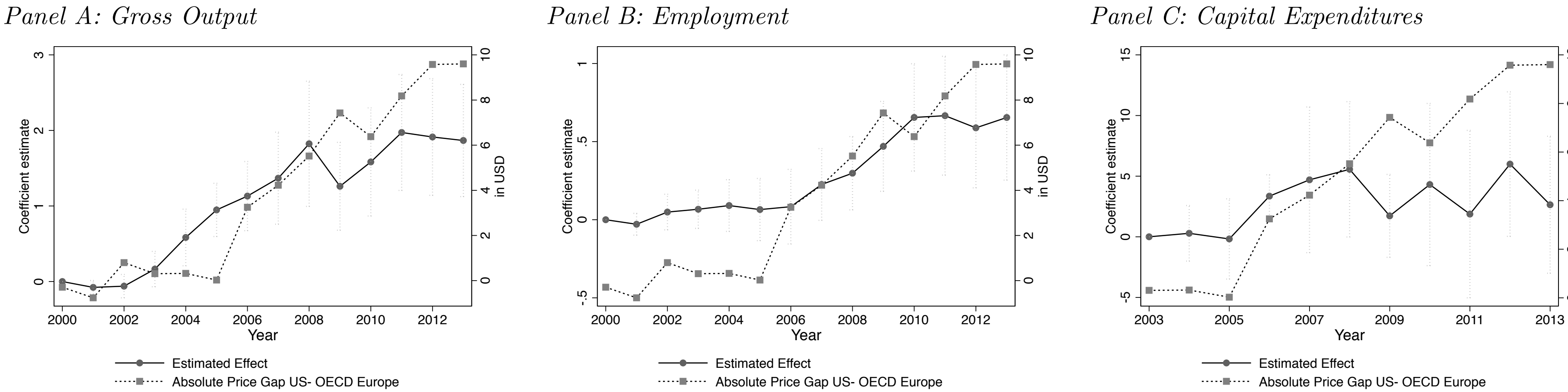


Figure 3.11: We increase the relative US energy endowment from 0.5 to 1.5 and plot our variables of interest against the ratio $(\bar{N}^{US}/\bar{L}^{US})/(\bar{N}^{OECD}/\bar{L}^{OECD})$.

Figure 3.12: Non-parametric Regressions for National Outcomes



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. 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.

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