Essays on Multinational Production and the Propagation of Shocks

by

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To my wife, for her incredible support, encouragement, patience, and love.

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CHAPTER I

Input Linkages and the Transmission of Shocks: Firm Level Evidence from the Tōhoku Earthquake

(joint with Christoph E. Boehm and Nitya Pandalai-Nayar)

Using novel firm-level microdata and leveraging a natural experiment, this paper provides causal evidence for the role of trade and multinational firms in the cross-country transmission of shocks. Foreign multinational affiliates in the U.S. exhibit substantial intermediate input linkages with their source country. The scope for these linkages to generate cross-country spillovers in the domestic market depends on the elasticity of substitution with respect to other inputs. Using the 2011 Tōhoku earthquake as an exogenous shock, we estimate this elasticity for those firms most reliant on Japanese imported inputs: the U.S. affiliates of Japanese multinationals. These firms suffered large drops in U.S. output in the months following the shock, roughly one-for-one with the drop in imports and consistent with a Leontief relationship between imported and domestic inputs. Structural estimates of the production function for these firms yield disaggregated production elasticities that are similarly low. Our results suggest that global supply chains are sufficiently rigid to play an important role in the cross-country transmission of shocks.

1.1 Introduction

The spillover effects of trade and financial linkages has been a preeminant topic in international economics in recent decades. The large expansions in trade and foreign direct investment (FDI) in the past twenty years have generated much discussion on whether they increase volatility (di Giovanni and Levchenko, 2012), increase comovement (Burstein, Kurz, and Tesar, 2008; Frankel and Rose, 1998) or lead to less diversified production and specialization (Imbs, 2004). Identifying the microfoundations underlying the role of these linkages in the increased interdependence of national economies is challenging. Advanced economies are highly connected, and most variables influenced by any candidate mechanism are often correlated with other developments in the source and destination countries. There is often little in the way of exogenous variation to isolate any particular mechanism from a host of confounding factors. Moreover, the requisite data to examine these issues at the necessary detail and disaggregation have been, until recently, unavailable.

This paper provides empirical evidence for the cross-country transmission of shocks via the rigid production linkages of multinational firms. The principal mechanism at work is not new; the idea of input-output linkages as a key channel through which shocks propagate through the economy dates back to at least Leontief (1936) or Hirschmann (1958). Two advances in this paper permit a new quantitative evaluation of the nature and magnitude of these linkages. First, we utilize a novel dataset that, for the first time, links restricted U.S. Census Bureau microdata to firms' international ownership structure. This information permits a forensic focus on particular firms and their underlying behavior. Second, we utilize the March 2011 Tōhoku earthquake and tsunami as a natural experiment of a large and exogenous shock disrupting the production linkages originating from Japan.

We study the role of imported intermediate inputs in the transmission of this shock to the United States economy. Because disruptions to imports of final goods would be unlikely to affect U.S. production, we develop a new methodology for isolating firm-level imports of intermediate inputs. We show that the U.S. affiliates of

Japanese multinationals are the most natural source of this transmission, due to their high exposure to imported intermediates from Japan. The scope for shocks to these imported inputs to pass through and affect the firm's U.S. production depends on how substitutable they are with inputs from alternative sources. In other words, the role of imported inputs in the transmission of shocks is governed by the elasticity of substitution with respect to domestic factors of production.

We estimate this elasticity using the relative magnitudes of high frequency input and output shipments in the months following the Tōhoku earthquake/tsunami. This proceeds in two steps. First, reduced form estimates corresponding to Japanese multinational affiliates on average show that output falls, without a lag, by a comparable magnitude to the drop in imports. These results suggest a near-zero elasticity of imported inputs. Second, we structurally estimate a firm-level production function that allows for substitution across different types of inputs. The structural estimation procedure we use is uniquely tailored to the experiment. In an initial period prior to the Tōhoku disruption, we infer information on the firm's productivity and optimal input mix. Then, applying this production function to the period of the disruption, we estimate the elasticity parameters based on how changes in the firm's input mix translate into changes in output.

This estimation strategy has a number of attractive features. Most importantly, it relies on very few assumptions. Direct estimation of the production function circumvents the many difficulties associated with specifying a firm's optimization problem in the period after the shock. Second, it yields transparent parameter identification. This is an advantage over traditional estimation strategies as it does not suffer from omitted variables and endogeneity concerns arising from correlated shocks. Third, it allows for the estimation across different subgroups of firms.

The structural estimates are broadly in agreement with the results from our reduced form exercise. For Japanese multinationals, the elasticity of substitution across material inputs is 0.2 and the elasticity between material inputs and a capital/labor aggregate is 0.03. For non-Japanese firms using inputs from Japan, the elasticity of substitution across material inputs is somewhat higher at 0.6. While the high cost share and particularly low elasticity for Japanese affiliates explains their predominant contribution to the direct transmission of this shock to the U.S., the elasticity estimates for non-Japanese firms are still substantially lower than typical estimates used in the literature. We argue that the substantial share of intra-firm intermediate trade implies greater complementarities in aggregate trade than is currently recognized.

There are a number of important implications for such low values of the elasticity of substitution. This parameter appears in various forms in a wide span of models involving the exchange of goods across countries. As discussed by Backus, Kehoe, and Kydland (1994) and Heathcote and Perri (2002) among others, this parameter is critically important for the behavior of these models and their ability to match key patterns of the data. Prior estimates of this parameter were based on highly aggregated data that naturally suffered from concerns about endogeneity and issues of product composition.[1] Reflecting the uncertainty of available estimates for the elasticity of substitution, it is a common practice to evaluate the behavior of these models along a wide range of parameter values.

It is well known that a low value for this parameter (interpreted as either substitution between imported and domestic goods in final consumption or as intermediates in production) improves the fit of standard IRBC models along several important dimensions. In particular, the elasticity of substitution plays a role in two highly robust failings of these models: i) a terms of trade that is not nearly as variable as the data, and ii) a consumption comovement that is significantly higher than that of output, whereas the data show the opposite relative ranking.[2]

To understand the relationship between the elasticity and comovement, it is helpful to recall that these models generate output comovement by inducing synchronization in factor supplies, a mechanism that by itself generally fails to produce the degree of comovement seen in the data. Complementarities among inputs together with het-

[1]For a very useful compendium of this research from this era, see Stern, Francis, and Schumacher (1976). More recently, work by Halpern, Koren, and Szeidl (2011) and Goldberg et al. (2010) demonstrate that materials inputs from foreign countries are imperfectly substitutable with domestic inputs for Hungary and India respectively.

[2]Due to the robust nature of these shortcomings, Backus, Kehoe, and Kydland (1995a) refer to them as the "price anomaly" and "quantity anomaly" respectively.

erogeneous input shocks will generate direct comovement in production, augmenting the output synchronization based on factor movements. Burstein, Kurz, and Tesar (2008) show that a low production elasticity of substitution between imported and domestic inputs reduces substitution following relative price movements, and thereby increases business cycle synchronization.[3] It is also relatively straightforward to see how a lower elasticity increases volatility in the terms of trade. When two inputs are highly complementary, deviations from the steady state mix are associated with large changes in their relative prices. In the words of Heathcote and Perri (2002, page 621): "greater complementarity is associated with a larger return to relative scarcity."

The estimates in this paper have implications for the role of trade in firm-level and aggregate volatility. Other research has argued that firms can diversify risk arising from country specific shocks by importing (Caselli et al. (2014)) or that firms with complex production processes of several inputs are less volatile as each input matters less for production (Koren and Tenreyro (2013)). On the other hand, there is a well-established fact that complementarities and multi-stage processing can lead to the amplification of shocks as in Jones (2011) and Kremer (1993). We discuss the potential for measured amplification in our context in Section 1.5.

This paper is also a contribution to the empirical evidence on the role of individual firms in aggregate fluctuations, emanating from the work of Gabaix (2011). Other related evidence comes from di Giovanni, Levchenko, and Méjean (2014), who use French micro-data to demonstrate that firm-level shocks contribute as much to aggregate volatility as sectoral and macroeconomic shocks combined. The so-called granularity of the economy is very much evident in our exercise; though the number of Japanese multinationals is small, they comprise a very large share of total imports from Japan, and are arguably responsible for a measurable drop in U.S. industrial production following the Tōhoku earthquake (see Figure 1.3).

The strong complementarity across material inputs implies that non-Japanese input use falls nearly proportionately, thereby propagating the shock to other upstream

[3] Although they do not estimate this parameter, the value they advocate (0.05) is indeed close to our estimates.

(and downstream) firms in both the U.S. economy and abroad. Many suppliers were thus indirectly exposed to the shock via linkages with Japanese affiliates that had i) high exposure to Japanese inputs and ii) a rigid production function with respect to other inputs. Network effects such as these can dramatically magnify the overall transmission of the shock (both across countries and within). And while such effects are commonly understood to exist, this paper provides unique empirical evidence of the central mechanisms at work.

As is the case with most research based on an event-study, some care should be taken in generalizing the results to other settings. Although we have already highlighted the aggregate implications of the effects we estimate, one might worry that the composition of Japanese trade or firms engaged in such trade is not representative of trade linkages more broadly. We believe the results we obtain are informative beyond the context of this particular episode for two reasons. First, the features of Japanese multinationals that are underlying the transmission of this shock are common to all foreign multinational affiliates in the United States.[4] Second, estimates of a low elasticity of substitution should not be particularly surprising: they correspond to firms engaged in input trade that is largely intra-firm trade embodying firm-specific knowledge and capabilities, such that one would not expect substitution with other inputs or suppliers to be easy. This type of trade accounts for a substantial share of total trade, particularly among advanced economies.

The next section describes the empirical strategy and data sources used in this paper and presents reduced form evidence in favor of a low production elasticity of imported inputs for Japanese multinational affiliates. In Section 2.2, we expand the scope of parameters we identify with a structural model of cross-country production linkages. We estimate the parameters of this model and discuss their implications. Section 1.5 discusses a number of checks and robustness exercises. The final section offers concluding thoughts.

[4]Intra-firm trade accounts for a large majority of the trade of Japanese affiliates. More generally, the intra-firm share of imported intermediates for all foreign affiliates in the U.S. is 71 percent.

1.2 Empirical Strategy and Specification

This section outlines the empirical approach of using an event-study framework surrounding the 2011 Tōhoku event to estimate the production elasticity of imported inputs. We discuss the relevant details of this shock, document the aggregate effects, and then outline the empirical specification for the firm-level analysis.

1.2.1 Background

The Tōhoku earthquake and tsunami took place off the coast of Northeast Japan on March 11, 2011. It had a devastating impact on Japan, with estimates of almost twenty thousand dead or missing (Schnell and Weinstein (2012)) and substantial destruction of physical capital. The magnitude of the earthquake was recorded at 9.0 on the moment magnitude scale (M_w), making it the fourth largest earthquake event recorded in the modern era.[5] Most of the damage and casualties were a result of the subsequent tsunami that inundated entire towns and coastal fishing villages. The effects of the tsunami were especially devastating in the Iwate, Miyagi, and Fukushima prefectures. The Japanese Meteorological Agency published estimates of wave heights as high as 7-9m (23-29ft), while the Port and Airport Research Institute (PARI) cite estimates of the maximum landfall height of between 7.9m and 13.3m (26-44ft).

Figure 1.1 shows the considerable impact of the Tōhoku event on the Japanese economy. Japanese manufacturing production fell by roughly 15 percentage points between February and March 2011, and did not return to trend levels until July. Much of the decline in economic activity resulted from significant power outages that persisted for months following damage to several power plants – most notably the Fukushima nuclear reactor.[6] Further, at least six Japanese ports (among them

[5]Since 1900, the three earthquakes of greater recorded magnitude are: the 1960 Great Chilean earthquake (magnitude 9.5), the 1964 Good Friday earthquake in Prince William Sound, Alaska (magnitude 9.2); and the 2004 Sumatra-Andaman earthquake (magnitude 9.2).

[6]For precautionary reasons, all nuclear power plants were immediately shut down following the earthquake, and remained largely offline until 2014 or later. Because the electricity infrastructure exists on two separate grids (a 60Hz to the south and west, and 50Hz to the north and east), the reduction in power supply in Northeast Japan was not easily remedied, and power outages persisted

the Hachinohe, Sendai, Ishinomaki and Onahama) sustained significant damage and were out of operation for more than a month, delaying shipments to both foreign and domestic locations. It should be noted, however, that the largest Japanese ports (Yokohama, Tokyo, Kobe) which account for the considerable majority of Japanese trade, re-opened only days after the event.

As expected, the economic impact of the event was reflected in international trade statistics, including exports to the United States. Figure 1.2 plots U.S. imports from Japan around the period of the Tōhoku event, with imports from the rest of the world for comparison. The large fall in imports occurs during the month of April 2011, reflecting the several weeks of transit time for container vessels to cross the Pacific Ocean. The magnitude of this drop in imports is roughly similar to that of Japanese manufacturing production: a 20 percentage point drop from March to April, with a full recovery by July 2011.

More striking is the response of U.S. industrial production in the months following the event. Figure 1.3 demonstrates that there is indeed a drop in U.S. manufacturing production in the months following the Japanese earthquake. Although the magnitudes are obviously much smaller — roughly a one percentage point drop in total manufacturing and almost two percentage points in durable goods — the existence of a measurable effect is clear.[7]

Though tragic, the Tōhoku event provides a glimpse into the cross-country spillovers following an exogenous supply shock. This natural experiment features many characteristics that are advantageous for this type of study. It was large and hence measurable, unexpected, and directly affected only one country. The shock was also short-lived, which rules out immediate supplier restructuring and allows for an estimate of the elasticity for a given supply chain.[8] On the other hand, the short duration of the shock presents a challenge for measurement as it limits the available datasets with information at the required frequency. We utilize a novel firm-level dataset to

for months.

[7]At the level of total U.S. GDP, both Deutsche Bank and Goldman Sachs revised 2nd quarter U.S. estimates down by 50 basis points explicitly due to the events in Japan.

[8]It also rules out large balance sheet effects that would make differential credit conditions an operative feature.

uncover the mechanisms at work behind the transmission of this shock.

1.2.2 Data

Several restricted-use Census Bureau datasets form the core of our firm-level analysis. The Longitudinal Business Database (LBD) collects the employment, payroll, and major industry of all establishments operating in the United States, and is maintained and updated as described by Jarmin and Miranda (2002). Longitudinal linkages allow the researcher to follow the establishment over time, and the annual Company Organization Survey (COS) provides a mapping from establishments to firms. All of the analysis in this paper will be at the firm-level.

An important component comes from the Longitudinal Foreign Trade Transactions Database (LFTTD), which links individual trade transactions to firms operating in the United States. Assembled by a collaboration between the U.S. Census Bureau and the U.S. Customs Bureau, the LFTTD contains information on the destination (or source) country, quantity and value shipped, the transport mode, and other details from point-of-trade administrative documents. Importantly for this study, the LFTTD includes import and export trade transactions at a *daily* frequency, which is easily aggregated to monthly-level trade flows. A number of important papers have utilized this resource, such as Bernard et al. (2007) and Bernard, Jensen, and Schott (2006).

We utilize two novel extensions to this set of Census data products. First, a new link between a set of international corporate directories and the Business Register (BR) of the Census Bureau provides information on the international affiliates of firms operating in the United States. These directories provide information, for the first time, to identify those U.S. affiliates part of a foreign parent company, as well as those U.S. firms with affiliate operations abroad. This information is a critical resource for identifying the characteristics of U.S. firms affected by the Tōhoku event. For information on these directories and the linking procedure used, please see Flaaen (2013b) and Appendix B.1.

The second novel data resource is a system to classify firm-level import transactions based on the expected use of the products. Although intermediate input trade represents as much as two-thirds of total trade (see Johnson and Noguera (2012)), the LFTTD does not classify a trade transaction based on its intended use. To overcome this limitation, we use information on the products produced by U.S. establishments in a given industry to identify the set of products intended for final sale *for that industry*.[9] The remaining products are presumably used by establishments in that industry either as intermediate inputs or as capital investment. Details on this classification procedure are available in Appendix C.1. In the aggregate, this firm-level classification procedure yields estimates of the intermediate share of trade that are consistent with prior estimates: 64 percent of manufacturing imports are classified as "intermediates" in 2007.

Finally, we utilize geographic information on the severity of the earthquake/tsunami that is compiled by the U.S. Geological Survey (USGS). By geocoding the Japanese addresses of firms with U.S. operations, we construct an earthquake intensity measure for each Japanese affiliate location. We then apply such information to the U.S. operations as a way to further measure the sample of firms plausibly affected by the shock. Please see Appendix D.1.2 for details. Figure 1.4 shows the geographic distribution of one such USGS measure — the modified mercalli index (MMI) — along with the geocoded affiliate locations.

The ideal dataset to evaluate the transmission of the Tōhoku event on U.S. firms would consist of high frequency information on production, material inputs, and trade, separated out by geographic and ownership criteria. Unfortunately, Census data on production and material inputs at the firm-level is somewhat limited. The Annual Survey of Manufacturers (ASM) contains such information, but at an annual frequency and only for a subset of manufacturing firms. On the other hand, firm-level trade information is available at a nearly daily frequency, and covers the universe of firms engaged in exporting/importing. For the purposes of characterizing the shock to firm-level imports of intermediate goods, the LFTTD (and supplements identified

[9] Note that products intended for final sale for a given industry may still be used as intermediates for other firms in a different industry. Alternatively, such "final goods" can be sold directly to consumers for ultimate consumption.

above) is ideal. There remain significant gaps in information on a firm's domestic input usage, a limitation we discuss in subsequent sections.

Because of the challenges of high-frequency information on firms' U.S. production, we utilize a proxy based on the LFTTD — namely the firm's exports of goods to North America (Canada and Mexico). The underlying assumption of this proxy is that all firms export a fixed fraction of their U.S. output to neighboring countries in each period. The advantage of this approach is the ability to capture the flow of goods at a specific point in time. There are few barriers to North American trade, and transport time is relatively short. Moreover, as documented in Flaaen (2013b), exporting is a common feature of these firms, of which exports to North America is by far the largest component. The obvious disadvantage of this approach is that it conditions on a positive trading relationship between firms in the U.S. and Canada/Mexico. We will assess the quality of this measure as a proxy for output in section 1.5.2.1.[10]

1.2.3 Basic Theory

Before moving to our firm-level analysis, it is useful to describe the basic theoretical structure of the features of firm-level production that we estimate. The transmission of shocks within a firm's production chain is governed by the flexibility of production with respect to input sourcing. Rather than model these complex networks directly, the literature typically summarizes this feature with the well-known elasticity of substitution within a C.E.S. production function. Our identification of this elasticity will rely on the relative impacts on output and imported inputs following the shock. To be concrete, consider the C.E.S. production function

$$x = \left[(1-\mu)^{\frac{1}{\psi}} \left[F_D \right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM \right]^{\frac{\psi-1}{\psi}} \right]^{\frac{\psi}{\psi-1}} \tag{1.1}$$

[10] Another consideration with the use of this proxy is whether it more accurately reflects production or sales, as the two are distinct in the presence of output inventories. In our case, this depends on whether the inventories are held in the U.S. or Canada/Mexico. Without further evidence, we interpret the proxy to be capturing some mix between production and sales. The structural estimation in section 2.2 will allow for such a mix.

where output consists of combining a domestic bundle of factors F_D (e.g. capital and labor) with a foreign imported input IM. The parameter μ reflects the relative weight on the input IM in production, conditional on prices and a given elasticity value. Suppose the firm purchases its inputs in competitive markets with prices p_D and p_M, respectively, and sells its good at price p_x. Our approach in this section will be to estimate the parameter ψ governing the degree of substitution between these inputs, using information on the output elasticity with respect to imported inputs, $\frac{\partial \ln p_x x}{\partial \ln p_M M}$, in the months following the shock.

The first order conditions imply that

$$\frac{F_D^*}{IM^*} = \frac{1-\mu}{\mu}\left(\frac{p_M}{p_D}\right)^{\psi}, \tag{1.2}$$

where F_D^* and IM^* denote the optimal quantities of inputs. We would like to show the theoretical foundations underlying the intuitive result that a one-for-one drop in output with the fall in imported inputs implies an elasticity of zero. To do this, we make the following assumptions, all of which we will relax to some degree in the estimation framework in Section 2.2:

1. Imported inputs shipments are disrupted, such that the firm receives a suboptimally low quantity of IM: $IM < IM^*$;
2. The firm is unable to adjust domestic inputs F_D^* or its price p_x after learning that it receives IM;
3. The firm does not shut down.

Given these assumptions, the following result holds:

Result 1. *Under assumptions 1) to 3):*

$$\frac{\partial \ln p_x x}{\partial \ln p_M IM} = \frac{1}{1+\left(\frac{IM^*}{IM}\right)^{\frac{\psi-1}{\psi}}\left(\frac{1-\mu}{\mu}\right)\left(\frac{p_M}{p_D}\right)^{\psi-1}} \in (0,1) \tag{1.3}$$

for any $\psi \in (0,\infty)$.

Proof. See Appendix A.1.1 for details. □

An immediate implication of this result is that the output elasticity is unity only when ψ approaches zero.[11] In this case $\left(\frac{IM^*}{IM}\right)^{\frac{\psi-1}{\psi}} \to 0$ (recall that $IM < IM^*$) and hence $\lim_{\psi\to 0} \frac{\partial \ln p_x x}{\partial \ln p_M IM} = 1$. Hence, observing a one-for-one drop in the value of output with the value of imported intermediates, we infer that ψ is close to zero. It is also straightforward to show that conditional on a value for $\psi \in (0, \infty)$, the output elasticity in (1.3) is increasing in the parameter μ. That is, conditional on a given drop in the imported input, a larger weight on this input leads to a larger percent response in output.

Our use of the natural experiment is critical for observing the effects of suboptimal input combinations (F_D^*, IM). To see this, suppose the firm could freely adjust F_D after learning it will receive $IM < IM^*$. Then, it would choose F_D such that $\frac{F_D}{IM} = \frac{F_D^*}{IM^*}$ and the firm would contract one-for-one with the drop in imports. It is a well-known fact that constant returns to scale production functions in competitive environments lead to indeterminate firm size. This has the implication that:

$$\frac{\partial \ln (p_x x)}{\partial \ln (p_M IM)} = \frac{\partial \ln (p_x x)}{\partial \ln (p_D F_D)} = \frac{\partial \ln (p_D F_D)}{\partial \ln (p_M IM)} = 1. \tag{1.4}$$

In this case it is not possible to learn anything about ψ from the joint behavior of output and the value of intermediate inputs. We provide evidence below that firms did not significantly adjust their domestic labor force following the disruption, so that a constant F_D is indeed a reasonable assumption in this simple framework. To be sure, there are a number of alternative frameworks where such behavior would not hold. We discuss some of these in Appendix A, and show that the mapping $\lim_{\psi\to 0} \frac{\partial \ln p_x x}{\partial \ln p_M IM} = 1$ is more general.

[11] There is a second case which we do not examine, where $\psi \to \infty$ and $p_M < p_D$ and thus the firm only uses IM. We discard this scenario because such a firm would not show up in our data (i.e. this case implies zero U.S. employment).

1.3 Reduced Form Evidence

This section will provide intuitive reduced-form evidence on the elasticity of substitution corresponding to the U.S. affiliates of Japanese multinationals. We discuss our strategy for understanding this elasticity via firm-behavior in the months following the Tōhoku event, and then report the results.

1.3.1 Framework

Our analysis of the production function (1.1) above demonstrates that a natural measure to evaluate the potential conduits of the Tōhoku shock to the United States would be the degree of reliance on Japanese imported inputs. This is best expressed as the cost share of inputs from Japan, and can be constructed in a Census year by taking a firm's Japanese imported inputs and dividing by all other inputs (which includes production worker wages and salaries, the cost of materials, and the cost of new machinery expenditures). Exposure to Japanese imported inputs is heavily concentrated among Japanese affiliates. In the year 2007, which is the closest available Census year, this cost share was nearly 22% on average for Japanese affiliates (see Table 1.1), compared to just 1% for other firms. For more detail on the heterogeneity across and within these firm groups, we construct a density estimate of such an exposure measure for the Japanese affiliates and non-Japanese multinationals. The results, shown in Figure 1.5, show little overlap between these distributions: there are few Japanese affiliates with low exposure to Japanese inputs, and few non-Japanese firms have substantial exposure.[12]

We now estimate the relative impacts on imported inputs and output for the Japanese affiliates as a group. To do this, we implement a dynamic treatment effects specification in which a firm is defined as being treated if it is owned by a Japanese parent company.[13] The effect on these firms can be inferred from the differential

[12] The exposure measure used in Figure 1.5 is from 2010 and does not include the cost of domestic material usage.

[13] We could have also used a threshold of Japanese input usage for the classification of treatment status. Doing so yields estimates that are very similar, which is due to the patterns evident in Figure 1.5. We have also tried conditioning on our geographic information (i.e. the firm-level Japanese MMI

impact of the variable of interest relative to a control group, which soaks up common seasonal patterns and other demand-driven factors in the U.S. market. While there are a number of competing methodologies for this type of estimation, we use normalized propensity score re-weighting due to the relatively favorable finite-sample properties as discussed in Busso, DiNardo, and McCrary (2014), as well as for its transparent intuition. Consistent estimation of the average treatment effect on the treated requires the assumption of conditional independence: the treatment/control allocation is independent of potential outcomes conditional on a set of variables. As the average Japanese firm differs considerably from other firms in the data, we use other multinational firms – both US and non-Japanese foreign- as our baseline control group prior to reweighting. To compute the propensity scores for reweighting, we control for size and industry, which ensures the control group has a similar industrial composition and size distribution as our treated sample.[14] Table 1.2 reports summary values for the sample, including statistics on the balancing procedure using the normalized propensity score.

The magnitude of the shock for a representative Japanese multinational is captured by the effect on total imported intermediate products at a monthly frequency.[15] Including non-Japanese imported intermediates is important for applying the control group as a counterfactual, and the shares by source-country gives the necessary variation for identification: as shown in Table 1.2 the share of imported inputs from Japan is 70% of the total for Japanese firms and only 3.5% for non-Japanese multinationals. Let $V_{i,t}^M$ be the value of intermediate imports of firm i in month t, after removing a firm-specific linear trend through March 2011. We fit the following regression:

$$V_{i,t}^M = \alpha_i + \sum_{p=-4}^{9} \gamma_p E_p + \sum_{p=-4}^{9} \beta_p E_p \text{JPN}_{i,p} + u_{i,t} \tag{1.5}$$

index) in defining a Japanese firm as being treated. The results are largely unchanged from those we report here, and for the sake of clarity we report results pertaining to the full sample.

[14]Using the predicted values (p) from the first stage regression, the inverse probability weights are $\frac{1}{1-p}$ for the control group and $\frac{1}{p}$ for the treated group. To normalize the weights such that the treated firms have weights equal to one, we then multiply each set of weights by p.

[15]We consider Japanese and non-Japanese intermediate imports separately in section 2.2.

where α_i are firm fixed-effects, γ_p are monthly fixed effects (with the indicator variables E_p corresponding to the calendar-months surrounding the event), and $u_{i,t}$ is an error term. The baseline sample will consist of January 2009 to December 2011. We denote March 2011 as t=0.

The β_p coefficients are of primary interest. The $\text{JPN}_{i,t}$ is an indicator variable equal to one if the firm is owned by a Japanese parent company. Interacting these indicator variables with each month of the panel allows for a time-varying effect of Japanese ownership on a firm's overall intermediate input imports, particularly during and after the Tōhoku event. The β_p coefficients will estimate the differential effect of the Tōhoku event on Japanese multinational affiliates in the U.S., compared to the control group of non-Japanese firms. To evaluate the differential impact on production for Japanese firms, we simply replace the dependent variable in equation (1.5) with the firm's North American exports, denoted $V_{i,t}^{NA}$.

It is important to highlight that the specification in (1.5) is in levels. There are several reasons for doing so, as opposed to using log differences or growth rates. First, allowing for the presence of zeros is important when the data are at a monthly frequency, particularly given the magnitude of the shock to imports for Japanese firms. The second reason is more conceptual. Because we are interested in calculating the average effect of these firms that represents (and can scale up to) the aggregate impact on the U.S. economy, it is appropriate to weight the firms based on their relative size. The levels specification does exactly this: the absolute deviations from trend will be greater for the bigger firms and hence will contribute disproportionately to the coefficient estimates.[16] In section 2.2, we evaluate this framework with the results one would obtain when estimating the effect on a firm-by-firm basis.

In addition to the Conditional Independence Assumption highlighted earlier, the β_p coefficients are valid estimates of the mean effect for Japanese affiliates only in so far as the control group is not itself impacted by the shock. This Stable Unit Treatment Value Assumption (SUTVA) implies that general equilibrium effects or

[16]See Appendix E.1.1 for more discussion, as well as results obtained using other specifications. Importantly, in a reduced sample abstracting from zeros, a weighted regression using percentage changes directly yields estimates that are very close to those presented here.

peer effects (e.g. strategic interaction) do not meaningfully effect the estimates. The share of imported inputs from Japan is low for the control group, and thus the shock is unlikely to have a measurable effect on imported inputs as a whole. We discuss strategic interaction in section 1.5.2.4.

1.3.2 Results: Total Manufacturing Sector

The top panel of Figure 1.6 plots the β_p coefficients from equation (1.5) for the months surrounding the Tōhoku event. Relative to the control group, there is a large drop in total intermediate input imports by Japanese firms in the months following the earthquake. The drop in intermediate inputs bottoms out at 4 million USD in $t = 3$ (June 2011) and the point estimates do not return back to the pre-shock trend until month $t = 7$ (October 2011).

More interesting are the results from panel B of Figure 1.6, which looks for evidence of the production/sales impact of this shock on Japanese firms via their North American exports. The differential time-path of N.A. exports also exhibits a substantial drop following the Tōhoku event, hitting a trough of 2 million USD below baseline in $t = 2$ (May 2011). The standard errors, which are clustered at the firm level, are themselves interesting. As made clear via the 95-percent confidence bands on the point estimates of Figure 1.6, the standard errors increase dramatically in the months following the shock, a feature we interpret to reflect heterogeneous incidence and timing of the shocks (as well as the recoveries) for the Japanese multinationals.

To gain a sense of the average percentage drops of these two data series for Japanese multinationals as a group, we take the two plots of the differential dollar amounts from Figure 1.6 and divide by the average pre-shock level for these firms (see Table 1.2). The results, plotted jointly in Figure 2.1, show the fraction below pre-shock trend levels for these firms, on average. There is a remarkable correlation between these two series – whereby there is essentially a one-for-one drop in output for a given drop in intermediate imports. Using the mapping from Result 1, these reduced form results suggest a production function that is essentially Leontief in the imported input.

One potential concern with the interpretation of these results is separating out the intermediate input channel with other channels, such as a direct "productivity shock" affecting the U.S. operations of Japanese affiliates. Separating an ownership channel from an imported input channel is difficult due to lack of substantial overlap we identified above: few Japanese firms have low input exposure and few non-Japanese firms have high input exposure. Nevertheless, to get a sense of the defining characteristics, we construct a simple probit model of a disruption in Japanese inputs and U.S. output:

$$Pr(X_{ik}^D = 1) = \Phi\left[\beta_1 \mathrm{JPN}_{ik} + \beta_2 Exposed_{ik} + \beta_3 MMI_{ik} + \beta_4 Port_{ik} + \gamma_k\right] \qquad (1.6)$$

where the dependent variable (X_{ik}^D) is an indicator equal to one if the N.A. exports of firm i in industry k are on average 20% below trend during the five months following the Tōhoku event. The independent variables are also indicators: $\mathrm{JPN}_{\mathrm{ik}}$, for affiliates of Japanese multinationals; $Exposed_{ik}$, for firms with an exposure to Japanese inputs above 0.05 of total material; MMI_{ik} for firms with an elevated MMI value pertaining to their average Japanese manufacturing locations; and $Port_{ik}$ for firms that typically rely on imports via ports damaged by the tsunami.[17] The γ_k term allows for industry-specific intercepts. To evaluate the determinants of an input disruption from Japan, we replace the dependent variable with J_{ik}^D, an indicator for a drop in Japanese imported inputs of 20% relative to trend.

Panel A of Table 1.3 evaluates firm characteristics predicting a drop in U.S. output (X_{ik}^D), as measured by our proxy. The columns (1)-(4) show the results from different specifications with various combinations of the covariates in equation (1.6). Both Japanese ownership and high exposure to Japanese inputs significantly increase the probability of an output disruption, as expected. In columns (3) and (4), we demonstrate that Japanese ownership is substantially more indicative of an output decline than high input exposure alone. In Panel B, we replace the dependent vari-

[17] Specifically, the $MMI_{ik} = 1$ if the average Japanese manufacturing establishment corresponding to a U.S. firm is above the median (roughly an MMI of 5.2) of all firms with Japanese manufacturing locations. The affected ports are: Onahama, Hitachi, Kashima, Haramachi, Shiogama, Sendai, Shimizu, Ishinomaki, Hashinohe, Miya Ko, Kamaishi, Ofunato, and Kessennuma.

able with the binary measure of a drop in Japanese intermediate inputs (J_i^D). The results from these regressions indicate, unsurprisingly, that high exposure to Japanese imports are highly predictive of a subsequent disruption following the Tōhoku event. Apart from their exposure to imports from Japan, the Japanese affiliates are no more likely to suffer a disruption to these imports (see column 8).[18] While the results from Table 1.3 are somewhat inconclusive, they nevertheless point to unique features of the production function of Japanese affiliates that yields direct pass-through of Japanese shocks to the U.S. economy. Our estimation procedure that follows should help to clarify this point further.

1.4 Structural Estimation of Cross Country Input Linkages

The relative movements of imported inputs and output of Japanese multinational firms point to little substitutability of Japanese intermediate inputs. In this section we expand our analysis by structurally estimating the production function of firms affected by the Tōhoku shock. We do this for three reasons. First, it is reassuring to find elasticities that are consistent with the heuristic evidence implied by our reduced-form results, when imposing a conventional production function framework. Second, by imposing additional structure, we are able to distinguish two elasticities: one between Japanese material inputs and other material inputs, and another between an aggregate bundle of material inputs and domestic capital and labor. Finally, by using an estimation procedure not relying on a control group we can obtain separate estimates for Japanese and non-Japanese firms. The results corroborate the claim that the supply chains of Japanese and non-Japanese exhibit different degrees of rigidity.

The estimation procedure will utilize information from two distinct periods: the six months preceding and the six months following the March 11 event. The pre-period, which we denote by $\tau - 1$, yields information on the production function of the firm under profit-maximizing conditions. In the post-period, denoted τ, we do not

[18]The combined effect of the coefficients on Japan and JPN*Exp is -0.16, and not significant.

impose that the firm is optimizing over its input use, due to the fact that shipments from Japan are to some extent beyond the control of the firm.

1.4.1 Framework

We assume that the firm's technology in any period t is given by the nested CES aggregate

$$x_{i,t} = \phi_i \left[\mu_i^{\frac{1}{\zeta}} \left(K_{i,t}^{\alpha} L_{i,t}^{1-\alpha} \right)^{\frac{\zeta-1}{\zeta}} + (1-\mu_i)^{\frac{1}{\zeta}} M_{i,t}^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}}, \tag{1.7}$$

where

$$M_{i,t} = \left(\nu_i^{\frac{1}{\omega}} \left(m_{i,t}^{-J} \right)^{\frac{\omega-1}{\omega}} + (1-\nu_i)^{\frac{1}{\omega}} \left(m_{i,t}^{J} \right)^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}}. \tag{1.8}$$

In this production function $x_{i,t}$, $K_{i,t}$, and $L_{i,t}$ denote the output, capital, and labor of firm i. The variable $M_{i,t}$ denotes an aggregate of intermediate inputs consisting of materials sourced from Japan ($m_{i,t}^{J}$) and materials sourced from all places other than Japan ($m_{i,t}^{-J}$), including domestic materials. We are interested in estimating ω and ζ, which parameterize the substitutability between Japanese and non-Japanese materials and that between the capital-labor aggregate and the aggregate of intermediate inputs. The parameters μ_i and ν_i are firm-specific weights and ϕ_i parameterizes the firm's productivity, all of which we assume are constant over the short time horizon we consider. Further, we assume that the firm is monopolistically competitive and faces a CES demand function

$$p_{i,t}^{x} = \left(\frac{Y_{i,t}}{x_{i,t}} \right)^{\frac{1}{\varepsilon}}. \tag{1.9}$$

As usual, $Y_{i,t}$ is the bundle used or consumed downstream and serves as a demand shifter beyond the control of the firm.

1.4.1.1 Pre-Tsunami period

Period τ corresponds to the period April-September 2011, and $\tau - 1$ the period September 2010 - February 2011. We exclude the month of March 2011. In period $\tau-1$ the firm operates in a standard environment, choosing capital, labor, and materials so as to maximize

$$p^x_{i,\tau-1}x_{i,\tau-1} - w_{\tau-1}L_{i,\tau-1} - R_{\tau-1}K_{i,\tau-1} - p^{-J}_{i,\tau-1}m^{-J}_{i,\tau-1} - p^J_{i,\tau-1}m^J_{i,\tau-1}$$

subject to (1.7), (1.8), and (1.9). The firm takes all factor prices as given. Material prices $p^J_{i,\tau-1}$ and $p^{-J}_{i,\tau-1}$ are firm-specific to indicate that different firms use different materials.

It is straightforward to show that this optimization problem implies

$$K_{i,\tau-1} = \frac{\alpha}{1-\alpha}\frac{w_{\tau-1}L_{i,\tau-1}}{R_{\tau-1}}, \tag{1.10}$$

$$\nu_i = \frac{\left(p^{-J}_{i,\tau-1}\right)^\omega m^{-J}_{i,\tau-1}}{\left(p^J_{i,\tau-1}\right)^\omega m^J_{i,\tau-1} + \left(p^{-J}_{i,\tau-1}\right)^\omega m^{-J}_{i,\tau-1}}, \tag{1.11}$$

$$\mu_i = \frac{\left(\left(\frac{R_{\tau-1}}{\alpha}\right)^\alpha \left(\frac{w_{\tau-1}}{1-\alpha}\right)^{1-\alpha}\right)^\zeta K^\alpha_{i,\tau-1}L^{1-\alpha}_{i,\tau-1}}{\left(P^M_{i,\tau-1}\right)^\zeta M_{i,\tau-1} + \left(\left(\frac{R_{\tau-1}}{\alpha}\right)^\alpha \left(\frac{w_{\tau-1}}{1-\alpha}\right)^{1-\alpha}\right)^\zeta K^\alpha_{i,\tau-1}L^{1-\alpha}_{i,\tau-1}}, \tag{1.12}$$

where

$$P^M_{i,\tau-1} = \left[\nu_i \left(p^{-J}_{i,\tau-1}\right)^{1-\omega} + (1-\nu_i)\left(p^J_{i,\tau-1}\right)^{1-\omega}\right]^{\frac{1}{1-\omega}}.$$

We will use these relationships in the structural estimation that follows below.

1.4.1.2 Post-Tsunami period

At the beginning of period τ many firms' production processes in Japan are disrupted. Obtaining the desired amount of shipments of materials from Japan may either be prohibitively expensive or simply impossible. Modeling firm behavior in this environment therefore requires modifications to the previous setup. One possibility is to assume that the quantity of materials that firms obtain from Japan is exogenous and that firms freely choose non-Japanese materials, capital and labor. This option is unattractive for two reasons. First, due to existing contracts it is unlikely that a firm is able to adjust the quantities of non-Japanese materials, capital, and labor without costs in such a short time frame. One remedy would be to add adjustment costs to the model. Although straightforward, this approach would require us to estimate additional parameters. Second, and more importantly, the materials sourced from Japan ($m^J_{i,t}$) may not be exogenous for *every* firm. Some suppliers in Japan may have been unaffected by the earthquake and tsunami such that materials could be shipped as desired. Hence, using this approach would require us to distinguish between firms whose supply chains are disrupted and those whose are not. That is, we would have to classify firms based on an endogenous outcome.

For these reasons we prefer an alternative approach, namely to estimate the production function without specifying the full optimization problem. We only assume that in period τ, firms operate the same technologies given by (1.7) and (1.8), and that no firm adjusts its capital stock such that $K_{i,\tau} = K_{i,\tau-1}$. Conditional on knowing the time-invariant features of the production function (ϕ_i, μ_i, ν_i), we next describe an estimation procedure that allows us to find the elasticity parameters most consistent with the observed input choices and output evident in the data.

1.4.2 Estimation

Recall that we use North American exports as a proxy for a firm's output $p^x_{i,t}x_{i,t}$, with the underlying assumption that the former is proportional to the latter. We continue here in the same spirit, though we now make this assumption explicit. Let $V^{NA}_{i,t}$ be the value of North American exports at time t and define

$$\kappa_i = \frac{V^{NA}_{i,\tau-1}}{p^x_{i,\tau-1}x_{i,\tau-1}}. \qquad (1.13)$$

In words, κ_i is the fraction of firm i's shipments exported to Canada and Mexico in the six months preceding the tsunami. We next make two assumptions that allow us to construct an estimation equation. First, we assume that a relationship analogous to (1.13) continues to hold in period τ, except for a log-additive error $u_{i,\tau}$. That is,

$$\ln V^{NA}_{i,\tau} = \ln \kappa_i p^x_{i,\tau} x_{i,\tau} + u_{i,\tau}. \qquad (1.14)$$

The second assumption is that $\mathbb{E}\left[u_{i,\tau}|X_i\right] = 0$ where X_i is a vector of all right-hand-side variables. Setting the conditional mean of $u_{i,\tau}$ to zero is a standard exogeneity assumption requiring that, loosely speaking, the error is uncorrelated with all right-hand-side variables. It rules out, for example, that in response to a fall in Japanese intermediate imports firms export a fraction of their shipments to Canada and Mexico that systematically differs from κ_i. We provide evidence in section 1.5.2.1 that demonstrates that this is a reasonable assumption.

Using equation (1.7) we can rewrite (1.14) as

$$\ln\left(V_{i,\tau}^{NA}\right) = \ln\left(\kappa_i\phi_i\right) + \ln\left(p_{i,\tau}^{x}\left[\mu_i^{\frac{1}{\zeta}}\left(K_{i,\tau}^{\alpha}L_{i,\tau}^{1-\alpha}\right)^{\frac{\zeta-1}{\zeta}} + \left(1-\mu_i\right)^{\frac{1}{\zeta}}\left(M_{i,\tau}\right)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}}\right) + u_{i,\tau}. \tag{1.15}$$

Values for ν_i and μ_i are obtained from equations (1.11) and (1.12).[19] Using (1.13), the intercept can be constructed from the previous period

$$\kappa_i\phi_i = \frac{V_{i,\tau-1}^{NA}}{p_{i,\tau-1}^{x}\left[\mu_i^{\frac{1}{\zeta}}\left(K_{i,\tau-1}^{\alpha}L_{i,\tau-1}^{1-\alpha}\right)^{\frac{\zeta-1}{\zeta}} + \left(1-\mu_i\right)^{\frac{1}{\zeta}}\left(M_{i,\tau-1}\right)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}}}.$$

Notice that κ_i and ϕ_i are not separately identified. Under standard assumptions, we can consistently estimate equation (1.15) using, e.g., nonlinear least squares. The only parameters to calibrate are the rental rate of capital R_τ and the capital share in the capital/labor aggregate α. We estimate the two elasticities, ζ and ω. Notice that ω appears in the intermediate aggregate $M_{i,\tau}$ as shown in equation (1.8). The estimates $(\hat{\zeta},\, \hat{\omega})$ solve $\min_{\{\zeta,\omega\}} \sum_{i=1}^{N} (u_{i,\tau})^2$.

Why do we restrict the sample to the year surrounding the Tōhoku event? To understand this, recall that the principal difficulty of estimating production functions lies in unobserved inputs and productivity. Since both are unobserved by the econometrician, they are absorbed into the error term. However, because they are known to the firm, other input choices depend on them. Hence, right-hand-side variables

[19] After constructing μ_i according to equation (1.12) we average by industry to reduce the level of noise.

and the error term will generally be correlated, rendering estimates inconsistent.[20]

By restricting the sample period to a single year, the assumption of constant firm productivity seems appropriate. If productivity is constant, it cannot be correlated with the error term, thereby ruling out one of the concerns.[21] The fact that the Tōhoku event was an unexpected shock negates much of the concern about endogeneity arising from unobserved inputs. To see why, consider the case when the firm anticipates a supply chain disruption in a future period. Firm adjustment of unobserved inputs in expectation of this shock will impact input choices – leading to an endogeneity problem where inputs are correlated with the shock. Put simply, the unexpected nature of the Tōhoku event works towards equalizing the information sets between the econometrician and the firm because factor choices are not affected prior to the shock being realized.[22]

Before turning to the data we briefly discuss the intuition of parameter identification. Unlike other approaches to estimating elasticities of substitution (e.g. Feenstra et al. (2014)), our method does not rely on the response of relative values to a change in relative prices.[23] In fact, in an econometric sense, our approach treats all inputs as *independent* variables.

A simple example illustrates how the parameters are identified. Consider the production function (1.7) and suppose that, for a particular firm, the initial period yields a value of $(1 - \mu) = 0.4$. The elasticity ζ determines how deviations from this measure of the optimal input mix between the intermediate aggregate $M_{i,\tau}$ and the capital labor aggregate translate into measured output. Thus, if we observe comparatively fewer intermediates $M_{i,\tau}$, reflecting a different mix of inputs than that given by 0.4, we obtain an elasticity estimate for ζ that best matches the response in output. Because the estimates for μ, ν, and $\kappa_i\phi_i$ are themselves functions of the

[20] This problem is discussed in greater detail in, for example, Ackerberg, Caves, and Frazer (2006).

[21] Of course, the size and exogeneity of the shock also helps with this concern: any idiosyncratic productivity movements during this time are surely subsumed by the earthquake/tsunami.

[22] An unobserved input that could remain operative in our case is that of factor utilization. Since the scope for substantial adjustment along this dimension seems quite limited, we remain confident that our estimates would be robust to the inclusion of this missing ingredient.

[23] Given that we observe little systematic variation in prices (see section 1.5.2.4), we believe that our approach is more appropriate in this setting.

elasticities, this procedure must iterate across the parameter space to find the estimate most consistent with the data. Similar reasoning applies for the identification of the ω elasticity based on relative movements in Japanese materials, non-Japanese materials, and output. The estimates we obtain are the best fit across the firms in each sample.

1.4.3 Connecting Model and Data

Estimation of the model requires data on employment, Japanese and non-Japanese material inputs, as well as on exports to North America and output prices for periods $\tau - 1$ and τ. Since data on firm-specific capital stocks are hard to obtain and likely noisy, we use equation (1.10) to construct it from firm payroll and a semi-annual rental rate of 7 percent for period $\tau - 1$.[24] Recall that the capital stock is not adjusted over this time horizon so that $K_{i,\tau} = K_{i,\tau-1}$. The parameter α is calibrated to 1/3.[25]

Quarterly employment information comes from the Business Register, which we adjust to reflect the average value over the 6 month periods we study, as they do not align with the quarters defined within a calendar year.[26] As discussed in earlier sections, the LFTTD contains firm-level data of Japanese imports and North American exports. For non-Japanese material inputs, we would ideally combine the non-Japanese imported materials with information on domestic material usage for these firms. As information on domestic material inputs is not available in Census data at this frequency, we utilize information on the *total* material expenditures from the Census of Manufacturers (CM) to construct a firm-level scaling factor to gross up non-Japanese intermediate imports. Put differently, we impute non-Japanese material inputs from non-Japanese input imports. For each firm, we construct the scaling factor as

$$\frac{P_i^M M_i - p_i^J m_i^J}{p_i^{-J} m_i^{-J}} \tag{1.16}$$

[24] This comes from assuming a real interest rate of 4 percent, combined with an annual depreciation rate of 10 percent, and then adjusting for a semi-annual frequency. The estimates are insensitive to alternative values of the rental rate.

[25] In principle it is possible to construct a firm-specific value for α, using value-added information available in a census year. We are currently exploring the feasibility of this option.

[26] Specifically: $L_{\tau-1} = \frac{1}{6}Emp_{2010Q3} + \frac{1}{2}Emp_{2010Q4} + \frac{1}{3}Emp_{2011Q1}$ and $L_{\tau} = \frac{1}{2}Emp_{2011Q2} + \frac{1}{2}Emp_{2011Q3}$.

from the latest CM year. Because the closest available CM year is 2007 in our data, there is some concern about missing or outdated information for this factor. We mitigate this by using industry-specific means for missing values, and winsorizing large outliers at the 90th/10th percentiles.

Regarding information on prices, the LFTTD records the value and quantity of each trade transaction (at the HS10 level), and thus it is possible to construct the associated price, or "unit-value" of each shipment directly.[27] Aggregating up these shipments into a firm-month observation is complicated, of course, by the differing quantity units. Lacking any better alternative, we simply average the transaction prices using the dollar value of each transaction as weights.

Finally, we restrict the sample of firms to those that have regular imports from Japan and non-Japan over the periods we study, as well as regular North American exports.[28] While this substantially limits the number of firms in each sample, the shares of trade represented by these firms in each category remains very high (see Table 1.4).

We obtain standard errors using bootstrap methods, which also allow us to account for the uncertainty implied by the imputation of non-Japanese material inputs. We draw randomly with replacement from our set of firms to construct 5000 different bootstrap samples. For each of these samples, the non-Japanese materials share is imputed as described above before the estimation proceeds.

1.4.4 Summary of Results

The results of the estimation are shown in Table 1.4. The elasticity between material inputs for Japanese affiliates is 0.2, while the elasticity between the aggregate material input and capital/labor is 0.03. Together, these estimates are indeed consistent with the reduced-form evidence for the (ψ) elasticity from section 1.3.2. The relative magnitudes are also intuitive: while Japanese imported inputs are strong

[27]Those transactions with missing or imputed quantity information are dropped. Future efforts will evaluate whether it is possible to recover the quantity values from prior transaction details.

[28]Specifically, we drop any firm that has more than 3 months of zeros for any of these values, over the period $\tau - 1$ or the period τ.

complements with other material inputs — consistent with the high share of intra-firm transactions comprising this trade — there is even less scope for substitution between material inputs and domestic capital/labor.

The estimation procedure also allows us to estimate these elasticities for a sample of non-Japanese multinationals. While the estimates for the ζ elasticity are indeed very close, the elasticity estimate corresponding to material inputs for non-Japanese multinationals is considerably higher, at 0.6. The lower share of intra-firm imports from Japan for this group is consistent with the argument that this type of trade is the key source of non-substitutability in the short-run. We should note, however, that the estimates for both parameters are significantly lower than what is commonly assumed (typically unity or higher) in the literature.

Other details from this estimation make intuitive sense. The weight on Japanese materials in the aggregate materials bundle (ν) is 0.17 for Japanese multinationals, and 0.04 for non-Japanese firms. The weight on domestic capital/labor (μ) is considerably lower for Japanese firms — 0.22 compared to 0.51 for non-Japanese firms — which could point to either i) a more assembly-oriented production or ii) a different industry mix.

Although the number of firms included in this estimation is small (105 Japanese affiliates and 304 non-Japanese multinationals), they account for a large share of economic activity in the United States. Looking at their combined share of total trade, these firms account for over 80% of Japanese intermediate imports, 68% of non-Japanese intermediate imports, and well over 50% of North American exports. Such high concentration of trade among relatively few firms is consistent with other studies using this data (see Bernard et al. (2007)).

1.5 Discussion

The structural estimates of the model are broadly in agreement with the evidence in section 1.3.2: imported inputs are strong complements with other inputs in the production function. The rigidity of the production function for multinational firms is likely due to the substantial presence of intra-firm trade in what is presumably highly specialized inputs.[29] This result has a number of important implications for how we think about business cycle co-movement, firm volatility, and multinational firms more broadly.

1.5.1 Implications

The rigid production networks of foreign-owned multinationals will have direct consequences on the destination (host) economy. Previous literature has hypothesized that input linkages could generate business-cycle comovement, but supportive empirical evidence has been difficult to find. This paper can be seen as a first step in establishing empirical evidence for a causal relationship between trade, multinational firms, and business cycle comovement. In a companion paper (Boehm, Flaaen, and Pandalai-Nayar (2014a)), we evaluate the quantitative importance of such complementarities of imported inputs by multinational affiliates. When separately accounting for intermediate input trade by multinationals and traditional trade in final goods, the model distinguishes between the production elasticity of imported inputs and the traditional "Armington" elasticity used to bundle together international goods for consumption. The complementarities in import linkages by multinationals increases value-added comovement in the model by 11 percentage points relative to a benchmark without such firms.

This model share similarities with several other existing models, particularly Burstein, Kurz, and Tesar (2008). A key advantage of Boehm, Flaaen, and Pandalai-Nayar (2014a), however, is a tight link to Census data for matching other features of multinationals and trade. Johnson (2014) also looks at the role of vertical linkages on comovement, but applies greater input-output structure on the model. Such features will generate increases in value-added comovement in his model, the magnitude of which becomes significant only when the elasticity of substitution among inputs is sufficiently low. Other work also identifies multinationals as a key source of

[29] The vertical integration of production across countries, within the firm, has shown to be a key driver of the decline in joint ventures (see Desai, Foley, and Hines (2004)).

the transmission of shocks: Cravino and Levchenko (2014) demonstrates that foreign multinational affiliates can account for about 10 percent of aggregate productivity shocks.[30]

The low value for ω indicates the presence of spillovers beyond the immediate effect from Japan. That is, imports from non-Japanese locations are lower as a result of the shock in Japan, and we would presume this applies to suppliers within the United States as well. Specifically, upstream suppliers (in countries other than Japan as well as within the U.S.) were affected indirectly due to the exposure of Japanese affiliates to the shock combined with the rigidity of their production with respect to those inputs. The presence of such spillovers combined with the large network of input linkages can indeed magnify the total effect of the transmission of the shock to the U.S. market. Such effects are also evident in a related paper, Carvalho, Nirei, and Sato (2014), which finds large spillovers in both upstream and downstream firms in Japan following the 2011 earthquake.

Another branch of literature on the diversification of risk has studied whether firms using complex production structures with several intermediates could be less volatile (Koren and Tenreyro (2013)). Kurz and Senses (2013) establish that firms with substantial imports and exports have lower employment volatility than domestic firms in the medium to long term, which they attribute partly to the diversification of risk.[31] The key result in this paper points to a possibly overlooked fact: the extent of the benefits from diversification depends heavily on the substitutability of inputs. Conditional on a given number of inputs used in production, a firm will likely experience greater volatility if each input is key to the production process and inputs are subject to heterogeneous shocks.[32] Conceptually, an increase in the use of imported inputs should not be viewed necessarily as diversification. A fragmentation of production can lead to an increased supply chain risk that is an important counterweight

[30] Of course, shocks can be passed through to affiliates through other means as well. See Peek and Rosengren (1997) and Peek and Rosengren (2000) for the case of U.S. affiliates from Japan.

[31] An interesting result from Kurz and Senses (2013) is that firms that only import are actually more volatile than the domestic-only benchmark.

[32] Pravin and Levchenko (2014) outline theoretical results showing that for a given elasticity value (in their case, Leontief), volatility in output per worker should be actually decreasing in the number of inputs used.

to whatever efficiencies such complex input sourcing might afford, particularly when the production elasticities are low.

The rigid production networks of multinational firms also influences our understanding of why firms segment production across country borders. In a related paper, Flaaen (2013b) shows that despite the presence of substantial and complex import linkages with the source country (consistent with a vertical framework of FDI), the motive for multinational production appears to be to serve the domestic market (consistent with the horizontal framework of FDI). The result could be called "horizontal FDI with production sharing."[33] The evidence for strong complementarities in this production sharing, however, presents a puzzle. Why does the firm replicate only select portions of the supply chain, considering the penalties for disruptions and mismatched inputs are so great? It is perhaps the case that the segments of the production chain that remain in the source country have a location-specific component that is not easily transferable when the firm moves production abroad.[34] Understanding the dynamics behind these sourcing decisions is an area in need of further research.[35]

Finally, the estimates from section 2.2 correspond to an average across the firms in each group (Japanese multinationals and non-Japanese firms), the results from section 1.3.2 correspond to the aggregated group of Japanese multinationals. Because the level of aggregation differs, it is important for the researcher to understand the appropriate model analogue when using these estimates for the calibration of theoretical models.[36] For example, a researcher may decide that a group-level elasticity is the most appropriate for an aggregate DSGE model populated by a representative multinational firm, where the focus is on understanding aggregate features such as

[33]Ramondo, Rappoport, and Ruhl (2014) is another recent example arguing for a more nuanced interpretation of multinational production.

[34]The model of knowledge sharing in Keller and Yeaple (2013) is one attempt to analyze the dynamics between such transfers being accomplished in embodied (intra-firm trade) or disembodied (direct communication) form. Alternatively, domestic content requirements may provide incentives to produce specified inputs in one location over another.

[35]For a recent example of how such investment and sourcing decisions can alter a country's comparative advantage over time, see Alviarez (2014).

[36]A recent paper by Imbs and Méjean (2011) argues that imposing homogeneity across sectors when estimating consumption elasticities can be overly restrictive, creating a heterogeneity bias which can be quantitatively large.

business cycle dynamics.

1.5.2 Robustness and Extensions

1.5.2.1 Mis-measurement of Firm Production

A natural concern with our analysis is the use of N.A. exports as a proxy for firm-level production. Perhaps it is the case that shipments abroad fall disproportionately more than domestic shipments following a shock to production. If this were the case, the N.A. exports would indeed be a poor proxy for production, and its usefulness in evaluating a production elasticity substantially compromised.

To evaluate this concern, we narrow our study to the automotive sector, which has data on production, sales, and inventory at a monthly frequency. Using the Ward's electronic databank, which reproduces the published series in the annual Automotive Yearbook, we obtain plant-level information on production, and model-line information on inventory, sales, and incentives.[37] The baseline specification is the same as in equation (1.5), where the dependent variable is now Q_{jit}: production of plant j of firm i in month t. The Japanese multinational firms are, in this case, those automakers with plants located within North America but whose parent company is headquartered in Japan.[38]

Figure 1.8 shows the results, where we once again divide by pre-shock levels to gain a sense of the percentage effects of these changes. Relative to their U.S. counterparts, Japanese automakers in the United States experienced large drops in production following the Tōhoku event. Production bottomed out in May of 2011 — two months after the event — at almost 60 percent below trend. [39] The point estimates return to a level near zero in September of 2011, implying that the shock affected production for nearly 6 months.[40] We interpret these results to be largely supportive of the results obtained using the exports-based proxy for production. The percentage drops in the

[37] Appendix E.1.5 details further features of this data and explains how the sample was constructed.

[38] These firms are Honda, Mitsubishi, Nissan, Toyota, and Subaru.

[39] The average monthly plant-level production at these firms during December 2010 through February 2011 was about 12,200 units a month. The magnitude of the drop in May was -7200 units.

[40] We describe additional results on the behavior of inventories, sales, incentives, and production in Japan in an appendix.

two series are remarkably similar: a trough of 59% at $t = 2$ in the automotive data vs 53% at $t = 2$ using the proxy. We conclude that, at least for this exercise, the proxy appears to be providing valuable information on a firm's U.S. production behavior.[41]

1.5.2.2 Intermediate Input Inventories

Inventories are another obvious feature that should influence the relationship between input shipments, production, and the elasticity of substitution. In particular, inventories of intermediate inputs allow the firm to absorb unforeseen shocks to input deliveries without an impact on the production process.[42] As it relates to the production elasticity, however, the presence of these inventories should serve to diminish or delay the production impact, thereby *increasing* the elasticity relative to what it would be without such inventories.

In fact, it is striking the extent to which we do not see any evidence for the role of intermediate input inventories in the production impacts of Figure 1.6 (Panel B) or Figure 1.8. The effect on production appears to be almost immediate, indicating that the stock of inventories of imported intermediates is low (less than one month's supply) for these firms.

We obtain a rough sense of the degree of inventory holdings from the Census of Manufacturers micro-data. Combining information on the beginning period stock of materials inventories with the annual usage of materials, we calculate the average monthly supply of inventories for each firm.[43] Panel A of Table 1.1 calculates the

[41] In addition, one might be concerned that the N.A. exports series may be contaminated with Japanese imports whose country of ultimate destination is Canada/Mexico (a.k.a "in-transit shipments" – imports to Canada/Mexico via U.S.). These shipments should not be picked up in the reporting systems underlying the LFTTD. According to section 30.2(d)(1) of the U.S. Code of Federal Regulations, "In-transit shipments of goods from one foreign country to another where such goods do not enter the consumption channels of the United States are excluded from filing the Electronic Export Information (EEI)." Additionally, the Army Corps of Engineers has suspended the requirement to file the Form 7513, Shippers Export Declaration (SED) for In-transit Goods leaving the United States via vessel. Finally, the corroborating results from section 1.5.2.1 should also serve to allay such concerns.

[42] The existence of final good inventories, on the other hand, makes a distinction between the production and sales of a particular product. Here, the presence of final good inventories implies that the firm can continue to sell from existing inventory stocks even while production is temporarily affected.

[43] Unfortunately, the CM data does not report imported materials inventory separately.

production-weighted averages over a select set of firm groups.[44] We see that on average, Japanese multinationals hold a little over 3-weeks supply of intermediate inputs as inventory. This is slightly less than non-multinational firms, a fact that aligns with the oft-cited "lean" production processes made famous by Japanese firms in previous decades. Though these data are for the year 2007, there is little reason to believe these relative magnitudes have changed substantially over a period of a few years. For completeness, Panel A of Table 1.1 also reports the corresponding estimates for output inventories.[45]

Low inventory holdings combined with an inelastic production function suggests that firms are willing to tolerate some degree of expected volatility in their production. Either the costs of holding inventories or diversifying sources of supply are sufficiently high, or firms believe the probability of disruption is low. In either case, these lean production strategies carry a greater potential for the propagation of shocks across countries, perhaps affecting firms with limited knowledge of their indirect exposure through complicated production chains.

1.5.2.3 Multi-Products and Sub-Optimal Mix

In the frameworks used in sections 1.3.1 and 2.2, we consider the aggregate bundles of imported intermediates, abstracting away from product-level detail. In reality, the firms in our dataset often import many distinct intermediate inputs from Japan. The structure of a CES production function implies that if each of these within-country inputs was non-substitutable with one another (a further, nested Leontief structure), the production impact of a disruption in the supply of just one input could be amplified relative to the value of that input.[46] We evaluate this possibility below.

[44] These numbers are broadly similar, though somewhat lower than other estimates in the literature. See Ramey (1989) for one example.

[45] At first glance, the average monthly supply of these output inventories looks surprisingly low. On the other hand, it is probably the case that inventories are held jointly by the manufacturer and wholesale/retail establishments Thus, considering the inventories of manufacturers alone could potentially under-represent the "true" level of output inventories available for smoothing out production disturbances.

[46] This point has been made in somewhat differing contexts, by Kremer (1993) and Jones (2011).

This is particularly true given the heterogeneous impact of the Tōhoku event across Japan (see Figure 1.4). This could translate into considerable dispersion in the impact on the *products* imported by a particular U.S. firm or Japanese affiliate. With product-level shocks, considering the effect on the aggregate import bundle amounts to assuming either 1) perfect substitutability among products, or 2) that the firm maintains an optimal within-country product mix at all times.

To be concrete, it may be more accurate to view the M_t in equation (1.1) as a further C.E.S. function of multiple products. Thus, we can define the proper measurement of this variable as

$$V_{i,t}^{M} = P_{i,t}^{M} \left(\sum_{n=1}^{N} \eta_n^{\frac{1}{\chi}} (m_{n,i,t}^{J})^{\frac{\chi-1}{\chi}} \right)^{\frac{\chi}{\chi-1}}, \tag{1.17}$$

where now $V_{i,t}^{M}$ is the value based on a combination of N distinct products, with weights η_n and elasticity χ.

Product-level heterogeneity in the production impact of the shock combined with imperfect coordination among input suppliers implies that the aggregate (measured) import bundle for a particular firm may turn out to be suboptimal. In this case, we are measuring $\widehat{V^M}_{i,t} = \sum_{n=1}^{N}(p_{n,t}^{m} m_{n,t}) \geq V_{i,t}^{M}$. And the lower the elasticity of substitution among products, the more severe the disconnect between the measured imports and the "effective" imports — that which is actually useful in downstream production.

A suboptimal product mix indicates that measured imports ($\widehat{V^M}_{i,t}$) are greater than the effective imports ($V_{i,t}^{M}$). As a result the measured output response to the import shock will be larger than otherwise, resulting in a downward "bias" in the elasticity estimates from section 1.3.1 and 2.2.[47] Such an effect is decreasing in the product-level elasticity parameter χ, as complementarity itself is the driving force between differences in $\widehat{V^M}_{i,t}$ and $V_{i,t}^{M}$. In addition, the effect is also increasing in the degree of deviation from the optimal product mix.

[47]Because the source of this downward pressure on the estimate for ψ (or ω) is itself a very low product-level elasticity, it is unclear whether this should be considered a bias in the traditional sense.

Does this exert a quantitatively large effect on our point estimates? Given the emphasis on low inventories and lean production processes in downstream operations, one might expect that across-product adjustment would take place before sending the inputs abroad. To analyze this empirically, we analyze whether there are significant deviations in the product composition of Japanese imports during the months following the Tōhoku event. To do this, we construct a measure of the distance of a firm's import bundle from a benchmark, which we will interpret to be the optimal bundle. Let $t = s^*$ be such a benchmark date. Then, using the product-level information in the LFTTD data we construct for each firm i, the share of total imports from Japan for a given product code n. Defining this share to be $s_{n,i,t}$, we then construct the average product-level distance from optimum $DO_{i,t}$ as:

$$DO_{i,t} = \frac{1}{N^i} \sum_{n=1}^{N^i} \left(|s_{n,i,t} - s_{n,i,s^*}| \right) \tag{1.18}$$

where N^i is the total number of products imported by firm i. We define the period s^* to be the months of April-June of 2010, and then evaluate DO_i at a monthly frequency, with particular interest in the months following the Tōhoku event. While there may be natural movements in the bundle of products imported from Japan, evidence for substantial coordination failure in product composition or heterogeneity in product-level shocks would come from any abnormal jumps in this index in the months of the disruption. One can calculate this at various levels of product aggregation (i.e. HS4, HS6, HS8, HS10), though we report results using the HS6 level.[48]

The results of this exercise are shown in Figure 1.9. We plot the average DO_i across Japanese firms for each month (the figure shows a 3-month moving average) during the period 2009-2011. Mechanically, this measure should be relatively close to zero in the months consisting of the benchmark (April-June 2010). While there is a secular rise in this measure on either side of this benchmark period, there do not

[48]The level of aggregation we use attempts to balance concerns along two dimensions. With less product aggregation (i.e. HS10 level), one might be concerned with the inherent lumpiness of product-level firm imports. More product aggregation, on the other hand, could mask important product differences within a particular product grouping.

appear to be any large jumps in the months directly following the Tōhoku event. More interesting, perhaps, are the considerably larger values for this measure during early 2009, which might reflect the effects of the trade collapse associated with the Great Recession. We interpret Figure 1.9 as evidence that the potential for suboptimal mix across products from Japan does not pose a serious problem to our measurement in previous sections.

1.5.2.4 Other Considerations

Strategic Behavior: Another possibility that could affect the interpretation of the results from Figure 2.1 might be strategic behavior, particularly on the part of the competitors of Japanese firms in the United States. These firms could raise production or prices following the negative supply shock affecting their competitors, which would serve to bias downward the β_p coefficients from the equation with $X_{i,t}^{NA}$ as the dependent variable.[49] To evaluate this possibility, we turn once again to the automotive data. Here, we can look directly at the production of non-Japanese automakers in the months directly following the Tōhoku event. Appendix Figure A1 plots the relative production of these firms, using time-series variation only. There appears to be no quantitatively meaningful responses in the months following March 2011. This should not come as a surprise given capacity constraints and utilization adjustment costs, particularly given the short time horizon. We provide evidence on the role of prices next.

Prices: Traditionally, estimating the elasticity of substitution is accomplished via price and quantity data for products over extended periods of time. For the short horizon we consider in this paper, there are several reasons why prices may not have the scope to adjust. Many supplier relationships negotiate prices for longer periods of time than one or two months. Second, and perhaps more importantly, Table 1.2 demonstrates that the large majority of imported intermediate inputs are intra-firm. The observed prices of these transactions are transfer-prices (within firm) and not

[49]Specifically, in equation (1.5) the γ_p's would be higher than would be expected without the shock, and hence the β_p's artificially low.

likely to change reflecting any short-term disturbance. However, because the LFTTD contains both quantity and price information, we can confirm whether or not prices remained relatively stable during this period. The results in Appendix Table E.2 confirm that there are few significant price movements on import or export transactions for either Japanese or non-Japanese multinationals surrounding the Tōhoku event.[50]

Domestic Inputs: It is also possible to evaluate the response of domestic inputs directly, using the limited information we have on quarterly firm-level employment and payroll information, taken from the Census Bureau's Business Register (BR).[51] We consider the evidence in Appendix E.1.3 and find no significant effects on either employment or payroll for Japanese firms in the quarter(s) following the shock (see Table E.1). Of course, there are a number of reasons — principally labor adjustment costs — why one would expect little, if any, impacts on employment following this short-lived shock. Press releases dispatched by the Japanese automakers during this time indicated that no layoffs would occur. Rather, the firms indicated that they would use the production stoppages for employee skill and safety training.

1.5.3 External Validity

Finally, we discuss the external validity of this result. The exogenous variation we use to identify this elasticity is tied to a particular event in time, making generalization subject to some caveats. On the other hand, there are few, if any, estimates of this parameter in the existing literature. The critical question is whether the mechanisms underlying the elasticity estimates are operative beyond the circumstances surrounding this event study.

When viewed in light of the substantial fraction of intra-firm imports comprising multinational affiliate trade, the low elasticity of substitution should not come as a surprise. One would not expect close substitutes for the sort of specialized products reflecting firm-specific knowledge that likely comprises this trade. Moreover, such a

[50] Further details on the construction of the data underlying the analysis of unit values is available in Appendix E.1.4.

[51] The BR itself receives quarterly payroll and employment information for business and organizational employers from the IRS: Form 941, the Employer's Quarterly Federal Tax Return. For more information on the BR (formerly the SSEL), see Walker (1997).

low estimate for an elasticity of this nature is not without precedent. Using different methodologies, recent work by Atalay (2014) highlights strong complementarities between intermediate inputs, using industry-level data for the United States.[52]

The pattern of strong intermediate input linkages with the source country is not restricted to Japanese affiliates only. As shown in Flaaen (2013b), over 45 percent of the imports for all foreign multinational affiliates are sourced from the country of the parent firm. The cost share of imported intermediates from the source country is 0.12 for all foreign affiliates, which is lower than the 0.22 for Japanese affiliates but still much larger than the representative importing firm in the United States. The cost share of all imported inputs is actually quite close: 35 percent for Japanese affiliates vs 32 percent for all foreign affiliates.

A related concern is whether the estimates for Japanese affiliates are driven solely by the automotive sector. The ideal check would be to run industry-by-industry subgroup estimates for the elasticities. Unfortunately, the small number of firms applicable for this analysis, combined with disclosure requirements associated with the Census Bureau data usage, prevents this degree of detail. Using the published data from the B.E.A., the automotive sector is a large but not overwhelming percentage of total Japanese manufacturing affiliates in the U.S. The entire motor vehicle sector as a whole comprises significantly less than half of value-added (roughly 40 percent) for the Japanese manufacturing affiliates.

Any elasticity estimate is tied to the time-horizon to which it corresponds. Ruhl (2004) emphasizes the difference between elasticities implied by responses to temporary vs permanent shocks. Larger values are calculated for an elasticity following a permanent shock, owing in part to firm responses along the extensive margin. In our context, we estimate the elasticity subject to a short-lived shock where the supply chain is plausibly fixed and extensive margin movements of supplier relationships would not apply. For this reason the elasticity parameters (ω, ζ) should likely generalize to other contexts of this horizon and for shocks of this general duration. Even

[52] The point estimate for the elasticity of substitution among intermediate inputs from Atalay (2014) is 0.03.

for a long-lived shock, the estimated elasticities would remain relevant while the firm makes changes to its network of suppliers. Evaluating whether there is evidence for long-term supply-chain reorganization following the Tōhoku event is an area of ongoing work.

1.6 Conclusions

Using a novel firm-level dataset to analyze firm behavior surrounding a large exogenous shock, this paper reveals the mechanisms underlying cross-country spillovers. We find complementarities in the international production networks of Japanese affiliates, such that the U.S. output of these firms declined dramatically following the Tōhoku earthquake, roughly in line with an equally large decline in imported inputs. The elasticity of substitution between imported and domestic inputs that would best match this behavior is very low – nearly that implied by a Leontief production function. The reliance on intra-firm imports by multinational affiliates from their source country is the most plausible explanation for such strong complementarities in production. Structural estimates of disaggregated elasticities are similarly low, and imply spillovers to upstream and downstream firms in the U.S. and abroad (non-Japan). The large impacts to Japanese affiliates together with the propagation to other U.S. firms explains the large transmission of the shock to the U.S. economy in the aggregate.

These elasticities play a critical role in the way international trade impacts both source and destination economies. Such complementarities between domestic and foreign goods have been shown to improve the ability of leading theoretical models to fit key moments of the data. We emphasize here the distinction between substitutability between domestic and foreign final goods (a "consumption" elasticity of substitution, or the so-called Armington elasticity) and substitutability between domestic and foreign intermediate goods (a "production" elasticity of substitution). In a companion paper (Boehm, Flaaen, and Pandalai-Nayar (2014a)), we document the behavior of a model with such complementarities in imported intermediates, and discuss how these elasticity parameters interact. Calibrating this model to the share of multinational affiliate trade in intermediates yields an increase in value-added comovement of 11 p.p., and reduces the gap between consumption and value-added comovement by a considerable margin.

Such rigid production networks will also play a substantial role in aggregate volatility, productivity growth and dispersion, and the international ownership structure of production. The novel datasets described in this paper may help to shed light on these and other areas of research in the future.

Table 1.1: Summary Statistics: Imported Inputs and Inventories by Firm Type

	Japanese Multinationals	Non Multinationals
Panel A: Avg. Monthly Supply of Inventories		
Inputs	0.83	1.08
Output	0.31	0.45
Panel B: Cost Share Of Imported Inputs		
from Japan	21.8	1.0
from all countries	35.0	17.5

Source: CM, LFTTD, DCA, and UBP as explained in the text. The data are for year 2007. This table reports the average monthly supply of inventories [(usage/12)/beginning period inventory stock] for materials and output, as well as the cost share of imported products.

Table 1.2: Baseline Sample: Summary Statistics

	Japanese Firms	Other Multinationals	Balancing Tests t	$p > \|t\|$	% Reduct |bias|
N.A. Exports	3,504,894	3,413,058	0.38	0.706	79.1
share intra-firm	72.0	52.2			
Intermediate Imports	8,075,893	7,596,761	0.87	0.384	88
share from Japan	70.0	3.5			
share intra-firm	86.0	21.7			
Industry (Avg)	–	–	0.009	0.965	97.8

Source: LFTTD, DCA, and UBP as explained in the text.
This table reports the baseline average values of N.A. exports and intermediate input imports, as well as the characteristics of that trade, for the two groups of firms: Japanese affiliates and other multinational firms. The statistics are calculated in the three months prior to the Tōhoku earthquake: Dec. 2010, Jan. 2011, and Feb 2011. The control group of other multinational firms has been re-weighted using the normalized propensity score, from a specification including the level of N.A. exports, int imports, and industry dummies. The final three columns report balancing tests of the equality of the means between the treated and control group.

Table 1.3: Predicting Japanese Import and U.S. Output Disruption by Firm Characteristics

	Panel A: Disruption to U.S. Output (proxy) $X_i^D = 1$				**Panel B: Disruption to Japanese Imports** $J_i^D = 1$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Japan	0.443***		0.352***	0.347**	0.707***		0.310***	0.686***
	(0.0921)		(0.117)	(0.152)	(0.0917)		(0.115)	(0.150)
Exposed		0.351***	0.145	0.140		0.814***	0.636***	0.991***
		(0.0886)	(0.112)	(0.149)		(0.0880)	(0.110)	(0.144)
JPN*Exp				-0.00771				-0.848***
				(0.228)				(0.222)
MMI	-0.176***	-0.121*	-0.178***	-0.178***	0.346***	0.389***	0.341***	0.306***
	(0.0676)	(0.0646)	(0.0676)	(0.0683)	(0.0691)	(0.0667)	(0.0694)	(0.0704)
Ports	-0.174	-0.144	-0.197		0.248	0.217	0.168	0.174
	(0.224)	(0.225)	(0.226)		(0.211)	(0.212)	(0.213)	(0.213)
Constant	-0.674	-0.674	-0.674	-0.674	-4.672	-4.672	-4.672	-4.668
	(0.681)	(0.681)	(0.681)	(0.681)	(85.78)	(85.78)	(85.78)	(85.00)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2451	2451	2451	2451	2451	2451	2451	2451

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

Source: LFTTD, DCA, UBP, and USGS as explained in the text. This table reports the results of a probit model prediction of JPN import and N.A. exports (output) disruption based on firm characteristics. See section 1.3.1 for a definition of the variables.

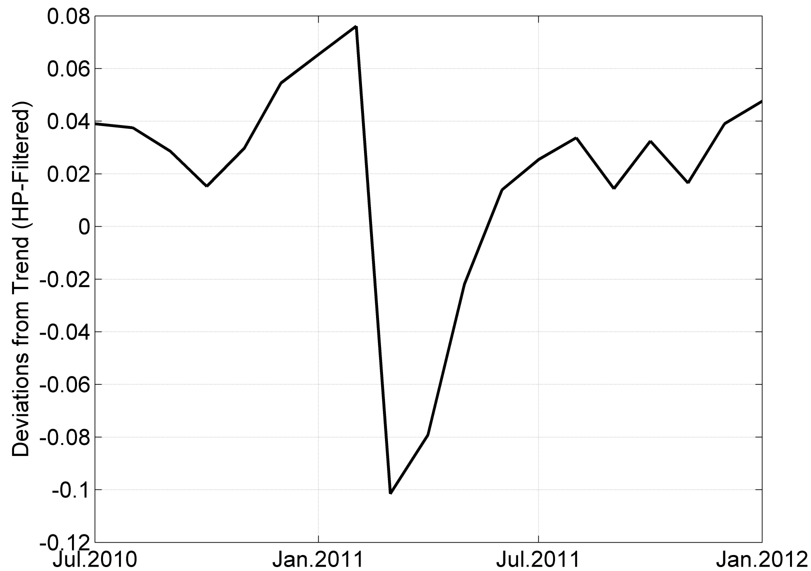
Table 1.4: Firm-Level Estimation: Summary Statistics and Results

Panel A: Calibration		
Parameter	**Value**	**Source/Justification**
R_t	0.07	
α	1/3	

Panel B: Estimation Results		
	Japanese Multinationals	Non-Japanese Multinationals
ω	0.201	0.624
	[0.02 0.43]	[0.16 0.69]
ζ	0.032	0.038
	[0.030 0.673]	[0.035 0.508]
	Sample Details	
Weight on K/L Aggregate ($\bar{\mu}$)	0.223	0.514
Weight on JPN Materials ($1-\bar{\nu}$)	0.173	0.044
Number of Firms	105	304
Share of Total Trade		
JPN int imports	0.60	0.23
Non-JPN int imports	0.02	0.66
N.A. exports	0.08	0.47

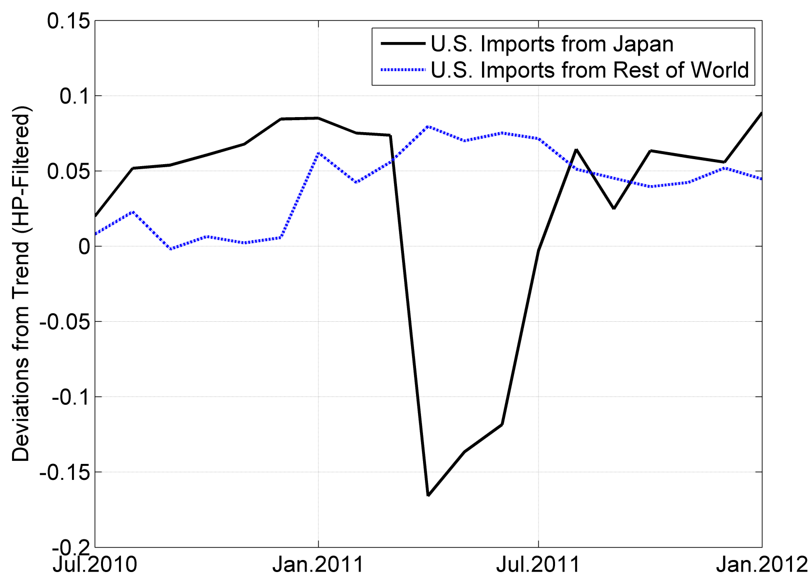
Source: CM, LFTTD, DCA, and UBP as explained in the text.
This table reports the results from the firm-level estimation detailed in section 2.2. Panel A outlines the parameters that are calibrated prior to estimation. The top two rows of Panel B reports the point estimates of the elasticities, and the corresponding 95 percent confidence intervals using a boostrapping procedure. (See Appendix E.1.2 for more details on the measurement of dispersion for these estimates.) Rows 3 and 4 report other estimates related to the calculated production functions. The final rows of Panel B describe features of the two estimation samples.

Figure 1.1: Index of Japanese Industrial Production: Manufacturing Jan.2010 - Jan-2012



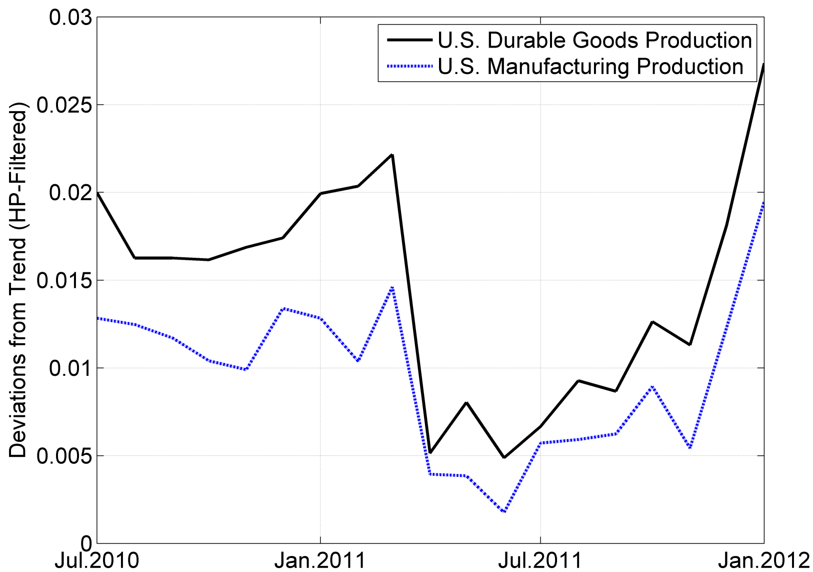
Source: Japanese Ministry of Economy, Trade, and Industry (METI). The series are logged, HP-Filtered, after seasonally adjusting.

Figure 1.2: U.S. Imports from Japan and Rest of World, Jan.2010 - Jan-2012



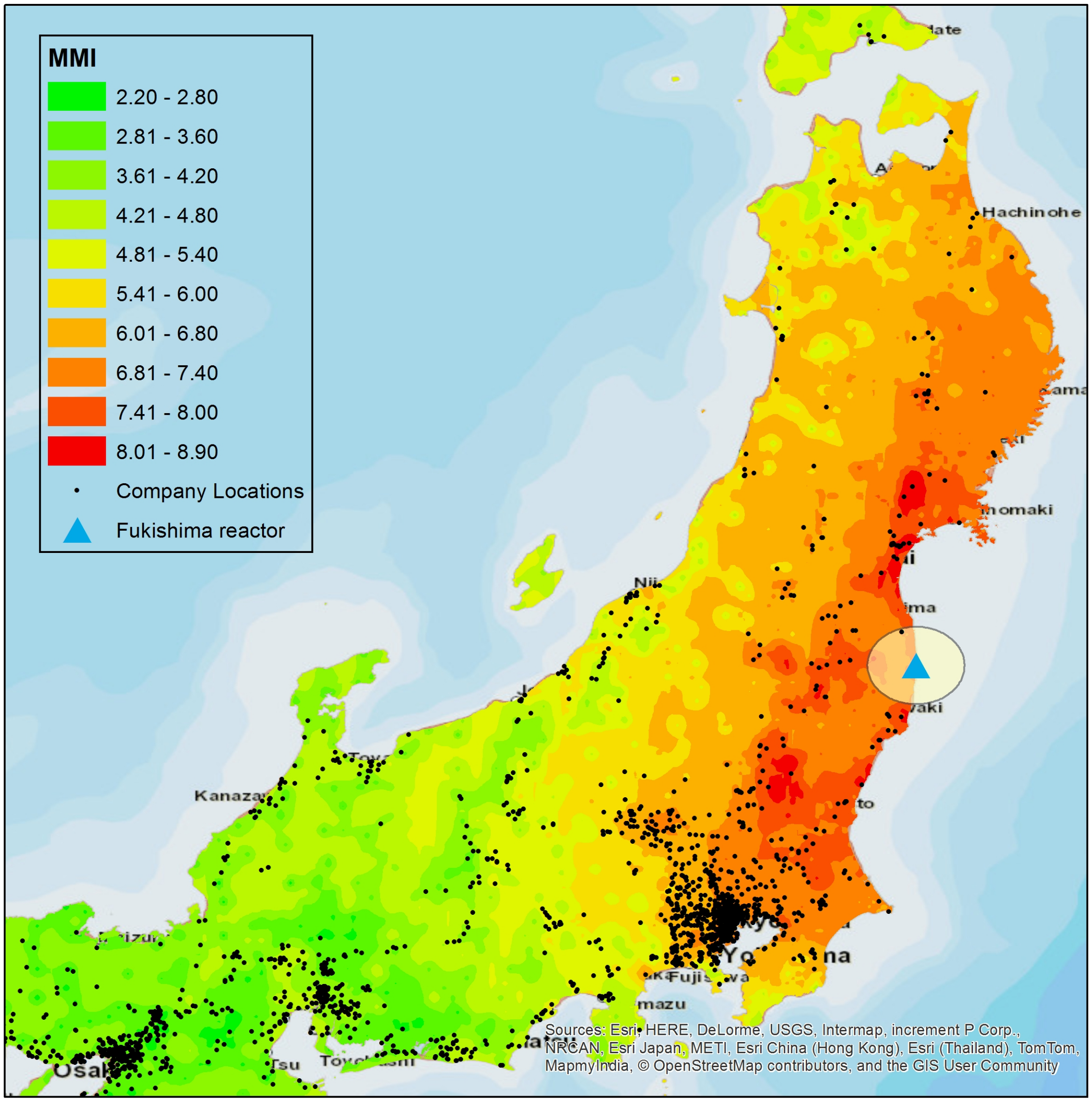
Source: U.S. Census Bureau, based on Published Totals. The series are logged, HP-Filtered, after seasonally adjusting.

Figure 1.3: U.S. Industrial Production: Manufacturing and Durable Goods



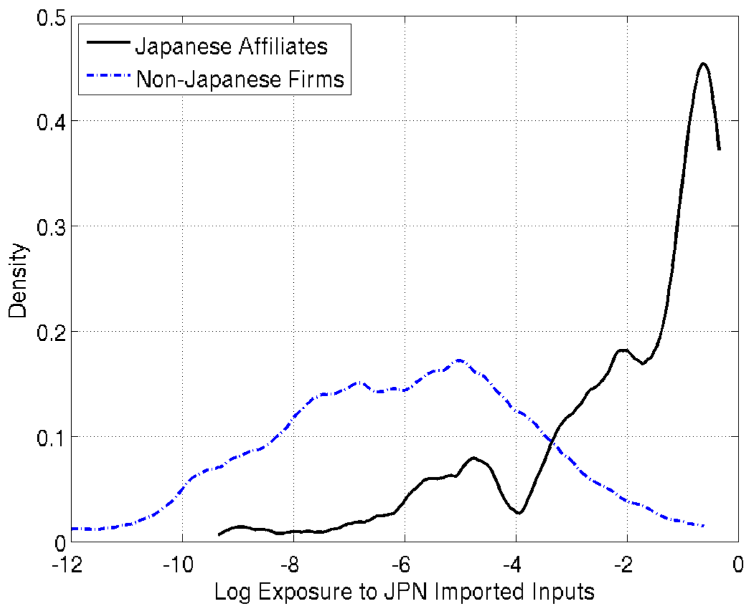
Source: Federal Reserve Board. Series is Seasonally Adjusted.

Figure 1.4: Geographic Distribution of Earthquake Intensity and Affiliate Locations



Source: USGS and DCA/Uniworld Directories
This figure plots the geographic distribution of the Tōhoku earthquake, based on recorded measurements taken directly after the event. The "Modified Mercalli Intensity" (MMI) scale is constructed based on a relation of survey response and measured peak acceleration and velocity amplitudes from prior major seismic events. Each dot corresponds to a geocoded Japanese affiliate location corresponding to a firm with U.S. operations. For more details, see Appendix D.1.2.

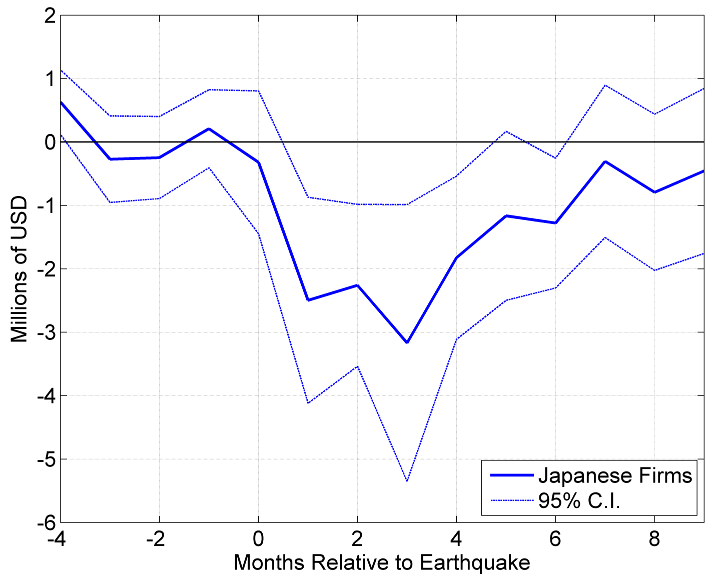
Figure 1.5: Density of Firm-Level Exposure to Japanese Imported Inputs: By Firm Type



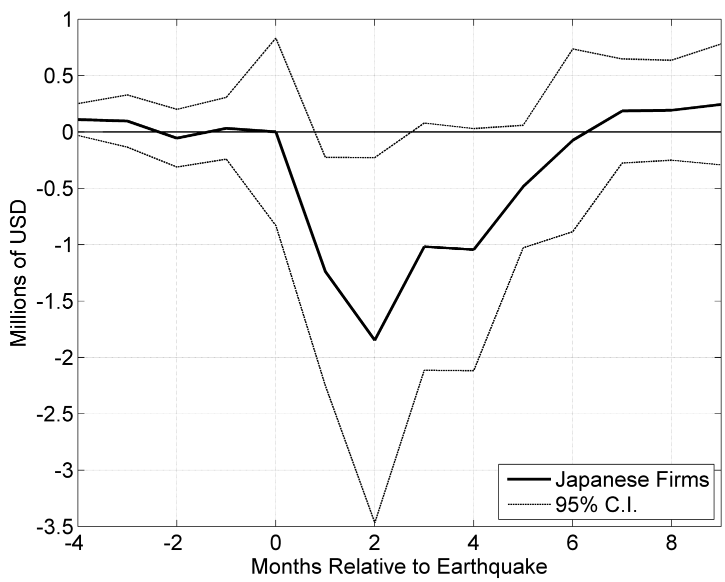
Source: LFTTD-DCA-UBP as explained in text.
This figure displays density estimates of the (log) exposure measure to Japanese imported inputs, separately for Japanese affiliates and non-Japanese multinational firms. The estimates correspond to year 2010. The exposure measure is defined as the ratio of Japanese imported inputs to total imported inputs plus U.S. salaries and wages. It is equivalent to the cost share measure shown in table 1.1 with the omission of domestic material usage and investment expenditures. Density estimates at either tail are suppressed for purposes of confidentiality.

Figure 1.6: Dynamic Treatment Effects: Japanese Firms

A. Relative Intermediate Input Imports of Japanese Firms

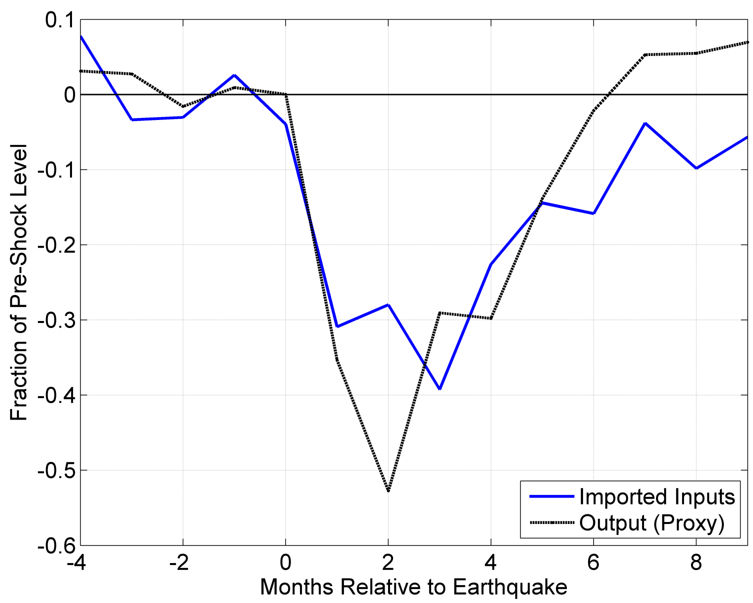


B. Relative North American Exports of Japanese Firms



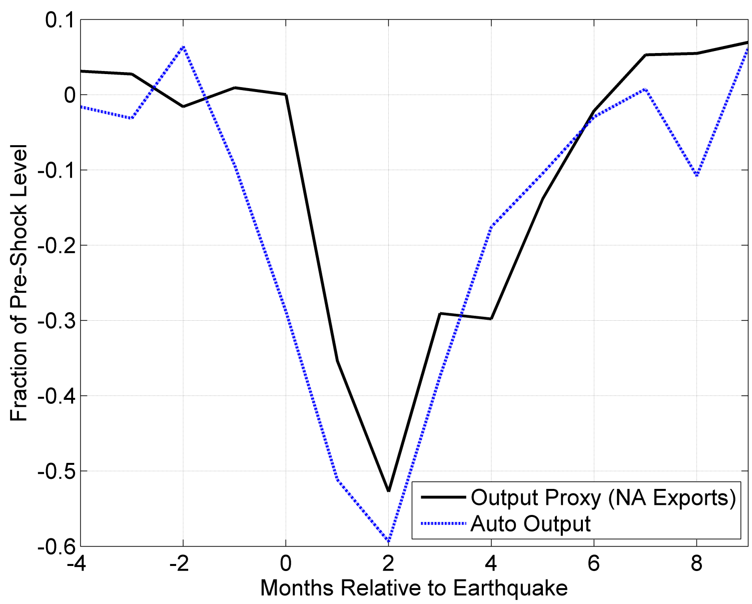
Source: LFTTD-DCA-UBP as explained in text.
These figures report the intermediate imports and North American exports of the U.S. affiliates of Japanese firms relative to a control group of other multinational firms. The values are coefficient estimates taken from an interaction of a Japanese-firm dummy with a monthly dummy – additional baseline monthly dummies remove seasonal effects. See equation 1.5 in the text. Standard errors are clustered at the firm level.

Figure 1.7: Relative Imported Inputs and Output (Proxy) of Japanese Firms: Fraction of Pre-Shock Level



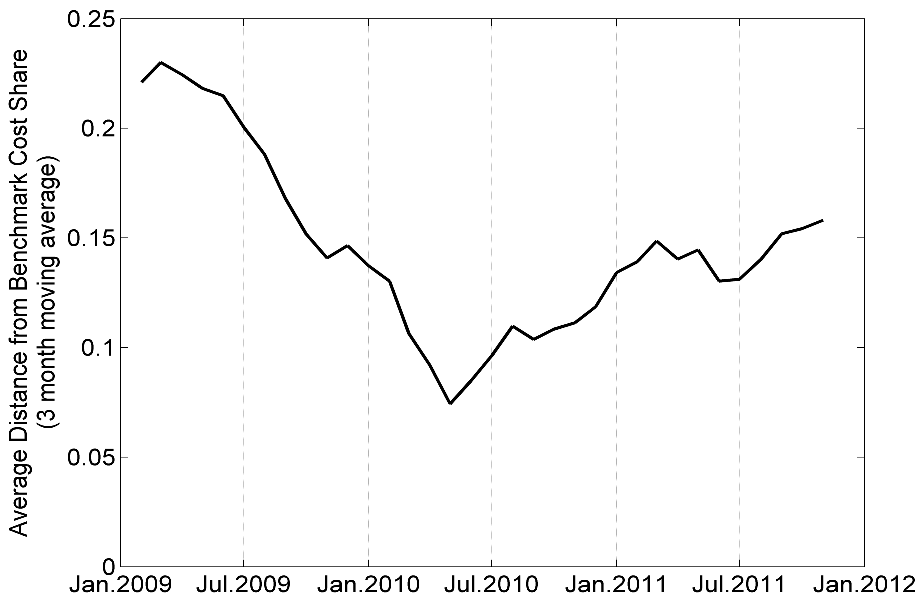
Source: LFTTD-DCA-UBP as explained in text.
This figure reports the intermediate imports and output proxy (North American exports) of the U.S. affiliates of Japanese firms relative to a control group of other multinational firms. The values are percent changes from the pre-shock level of each series, defined as the average of the months December 2010, January 2011, and February 2011.

Figure 1.8: Assessing the Output Proxy Using Monthly Automotive Production



Source: Ward's Automotive Database
This figure reports the production levels of Japanese auto plants relative to a control group of non-Japanese auto plants. The values are percent changes from a pre-shock level, defined as the average of the months December 2010, January 2011, and February 2011. See equation E.3 in the text. For purposes of comparison, we also include the equivalent measure corresponding to total manufacturing of Japanese affiliates using the output proxy frocm Census data (from Figure 2.1). The Japanese automakers are Honda, Mazda, Mitsubishi, Nissan, Toyota, and Subaru. For the sake of clarity, we suppress the standard errors for the automotive series, though there are 4 months with below zero production based on a 95 percent confidence interval. See section E.1.5 for more details.

Figure 1.9: Japanese Products: Average Distance from Benchmark Cost Shares: JPN Multinationals



Source: LFTTD-DCA-UBP as explain in the text
Underlying this figure is the calculation of the average total (absolute) deviations from a benchmark measure of a firm's cost shares across input products from Japan. See equation 1.18 in the text. The figure reports the mean across the Japanese multinationals used in the section 2.2.

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CHAPTER II

Complementarities in Multinational Production and Business Cycle Dynamics

(joint with Christoph E. Boehm and Nitya Pandalai-Nayar)

The role of trade and foreign investment in explaining the magnitude and growth of business cycle synchronization has been the subject of some debate. In previous work, Boehm, Flaaen, and Pandalai-Nayar (2014b), we have shown that the imports of multinational firms exhibit very little substitutability with other domestic factors in the short run. We incorporate these complementarities of intermediate input trade by multinationals into an otherwise conventional model of cross-country business cycle dynamics and show that this channel does indeed generate substantial effects in the aggregate. In the baseline model value-added co-movement increases by 11 percentage points relative to a model where such vertical linkages are absent. The model demonstrates that real linkages – in addition to financial linkages and policy spillovers – can play a quantitatively meaningful role in aggregate business cycle synchronization.

2.1 Introduction

A prominent feature of advanced economies is a high and growing degree of output comovement. The median correlation between a measure of world GDP and country-level GDP among OECD countries during the period 1995-2010 is 0.68. By contrast, the equivalent figure for the period 1980-1995 was 0.35.[1] Viewed in light of the massive increase in international linkages over the past several decades, this increase in comovement should seem unsurprising. Indeed, over the same period (1980-2010) international trade nearly quadrupled in real terms for this set of countries, and gross flows of foreign direct investment increased by almost a factor of seven. However, it has proven difficult to understand and quantify the role of these linkages in international business cycles, and leading models have largely failed to either generate the comovement seen in the data or capture the role of international trade and investment in the transmission of shocks.

On the empirical side, the central challenge has been the difficulty of separating out a proposed mechanism of business cycle transmission from other potentially omitted variables that could be simultaneously correlated with the object of study. In a celebrated finding, Frankel and Rose (1998) established that countries that trade more with one another tend to have higher business cycle correlations. Subsequent research by Imbs (2004) and others, however, argue that this relationship need not be causal. Countries with high bilateral trade also tend to exhibit similar industrial structure, and thus will be subject to common sectoral shocks potentially unrelated to trade. The high share of intra-industry trade between these countries would then naturally give rise to a relationship between trade and comovement that is consequent, rather than causal.

This paper points to the rigid cross-country supply chains of multinational firms as the key subset of trade that contains the causal link between trade and comovement underlying the Frankel and Rose (1998) result. We show in a related paper (Boehm,

[1] If one excludes the recent financial crisis, and instead evaluates the period 1992-2007, the median correlation is 0.60. For more detailed information on the data and methodology behind these calculations, see Appendix F.1.

Flaaen, and Pandalai-Nayar (2014b)) that the production elasticity of substitution for imported inputs by multinationals is extremely low — essentially that implied by a Leontief production function. Such rigid production networks can promote the pass-through of component-specific shocks throughout the supply chain, which often spans multiple countries. This was, for instance, the case for the U.S. affiliate operations of Japanese multinationals following the 2011 Tōhoku earthquake. This is perhaps intuitive: transactions conducted within the firm may imply a high degree of firm-specific knowledge embodied in the good being traded.

We use an otherwise standard dynamic two-country model to explore the role of rigid trade linkages by multinationals in business cycle comovement. A critical advantage of this exercise is a novel link to Census microdata on exporting and multinational firms, which allows for a tight calibration to the relevant features of the data. We find that the complementarities in multinational input trade can generate quantitatively meaningful comovement in the model. Relative to the case with no multinational presence, the baseline model calibrated to the share of multinationals in the data — combined with the production elasticity of imported inputs from Boehm, Flaaen, and Pandalai-Nayar (2014b) — increases the value-added comovement by 11 percentage points.

The model makes progress toward explaining several puzzles in theoretical work. It is well-known that leading IRBC models (e.g. Backus, Kehoe, and Kydland (1995b)) fail to generate substantial (and sometimes even positive) endogenous value-added comovement in a two-country setting.[2] In many cases, these models build in an exogenous "spillover component" to the aggregate shock process in an attempt to match the comovement seen in the data. This paper proposes one intuitive mechanism for endogenous comovement of output.

Moreover, the structure of trade in the model naturally gives rise to strong comovement in exports as well, consistent with the result in Frankel and Rose (1998). Reflecting the difficulty of leading theoretical models to match this result, Kose and Yi

[2]In the data, output is consistently more highly correlated than consumption, whereas a large class of models produce the opposite result. In fact, most standard real business cycle models deliver a negative correlation of output.

(2006) identify a “trade comovement puzzle”. Using a three-country version, the authors can generate a positive relationship between the trade and GDP co-movement, but the correlation falls far short of what is evident in the data. Asserting a low consumption elasticity between imported and domestic goods appears to improve the relationship, a finding that is closely related to the mechanism behind our results.

We are not the first to explore the role of multinational firms in explaining business cycle synchronization. In a study using detailed firm-level data from France, Kleinert, Martin, and Toubal (2014) demonstrate that the degree of multinational affiliate activity of a given nationality across regions in France influences the comovement of that region with the origin country of the multinational affiliates. More surprisingly, Kleinert, Martin, and Toubal (2014) show that the trade-business cycle link finding from Frankel and Rose (1998) becomes insignificant when multinationals are accounted for separately. Moreover, Cravino and Levchenko (2014) document positive co-movement between multinational parent and affiliate sales. Finally, Peek and Rosengren (1997) and Peek and Rosengren (2000) discuss the transmission of financial shocks via multinationals, using large fluctuations in stock prices and credit supply in Japan in the late 1980s and early 1990s.

Another strand of research has focused on vertical trade linkages between countries. A study by Johnson (2014) looks at whether intermediate input linkages can generate greater business cycle comovement, but applies greater input-output structure to the model. Vertical linkages in this model generate some comovement in output, but value added comovement remains low. In a two sector model with intermediate input trade, Ambler, Cardia, and Zimmerman (2002) find that intermediate inputs are not the mechanism through which business cycles are transmitted. Arkolakis and Ramanarayanan (2009) feature endogenous specialization across a two stage production model, but once again generate very little relationship between trade and correlation of GDP. A more encourageing finding comes from di Giovanni and Levchenko (2010), which uses sectoral trade and production together with input-output matrices to separate out the role of vertical production linkages in cross-country comovement. Finally, Burstein, Kurz, and Tesar (2008) explore the use of intermediate inputs in a vertical FDI setting. Their preferred value for the production elasticity of substitution is indeed close to what we estimate in our earlier work.

In the next section, we outline the model we use to quantify the role of input trade by multinationals in business cycle synchronization. Section 3 describes the calibration of the model. Section 4 discusses results and robustness. The final section offers concluding thoughts.

2.2 An IRBC Model of Trade and Multinational Production

In this section we present a simple two-country model to illustrate the aggregate implications of vertically integrated multinational firms. Production takes place across three types of firms: A multinational firm (M) that is vertically integrated, producing in both countries and selling in the destination country, a non-multinational exporter (X) of final goods, and a non-multinational, non-exporting firm (D) producing only for domestic consumption. As we will show below, the critical feature for generating GDP comovement is the degree of complementarity between imported inputs and inputs in the destination country of the multinational firm.

We attempt to keep much of the remainder of the model standard. Time is discrete, a period is one month, markets are complete and the economy consists of two symmetric countries which we refer to as home (H) and foreign (F). Both countries are inhabited by a representative household who owns the capital stock, faces a standard consumption-savings choice and supplies labor. Firms in the final goods sector hire labor and rent capital to produce goods which are subsequently sold in a perfectly competitive market to the representative consumer. The consumer aggregates these goods into a composite which is used for consumption and investment.

An important distinction from most international RBC models is that we focus on short-lived shocks. The estimates we use from our previous work are based on such a short-lived shock, so that the firm is unlikely to completely restructure its supply chain. For this reason we calibrate the model to exhibit low persistence in the shock-generating process, and ignore the role of the extensive margin in the aggregate dynamics. Due to our focus on short-lived shocks at a monthly frequency, we must also account for the well-documented frictions in adjusting a firm's capital and labor in the short run. A number of recent papers, such as Bloom (2009), have highlighted the importance of such adjustment costs.

Regarding notation, we adopt the convention that superscripts denote the origin and subscripts denote the mode in which the destination market is served. For example, $l^H_{X,t}$ are the units of labor hired by home firms to produce goods for export to the foreign country. Similarly, $l^H_{M,t}$ represents the labor hired by home multinational firms for production in the foreign country. For the sake of brevity we will present only the optimization problems for agents of the home country. Foreign agents face analogous choices.

2.2.1 Households

Let $s^t = (s_1, ..., s_t)$ denote the history of states of the economy up to time t and denote by $\pi(s^t)$ the probability of the occurrence of such a state. In state s^t households in the home country choose purchases of final goods $y^H_D(s^t)$, $y^F_X(s^t)$, $y^F_M(s^t)$, consumption $C^H(s^t)$, labor $L^H(s^t)$, investment $I^H(s^t)$, and a full set of state-contingent claims $b^H(s^t, s_{t+1})$ so as to maximize

$$\sum_{t=0}^{\infty}\sum_{s^t}\beta^t\pi\left(s^t\right)\left(\frac{\left[C^H\left(s^t\right)\right]^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}-\phi\frac{\left[L^H\left(s^t\right)\right]^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}}\right) \tag{2.1}$$

subject to

$$\begin{aligned}\rho^H_D\left(s^t\right)y^H\left(s^t\right)+\rho^F_X\left(s^t\right)y^F_X\left(s^t\right)+\rho^F_M\left(s^t\right)y^F_M\left(s^t\right)+I^H\left(s^t\right)+\sum_{s_{t+1}|s^t}q\left(s^t,s_{t+1}\right)b^H\left(s^t,s_{t+1}\right)\\ =w^H\left(s^t\right)L^H\left(s^t\right)+R^H\left(s^t\right)K^H\left(s^t\right)+b^H\left(s^t\right)+\Pi^H\left(s^t\right),\end{aligned} \tag{2.2}$$

$$K^H\left(s^{t+1}\right)=\left(1-\delta\right)K^H\left(s^t\right)+I^H\left(s^t\right), \tag{2.3}$$

$$Y^H\left(s^t\right)=\left(\left(y^H_D\left(s^t\right)\right)^{\frac{\varepsilon-1}{\varepsilon}}+Z_X\left(\tau^{-1}y^F_X\left(s^t\right)\right)^{\frac{\varepsilon-1}{\varepsilon}}+Z_M\left(y^F_M\left(s^t\right)\right)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2.4}$$

$$Y^H\left(s^t\right) = C^H\left(s^t\right) + I^H\left(s^t\right) + \Xi^H\left(s^t\right). \tag{2.5}$$

and a no-Ponzi game condition. Equation (2.2) is the household's budget constraint and (2.3) is the standard capital accumulation equation. Relationship (2.4) is a CES aggregator used to combine goods purchased from home domestic firms, foreign exporters, and foreign multinationals into the final good $Y^H(s^t)$ which, as equation (2.5) shows, is used for consumption, investment, as well as adjustment costs $\Xi^H(s^t)$ (to be explained below). All exported goods are subject to iceberg trade costs τ. The weights Z_X and Z_M determine the importance of exporters and multinationals in the final bundle Y_t^H. Parameter ε is the Armington elasticity. Further, $K^H(s^t)$ denotes the capital stock, $w^H(s^t)$ the real wage, $R^H(s^t)$ the real rental rate, and $q(s^t)$ the state-claim price of state s^t. For notational convenience, we suppress the state s^t in the remainder of the paper, using only a t subscript to denote time.

Note that all three prices $\rho_{D,t}^H$, $\rho_{X,t}^F$ and $\rho_{M,t}^F$ are measured in units of the home country's aggregate, Y_t^H, that is used for home consumption and investment. Since Y_t^H is not GDP, an issue we return to below, we refer to the units of Y_t^H as the home bundle (and to the units of Y_t^F as the foreign bundle). Throughout this paper, we adopt the convention that prices are measured in bundles of the destination market.

2.2.2 Firms

The three final goods firms face dynamic production problems, due to the adjustment costs payable for changing capital and labor.

2.2.2.1 Production decision

The domestic and exporting firms hire labor and rent capital to produce goods $y_{s,t}^H,\ s \in \{D, X\}$ with Cobb-Douglas production functions of the form

$$y_{D,t}^H = A_t^H\left(k_{D,t}^H\right)^\alpha\left(l_{D,t}^H\right)^{1-\alpha}, \tag{2.6}$$

$$y_{X,t}^H = A_t^H\left(k_{X,t}^H\right)^\alpha\left(l_{X,t}^H\right)^{1-\alpha}. \tag{2.7}$$

The home multinational's affiliate in the foreign country produces its output using an intermediate good imported from Home, as well as an intermediate produced using foreign labor and capital. The home intermediate is produced with production function

$$x^H_{\iota,t} = A^H_t \left(k^H_{\iota,t}\right)^\alpha \left(l^H_{\iota,t}\right)^{1-\alpha}. \tag{2.8}$$

and combined with an intermediate $A^F_t \left(k^H_{M,t}\right)^\alpha \left(l^H_{M,t}\right)^{1-\alpha}$ produced in Foreign. We assume that the intermediate in the destination country is produced only with the technology of the country of production.[3] Source and destination intermediate goods are assembled into the multinational final good using the aggregator

$$y^H_{M,t} = \left(\mu^{\frac{1}{\psi}} \left(A^F_t \left(k^H_{M,t}\right)^\alpha \left(l^H_{M,t}\right)^{1-\alpha}\right)^{\frac{\psi-1}{\psi}} + (1-\mu)^{\frac{1}{\psi}} \left(\frac{y^H_{\iota,t}}{\tau}\right)^{\frac{\psi-1}{\psi}}\right)^{\frac{\psi}{\psi-1}}. \tag{2.9}$$

Here, μ is the weight on foreign inputs and ψ is the elasticity of substitution between home and foreign inputs. In the four production functions above, $l^H_{s,t}$ and $k^H_{s,t}$, $s \in \{D, X, M, \iota\}$, denote capital and labor. A^H_t (A^F_t) is the productivity of the home (foreign) country.

Domestic firms Perfectly competitive domestic firms choose $l^H_{D,t}$ and $k^H_{D,t}$ so as to maximize

$$E_0 \sum_{t=0}^{\infty} m^H_{0,t} \left\{\rho^H_{D,t} y^H_{D,t} - w^H_t l^H_{D,t} - R^H_t k^H_{D,t} - \xi_L \left(l^H_{D,t}, l^H_{D,t-1}\right) - \xi_K \left(k^H_{D,t}, k^H_{D,t-1}\right)\right\} \tag{2.10}$$

subject to equation (2.6). Here, $m^H_{0,t}$ denotes the stochastic discount factor and ξ_K and ξ_L are the firm-specific adjustment costs for capital and labor.

[3]It is possible that the appropriate technology for this stage of production could be some combination of the origin and destination countries. Such a direct spillover from multinational production would only serve to further increase co-movement in the model; but because research on the direct spillover channel is still preliminary (see Cravino and Levchenko (2014)) we leave them out.

Exporters Exporting firms solve

$$\max_{l^H_{X,t},k^H_{X,t}} E_0 \sum_{t=0}^{\infty} m^H_{0,t} \left\{ Q_t \rho^H_{X,t} y^H_{X,t} - w^H_t l^H_{X,t} - R^H_t k^H_{X,t} - \xi_L \left(l^H_{X,t}, l^H_{X,t-1} \right) - \xi_K \left(k^H_{X,t}, k^H_{X,t-1} \right) \right\} \tag{2.11}$$

subject to the equation (2.7). Q_t denotes the real exchange rate (in units of home bundles per foreign bundle). As noted above, the price of the exported good is measured in units of the final goods bundle of the destination market (in this case Foreign).

Multinationals Multinational firms produce and sell in both countries. In the home country, multinationals hire labor $l^H_{\iota,t}$ and rent capital $k^H_{\iota,t}$ to produce the intermediate $y^H_{\iota,t}$ which it sells to the foreign assembling firm. The affiliate abroad hires foreign labor $l^H_{M,t}$ at wage w^F_t, rents foreign capital $k^H_{M,t}$ at rental rate R^F_t and uses the intermediate $y^H_{\iota,t}$ (after paying transport costs τ). The home multinationals' optimization problem can be conveniently broken into two parts. In the source country they solve

$$\max_{l^H_{\iota,t},k^H_{\iota,t}} E_0 \sum_{t=0}^{\infty} m^H_{0,t} \left\{ Q_t \rho^H_{\iota,t} y^H_{\iota,t} - w^H_t l^H_{\iota,t} - R^H_t k^H_{\iota,t} - \xi_L \left(l^H_{\iota,t}, l^H_{\iota,t-1} \right) - \xi_K \left(k^H_{\iota,t}, k^H_{\iota,t-1} \right) \right\} \tag{2.12}$$

subject to equation (2.8). Similarly, in the destination country they solve

$$\max_{l^H_{M,t},k^H_{M,t}} E_0 \sum_{t=0}^{\infty} m^H_{0,t} Q_t \left\{ \rho^H_{M,t} y^H_{M,t} - w^F_t l^H_{M,t} - R^F_t k^H_{M,t} - \rho^H_{\iota,t} y^H_{\iota,t} - \xi_L \left(l^H_{M,t}, l^H_{M,t-1} \right) - \xi_K \left(k^H_{M,t}, k^H_{M,t-1} \right) \right\} \tag{2.13}$$

subject to equation (2.9).

We will assume that TFP follows a vector autoregressive process of the form

$$\begin{pmatrix} A^H_t \\ A^F_t \end{pmatrix} = \begin{pmatrix} \varrho^H & a^F_H \\ a^H_F & \varrho^F \end{pmatrix} \begin{pmatrix} A^H_{t-1} \\ A^F_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon^H_t \\ \varepsilon^F_t \end{pmatrix}, \tag{2.14}$$

where we dropped constant terms. ϱ^H and ϱ^F determine the persistence of shocks while lagged spillovers are parameterized by the choice of a^F_H and a^H_F. Furthermore, simultaneous innovations can be captured in the covariance matrix of $\left(\varepsilon_t^H, \varepsilon_t^F\right)$.

2.2.2.2 Adjustment costs and market clearing

In this model adjustment costs are measured in units of the final bundle of the country in which production takes place. Summing these adjustment costs gives

$$\Xi_t^H = \sum_{s\in\{D,X,\iota\}} \left[\xi_L\left(l_{s,t}^H, l_{s,t-1}^H\right) + \xi_K\left(l_{s,t}^H, l_{s,t-1}^H\right)\right] + \xi_L\left(l_{M,t}^F, l_{M,t-1}^F\right) + \xi_K\left(l_{M,t}^F, l_{M,t-1}^F\right), \tag{2.15}$$

which enters the material balance (2.5). To complete the model, we state the market clearing conditions. Labor and capital market clearing in the home country require that

$$L_t^H = l_{D,t}^H + l_{X,t}^H + l_{\iota,t}^H + l_{M,t}^F \tag{2.16}$$

and

$$K_{t-1}^H = k_{D,t}^H + k_{X,t}^H + k_{\iota,t}^H + k_{M,t}^F. \tag{2.17}$$

Finally, the bond market clearing condition is

$$b_t^H + b_t^F = 0. \tag{2.18}$$

2.2.3 Equilibrium

The aggregate state is summarized in $\Omega_t := \left(A_t^H, A_t^F, K_{t-1}^H, K_{t-1}^F\right)$. A recursive competitive equilibrium in this economy is, for $i \in \{H, F\}$, a set of optimal consumer policies $C^i\left(\Omega_t\right),\ L^i\left(\Omega_t\right),\ I^i\left(\Omega_t\right),\ Y^i\left(\Omega_t\right),\ y_s^i\left(\Omega_t\right),\ s \in \{D, X, \iota, M\}$, firms' factor inputs $l_s^i\left(\Omega_t\right),\ k_s^i\left(\Omega_t\right),\ s \in \{D, X, \iota, M\}$, goods prices $\rho_s^i\left(\Omega_t\right),\ s \in \{D, X, \iota, M\}$, wages $w^i\left(\Omega_t\right)$, rental rates $R^i\left(\Omega_t\right)$, and a real exchange rate $Q\left(\Omega_t\right)$ such that the following conditions are satisfied.

1. Taking prices as given, $C^i\left(\Omega_t\right)$, $L^i\left(\Omega_t\right)$, $I^i\left(\Omega_t\right)$, $Y^i\left(\Omega_t\right)$, $y_s^i\left(\Omega_t\right)$, $s \in \{D, X, \iota, M\}$ solve the household's problem as described in equations (2.1) to (2.5).

2. Taking prices as given, $l_s^i\left(\Omega_t\right)$, $k_s^i\left(\Omega_t\right)$, $s \in \{D, X, \iota, M\}$ solves the firms' op-

timization problems as described in (2.10) to (2.13) subject to the respective production functions (2.6) to (2.9).

3. All markets clear, that is, equations (2.15) to (2.18) hold.
4. The exogenous process for the evolution of technology is given in (2.14).

The next section discusses the calibration.

2.3 Calibration

We will present results from the baseline calibration of our model as well as several counterfactual calibrations to illustrate the role of the production elasticity in transmitting shocks and generating endogenous comovement. Table 2.1 summarizes the various calibrations. The majority of parameter values are kept at conventional values in the literature, modified to reflect the calibration to a monthly frequency. Panel A of Table 2.1 describes the values chosen for these parameters, which will remain constant across the various calibrations. In the steady state, the two countries are symmetric.

We draw attention to the parameters governing the exogenous shock process. The standard deviation of the innovations (ε^H, ε^F) is set to that used in Backus, Kehoe, and Kydland (1995b) (henceforward BKK). Unlike BKK however, we set the off diagonal terms (the a_F^H and a_H^F terms) to zero. This shuts down all exogenous comovement coming directly from the model, which serves to focus attention to the mechanisms we highlight in generating endogenous output co-movement. The persistence of the shock process given by ϱ is somewhat unconventional. In line with other features of this model, we set the persistence to match the time-path of Japanese industrial production following the 2011 Tōhoku earthquake. This amounts to a ρ of 0.71 (a half life of two months), and thus serves to capture only the effects of a short lived shock. We discuss the implications of this choice in section 2.4.4.

We utilize a novel micro-level dataset to calibrate the remaining parameters of the model. We begin with the universe of U.S. manufacturing firms in the 2007 Census of Manufacturers (CM), which is then matched to information on firm-level trade from the Longitudinal Foreign Trade Transactions Database (LFTTD). We identify multinationals using a new link to firm-level variables indicating multinational activity, coming from information from international corporate directories that have been matched to the Census Bureau Business Register for many years (see Appendix B.1 and Flaaen (2013b) for more details). We use a new methodology for classifying firm-level imports as intermediate goods for further processing or final goods for sale to the consumer (see Boehm, Flaaen, and Pandalai-Nayar (2014b) for a description of this methodology).[4] Our data points to the importance of vertical linkages between multinationals and their source country. Roughly one-third of U.S. imports of intermediate goods occur through foreign multinational affiliates, and of this trade roughly 45 percent are sourced from the country of the parent organization. Moreover, 71 percent of these intermediate imports are intra-firm transactions, precisely the type of trade that one would presume would exhibit low substitutability with other domestic inputs. In light of these facts, we focus attention on intermediate trade via multinational firms in this paper.

The parameter values novel to our baseline model are shown in Panel B of Table 2.1. For the baseline case we assume a CES production function for multinationals. We calibrate the Z_M, Z_X and μ parameters to match three observations from the data: (1) The value added share of multinationals in the Census of Manufacturers (CM) in 2007, (2) the value added share of non-multinational exporters in the CM in 2007 and (3) the cost share of intermediates in multinational production.[5] The CM data indicates that foreign multinational affiliates account for 14.5 percent of value-added, while exporting (non-multinational) firms are responsible for 21.1 percent of value-added. The cost share of intermediate inputs for these firms in our data is quite high, at 32 percent (see Boehm, Flaaen, and Pandalai-Nayar (2014b) for details).

The production elasticity of substitution ψ is a critical parameter in governing the

[4]It is well-known that some firms classified as manufacturing continue to import final goods destined for final consumption, thereby serving as the wholesale/retail operations of the firm.

[5]GDP at constant prices is defined as $GDP_t^H = \rho_D^H y_{D,t}^H + Q\rho_X^H y_{X,t}^H + \rho_M^F y_{M,t}^F - \rho_\iota^F y_{\iota,t}^F + Q\rho_\iota^H y_{\iota,t}^H$. We assume that real GDP is directly observable (see Arkolakis and Ramanarayanan (2009) for how measurement issues impact observable GDP).

degree of co-movement in the model. While it is well-known that the performance of this class of models depends heavily on this parameter (see Heathcote and Perri (2002)), difficulties in the empirical estimation of this parameter has led to considerable uncertainty in calibration procedures. As highlighted above, in a companion paper (Boehm, Flaaen, and Pandalai-Nayar (2014b)) we estimate this elasticity using the microdata at our disposal, while leveraging the 2011 Tōhoku event for identification. The parameter value we assign to multinational input trade, $\psi = 0.01$, is substantially lower than most estimates used in these models.

Finally, we turn to the calibration adjustment costs for capital and labor. We choose the simple specifications

$$\xi_L\left(l^i_{s,t}, l^i_{s,t-1}\right) = \frac{\zeta^L}{2} l^i_{s,t-1}\left(\frac{l^i_{s,t}}{l^i_{s,t-1}} - 1\right)^2, \; \xi_K\left(k^i_{s,t}, k^i_{s,t-1}\right) = \frac{\zeta^K}{2} k^i_{s,t-1}\left(\frac{k^i_{s,t}}{k^i_{s,t-1}} - 1\right)^2 \tag{2.19}$$

for $i \in \{H, F\}$ and $s \in \{D, X, M, \iota\}$. While a number of recent papers estimate positive and significant values for these — even at a quarterly frequency — the exact mapping to our current framework is not clear. Bloom (2009) estimates a series of adjustment cost parameters for capital and labor in a monthly model. Among other such costs, Bloom (2009) finds a quadratic labor adjustment cost (similar to our ζ_L) of close to unity. On the capital side, he finds the quadratic cost estimate is similar in magnitude to that of labor, but finds that non-convex adjustment costs also play a large role. These costs do not map exactly to our model, so we calibrate ζ_L to one times the steady state wage and ζ_K to 10 times the steady state rental rate. We explore the sensitivity of our results to these calibration choices in the subsequent section.

2.4 Results and Discussion

In this section we discuss the behavior of the model, and in particular the role of vertical linkages in generating GDP co-movement. We provide intuition for the mechanisms at work by successively turning off features of the model and discussing how these features affect aggregate behavior. We also evaluate whether the model captures the salient time series properties of the data around the 2011 Tōhoku Earthquake/Tsunami, and finally discuss robustness.

2.4.1 Behavior of the Model

In the following discussion, we assume that the foreign country experiences a one percentage point negative shock to total factor productivity (A^F). Our focus is on understanding the behavior of GDP, which is composed of the value added of the four different types of production: domestic, exporter, intermediate and multinational production in the destination country. The responses of these firms are determined by demand and supply side factors. On the demand side, foreign demand for the final good drops by more than home demand. Further, substitution occurs towards the goods that are relatively cheaper as a result of the shock. Supply side factors include the technology change, factor prices and adjustment costs. The brevity of this shock implies little movement in the real exchange rate, so we do not emphasize its effects in our discussion. Table 2.3 presents the simulated moments of all versions of the model.

First we discuss transmission in the baseline version, in which the firms are subject to moderate costs of adjusting their labor and capital inputs. Figure 2.2 plots the impulse response functions of production of the domestic firms and the multinationals, as well as intermediate input production. The foreign domestic firm reduces production the most, as it faces both lower demand and worse productivity. In contrast, the foreign multinational faces relatively higher demand from the home country, and only part of its production chain is affected by the negative TFP shock. It raises factor inputs to compensate for the productivity loss in intermediate production, but adjustment costs prevent the firm from completely offsetting the shock. As a result, both the foreign intermediate good production and foreign multinational good production fall. Notice that intermediate goods production moves essentially in lock-step with multinational output, due to the low elasticity ψ. This simultaneous drop in production of the two goods generates co-movement in value-added.

A second source of spillovers comes through the home multinational. As a result of lower foreign TFP and reduced foreign demand, home multinational production of final goods in the foreign country falls, reducing foreign GDP. The low elasticity of production then implies that the home multinational also cuts production of intermediates in Home, lowering home GDP (and thereby inducing GDP co-movement). Interestingly, the combined drop in TFP and foreign demand results in home multinational output falling by more than foreign multinational output. Thus, in the baseline version of the model, the home multinational contributes more to GDP comovement than the foreign multinational. Although previous research on the 2011 Tōhoku event has not studied this channel, it is an immediate consequence of a low elasticity ψ. The home domestic firm slightly increases production as it faces higher demand due to changing prices at Home. However, the adjustment costs dampen its response.

We briefly discuss the overall performance of the model relative to the data. Table 2.2 compiles the relevant moments using the median over a sample of OECD countries. We show the data benchmarks at a quarterly frequency, as is standard, and at a monthly frequency where the data allows. As is well known, in the data GDP is strongly positively correlated across countries. Our model delivers a positive GDP correlation, but falls short in terms of magnitude. Of course, this is to be expected when focusing attention on only one mechanism for cross-country spillovers. Notice that the positive correlation is an improvement relative to many other frameworks. Consumption, investment and hours are all positively correlated across countries in our model as in the data. As is common, the consumption correlation in the model is too high. Additionally our model delivers very high hours correlation. This is partly due to the vertical linkages: the foreign multinational increases labor used in the first stage of its production, dampening the drop in hours in Foreign. By contrast, home intermediate production requires less labor input relative to other firms producing in Home, which reduces overall hours worked and leads to positive hours comovement.

As Engel and Wang (2011) point out, the negative correlation of net exports with GDP in the data is driven by a combination of a positive correlation of exports with

GDP and an even higher positive correlation of imports with GDP.[6] In our model, the correlation of imports with GDP is positive but lower than exports with GDP. However, the correlation of intermediate input imports is higher than that of exports with GDP. As we focus on input trade through multinationals, our model understates the share of intermediate input trade in total trade. A larger input share would likely move the correlation of the trade balance with GDP closer to that in the data.

To understand the role of adjustment costs in the model, we next turn to the version without adjustment costs so that labor and capital freely moves between firms in response to changes in factor demand. Figure 2.3 plots the corresponding impulse response functions for the case with no adjustment costs. In this case strong home demand induces the foreign multinational firm to increase production. It now overcompensates for the productivity loss by hiring cheap labor and capital. Again, the increase in output and intermediate production of the foreign multinational is one-for-one. Home multinationals respond to the productivity shock by sharply decreasing production in both stages.

Although the low elasticity ψ still implies that multinational firms increase output comovement, the behavior is inconsistent with our narrative. We would expect – and indeed did empirically document for the 2011 Tōhoku shock – that Foreign multinationals decrease production in response to the TFP shock in the source country. In this version of the model value-added comovement is low because of the extreme responses of the home and foreign domestic firms which generate the bulk of value added: While foreign domestic firms decrease output in response to the shock, home domestic firms raise production to satisfy increased demand for investment goods (not shown).

2.4.2 Counterfactual Experiments

In our first counterfactual, we change the fraction of value added generated by multinational firms in both countries, while keeping the value added shares of the

[6] In fact, the median correlation of net exports with GDP in the OECD countries in our sample is close to zero for the period 1995-2010. An earlier sample, 1980-1995, yields a negative correlation for this statistic.

exporting firms constant. The goal is to understand how GDP comovement changes when a larger fraction of output is produced by vertically integrated firms. Table 2.3 and Figure 2.4 present the results. In the version without multinational firms, GDP comovement is 13 percent. When we raise the fraction of value added generated by multinationals to 14.5 percent, as in our baseline calibration, the correlation between Home and Foreign GDP rises to 24 percentage points. Finally, as we double multinational value added (to 29 percent), output comovement increases to 38 percent. Thus the channels highlighted in the model could help explain the role of the large increases in trade and direct investment in the increases in business cycle synchronization over the past few decades.

In our next counterfactual we modify the baseline calibration by raising the production elasticity ψ to 2. As a consequence, the GDP correlation drops to 15 percent, 9 percentage points lower than in the baseline and quite close to the correlation evident without multinational firms. We conclude that multinational firms together with a low production elasticity ψ and adjustment costs are a powerful source of business cycle synchronization. Figure 2.4 illustrates the strength of spillovers to home GDP across the various versions of the model discussed in the paper.

2.4.3 Capturing Firm Behavior following the Tōhoku Earthquake

Upon comparing Figures 2.2 and 2.1 one may conclude that production of the multinational firm in the model does not well mimic the large drop following the Tōhoku event. On the one hand this is not surprising as the TFP shock poorly approximates the Tōhoku disruption, with the full set of consequences including destruction of capital, human loss, and widespread power outages that resulted. However, and as Figure 2.2 shows more specifically, in the model the foreign multinational (intermediate) increases its labor input usage substantially following the shock, in order to offset the productivity loss. Such an adjustment was presumably not possible after the Tōhoku earthquake/tsunami.

Very large adjustment costs might appear to solve this problem. To explore this possibility, we consider the case in which the adjustment costs in the intermediate production step become infinite.[7] In this case Figure 2.5 shows that production of the foreign multinational falls in both stages, roughly consistent with the data. Additionally, the GDP correlation rises to 30 percent, 17 percentage points higher than in the calibration without multinationals (not shown).

2.4.4 Alternative Parameterizations

Other papers, such as Baxter and Crucini (1995) and Heathcote and Perri (2002), have shown that international RBC models perform better along a variety of dimensions with low Armington elasticities and shocks of low persistence. When we increase the Armington elasticity to 5, GDP comovement falls to 0.11 percent. With a higher Armington elasticity, consumers are more willing to substitute between the goods available and react more strongly to price changes of the multinational good. The resulting expenditure switching by consumers shows how the relationship between the production elasticity (ψ) and Armington elasticity (ϵ) is important for the degree of spillovers in the model. This point has been made in greater detail in a recent paper by Bems and Johnson (2014).

We next increase the persistence of the shock to 0.983 which corresponds to a persistence of 0.95 in a quarterly calibration. GDP comovement now falls to 0.08 percentage points. This is partly due to the strong depreciation of the real exchange rate from the viewpoint of the home consumer. With this adjustment purchases of foreign export goods become expensive. As a result the foreign export firm contracts by more than in the baseline version with short-lived shocks.

[7] The economy cannot simultaneously feature a Leontief production function and very high adjustment costs for all production stages. To see this, consider the production function $min\left\{A_t^H\left(k_{M,t}^F\right)^{\alpha}\left(l_{M,t}^F\right)^{(1-\alpha)}, y_{\iota,t}^F\right\}$. The log-linearized version of the associated optimality condition requires that

$$\tilde{A}_t^H + \alpha \tilde{l}_{M,t}^F + (1-\alpha)\,\tilde{k}_{M,t}^F = \tilde{y}_{\iota,t}^F. \tag{2.20}$$

With infinite adjustment costs, and $\tilde{A}_t^H = 0$, this relationship only holds if $\tilde{y}_{\iota,t}^F = 0$ which is not possible if the intermediate firm cannot raise its labor and capital inputs. In short: Infinite adjustment costs, firm optimization, and a Leontief production function are inconsistent.

2.5 Conclusion

Whether cross country linkages of trade and investment cause the business cycle correlations evident in the data has been a subject of much debate, both on the empirical and theoretical side. This paper builds on the empirical results of our previous work to demonstrate that the rigid supply chains of multinational firms — embodied in a very low production elasticity of substitution — can indeed generate substantial value-added co-movement in otherwise conventional models of cross-country business cycle dynamics.

An important conclusion of this paper is that all trade need not necessarily contribute to increased synchronization. It is reasonable to believe that intermediate input trade is less substitutable in the short run than trade in final goods. Moreover, the intra-firm trade of multinational firms is likely to exhibit a high degree of complementarity with other inputs, given the increased specificity of the inputs involved in these transactions. A natural corollary of these observations is that the degree of business cycle correlation would likely vary based on the composition of trade along the intermediate/final and intra-firm/arms-length dimensions. Evaluating whether these characteristics of bilateral trade helps to further understand cross-country spillovers will be the focus of future work.

Table 2.1: Calibration Details

Panel A: Standard Parameter Values

α	0.33		
τ	1.15	Shock Process	
δ	0.0087	ϱ^H , ϱ^F	0.5
σ	0.5	a_H^F , a_F^H	0
β	0.9975	ε^H , ε^F	0.01
η	1		

Panel B: Non-Standard Parameter Values

Parameter	Baseline	No Adj Costs	No Mults	High Adj Costs	High ψ	High Mults	High ε	High ρ
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ψ	0.01	0.01	N/A	0.01	2	0.01	0.01	0.01
ε	1.5	1.5	1.5	1.5	1.5	1.5	5	1.5
ρ	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.98
V.A. Share Mults	0.145	0.145	0	0.145	0.145	0.29	0.145	0.145
V.A. Share Exporters	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251
μ	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
ζ^L/w	1	0	1	100	1	1	1	1
ζ^K/R	10	0	10	1000	10	10	10	10

Source: Parameter values are chosen to match those in Backus, Kehoe, and Kydland (1995b), modified for a monthly frequency, unless specified otherwise in the text. The baseline value for ψ is taken from Boehm, Flaaen, and Pandalai-Nayar (2014b). The value-added share of exporters is chosen, together with the value-added share of multinationals and the value of μ, such that multinational input trade represents 21 percent of U.S. trade in goods.

Table 2.2: Summary of Business Cycle Moments: OECD Countries 1995-2010

Moment	Quarterly Frequency	Monthly Frequency[1]
Corr(GDPH,GDPF)	0.74	0.71
Corr(CH,CF)	0.45	–
Corr(LH,LF)	0.56	–
Corr(IH,IF)	0.70	–
Corr(GDP,EXP)	0.84	0.53
Corr(GDP,IMP)	0.83	0.49
Corr(GDP,INTIMP)	–	–
Corr(GDP,TB/GDP)	0.01	–

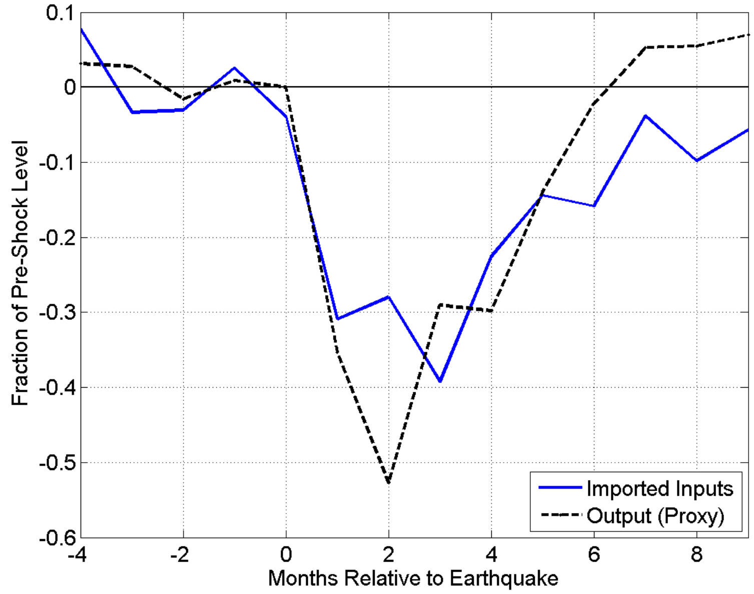
Source: International Financial Statistics IMF, Ohanian and Raffo (2012), and OECD as described in Appendix F.1. Numbers correspond to median correlations over a sample of OECD countries. The underlying sample of OECD countries may differ slightly across the statistics, based on data availability.
[1]Monthly data for GDP corresponds to gross output, rather than value-added.

Table 2.3: Summary of Model Moments by Calibration

Moment	Baseline	No Adj Costs	No Mults	High Adj Costs	High ψ	High Mults	High ε	High ρ
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Corr(GDPH,GDPF)	0.24	0.03	0.13	0.13	0.15	0.38	0.11	0.08
Corr(CH,CF)	0.80	0.34	0.75	0.80	0.88	0.88	0.96	0.81
Corr(LH,LF)	0.84	0.13	0.51	-0.79	0.62	0.77	0.40	0.36
Corr(IH,IF)	0.37	-0.68	0.27	0.76	0.45	0.57	0.49	0.05
Corr(GDP,EXP)	0.87	-0.28	0.86	1.00	0.92	0.91	0.96	0.81
Corr(GDP,IMP)	0.60	0.88	0.49	0.17	0.41	0.66	0.32	0.53
Corr(GDP,INTIMP)	0.97	0.78	0.02	0.61	0.33	0.98	0.90	0.97
Corr(GDP,TB/GDP)	0.29	-0.62	0.33	0.62	0.45	0.32	0.51	0.11

Notes: The calculation of model correlations matches that from the data. We take the simulated data series from the model, take logs, and then HP-filter.

Figure 2.1: Relative Imported Inputs and Output (Proxy) of Japanese Firms: Fraction of Pre-Shock Level



Source: Boehm, Flaaen, and Pandalai-Nayar (2014b).
This figure reports the intermediate imports and North American exports of the U.S. affiliates of Japanese firms relative to a control group of other multinational firms following the March 2011 Tōhoku Earthquake/Tsunami. The values are percent changes from the pre-shock level of each series, defined as the average of the months December 2010, January 2011, and February 2011. See Boehm, Flaaen, and Pandalai-Nayar (2014b) for details.

Figure 2.2: Impulse Response: Negative TFP Shock in Home: Baseline Model

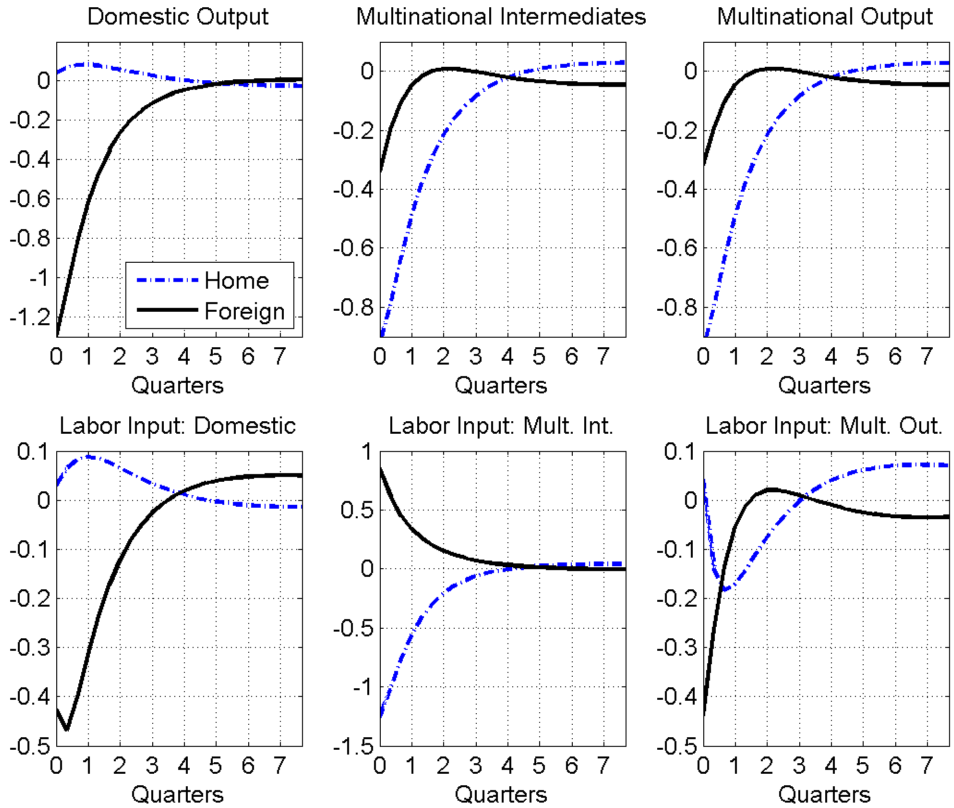


Figure 2.3: Impulse Response: Negative TFP Shock in Home: No Adjustment Costs Model

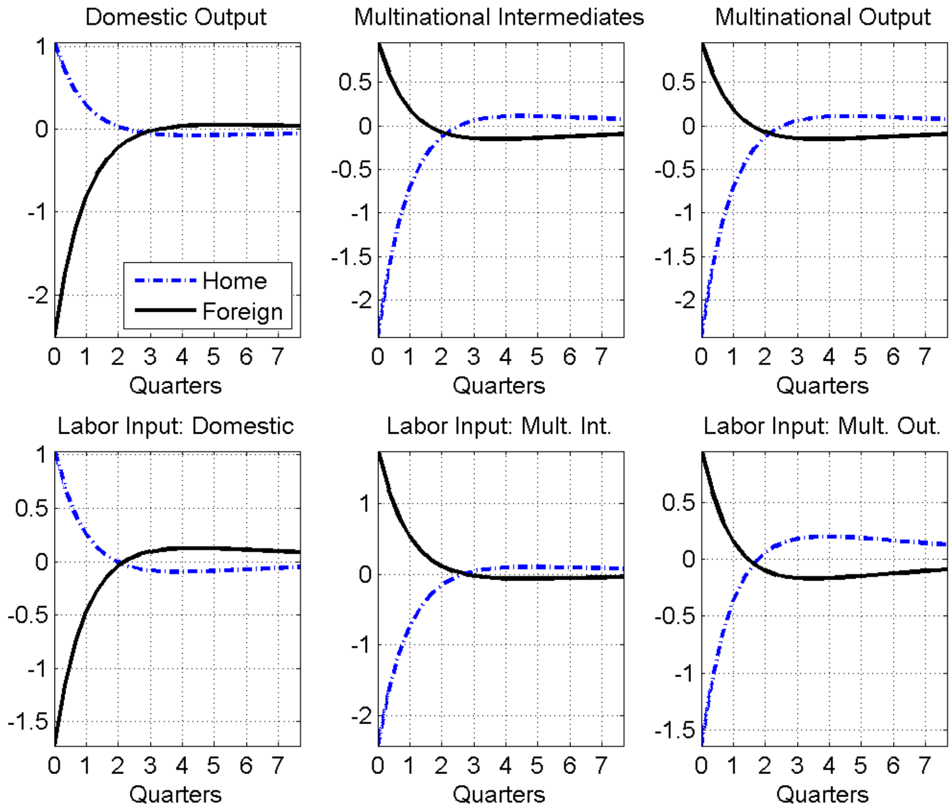


Figure 2.4: Impulse Response: Home Country Spillovers Following Shock in Foreign

GDP (Value-Added) in Home by Model Type

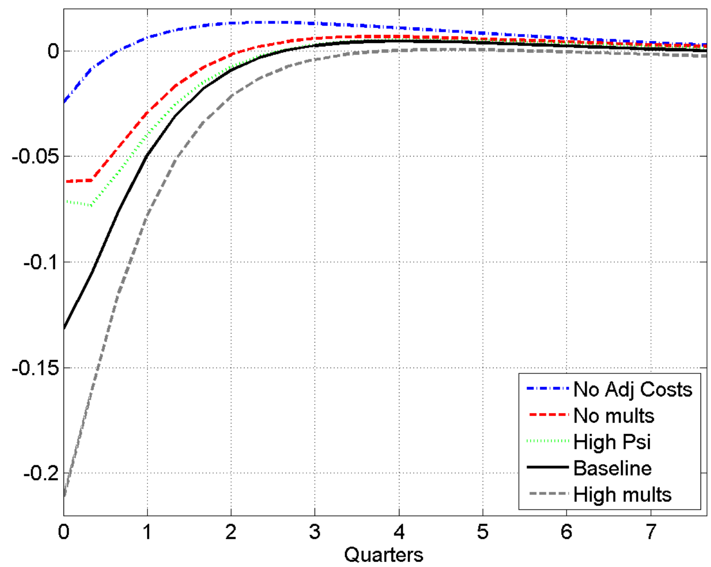
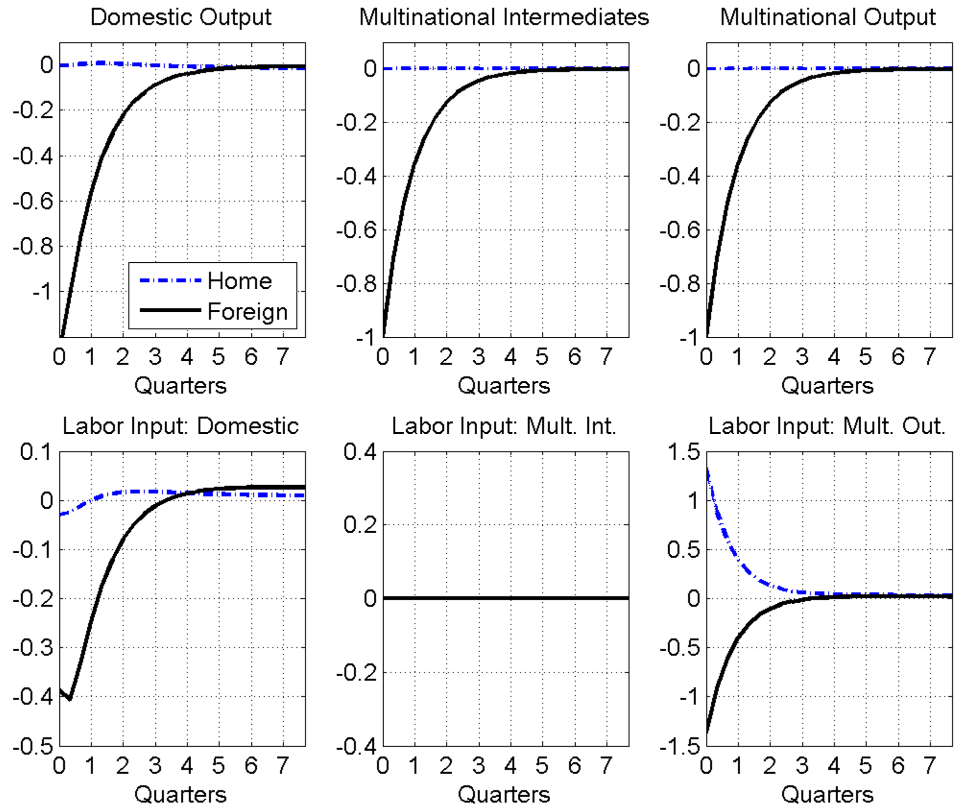


Figure 2.5: Impulse Response: Negative TFP Shock in Home: Infinite Adjustment Costs in Intermediate Production



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CHAPTER III

Multinational Firms in Context

Using a novel firm-level dataset linking directories of international ownership to the universe of manufacturing establishments in the Census Bureau, this paper studies multinational firms in the context of their exporting (non-multinational) and domestic-only counterparts. Multinational firms are shown to be larger, more productive, more capital-intensive, and pay higher wages than either domestic-only or exporting firms. The magnitude of this "multinational premium" is consistently 3-4 times that of the so-called "exporter premium" documented in previous research. Although 70 percent of multinational firms record positive levels of exports, the share of sales destined for outside the U.S. is small - only 10 percent. Ownership patterns have a large effect on trade flows. Roughly 45 percent of the imports to a foreign multinational affiliate in the U.S. originate from the country of the parent company. The empirical evidence offers valuable guidance on the theoretical framework most applicable for multinational production in the U.S.

Multinational firms are a dominant feature of the world economy. According to aggregate numbers published by the Bureau of Economic Analysis (BEA), U.S. majority-owned manufacturing affiliates abroad recorded sales of over 2 trillion USD in 2009. By comparison, U.S. manufacturing exports in 2009 amounted to just 916 billion USD. These firms also account for a large fraction of trade flows. A study by Bernard et al. (2010) indicates that 46 percent of U.S. imports are intra-firm.

Understanding the nature and determinants of multinational production has been complicated, however, by a general scarcity of firm-level data. Prior work on these firms has relied on data that have either neglected the heterogeneity that firm-level analysis can afford, or have failed to place these firms in the context of their exporting (non-multinational) and domestic-only counterparts. An accurate assessment of how and why firms decide to locate production abroad should naturally consider an alternate method, namely trade, of accessing foreign markets and country-specific factors of production. Put differently, it is potentially misleading to look at exports without considering multinational production, and vice-versa.

This paper documents a number of stylized facts about multinational firms, using novel data linking directories of international firm structure to the universe of manufacturing establishments in the United States. In addition to providing critical benchmark groups for the analysis, these new data allow for multinational firms to be separated into those originating in the United States (U.S. multinationals) and those operating in the U.S., but originating abroad (Foreign multinationals). Indeed, standard models of FDI and multinational production would expect these firms to behave differently.

Such a novel dataset allows this research to explore questions that have been previously unanswered in the literature. This paper explores how multinational firms differ from exporting and domestic-only firms, how ownership patterns affect trade flows, and the degree of heterogeneity across these types of firms at the industry-level. Underlying all of these questions are two competing frameworks with which to view multinational production. The "horizontal" framework of FDI is defined as the replication of production across countries in order to save on transport and tariff costs to more cheaply access foreign consumers. This framework is exemplified in the "proximity-concentration tradeoff" popularized by Krugman (1983) and Brainard (1997). A second framework – termed vertical FDI – is defined as the fragmentation of the production process in order to take advantage of differing cross-country factors of production.[1] Hence, these frameworks differ not only in the motivation for multinational production, but critically in the destination of sales: horizontal FDI seeks to principally sell to the local market, whereas vertical FDI does not.

Section 3.1 provides information on the traditional sources of data on multinational firms and documents the datasets used in the present analysis. Section 3.2 presents some key findings of how multinational firms compare. The section shows that multinational firms are larger, more productive, more capital-intensive, pay higher wages, and employ more non-production workers than either domestic-only or exporting firms. This "multinational premium" is consistently 3-4 times the magnitude of the so-called "exporter premium" that has been previously examined in the literature.

Section 3.3 discusses the influence of international ownership patterns on trade flows. Although 70 percent of multinational firms in the manufacturing sector record positive levels of exports, the median share of a multinational firm's U.S. production that is destined for sale outside the U.S. market is small - only 10-12 percent. Foreign multinational affiliates in the U.S. send roughly 18 percent of exports to the country of their parent firm. A considerably larger share of exports - 36 percent - is directed to the economies of Canada and Mexico. The composition of the source countries of foreign affiliate imports is even more striking: roughly 45 percent originate from the country of the parent company.

Section 3.4 summarizes how the empirical evidence from the preceding sections speaks to the nature and determinants of multinational production. There is suggestive evidence for the presence of both horizontal and vertical motives of FDI, making any binary characterization of all multinational production in an economy necessarily

[1]This framework is also referred to as the "factor proportions hypothesis", and dates back to at least Helpman (1984).

incorrect. However, it appears to be the case that the large majority of the sales of Foreign multinationals in the United States is intended for local sale, consistent with horizontal FDI. At the same time, large shares of import flows for these firms from their home country suggest some fragmentation of production where intermediate inputs from the parent are assembled in the host country for local sale. This view is consistent with a "capabilities" definition of the firm as argued by Atalay, Hortacsu, and Syverson (2014), among others.

Finally, section 3.5 examines industry heterogeneity in the composition of exporting and multinational production. Separating the data into 18 manufacturing categories (roughly corresponding to the 3-digit NAICS subsectors) allows for an examination of the sectoral distribution of plants, sales, employment, and exports by firm type. The results show significant heterogeneity of multinational behavior across sectors. For example, Foreign multinational firms account for 27 percent of total sales in the Chemical Products sector, 28 percent in Nonmetallic Minerals, but only 8.3 percent in Fabricated Metals. In addition, the bulk of exporting activities by U.S. and Foreign multinationals are concentrated in the Chemical Products, Computer and Electronics, and Transport Equipment sectors. Although these three sectors comprise roughly 40-45 percent of total sales for these two groups of firms, they account for over 60 percent of total exports.

3.1 Data Description and Matching Procedure

This section outlines the traditional data sources used to study multinational firms, documents their relative strengths and weaknesses, and presents the details of the dataset used in the remainder of the paper.

3.1.1 Traditional Data Sources on Multinational Firms

Prior research has primarily relied on two principal data sources to infer information about multinational firms in the United States. Each source has some advantages while also suffering from important drawbacks.

The primary source for firm-level analysis of multinationals in the U.S. has been the annual surveys conducted by the Bureau of Economic Analysis. The Foreign Direct Investment in the United States (FDIUS) is an annual survey with benchmark years being conducted in the years ending in a 2 or 7 (concurrently with the Economic Censuses of the Census Bureau). The U.S. Direct Investment Abroad (USDIA) survey conducts benchmark surveys in those years ending in a 4 or 9. Numerous studies have used the aggregate totals from these surveys, or conducted firm-level analysis using the restricted datasets.[2] There are two primary disadvantages with the BEA data. First, the surveys sample *only* multinational firms, and thus there are no relevant comparison groups for the researcher interested in issues such as multinational entry/exit, export vs FDI decisions, and other questions where relevant comparison groups are necessary. Second, the lack of standardized firm identifiers in the BEA data makes it difficult to link firms across time. Moreover, the sampling criteria in the non-benchmark years have changed frequently, making longitudinal analysis even more difficult.

A second source for identifying multinational firms has been the Longitudinal Foreign Trade Transactions Database (LFTTD). The LFTTD links individual trade transactions to firms operating in the U.S., and is assembled via a collaboration between the U.S. Census Bureau and the U.S. Customs Bureau. The LFTTD contains information on destination (or source) country, quantity and value shipped, the transport mode, and other details from point-of-trade administrative documents. Existing studies (e.g. Bernard et al. (2007), Bernard, Jensen, and Schott (2006), and Bernard, Jensen, and Schott (2009)) have identified multinational firms from a variable in the LFTTD that identifies whether a trade transaction took place at "arms-length" or with a "related party". Using this variable, researchers have been able to infer multinational status depending on whether a firm has *any* related party trade.[3]

There are three primary difficulties with this approach. First, the ownership threshold that classifies a foreign trade transaction as between related parties differs

[2] A select sample of papers using the BEA data are: Zeile (1998), Borga and Zeile (2004), Ramondo, Rappoport, and Ruhl (2014), Yeaple (2009), and Helpman, Melitz, and Yeaple (2004).

[3] For an excellent summary of the sources of intra-firm trade statistics in the U.S., see Ruhl (2013).

between exports and imports, and is generally low relative to common definitions of international subsidiaries.[4] Second, the LFTTD data are unable to differentiate between a U.S.-based multinational with affiliates abroad, and a Foreign-based multinational with affiliates located within the United States. Finally, by its nature the LFTTD-based definition of a multinational will miss the firm-level international ownership patterns that do not rely on frequent intra-firm trade.

This is not the first paper to seek alternative sources for identifying multinational firm behavior. Perhaps the study closest to the present paper is work by Doms and Jensen (1998), which utilized a short-lived link between the Census and BEA data for a select year in 1987.[5] That paper found foreign-owned plants to be more capital-intensive, more productive, pay higher wages, and use a higher proportion of nonproduction workers than typical U.S. plants. The study also found U.S. multinationals (defined by the paper as those U.S.-owned plants with $>$ 10 percent of total assets held abroad) to outperform foreign-owned plants on the same set of criteria, though the differences were small.

Rowland and Tesar (2004) classify multinationals based on a listing of multinational corporations in the "Worldwide Branch Locations of Multinational Companies" (Hoopes, 1994). They examine whether investors can obtain international diversification via multinational firms, and find conflicting evidence depending on the country of portfolio. A recent paper by Fort (2013) uses a special inquiries section on the 2007 Census of Manufacturers which asks whether an establishment purchased contract manufacturing services either domestically or abroad. Using this information, the author shows that domestic fragmentation is considerably more common than foreign fragmentation. Finally, Alfaro and Charlton (2009) use a large proprietary directory from Dunn and Bradstreet to characterize FDI according to the industry classification of foreign affiliates. The authors argue that greater industry-level detail

[4] Firms are designated as "related" on the import side if either owns, controls, or holds voting power equivalent to 6 percent of the outstanding voting stock or shares of the other organization. (see Section 402(e) of the Tariff Act of 1930). On the export side, firms are designated as "related" if either party owns, directly or indirectly, 10 percent or more of the other party (see Section 30.7(v) of The Foreign Trade Statistics Regulations).

[5] The BEA-Census link for establishment-level detail in manufacturing existed between 1987 and 1991. For more information on this link, see of Commerce (1992).

reveals considerably more vertical FDI than previously measured, thus labeling these affiliates “intra-industry” FDI.

3.1.2 Data Description

The strategy adopted by this paper is to leverage, when possible, the firm-level operating and trade data contained within the Census Bureau data architecture. To improve the identification of multinational firms in this data, this paper employs proprietary directories of international firm structure which are matched at the establishment level to data from the Census Bureau. The result is a unique dataset containing indicators of multinational status and ownership information, together with a host of other firm-level characteristics.

The primary directory used is the LexisNexis Directory of Corporate Affiliations (DCA), which provides information on the ownership, organization, and locations of firms headquartered in the U.S. and abroad. The DCA consists of three separate databases: U.S. Public Companies, U.S. Private Companies, and International – those parent companies with headquarters located outside the United States. The U.S. Public database contains all firms traded on the major U.S. exchanges, as well as major firms traded on smaller U.S. exchanges. To be included in the U.S. Private database, a firm must demonstrate revenues in excess of $1 million, 300 or more employees, or substantial assets.[6] Those firms included in the International database, which include both public and private companies, generally have revenues greater than $10 million. Each database contains information on all parent company subsidiaries/affiliates, regardless of the location in relation to the parent company.

The second source used to identify multinational firms comes from Uniworld Business Publications (UBP). This company has produced periodic volumes documenting the locations and international scope of i) American firms operating in foreign countries; and ii) foreign firms with operations in the United States. Although only published biennially, these directories benefit from a focus on multinational firms, and from no sales threshold for inclusion. Hence, the UBP directory should increase the

[6] This inclusion threshold changed in 2003, before which the criteria were mildly more restrictive.

coverage of multinationals significantly. Both these directories include establishment-level information on affiliate name, location, and industry classification; however, operating information on sales and employment is not always reported.

The paper links these directories to the Business Register (BR) of the U.S. Census Bureau. Originally known as the Standard Statistical Establishment List (SSEL), this register of information forms the backbone of many firm and establishment-level reporting to statistical and other federal agencies. In 2002 the SSEL was renamed the Business Register after a through redesign in order to improve coverage and quality control. There are two primary sources of information: First the IRS compiles information on single establishments and the administrative units of multi-establishment firms from payroll tax records. The Census Bureau's annual Company Organization Survey (COS) provides information on multi-unit establishments. The content of the Business Register includes business name and address, industry classification, and selected operating data (such as sales and employment). The frequency for updating individual data items varies from every quarter to every five years. The establishment and firm identifiers in the BR allow the researcher to match information to a wide array of other Census Bureau Data products. Specifically, this paper will use the 2007 Census of Manufacturers, along with the 2007 annual LFTTD files detailed above.

The Census of Manufacturers (CMF) is undertaken every five years (in years ending in a 2 and 7), and contains information on the universe of manufacturing establishments in the United States. Basic information collected from all establishments include kind of business, geographic location, type of ownership, annual and first quarter payroll, total revenue, and employees in the pay period including March 12. Larger and multi-unit establishments are required to report much more information, such as inventories, capital expenditures, value of shipments, cost of materials, and product-level material expenditures.

3.1.3 Matching procedure

As there are no common firm or establishment identifiers linking the LexisNexis and Uniworld directories to the BR, the matching procedure relies on name and address information to link the datasets at the establishment level. The presence of misspellings, alternate name and address conventions, abbreviations, and other issues is a central challenge of this form of data linking, and as a result the researcher is forced to move beyond exact matches and consider linking records that have a high degree of similarity. Such probabilistic record linking algorithms are an active field of research across a wide array of different disciplines.

Appendix B.1 provides detailed information on the matching process and reports various statistics on the match rate. In brief, the matching procedure utilizes a multi-variable weighted bigram matching algorithm as detailed by Blasnik (2010), and iterates several times with decreasingly stringent sets of match standards.[7] As is frequently the case with such exercises, a degree of "clerical review" is used to supplement the automated steps in order to maintain a high degree of both accuracy and coverage. Although the matching is done at the establishment level, the foreign ownership and affiliate location information are firm-level objects. The advantage of this feature is that these variables can be pulled through to all establishments within a firm even though only a subset of possible establishments may be matched.[8]

3.2 Multinational Firms in the U.S. Manufacturing Sector

This section documents a series of stylized facts regarding the characteristics of multinational firms relative to other firms. The baseline dataset consists of manufacturing firms with operations in the United States in the year 2007. All information has been aggregated to the level of the firm.

[7]For an update on the matching algorithm, along with several other utilities helpful for company name/address matching, please see Flaaen and Wasi (2014).

[8]There are two complications that make the establishment-firm linkage more cumbersome. The first is joint ventures, which make choosing the relevant parent firm less clear. The second complication comes from when there are disagreements between the proprietary directories and Census identifiers as to the boundaries of the firm. A discussion of the treatment of these special cases can be found in Appendix B.1.

3.2.1 Non-Parametric Estimates of Firm Distributions

Standard models of multinational production with fixed costs would predict multinational firms to be the largest in the economy, with exporting firms being larger than domestic-only firms.[9] To evaluate whether this prediction finds evidence in the data, Figure 3.1 plots non-parametric kernel density estimates of the distributions of each firm type according to log employment, a standard measure of firm size.[10] The figure confirms the predicted size ordering by firm type from theory. On the other hand, standard models abstracting from sunk or idiosyncratic fixed costs would predict a strict ordering – that is, the largest exporting firm should be smaller than the smallest multinational firm. This, of course, does not find evidence in the data as the densities exhibit substantial overlap by size. It is worth emphasizing the log scale in Figure 3.1 – the difference in central tendency in the multinational vs exporter densities is roughly $log(2.5)$, which corresponds to a factor of 12 difference in size. The typical multinational firm is larger than the typical domestic-only firm by a factor of almost 30.

While Figure 3.1 considers the distribution of firm size within each group of firms, it does not reflect the relative number of firms across these groups. The CMF identifies roughly $150,000$ manufacturing firms in the U.S. in 2007. This analysis identifies 80 percent of these firms as "domestic-only," 18 percent as recording positive exports without foreign operations, and only 1.7 percent as "multinational." To convey these relative disparities in the number of firms, figure 3.2 re-weights the distributions from figure 3.1 according to their relative shares. In other words, adding together these three distributions will accurately convey the firm-size distribution of all manufacturing firms in the U.S. This figure visually conveys the significant skewness in the right tail of the firm size distribution, which is significantly occupied by multinational firms.

Next, figure 3.3 examines whether the ordering follows through to productivity,

[9] Helpman, Melitz, and Yeaple (2004) being the classic example.

[10] Note that this consists of employment in a firm's *manufacturing* establishments. A firm's employment in establishments identified in other industries is not counted.

measured by log value added per worker.[11] This indeed appears to be the case: relative to domestic firms, the density estimate for exporting firms is shifted to the right and the kernel density for multinational firms even more so.[12] Of course, there is substantial heterogeneity of productivity levels across industries, and thus it is possible that the productivity advantages of exporting and multinational firms may reflect a larger concentration in relatively high-productivity industries, rather than firm-level advantages. To account for this possibility, one can remove the common industry component from each productivity estimate. Following Lileeva (2008), I further scale by the inter-quartile range, to account for varying degrees of industry dispersion in productivity. Specifically, let $z_{i,j}$ be the productivity of firm i in industry j. Then the adjusted productivity measure $\tilde{z}_{i,j}$ is defined as follows:

$$\tilde{z}_{i,j} = \frac{z_{i,j} - \bar{z}_j^{50}}{\bar{z}_j^{75} - \bar{z}_j^{25}} \quad , \tag{3.1}$$

where $\bar{z}_j^x$ is the xth percentile of industry j. Figure 3.4 displays the results. By construction, the overall density estimate is now centered around zero. As expected, the productivity distribution of domestic-only firms is largely symmetric about zero, with perhaps slightly more mass in the negative region of the plot. The distribution of exporting firms is shifted (albeit slightly) to the right, and once again the distribution of multinational firms shifted further.

3.2.2 Multinational Premia vs Exporter Premia

This subsection turns to a basic regression framework to further analyze how multinational firms compare to their exporting and domestic counterparts. In an important contribution, Bernard et al. (2007) use the 2002 Census of Manufacturers to document a number of "premia" associated with exporting activity. The additional

[11] Value added is measured as gross output minus material inputs (raw materials plus intermediate inputs).

[12] While this is possibly the first such picture corresponding to manufacturing firms in the U.S. economy, a number of other papers have documented similar results using data from other countries. For instance, see Mayer and Ottaviano (2007) for Belgium, Girma, Gorg, and Strobl (2004) for Ireland, and Antrás and Yeaple (2013) for Spain. The results from these studies largely align with the U.S. findings.

information in the present analysis allows for an extension of this prior work to include the premia associated with multinational activity. Moreover, separating out multinationals from firms engaging foreign markets exclusively through exporting allows for a more precise identification of premia corresponding to the act of export activity itself. To be concrete, some firms may primarily engage in multinational production to access foreign consumers, but nonetheless export to a small degree. Including these firms in the "exporter" category is not entirely accurate, and to the extent these firms exhibit higher premia will in a sense bias upward the estimates for the exporter category. On the other hand, there is also the potential for a multinational firm to exhibit no exports – either because it is a foreign affiliate solely accessing the U.S. market, or a U.S. multinational firm that *only* utilizes FDI to serve foreign markets. Grouping such a firm in the "non-exporter" category is also inaccurate, and may potentially affect the estimate for an "export-specific" premia in the opposite direction.

Specifically, rather than regress features of firm behavior on a dummy variable indicating the firm's export status, the analysis below separates out separate effects for three types of firms. Thus, to consider a specific dependent variable $X_{i,j}$ of firm i in industry j the specification,

$$log(X_{ij}) = \alpha_j + \beta^D E^D_{ij} + \beta^{MF} M^F_{ij} + \beta^{MU} M^{US}_{ij} + u_{ij} \tag{3.2}$$

allows for greater heterogeneity in separating out the mean effect by firm type. Here, the variable $E^D = 1$ when a firm reports positive exports (but is not identified as a multinational), $M^F = 1$ identifies a Foreign multinational firm, and $M^{US} = 1$ for U.S. multinational firms. The term α_j removes an industry fixed effect. The control group are those firms without international exposure – the domestic-only group.

Tables 3.1 and 3.2 contain the results of these regressions, using a number of different firm characteristics as dependent variables. In each case the first and third columns correspond to using the exporter dummy by itself – that is, these columns are a 2007 update to the calculations made in Table 3 of Bernard et al. (2007). These numbers largely confirm the results of the earlier study. Columns two and four report the results for the more flexible specification outlined in equation 3.2.

Table 3.1 compares the size and productivity-related regression coefficients corresponding to each type of firm identified above. The estimate of the premia associated with exporting when multinationals are treated separately are quite similar to the baseline. This is likely due to the small share of multinational firms relative to both the non-multinational exporters and the control group of domestic-only firms. The estimated premia associated with multinational status, however, are generally three to four times the magnitude for exporting. The estimated productivity premia between the Foreign multinationals and U.S. multinationals are broadly similar, though Foreign multinationals appear to be slightly more productive.

Table 3.2 considers other firm characteristics, such as the capital intensity, average wage, and share of non-production workers in total employment. Once again the exporter premia are largely consistent with the estimates corresponding to the specification from Bernard et al. (2007) when multinationals are not included. The exception is the premia associated with capital intensity, which was measured to be in the 4 to 12 percent range in the 2002 data, are actually reported to be negative in some specifications in 2007. The Foreign and U.S. multinationals, on the other hand, are roughly 60-80 percent more capital intensive than the control group of domestic-only firms. Exporting firms pay on average 5 percent more in average wage than a domestic-only firm, but the wage premia for multinationals is once again considerably higher: multinationals pay roughly 20 percent higher wages than the baseline firm.

Finally, it is interesting to note that the premia associated with the share of non-production workers in total employment is lower for Foreign multinationals than U.S. multinational firms. This likely reflects some share of the "headquarter services" for foreign multinationals to be taking place in the country of origin, and thus not being picked up in the U.S. statistics. On the other hand, the premia is still significantly higher than the baseline, domestic-only firm.

We consider how these results speak to the horizontal vs vertical FDI frameworks in section 3.4.

3.3 The Impact of Ownership on Trade Flows

Information on the participation and size of trade at the firm level provide valuable insight into the determinants of aggregate trade flows. Moreover, combining this with the multinational status of the firm allows one to draw further conclusions regarding the nature and purpose of locating production outside of a firm's home country. This section explores these questions using export data from the CMF, as well as transaction level import/export data from the LFTTD.

3.3.1 Multinational Exporters

Table 3.3 reports summary statistics on export activity among the three specific types of exporters: non-multinationals, U.S. multinational firms, and foreign affiliates in the United States. First, the table confirms the stylized fact from Bernard et al. (2007) that just under 20% of firms export. However, among U.S. multinational firms, the number is significantly higher: 68% report non-zero exports. Remarkably, the number is nearly the same for foreign affiliates operating in the United States. At first glance, this number seems to provide substantial support for the vertical notion of FDI, as the country of sale for multinational affiliates is often distinct from the country of production.

Exploring further, table 3.3 takes the number of firms recording positive exports, and then calculates the share of export sales in the total sales reported by the firm. This exercise makes clear that exports represent a small portion of total sales regardless of firm type. For the median domestic-exporter, only 6.7% of firm sales are destined for outside the United States. The corresponding numbers for Foreign and U.S. multinationals are slightly higher, at 10% and 12% respectively. Although this is a relatively small number, it does not rule out the presence of a subset of largely export-oriented multinationals. The distribution of firms is known to be highly skewed in a number of different dimensions, and thus the median could mask significant detail in the right tail. To explore this possibility, the table then reports other moments of the distribution: the mean, 25th, and 75th percentiles. Even when considering the

75th percentile of this statistic, the share of exports in total sales is still only between 19 and 26%.

For a final check on the potential for a small subset of predominantly exporting multinationals in the U.S., we rank each firm type by total export sales, and then consider the top 5% according to exports by each firm type. Remarkably, the exports in total sales for this select group remains surprisingly low: the median Foreign multinational in this group records 16% of exports in sales, and for the median U.S. multinational, only 20%. As might be expected when considering the results in table 3.1, the figure for non-multinationals is slightly higher.

3.3.2 Export Destinations and Import Sources

The analysis now turns to the destinations of exports and source of imports by firm type. Put differently, the paper will now examine the extent to which firm ownership patterns affect trade flows. As such, this section switches the source of trade from the CMF to the LFTTD. The drawback is that the connection to other firm attributes, such as sales, material inputs, etc, is less strong. The advantage is the ability to consider country-specific exports, and the ability to separately consider import flows.

For ease of exposition, we first compare the trade flows of Foreign multinationals from a single source country – Japan – to U.S. multinationals and exporting/importing non-multinationals. Panel A of Table 3.5 divides the destination of exports into five broad groups: Japan, North America, EU-15, "Low- Wage", and a residual "Other" category.[13] A country is defined as "low-wage" if its GDP-per capita was less than 20% of the U.S. value in 2007.[14] For Japanese multinationals operating in the U.S., the exports to Japan represent exports back to the "source" country.

Over 21 percent of the exports of Japanese multinationals in manufacturing are destined to the "source" country of Japan. This is substantially larger than the

[13]The EU-15 consists of the European Union member countries prior to the 2004 enlargement. The 15 countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

[14]The list of countries in this category is provided in Table 3.4. Using a threshold of 10% of U.S. GDP per capita generated qualitatively similar results.

average U.S. multinational or non-multinational firm, which report less than 5 percent of exports destined for Japan. In contrast, all three firm types report the predominant share of exports to be destined for North America.

Panel B of Table 3.5 replicates Panel A but instead considers the source countries of firm imports. Most striking is that Japanese multinationals on average receive over 60 percent of imports from their source country. This is in contrast to the average non-Japanese multinational importing firm, which records only about 4-5 percent of imports sourced from Japan. U.S. multinationals and importing non-multinationals, on the other hand, rely most heavily on imports from "low-wage" source countries, as well as countries comprising the EU-15. Japanese multinational affiliates import comparatively less from North America and the EU-15, though still import about 16 percent of the total from "low-wage" countries.

Table 3.6 expands the analysis from Table 3.5 to include Foreign multinationals from all source countries. In this table, the destination/source of Japan has been replaced with the corresponding "Source Country" label, which is calculated as the statistic representing the average Foreign multinational firm. To be precise, the shares for the Foreign multinational category are a weighted average using the number of Foreign multinational firms in each country as weights. These country weights are then applied to the U.S. multinational and non-multinational groups as well, to keep the comparisons meaningful.[15][16]

The results are broadly similar to the case using Japanese multinationals as the benchmark. Country ownership continues to be a strong driver of trade flows, particularly for imports to the United States. For the average Foreign multinational firm, roughly 17 percent of exports are destined back to the source country, and almost 45 percent of imports originate from the source country. In contrast, U.S. multinationals and non-multinational firms export roughly 5 percent to – and import roughly

[15]It is important to note that the destination/source groups are not mutually exclusive for all countries. For example, the exports to the EU-15 for a Foreign multinational from France would correspond to all non-French EU-15 countries, as exports to France would already be counted in the "source country" category.

[16]Using other weights to aggregate the Foreign multinational country groups up to an aggregate (such as employment of affiliate, or size of trade) yield qualitatively similar results.

5 percent from – the average country representing this group. The North American countries of Canada and Mexico are the most significant export markets for all three types of firms.

The large disparity in export/import shares to/from the source country raise questions as to the relative values of trade for these firm types. Exploring further, Table 3.7 documents the average magnitudes of exports and imports for the three types of firms. On average, Foreign multinational firms import substantially more (roughly 3 times as much) than they export. Multinational firms headquartered in the United States, on the other hand, actually report a higher share of exports than imports. Interestingly, the non-multinational firms also display a large deficit between the average export and import values, though not as large as the Foreign multinationals. Not surprisingly, the average trade values of non-multinationals are two orders of magnitude smaller than either multinational group.

The second set of rows in Table 3.7 aggregates the trade flows by firm type. In the year 2007, Foreign multinationals in the United States recorded a trade deficit of 222.5 billion USD. The published trade deficit in goods for that year recorded by the BEA was 822.7 billion, implying that Foreign multinationals accounted for over 27 percent of the total U.S. goods trade deficit. Of course, if we restrict the trade flows to only those manufacturing firms (for which we have firm identifiers in the LFTTD) in the U.S. economy, the share rises to over 56 percent.[17] It is also worth noting that the U.S. multinationals recorded a small trade surplus, but not nearly as large as the deficit incurred by Foreign multinationals.

There are a number of potential explanations for the high ratio of imports to exports corresponding to Foreign multinational firms. First, the U.S. affiliates of these firms may concentrate on the final goods assembly for sale in the U.S., which may require substantial import of intermediate inputs and limited export to other markets. A second explanation may be that these firms also consist to some degree as the wholesale/retail operations for final goods imported directly from the source country. Finally, it is possible that the import and export numbers for multinational firms

[17] This number is calculated as $\frac{222{,}496}{(222496+206604-33956)}$.

(both Foreign and U.S.) are influenced by transfer pricing considerations for motives such as profit shifting.[18] An obvious method of differentiating the first and second explanations would be to differentiate the import values into categories based on intended use: final consumption goods, intermediate inputs for further manufacture, and capital goods. Unfortunately, the LFTTD provides no direct information on the intended use of the product being traded.

One resource to understand the composition of imports for Foreign multinationals is the FDIUS surveys administered by the BEA. These surveys ask firms to separate out trade transactions by the intended use: 1) capital goods; 2) goods for resale without further manufacture; and 3) goods for further manufacture. The published totals using the benchmark 2007 survey indicate that the share of imports "for further manufacture" from all countries among U.S. foreign affiliates is 0.66 in the manufacturing sector.[19] Unfortunately, the published tables do not break down this industry-level detail based on the origin of the import, or whether the import came from the foreign parent group. Looking at the share of "for further manufacture" in total imports for all industries from the foreign parent group, the share is somewhat higher at 0.75 (see table II.G23).[20] Thus, one could infer that somewhere between 65 and 75 percent of a foreign affiliate's U.S. imports from the parent group are for further manufacture.[21]

An alternate strategy is to use the product-level information within the Census Bureau data to classify imports shipments. The Products trailer file of the Census of Manufacturers contains the product-level shipments of goods at the establishment level. Using this information, it is straightforward to construct, for each industry, a set of product codes that are the the primary products produced in the United

[18]For an analysis of the transfer pricing behavior of "U.S. based multinationals" (which include the U.S. multinationals and foreign multinational affiliate operations in the U.S.) see Bernard, Jensen, and Schott (2006).

[19]This share is calculated by dividing the manufacturing totals using tables II.G24 and II.G6.

[20]BEA data estimate that the share of imports from the foreign parent group represent 67 percent of total imports in the manufacturing sector.

[21]See Zeile (1998) for a more complete analysis of the trade and input sourcing of Foreign multinationals, using the 1992 benchmark FDIUS data. For this activity based on USDIA data, see Borga and Zeile (2004). Interestingly, Zeile (1998) also presents estimates from the BEA on the share of imports of foreign multinationals arriving from the investing (source) country. The average for manufacturing affiliates of 60 percent is even higher than the estimates reported above in table 3.6 for 2007.

States. Thanks in part to a recent concordance between NAICS product classes and HS codes detailed in Pierce and Schott (2012), we can map these product codes into those available in the LFTTD. A firms' import of one of these "final" products of it's particular industry would be assumed to be intended for resale without additional manufacture. The residual (consisting of both capital goods and intermediate goods) can be considered separately. Appendix C.1 provides the details of this classification procedure. The results of this classification procedure are consistent with the information from the BEA. Approximately 62 percent of the imports of foreign manufacturing affiliates in the U.S. are "intermediate" goods, whereas the remaining 38 percent are likely to be entering the consumption channels immediately.

Collectively, the evidence from this section points to the presence of substantial input linkages between foreign affiliates and their source country. These flows are important themselves in understanding trade patterns, and also help to clarify the motives for multinational production. Finally, future research should look to the consequences of these linkages for the transmission of shocks, patterns of firm-level volatility, and the price index dynamics of trade.

3.4 Vertical vs Horizontal FDI

The empirical picture formed from the results of the preceding sections offers valuable guidance on how to properly motivate and model multinational production.

Recall that a critical distinction between the competing horizontal-vs-vertical theories of multinational production is the location of final sale. Vertical FDI seeks to take advantage of differing factors of production, whereas horizontal FDI locates production abroad to save on transport costs in accessing the host country market. Taken as a whole, the results from this paper show that a binary classification of foreign investment in the United States is misleading. As is clear in Table 3.3, firms with production abroad engage in trade to a large extent. Roughly 70 percent of the foreign affiliates operating in the United States export goods abroad, and the fraction is remarkably similar for U.S. multinationals. This would seemingly give support to the vertical notion for Foreign multinationals, in which the ultimate sale is outside of the location of production. Moreover, a surprising finding of this paper is the extent to which foreign affiliate operations rely on imported goods (and what could arguably be called imported intermediate goods) from their source country. This finding goes against the strict tradeoff between exporting and multinational production that is implied in the horizontal view of FDI, and suggests a fragmentation of the productin process as given by the vertical view. The presence of exporting behavior among U.S. multinationals has similar implications.

Yet, other features of the data lend support to the horizontal framework. While a strong majority of multinational firms also export, the share of exports in total shipments is quite small. Table 3.3 shows that the share of exports for the average firm is small – the median Foreign multinational firm exports only 10 percent of its shipments in 2007. Even when considering the right tail of the exporting distribution of multinational firms, the share of exports does not surpass 25 percent. Moreover, Table 3.6 indicates that a substantial share of these exports are destined for either Canada and Mexico — which could arguably be classified as a common market with the U.S. Finally, the evidence of large import shares from the country of origin — substantially composed of intermediate inputs — lends support to a framework in which the multinational firm relies on intermediate inputs from the source country for further production and sale principally in the host market.[22]

Such a hybrid horizontal/vertical framework requires a careful re-thinking of the role of the firm across national boundaries. Why might it be the case that a multinational affiliate sources intermediate inputs from the source country for sale in the host market? The "capabilities" notion of the firm as emphasized by Atalay, Hortacsu, and Syverson (2014) offers one potential explanation. Suppose there is a firm born in the Home country that is endowed with a particular capability. If some degree of that capability is location dependent, then the firm's international sales will be subject to

[22]The model of input sourcing and multinational firms in Garetto (2013) is an important contribution of how to endogenize production decisions across locations. The model, however, rules out horizontal FDI. Irarrazabal, Moxnes, and Opromolla (2013) is another example of the integration of intra-firm trade and multinational production.

other considerations beyond those present in the proximity/concentration or factor-proportions frameworks. The firm may optimally maintain some production phases in the country of origin while expanding others (less location-dependent capabilities) abroad. Such a framework would be consistent with the fact that Toyota continues to send 2 million transmissions a year to North America, despite having numerous production facilities in the United States and Mexico.[23] Further evaluation of such a capabilities-driven framework is an area for future research.

How might one reconcile the evidence supporting this nuanced view of multinational firm behavior with the findings from previous research in support of either horizontal or vertical FDI? Specifically, there are two recent papers that emphasize the vertical dimension of multinational behavior: the export platform FDI emphasized in Tintelnot (2014), and the intra-industry FDI pointed out in Alfaro and Charlton (2009). While this paper supports the presence of export platform FDI, it finds the quantitative magnitude of this behavior to be small. In the United States, foreign firms locate production principally for local sale. The statistic cited in Tintelnot (2014) of exports accounting for roughly 40 percent of U.S. multinational affiliate output in Europe is likely due to the unique market environment of the European Union. At the same time, however, the low export share in the United States is also surely influenced by the fact that the U.S. is a large and relatively isolated market. These distinctions point to the importance of geographic factors, market size, and development status as other determinants of the form of multinational production and should be areas for further research.

Alfaro and Charlton (2009) emphasize that previous studies relying on coarse industry classifications across firm locations may tend to mischaracterize the form of FDI. Using a more highly disaggregated 4-digit industry classification of affiliate locations, the authors argue that the share of vertical FDI is considerably higher than previously thought. The authors rely on a definition of horizontal FDI as any affiliate operation in the same 4 digit SIC industry as its parent firm. An important drawback of this definition is that it ignores the "replication of production" feature inherent

[23]See Chappell (2011)

in the proximity-concentration tradeoff, particularly for firms whose establishments span many industries even within their home country.[24] To explore the extent of this disconnect, I use the industry and affiliate information in the DCA data for 2007 and calculate the implied shares of vertical FDI based on several definitions of such a intra-firm industry classification.

Table 3.8 presents the results. Looking at the foreign affiliates of manufacturing parent firms (the middle column), the Alfaro and Charlton (2009) definition of horizontal FDI does indeed represent a low share of foreign affiliate operations – only 38.7. However, if you expand the definition to include those cases when a foreign affiliate replicates the industry of a domestic affiliate within the same parent firm, the share increases substantially. Finally, if a foreign affiliate shares any industry with a domestic establishment within the same firm (parent or domestic affiliate), the share climbs to over 62 percent. An alternate exposition of this point is to consider the scatterplots comprising Figure 3.5. Here we take each parent firm in the manufacturing sectors (based on 4 digit SIC), and plot the industries of each domestic affiliate. The top panel demonstrates the substantial degree of vertical integration even within a firm's home country. The bottom panel overlays the parent firm's foreign affiliates in red. It is remarkable the extent to which the within-firm industry clustering abroad mirrors that at home.

Ramondo, Rappoport, and Ruhl (2014) eschews industry as a reliable indicator of the horizontal-vertical nature of foreign affiliates. Among other useful empirical evidence from the confidential firm-level BEA data, the authors document that almost 55 percent of affiliates report no shipments to their parent. The paper does not, however, devote much attention to the flow of trade in the other direction – from parent firm to foreign affiliate.

[24] It should be noted, however, that Alfaro and Charlton (2009) emphasize that the horizontal-vertical distinction is not always clear-cut.

3.5 Industry Composition

This section separates the data into 18 manufacturing sectors, (roughly corresponding to the 3-digit NAICS subsectors) to examine industry heterogeneity in the composition of exporting and multinational production. It is important to note here that the nature of the data linking prevents any claim for the samples of U.S. and Foreign multinationals to be complete; however, it is likely that the considerable majority of these firms are included.

Table 3.9 documents the distribution of manufacturing plants across industries and firm type. Although most manufacturing establishments are domestic-only in nature, the totals hide substantial variation across industry subsectors. U.S. multinationals represent 24 percent of plants in the Paper Products subsector, while non-multinational exporters represent over 31 percent of the plants in the machinery and computer/electronics subsectors. The share of domestic-only plants ranges from a low of 46.3 percent in the Chemical products subsector to a high of over 90 percent in the furniture and related subsector.

Multinational firms represent a considerably larger share of firm sales, as is evident in Table 3.10. The sales of Foreign multinational firms tend to be largely in the Petroleum and Coal, Chemical Products, and Transport Equipment, which together make up 56 percent of the total sales by this group. At the same time, there is substantial heterogeneity in the representation of this group of firms within a particular subsector. For example, Foreign multinational firms account for 27 percent of total sales in the Chemical Products sector, 28 percent in Nonmetallic Minerals, but only 8.3 percent in Fabricated Metals. As Table 3.11 demonstrates, the employment is spread more evenly across the subsectors.

The largest degree of concentration within industries and type of firm appears when considering export activity. This is shown in Table 3.12. The bulk of exporting activities by U.S. and Foreign multinationals are concentrated in the Chemical Products, Computer and Electronics, and Transport Equipment subsectors. Although these three subsectors comprise roughly 40-45 percent of total sales for these two groups of firms, the account for over 60 percent of total exports. This fact is also present when comparing the share of exports in total shipments for these subsectors, shown in Table 3.13.

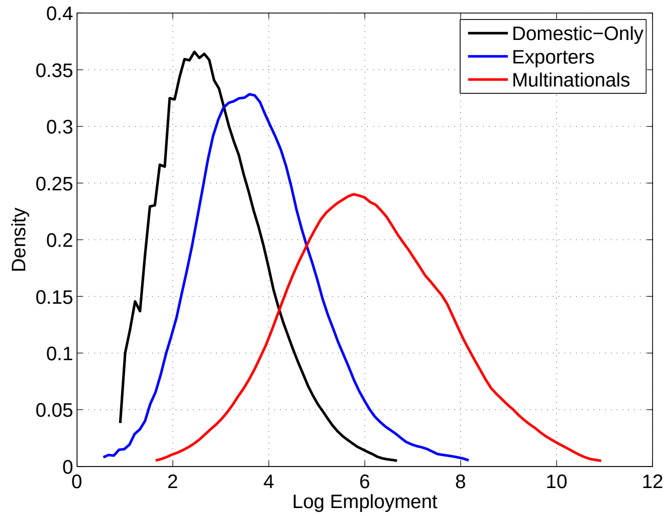
3.6 Conclusion

This paper utilizes a novel dataset to examine the behavior and operations of multinational firms in the context of other manufacturing firms in the U.S. economy. The benchmark groups allow for a more complete picture of the firm size distribution as it relates to international exposure, as well as accurate estimates of the "premia" associated with firms engaged in exporting and multinational production. The country of ownership of Foreign multinationals in the United States is a strong predictor of trade flows, particularly on the import side.

Although this study contains several new insights into multinational firm behavior, there are a number of unanswered questions for future work. In particular, further steps should be taken to evaluate the reliability of the trade classification system using industry product-level production patterns. Moreover, using the arms-length and related-party indicators in the LFTTD data should help characterize the extent of intra-firm trade between affiliates and their country of origin. This information may also help to clarify the extent to which transfer-pricing influences a firms' reported trade values.

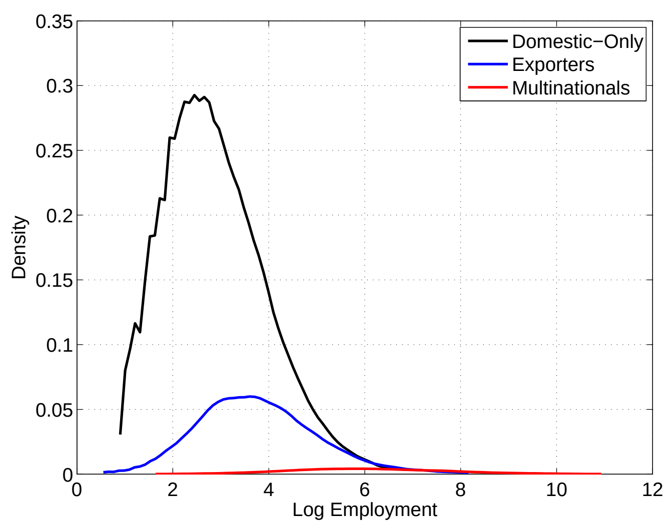
Hopefully the empirical picture of the multinational firm in this and future research will help inform further study on the role of these firms in subjects such as international business cycles, domestic employment dynamics, and other aggregate phenomena.

Figure 3.1: Kernel Density Estimates of Firm Size Distribution



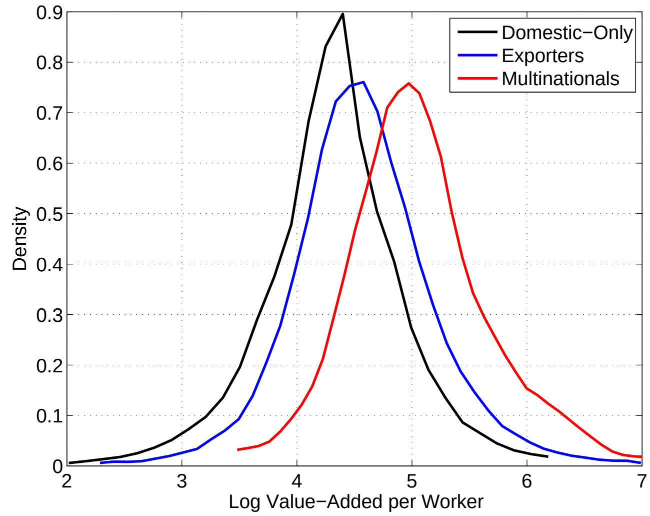
Source: CMF, DCA, and UBP as explained in the text. The data are for year 2007. This figure plots the kernel density estimate of firm size (measured by log employment) based on three firm types: domestic-only, exporting (non-multinational) and multinational firms.

Figure 3.2: Kernel Density Estimates of Firm Size Distribution



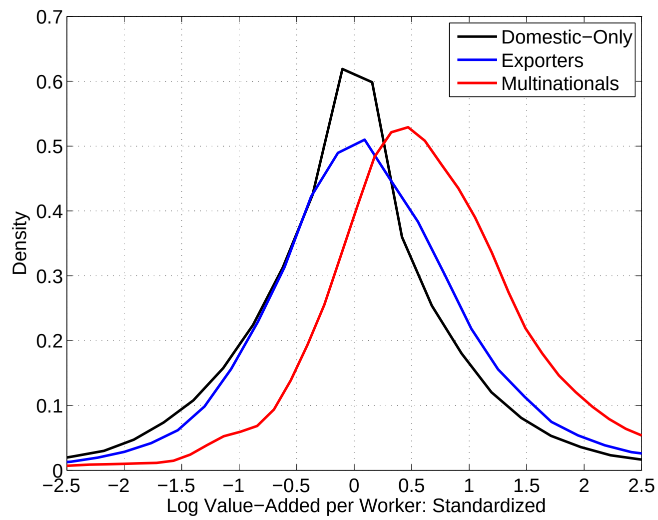
Source: CMF, DCA, and UBP as explained in the text. The data are for year 2007. This figure plots the kernel densities from figure 3.1 but re-weights each density based on its share of the total manufacturing firms in the U.S. economy. The domestic-only group represents roughly 80 percent of all manufacturing firms, the exporting group 18 percent, and the multinationals only 2 percent.

Figure 3.3: Kernel Density Estimates of Firm Productivity Distribution



Source: CMF, DCA, and UBP as explained in the text. The data are for year 2007. This figure plots the the kernel density estimate of firm productivity (measured by log value-added) based on three firm types: domestic-only, exporting (non-multinational) and multinational firms.

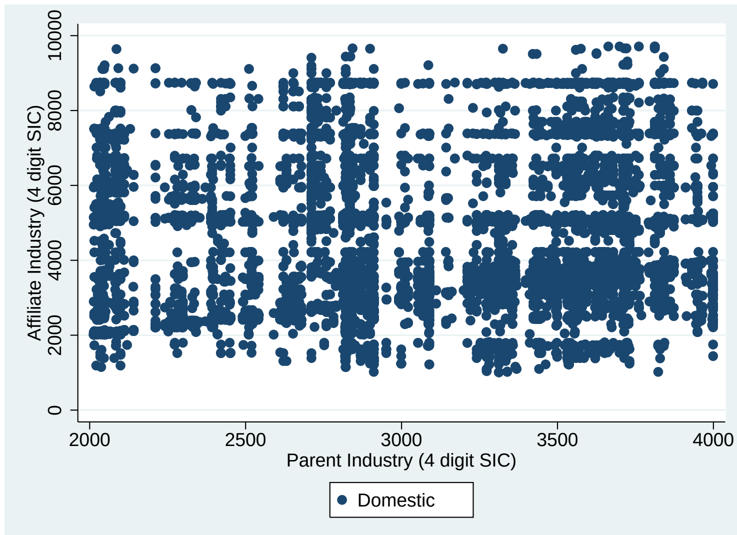
Figure 3.4: Kernel Density Estimates of Firm Productivity Distribution



Source: CMF, DCA, and UBP as explained in the text. The data are for year 2007. This figure plots the kernel density estimate of firm productivity (measured by employment) that has been standardized to account for differences across industry. See equation 3.1 in the text. The kernel density estimates are shown separately for three firm types: domestic-only, exporting (non-multinational) and multinational firms.

Figure 3.5: Industry of Affiliate by Industry of Parent: Parent Manufacturing Firms

A. Domestic Affiliate Locations



B. Domestic and Foreign Affiliate Locations

Source: DCA, 2007.
This figure plots the scatters pertaining to the industry of domestic and foreign affiliate establishments for parent firms in the manufacturing sector. Each dot represents a particular industry of a parent firm's affiliate.

Table 3.1: Size and Productivity Premia for Exporting and Multinational Activity

Var	Log Shipments				Log Output per Worker				Log Value-Added per Worker			
Exporter	1.07		0.14		0.20		0.18		0.13		0.14	
Domestic Exporter		0.94		0.13		0.18		0.17		0.12		0.13
Foreign Multinational		3.26		0.64		0.70		0.67		0.50		0.53
U.S. Multinational		3.65		0.49		0.56		0.52		0.45		0.49
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Employment	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	No
Observations	151,635				151,635				151,170			

Source: CMF, DCA, and UBP as explained in the text. The data are for year 2007.
*All Coefficients are significant at the 1% level. This table reports the regression coefficients corresponding to dummy variables assigned by firm type. See equation 3.2 in the text.

Table 3.2: Other Premia for Exporting and Multinational Activity

Var	Log Capital per Worker				Log Wages				Log Skill per Worker			
Exporter	-0.02		0.00[1]		0.05		0.06		0.06		0.15	
Domestic Exporter		-0.05		-0.01		0.05		0.05		0.06		0.14
Foreign Multinational		0.76		0.88		0.19		0.20		0.05		0.33
U.S. Multinational		0.61		0.75		0.19		0.21		0.07		0.41
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Employment	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	No
Observations	151,257				151,669				139,763			

Source: CMF, DCA, and UBP as explained in the text. The data are for year 2007.
*All Coefficients are significant at the 1% level. This table reports the regression coefficients corresponding to dummy variables assigned by firm type. See equation 3.2 in the text.
[1] indicates coefficient is not significant

Table 3.3: Exports by Firm Type

	Foreign Multinationals	U.S. Multinationals	Non Multinationals
Percent Exporters	70.7	68.3	19.1
Exports as % of Total Shipments			
Mean	16.0	19.1	16.3
25th Percentile	4.1	4.9	1.9
50th Percentile	10.6	12.4	6.7
75th Percentile	20.3	26.8	19.2
Top 5% by Volume of Exports			
Mean	24.2	25.5	34.8
50th Percentile	16.1	20.0	25.9

Source: CMF, DCA, and UBP as explained in the text. The data are for year 2007.

Table 3.4: Selected Country List: Less than 20% of US GDP per Capita

* All Africa *	El Salvador	Paraguay
Afghanistan	Guatemala	Peru
Argentina	Haiti	Philippines
Albania	Honduras	Romania
Bangladesh	India	Russian Federation
Bolivia	Indonesia	South Africa
Brazil	Iran, Islamic Rep.	Thailand
Bulgaria	Iraq	Tunisia
Cambodia	Jamaica	Turkey
China	Jordan	Ukraine
Colombia	Kazakhstan	Uruguay
Costa Rica	Malaysia	Uzbekistan
Cuba	Mozambique	Venezuela, RB
Dominican Republic	Nepal	Vietnam
Ecuador	Nicaragua	Yemen, Rep.
Egypt, Arab Rep.	Pakistan	

[1] Source: World Bank (2007)

Table 3.5: Trade by Destination/Source and Firm Type: Japanese Multinationals

Destination / Source	Japanese Multinationals	U.S. Multinationals	Non Multinationals
		Panel A: Exports	
Japan	21.3	4.7	3.0
North America	39.1	33.6	45.3
EU-15	14.9	23.8	18.2
Low-Wage[1]	11.9	17.8	13.9
Other	12.8	20.1	19.6
		Panel B: Imports	
Japan	61.2	5.4	4.5
North America	9.0	20.0	11.8
EU-15	7.0	29.2	27.9
Low-Wage[1]	16.2	30.4	37.8
Other	6.6	15.0	18.0

Source: CMF, LFTTD, DCA, and UBP as explained in the text. The data are for year 2007. This table reports the share of trade based on the destination/source for the three firm types. For the sake of clarity, the Foreign multinationals are restricted to only those from Japan.
[1] Defined as GDP per capita less than 20% of U.S. level in 2007.

Table 3.6: Trade by Destination/Source and Firm Type: All Multinationals

Destination / Source	Foreign Multinationals	U.S. Multinationals	Non Multinationals
		Panel A: Exports	
Source Country	17.5	5.4	5.7
North America	35.7	31.4	41.9
EU-15	15.0	21.9	16.7
Low-Wage[1]	13.9	17.8	13.9
Other	17.7	23.4	21.6
		Panel B: Imports	
Source Country	44.0	4.9	4.2
North America	11.3	19.1	11.2
EU-15	18.8	26.7	25.5
Low-Wage[1]	16.2	30.3	37.8
Other	9.5	18.7	20.9

Source: CMF, LFTTD, DCA, and UBP as explained in the text. The data are for year 2007.
This table reports the share of trade based on the destination/source for the three firm types. The shares for Foreign multinatioanls are calculated from averaging the shares from each source country and using the number of firms from each source country as weights. These averages are then applied to the U.S. and non-multinational samples, to keep the comparisons meaningful.
[1] Defined as GDP per capita less than 20% of U.S. level in 2007.

Table 3.7: Exports vs Imports by Firm Type (Millions USD)

	Foreign Multinationals	U.S. Multinationals	Non Multinationals
Average Value of Trade			
Exports	108.7	255.8	1.3
Imports	298.6	233.7	2.6
Ratio	**2.7**	**0.91**	**2.0**
Total Value of Trade			
Exports	126,776	382,238	195,481
Imports	349,272	348,281	402,086
Deficit	**-222,496**	**33,956**	**-206,604**

Source: CMF, LFTTD, DCA, and UBP as explained in the text. The data are for year 2007.

Table 3.8: Industry Composition of Affiliates: DCA 2007

		All Foreign Affiliates	Foreign Affiliates of Manuf. Parents	Foreign Manuf. Affiliates of Manuf. Parents
Number of Affiliates		56,942	30,665	21,393
Same Industry as Parent?	Yes	21,270	11,864	11,245
	No	35,672	18,801	10,148
	% Same	37.4	38.7	52.6
Same Industry as Domestic Affiliate?	Yes	29,554	15,545	12,686
	No	27,388	15,120	8,707
	% Same	51.9	50.7	59.3
Same Industry as Parent or Domestic Affiliate?	Yes	36,185	19,062	15,959
	No	20,757	11,603	5,434
	% Same	63.5	62.2	74.6

Source: Directory of Corporate Affiliations (DCA), 2007

Table 3.9: Percent of Plants by Industry: 3 Digit NAICS Industries

NAICS	Description	Total	US. Mult	Foreign Mult	Exporter	Domestic Only	US. Mult	Foreign Mult	Exporter	Domestic Only
		Within Types					Across Types			
311	Food	7.5	8.7	5.7	5.0	8.0	7.9	3.0	11.0	78.1
312	Beverage & Tobacco	1.0	1.7	1.1	0.9	1.0	11.2	4.1	15.1	69.7
31X	Textile, Apparel, Leather	6.2	2.1	1.0	4.2	7.3	2.3	0.6	11.2	85.9
321	Wood Products	4.9	3.7	1.0	3.0	5.6	5.2	0.8	9.9	84.1
322	Paper Products	2.1	7.3	2.3	2.2	1.6	24.0	4.3	17.0	54.7
323	Printing & Related	9.5	3.5	1.5	3.8	11.7	2.6	0.6	6.7	90.2
324	Petroleum and Coal	1.0	0.8	5.8	0.5	0.9	5.5	22.3	8.4	63.8
325	Chemical Products	4.6	11.9	13.3	7.1	2.9	17.6	11.2	24.9	46.3
326	Plastic & Rubber	4.8	7.2	6.1	7.7	3.9	10.2	5.0	26.2	58.7
327	Nonmetallic Mineral	6.5	2.4	25.9	2.4	6.8	2.5	15.5	6.0	76.0
331	Primary Metals	1.8	3.5	3.2	2.6	1.3	13.6	7.2	24.4	54.8
332	Fabricated Metals	18.5	10.1	7.9	17.4	20.1	3.7	1.7	15.5	79.2
333	Machinery	8.3	10.3	8.2	16.0	6.3	8.6	3.9	31.8	55.8
334	Computer & Electronics	4.0	9.8	5.1	7.6	2.6	16.9	5.0	31.1	47.0
335	Electrical Equipment	1.9	4.2	2.7	3.4	1.3	15.4	5.7	29.2	49.8
336	Transport Equipment	3.8	7.2	5.6	5.6	3.0	12.9	5.8	24.1	57.2
337	Furniture & Related	5.5	1.8	0.5	2.3	6.8	2.3	0.4	7.0	90.4
339	Miscellaneous	8.2	3.8	3.1	8.2	8.9	3.2	1.5	16.4	79.0
	TOTAL	100	100	100	100	100	6.9	3.9	16.4	72.9

Source: Census of Manufacturers, Directory of Corporate Affiliations, and Uniworld Business Publications as explained in the text. Data are for the year 2007.

Table 3.10: Percent of Sales by Firm Type: 3 Digit NAICS Industries

NAICS	Description	Total	US. Mult	Foreign Mult	Exporter	Domestic Only	US. Mult	Foreign Mult	Exporter	Domestic Only
		Within Types					Across Types			
311	Food	11.1	11.3	6.8	9.0	15.1	35.9	9.7	18.6	35.9
312	Beverage & Tobacco	2.4	4.0	1.1	1.7	1.7	57.8	6.9	16.2	19.0
31X	Textile, Apparel, Leather	1.7	1.2	0.4	2.0	3.0	24.9	3.8	26.2	45.1
321	Wood Products	1.9	0.9	0.2	1.5	4.4	17.7	1.5	18.4	62.4
322	Paper Products	3.4	4.8	2.0	2.9	2.6	50.9	9.5	19.4	20.2
323	Printing & Related	1.9	1.1	0.8	1.1	4.4	20.5	6.4	12.5	60.5
324	Petroleum and Coal	11.7	8.0	15.7	13.9	12.2	24.1	21.1	27.1	27.6
325	Chemical Products	13.5	14.7	23.6	12.3	7.0	38.4	27.4	20.6	13.6
326	Plastic & Rubber	3.9	2.7	3.2	4.8	5.2	24.1	12.9	27.9	35.1
327	Nonmetallic Mineral	2.4	0.7	4.3	1.3	4.5	10.2	28.1	12.2	49.5
331	Primary Metals	4.9	5.2	5.5	5.3	3.7	37.7	17.8	24.7	19.9
332	Fabricated Metals	6.4	3.7	3.4	6.9	11.4	20.2	8.3	24.4	47.1
333	Machinery	6.6	7.7	6.3	7.4	4.4	41.5	15.0	25.8	17.7
334	Computer & Electronics	7.4	11.4	5.4	4.9	5.5	54.0	11.4	15.0	19.6
335	Electrical Equipment	2.4	2.7	2.3	2.6	2.0	39.0	14.7	24.5	21.8
336	Transport Equipment	14.1	15.9	17.2	18.1	6.5	39.6	19.1	29.2	12.2
337	Furniture & Related	1.6	1.2	0.3	1.3	3.1	26.8	2.7	19.1	51.3
339	Miscellaneous	2.8	2.8	1.6	3.0	3.2	35.1	9.2	25.1	30.7
	TOTAL	100	100	100	100	100	35.2	15.7	22.8	26.3

Source: Census of Manufacturers, Directory of Corporate Affiliations, and Uniworld Business Publications as explained in the text. Data are for the year 2007.

Table 3.11: Percent of Employment by Firm Type: 3 Digit NAICS Industries

NAICS	Description	Total	US. Mult	Foreign Mult	Exporter	Domestic Only	US. Mult	Foreign Mult	Exporter	Domestic Only
		Within Types					Across Types			
311	Food	11.0	10.2	8.2	9.8	13.0	25.0	7.1	20.4	47.5
312	Beverage & Tobacco	1.2	1.5	1.2	0.9	1.1	36.1	9.9	17.0	37.0
31X	Textile, Apparel, Leather	3.8	2.1	1.1	3.8	5.5	15.1	2.9	23.5	58.5
321	Wood Products	3.8	2.1	0.4	2.7	6.4	14.8	1.0	16.3	67.8
322	Paper Products	3.2	4.7	2.7	2.9	2.5	39.7	8.0	20.6	31.6
323	Printing & Related	4.7	2.5	2.4	2.4	8.1	14.1	4.9	11.5	69.5
324	Petroleum and Coal	0.8	0.5	1.8	0.8	0.8	16.7	21.6	22.7	39.0
325	Chemical Products	6.1	7.9	11.8	6.1	3.5	35.3	18.6	23.1	23.0
326	Plastic & Rubber	6.3	4.8	6.4	8.1	6.3	20.7	9.7	29.3	40.3
327	Nonmetallic Mineral	3.6	1.1	7.2	2.1	5.2	8.6	19.1	13.6	58.7
331	Primary Metals	3.4	3.6	5.3	4.2	2.2	29.4	15.2	28.4	27.0
332	Fabricated Metals	11.9	5.9	6.7	12.5	16.7	13.5	5.4	24.2	57.0
333	Machinery	8.6	9.8	10.6	11.6	5.6	31.0	11.7	31.0	26.4
334	Computer & Electronics	8.0	14.6	8.7	6.9	4.0	49.7	10.4	19.8	20.0
335	Electrical Equipment	3.2	3.8	4.0	3.8	2.2	32.4	11.8	27.5	28.3
336	Transport Equipment	12.0	18.2	17.2	13.0	6.1	41.1	13.6	24.9	20.4
337	Furniture & Related	3.7	2.6	0.7	3.0	5.7	18.7	1.9	18.1	61.3
339	Miscellaneous	4.8	4.1	3.7	5.6	5.1	22.9	7.4	26.7	43.0
	TOTAL	100	100	100	100	100	27.1	9.6	23.0	40.3

Source: Census of Manufacturers, Directory of Corporate Affiliations, and Uniworld Business Publications as explained in the text. Data are for the year 2007.

Table 3.12: Percent of Exports by Firm Type: 3 Digit NAICS Industries

NAICS	Description	Total	US. Mult	Foreign Mult	Exporter	US. Mult	Foreign Mult	Exporter
		Within Types				Across Types		
311	Food	5.5	4.2	5.0	7.5	37.7	14.0	48.3
312	Beverage & Tobacco	1.0	1.6	0.2	0.5	78.9	2.7	18.4
31X	Textile, Apparel, Leather	1.3	0.7	0.7	2.4	28.0	8.2	63.8
321	Wood Products	0.5	0.1	0.1	1.3	11.4	2.5	86.1
322	Paper Products	2.3	2.8	1.5	2.1	58.6	9.9	31.4
323	Printing & Related	0.4	0.2	0.1	0.8	24.7	4.0	71.4
324	Petroleum and Coal	2.5	1.2	(D)	3.8	23.7	(D)	55.0
325	Chemical Products	17.5	15.6	27.4	15.9	43.8	24.1	32.1
326	Plastic & Rubber	2.5	1.7	2.7	3.4	34.6	16.8	48.6
327	Nonmetallic Mineral	1.1	1.0	1.4	1.1	44.4	19.9	35.7
331	Primary Metals	4.2	4.0	2.7	5.2	46.6	9.7	43.7
332	Fabricated Metals	4.1	3.0	3.2	6.1	35.5	11.8	52.6
333	Machinery	11.5	12.5	9.8	10.9	53.4	13.2	33.4
334	Computer & Electronics	16.8	23.1	11.0	10.5	67.7	10.1	22.2
335	Electrical Equipment	2.7	2.5	3.0	2.9	45.3	17.1	37.6
336	Transport Equipment	22.7	22.6	25.9	21.4	49.0	17.6	33.4
337	Furniture & Related	0.4	0.3	(D)	0.7	32.7	(D)	63.4
339	Miscellaneous	3.1	3.2	2.1	3.6	49.4	10.1	40.6
	TOTAL	100	100	100	100	49.2	15.4	35.3

Source: Census of Manufacturers, Directory of Corporate Affiliations, and Uniworld Business Publications as explained in the text. Data are for the year 2007.
A “(D)” indicates that the data have been suppressed to avoid the disclosure of data of individual companies.

Table 3.13: Exports as Percent of Shipments by Firm Type

NAICS	Description	Total	US. Mult	Foreign Mult	Exporter	Domestic Only
311	Food	2.2	8.8	15.0	16.2	
312	Beverage & Tobacco	1.6	13.4	17.9	7.2	
31X	Textile, Apparel, Leather	1.9	19.3	18.9	15.0	
321	Wood Products	1.8	12.5	16.2	17.3	
322	Paper Products	3.4	9.3	12.1	12.9	
323	Printing	1.0	6.6	9.4	13.7	
324	Petroleum and Coal	1.8	10.2	(D)	16.0	
325	Chemical Products	6.5	18.3	20.4	16.0	
326	Plastic & Rubber	3.8	13.7	13.8	10.8	
327	Nonmetallic Mineral	1.2	17.0	15.7	14.9	
331	Primary Metals	4.7	14.2	15.7	13.3	
332	Fabricated Metals	2.4	13.6	13.8	13.0	
333	Machinery	7.0	21.5	21.1	17.4	
334	Computer & Electronics	11.0	30.9	26.7	23.9	
335	Electrical Equipment	6.4	17.8	18.6	15.3	
336	Transport Equipment	5.6	18.2	18.4	15.4	
337	Furniture & Related	1.0	5.2	(D)	13.2	
339	Miscellaneous	3.2	18.2	18.3	16.6	
	TOTAL	3.3	17.3	18.1	15.5	

Source: Census of Manufacturers, Directory of Corporate Affiliations, and Uniworld Business Publications as explained in the text. Data are for the year 2007.
A "(D)" indicates that the data have been suppressed to avoid the disclosure of data of individual companies.

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APPENDICES

APPENDIX A

Basic Theory Appendix

A.1 Basic Theory Appendix

A.1.1 Proof of Result 1

Suppose that the firm solves

$$\max p_x x - p_D F_D - p_M IM$$

subject to

$$x = \left[(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM\right]^{\frac{\psi-1}{\psi}} \right]^{\frac{\psi}{\psi-1}}$$

and

$$p_x = \left(\frac{Y}{x}\right)^{\frac{1}{\varepsilon}}$$

The first order conditions are

$$\left(1 - \frac{1}{\varepsilon}\right) (Y)^{\frac{1}{\varepsilon}} (x)^{\frac{1}{\psi}-\frac{1}{\varepsilon}} (1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{-\frac{1}{\psi}} = p_D$$

$$\left(1 - \frac{1}{\varepsilon}\right) (Y)^{\frac{1}{\varepsilon}} (x)^{\frac{1}{\psi}-\frac{1}{\varepsilon}} \mu^{\frac{1}{\psi}} \left[IM\right]^{-\frac{1}{\psi}} = p_M$$

Dividing one by the other gives

$$\frac{F_D^*}{IM^*} = \frac{1-\mu}{\mu} \left(\frac{p_M}{p_D}\right)^{\psi}.$$

The same equation can be obtained under perfect competition.

Now take the production function and multiply it by p_x

$$p_x x = p_x \left[(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + (p_M)^{-\frac{\psi-1}{\psi}} \mu^{\frac{1}{\psi}} \left[p_M IM\right]^{\frac{\psi-1}{\psi}} \right]^{\frac{\psi}{\psi-1}}$$

Taking logs gives

$$\ln(p_x x) = \frac{\psi}{\psi-1}\ln\left(p_x\left[(1-\mu)^{\frac{1}{\psi}}[F_D]^{\frac{\psi-1}{\psi}} + (p_M)^{-\frac{\psi-1}{\psi}}\mu^{\frac{1}{\psi}}[p_M IM]^{\frac{\psi-1}{\psi}}\right]\right) \tag{A.1}$$

$$= \frac{\psi}{\psi-1}\ln\left(p_x\left[(1-\mu)^{\frac{1}{\psi}}\exp\left(\frac{\psi-1}{\psi}\ln[F_D]\right) + (p_M)^{-\frac{\psi-1}{\psi}}\mu^{\frac{1}{\psi}}\exp\left(\frac{\psi-1}{\psi}\ln[p_M IM]\right)\right]\right) \tag{A.2}$$

Before differentiating, recall the assumption that the firm takes prices p_M as given and that it cannot change p_x after learning about the shock. Then

$$\frac{\partial \ln p_x x}{\partial \ln p_M M} = \frac{\psi}{\psi-1}\frac{p_x (P_M)^{-\frac{\psi-1}{\psi}}\mu^{\frac{1}{\psi}}\exp\left(\frac{\psi-1}{\psi}\ln[p_M IM]\right)\frac{\psi-1}{\psi}}{p_x\left[(1-\mu)^{\frac{1}{\psi}}\exp\left(\frac{\psi-1}{\psi}\ln[F_D]\right) + (p_M)^{-\frac{\psi-1}{\psi}}\mu^{\frac{1}{\psi}}\exp\left(\frac{\psi-1}{\psi}\ln[p_M IM]\right)\right]} \tag{A.3}$$

$$= \frac{1}{1+\left(\frac{1-\mu}{\mu}\right)^{\frac{1}{\psi}}\left[\frac{F_D}{IM}\right]^{\frac{\psi-1}{\psi}}} \tag{A.4}$$

We evaluate this elasticity at

$$\frac{F_D^*}{IM} = \frac{IM^*}{IM}\frac{1-\mu}{\mu}\left(\frac{p_M}{p_D}\right)^{\psi}$$

so that

$$\frac{\partial \ln p_x x}{\partial \ln p_M IM} = \frac{1}{1+\left(\frac{IM^*}{IM}\right)^{\frac{\psi-1}{\psi}}\frac{1-\mu}{\mu}\left(\frac{p_M}{p_D}\right)^{\psi-1}}$$

A.1.2 On Flexibility in Domestic Inputs

Under the assumption of perfect competition, the first order conditions are:

$$x(1-\mu) = (p_D)^{\psi} F_D$$
$$x\mu = (p_M)^{\psi} IM$$

If the firm takes prices p_x, p_M, and p_D as given, the following elasticities are immediate:

$$\frac{\partial \ln(p_x x)}{\partial \ln(p_D F_D)} = \frac{\partial \ln(p_x x)}{\partial \ln(p_M M)} = \frac{\partial \ln(p_D F_D)}{\partial \ln(p_M M)} = 1.$$

The above equations demonstrate that a constant returns to scale production function combined with these assumptions on market structure imply that the output elasticity will equal one for all values of the elasticity of substitution. For this reason, we require some assumptions limiting the flexibility of domestic inputs following the import disruption.

Below we show an alternative way of understanding the interaction of competitive factor markets, changes in domestic inputs, and the mapping of the output elasticity into parameter values for the elasticity of substitution. Consider the total derivative of $\ln(x)$:

$$d\ln x = \frac{\partial \ln x}{\partial IM} d\ln IM + \frac{\partial \ln x}{\partial F} d\ln F \tag{A.5}$$

$$d\ln x = \frac{\mu^{\frac{1}{\psi}} (IM)^{\frac{\psi-1}{\psi}} d\ln IM}{(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM\right]^{\frac{\psi-1}{\psi}}} + \frac{(1-\mu)^{\frac{1}{\psi}} (F_D)^{\frac{\psi-1}{\psi}} d\ln F_D}{(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM\right]^{\frac{\psi-1}{\psi}}} \tag{A.6}$$

Dividing by $d\ln IM$ yields:

$$\frac{d\ln x}{d\ln IM} = \frac{\mu^{\frac{1}{\psi}} (IM)^{\frac{\psi-1}{\psi}}}{(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM\right]^{\frac{\psi-1}{\psi}}} + \frac{(1-\mu)^{\frac{1}{\psi}} (F_D)^{\frac{\psi-1}{\psi}}}{(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM\right]^{\frac{\psi-1}{\psi}}} \frac{d\ln F_D}{d\ln IM}$$

Now, as before, combining the first order conditions from the profit maximization problem, we have:

$$\frac{F_D(\cdot)}{IM} = \frac{1-\mu}{\mu} \left(\frac{p_D}{p_M}\right)^{-\psi} \tag{A.7}$$

Log-differentiating this expression:

$$\begin{aligned} d\ln\left(\frac{F_D}{IM}\right) &= -\psi d\ln\left(\frac{p_D}{p_M}\right) \\ d\ln F_D - d\ln IM &= -\psi d\ln\left(\frac{p_D}{p_M}\right) \\ \frac{d\ln F_D}{d\ln IM} &= 1 - \psi \frac{d\ln\left(\frac{p_D}{p_M}\right)}{d\ln IM} \end{aligned} \tag{A.8}$$

Finally, we have:

$$\frac{d\ln x}{d\ln IM} = \frac{\mu^{\frac{1}{\psi}} (IM)^{\frac{\psi-1}{\psi}}}{(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM\right]^{\frac{\psi-1}{\psi}}} + \frac{(1-\mu)^{\frac{1}{\psi}} (F_D)^{\frac{\psi-1}{\psi}} \left[1 - \psi \frac{d\ln\left(\frac{p_D}{p_M}\right)}{d\ln IM}\right]}{(1-\mu)^{\frac{1}{\psi}} \left[F_D\right]^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} \left[IM\right]^{\frac{\psi-1}{\psi}}} \tag{A.9}$$

Thus, if there is no change in the relative input price following the disruption in IM of the firm: $\frac{d\ln\left(\frac{p_M}{p_D}\right)}{d\ln IM} = 0$, then the output elasticity will be equal to one regardless of the value of ψ. On the other hand, any assumptions that yield a non-zero change in the relative input prices will then yield the result that $\frac{d\ln x}{d\ln IM} = 1$ provided $\psi \to 0$.

APPENDIX B

Matching Corporate Directories to the Business Register

B.1 Matching Corporate Directories to the Business Register

The discussion below is an abbreviated form of the full technical note (see Flaaen (2013a)) documenting the bridge between the DCA and the Business Register.

B.1.1 Directories of International Corporate Structure

The LexisNexis Directory of Corporate Affiliations (DCA) is the primary source of information on the ownership and locations of U.S. and foreign affiliates. The DCA describes the organization and hierarchy of public and private firms, and consists of three separate databases: U.S. Public Companies, U.S. Private Companies, and International – those parent companies with headquarters located outside the United States. The U.S. Public database contains all firms traded on the major U.S. exchanges, as well as major firms traded on smaller U.S. exchanges. To be included in the U.S. Private database, a firm must demonstrate revenues in excess of $1 million, 300 or more employees, or substantial assets. Those firms included in the International database, which include both public and private companies, generally have revenues greater than $10 million. Each database contains information on all parent company subsidiaries, regardless of the location of the subsidiary in relation to the parent.

The second source used to identify multinational firms comes from Uniworld Business Publications (UBP). This company has produced periodic volumes documenting the locations and international scope of i) American firms operating in foreign countries; and ii) foreign firms with operations in the United States. Although only published biennially, these directories benefit from a focus on multinational firms, and from no sales threshold for inclusion.

Because there exist no common identifiers between these directories and Census Bureau data infrastructure, we rely on probabilistic name and address matching — so-called "fuzzy merging" — to link the directories to the Census data infrastructure.

B.1.2 Background on Name and Address Matching

Matching two data records based on name and address information is necessarily an imperfect exercise. Issues such as abbreviations, misspellings, alternate spellings, and alternate name conventions rule out an exact merging procedure, leaving the researcher with probabilistic string matching algorithms that evaluate the "closeness" of match — given by a score or rank — between the two character strings in question. Due to the large computing requirements of these algorithms, it is common to use so-called "blocker" variables to restrict the search samples within each dataset. A "blocker" variable must match exactly, and as a result this implies the need for a high degree of conformity between these variables in the two datasets. In the context of name and address matching, the most common "blocker" variables are the state and city of the establishment.

The matching procedure uses a set of record linking utilities described in Wasi and Flaaen (2014). This program uses a bigram string comparator algorithm on multiple variables with differing user-specified weights.[1] This way the researcher can apply, for example, a larger weight on a near *name* match than on a perfect *zip code* match. Hence, the "match score" for this program can be interpreted as a weighted average of each variable's percentage of bigram character matches.

B.1.3 The Unit of Matching

The primary unit of observation in the DCA, UBP, and BR datasets is the business establishment. Hence, the primary unit of matching is the establishment, and not the firm. However, there are a number of important challenges with an establishment-to-establishment link. First, the DCA (UBP) and BR may occasionally have differing definitions of the establishment. One dataset may separate out several operating groups within the same firm address (i.e. JP Morgan – Derivatives, and JP Morgan - Emerging Markets), while another may group these activities together by their common address. Second, the name associated with a particular establishment can at times reflect the subsidiary name, location, or activity (i.e. Alabama plant, processing division, etc), and at times reflect the parent company name. Recognizing these challenges, the primary goal of the matching will be to assign each DCA (UBP) establishment to the most appropriate business location of the parent firm identified in the BR. As such, the primary matching variables will be the establishment name, along with geographic indicators of street, city, zip code, and state.

[1] The term bigram refers to two consecutive characters within a string (the word *bigram* contains 5 possible bigrams: "bi", "ig", "gr", "ra", and "am"). The program is a modified version of Blasnik (2010), and assigns a score for each variable between the two datasets based on the percentage of matching bigrams. See Flaaen (2013a) or Wasi and Flaaen (2014) for more information.

B.1.4 The Matching Process: An Overview

The danger associated with probabilistic name and address procedures is the potential for false-positive matches. Thus, there is an inherent tension for the researcher between a broad search criteria that seeks to maximize the number of true matches and a narrow and exacting criteria that eliminates false-positive matches. The matching approach used here is conservative in the sense that the methodology will favor criteria that limit the potential for false positives at the potential expense of slightly higher match rates. As such, the procedure generally requires a match score exceeding 95 percent, except in those cases where ancillary evidence provides increased confidence in the match.[2]

This matching proceeds in an iterative fashion, in which a series of matching procedures are applied with decreasingly restrictive sets of matching requirements. In other words, the initial matching attempt uses the most stringent standards possible, after which the non-matching records proceed to a further matching iteration, often with less stringent standards. In each iteration, the matching records are assigned a flag that indicates the standard associated with the match.

See Table B.1 for a summary of the establishment-level match rate statistics by year and type of firm. Table B.2 lists the corresponding information for the Uniworld data.

B.1.5 Construction of Multinational Indicators

The DCA data allows for the construction of variables indicating the multinational status of the U.S.-based establishment. If the parent firm contains addresses outside of the United States, but is headquartered within the U.S., we designate this establishment as part of a U.S. multinational firm. If the parent firm is headquartered outside of the United States, we designate this establishment as part of a Foreign multinational firm. We also retain the nationality of parent firm.[3]

There can be a number of issues when translating the DCA-based indicators through the DCA-BR bridge for use within the Census Bureau data architecture. First, there may be disagreements between the DCA and Census on what constitutes a firm, such that an establishment matches may report differing multinational indicators for the same Census-identified firm. Second, such an issue might also arise due to joint-ventures. Finally, incorrect matches may also affect the degree to which establishment matches agree when aggregated to a firm definition. To address these issues, we apply the following rules when using the DCA-based multinational indicators and aggregating to the (Census-based) firm level. There are three potential cases:[4]

Potential 1: A Census-identified firm in which two or more establishments match to different foreign-country parent firms

[2] The primary sources of such ancillary evidence are clerical review of the matches, and additional parent identifier matching evidence.

[3] The multinational status of firms from the UBP directories are more straightforward.

[4] Some of these cases also apply to the UBP-BR bridge.

1. Collapse the Census-identified firm employment based on the establishment-parent firm link by country of foreign ownership
2. Calculate the firm employment share of each establishment match
3. If one particular link of country of foreign ownership yields an employment share above 0.75, apply that link to all establishments within the firm.
4. If one particular link of country of foreign ownership yields an employment share above 0.5 and total firm employment is below 10,000, then apply that link to all establishments within the firm.
5. All other cases require manual review.

Potential 2: A Census-identified firm in which one establishment is matched to a foreign-country parent firm, and another establishment is matched to a U.S. multinational firm.

1. Collapse the Census-identified firm employment based on the establishment-parent firm link by type of DCA link (Foreign vs U.S. Multinational)
2. Calculate the firm employment share of each establishment match
3. If one particular type of link yields an employment share above 0.75, apply that link to all establishments within the firm.
4. If one particular type of link yields an employment share above 0.5 and total firm employment is below 10,000, then apply that link to all establishments within the firm.
5. All other cases require manual review.

Potential 3: A Census-identified firm in which one establishment is matched to a non-multinational firm, and another establishment is matched to a foreign-country parent firm (or U.S. multinational firm).

Apply same steps as in Potential 2.

Table B.1: DCA Match Statistics: 2007-2011

	# of DCA Establishments	Matched to B.R.	Percent Matched
Total			
2007	112,346	81,656	0.73
2008	111,935	81,535	0.73
2009	111,953	81,112	0.72
2010	111,998	79,661	0.71
2011	113,334	79,516	0.70
U.S. Multinationals			
2007	22,500	16,396	0.73
2008	23,090	16,910	0.73
2009	22,076	16,085	0.73
2010	21,667	15,785	0.73
2011	21,721	15,557	0.72
Foreign Multinationals			
2007	10,331	7,555	0.73
2008	9,351	6,880	0.74
2009	11,142	8,193	0.74
2010	11,308	8,181	0.72
2011	11,619	8,357	0.72

Table B.2: Uniworld Match Statistics: 2006-2011

	# of Uniworld Establishments	Matched to B.R.	Percent Matched
Foreign Multinationals			
2006	3,495	2,590	0.74
2008	3,683	2,818	0.76
2011	6,188	4,017	0.65
U.S. Multinationals[1]			
2007	4,043	3,236	0.80
2009	4,293	3,422	0.80

[1]U.S. multinationals include only the establishment identified as the U.S. headquarters.

APPENDIX C

Classifying Firm-Level Trade

C.1 Classifying Firm-Level Trade

The firm-level data on imports available in the LFTTD does not contain information on the intended use of the goods.[1] Disentangling whether an imported product is used as an intermediate input for further processing — rather than for final sale in the U.S. — has important implications for the nature of FDI, and the role of imported goods in the transmission of shocks. Fortunately, the Census Bureau data contains other information that can be used to distinguish intermediate input imports from final goods imports. Creating lists of the principal products produced by firms in a given detailed industry in the United States should indicate the types of products that, when imported, should be classified as a "final" good – that is, intended for final sale without further processing. The products imported outside of this set, then, would be classified as intermediate goods.[2] Such product-level production data exists as part of the "Products" trailer file of the Census of Manufacturers. As detailed in Pierce and Schott (2012) (see page 11), combining import, export, and production information at a product-level is useful for just such a purpose.

C.1.1 Creating a NAICS-Based set of Final/Intermediate Products

As part of the quinquennial Census of Manufacturers (CM), the Census Bureau surveys establishments on their total shipments broken down into a set of NAICS-based (6 digit) product categories. Each establishment is given a form particular to its industry with a list of pre-specified products, with additional space to record other product shipments not included in the form. The resulting product trailer file to the CM allows the researcher to understand the principal products produced at each manufacturing establishment during a census year.

[1] This is one advantage of the survey data on multinational firms available from the Bureau of Economic Analysis. There are, however, a number of critical disadvantages of this data source, as outlined in Flaaen (2013b).

[2] To be more precise, this set will include a combination of intermediate and capital goods.

There are several data issues that must be addressed before using the CM-Products file to infer information about the relative value of product-level shipments by a particular firm. First, the trailer file contains product-codes that are used to "balance" the aggregated product-level value of shipments with the total value of shipments reported on the base CM survey form. We drop these product codes from the dataset. Second, there are often codes that do not correspond to any official 7-digit product code identified by Census. (These are typically products that are self-identified by the firm but do not match any of the pre-specified products identified for that industry by Census.) Rather than ignoring the value of shipments corresponding to these codes, we attempt to match at a more aggregated level. Specifically, we iteratively try to find a product code match at the 6, 5, and 4 digit product code level, and use the existing set of 7-digit matches as weights to allocate the product value among the 7-digit product codes encompassing the more aggregated level.

We now discuss how this file can be used to assemble a set of NAICS product codes that are the predominant output (final goods) for a given NAICS industry. Let x_{pij} denote the shipments of product p by establishment i in industry j during a census year. Then the total output of product p in industry j can be written as:

$$X_{pj} = \sum_{i=1}^{I_j} x_{pij},$$

where I_j is the number of firms in industry j. Total output of industry j is then:

$$X_j = \sum_{p=1}^{P_j} X_{pj}.$$

The share of industry output accounted for by a given product p is therefore:

$$S_{pj} = \frac{X_{pj}}{X_j}.$$

One might argue that the set of final goods products for a given industry should be defined as the set of products where $S_{pj} > 0$. That is, a product is designated as a "final good" for that industry if *any establishment* recorded positive shipments of the product. The obvious disadvantage of employing such a zero threshold is that small degrees of within-industry heterogeneity will have oversized effects on the classification.

Acknowledging this concern, we set an exogenous threshold level W such that any p in a given j with $S_{pj} > W$ is classified as a final good product for that industry. The upper portion of Table C.1 documents the number of final goods products and the share of intermediate input imports based on several candidate threshold levels. The issues of a zero threshold are quite clear in the table; a small but positive threshold value (0.1) will have a large effect on the number of products designated as final goods. This shows indirectly that there are a large number of products produced by establishments in a given industry, but a much smaller number that comprise the bulk of total value.

There are several advantages to using the CM-Products file rather than using an input-output table.[3] First, within a given CM year, the classification can be done at the firm or establishment level rather than aggregating to a particular industry. This reflects the fact that the same imported product may be used as an input by one firm and sold to consumers as a final product by another. Second, the CM-Products file is one of the principal data inputs into making the input-output tables, and thus represents more finely detailed information. Related to this point, the input-output tables are produced with a significant delay – the most recent available for the U.S. is for year 2002. Third, the input-output tables for the U.S. are based on BEA industry classifications, which imply an additional concordance (see below) to map into the NAICS-based industries present in the Census data.

We now turn to the procedure to map firm-level trade into intermediate and final goods using the industry-level product classifications calculated above.

C.1.2 Mapping HS Trade Transactions to the Product Classification

The LFTTD classifies products according to the U.S. Harmonized Codes (HS), which must be concorded to the NAICS-based product system in order to utilize the classification scheme from the CM-Products file. Thankfully, a recent concordance created by Pierce and Schott (2012) can be used to map the firm-HS codes present in the LFTTD data with the firm-NAICS product codes present in the CM-Products data.

A challenge of this strategy is that the LFTTD exists at a firm-level, while the most natural construction of the industry-level classification scheme is by establishment. More concretely, for multi-unit, multi-industry firms, the LFTTD is unable to decompose an import shipment into the precise establishment-industry of its U.S. destination. [4] While recognizing the caution that should be used in this regard, we adopt the approach that is commonly used in such circumstances: the industry of the firm is defined as that industry encompassing the largest employment share.

Once the firm-level trade data is in the same product classification as the industry-level filter created from the CM-Products file, all that is left is to match the trade data with the filter by NAICS industry. Thus, letting M_{ij} denote total imports from a firm i (firm i is classified as being in industry j), we can then categorize the firm's trade according to:

[3] Another option is to use the CM-Materials file, the flip side of the CM-Products file. Unfortunately, the CM-Materials file contains significantly more problematic product codes than the Products file, and so concording to the trade data is considerably more difficult.

[4] It is worth pointing out that the most obvious way that this would materialize is by vertical integration of the firm in its U.S. operations. Provided that the industry designation of the firm pertains to its most downstream operations, then this is would not serve to bias the firms' classification of imported goods, as the upstream products are not actually "final" goods for that firm.

$$\left.\begin{aligned} M_{ij}^{\text{int}} &= \sum_{p \notin P_j} M_{ipj} \\ M_{ij}^{\text{fin}} &= \sum_{p \in P_j} M_{ipj} \end{aligned}\right\} \qquad \text{where} \qquad P_j = \{p \mid S_{pj} \geq W\}\,. \tag{C.1}$$

The bottom section of Table C.1 shows some summary statistics of the intermediate share of trade according to this classification system, by several values of the product-threshold W. There are at least two important takeaways from these numbers. First, the share of intermediates in total imports is roughly what is reported in the literature using IO Tables. Second, the share of total trade occupied by intermediate products is not particularly sensitive to the exogenous threshold level. While there is a small increase in the share when raising the threshold from 0 to 0.1 (about 3 percentage points), the number is essentially unchanged when raising it further to 0.2.

Table C.1: Appendix Table Comparing the Results from Threshold Values W

	Threshold Values		
	$W = 0$	$W = 0.1$	$W = 0.2$
Number of Final Good Products per Industry			
Median	19	1	1
Mean	25	1.52	1.14
Min	1	1	0
Max	154	6	3
Implied Share of Intermediate Inputs			
Imports	60.9	63.90	63.97
Exports	52.0	54.96	55.04

APPENDIX D

Description of Sample Construction

D.1 Description of Sample Construction

D.1.1 Constructing the Baseline Dataset

This section will discuss the steps taken to construct the sample used in section 1.3.1.

Beginning with the raw files of the LFTTD export/import data, we drop any transactions with missing firm identifiers, and those pertaining to trade with U.S. territories. Next, we merge the LFTTD files with the HS-NAICS6 product concordance from Pierce and Schott (2012); if there is no corresponding NAICS6 code for a particular HS code, then we set NAICS6 equal to XXXXXX. We then aggregate up to the level of Firm-Country-Month-NAICS6, and then create extracts according to three sets of destinations/sources: Japan, Non-Japan, and North America (Canada and Mexico). Then, assigning each firm to an LBD-based industry (see below), we run the NAICS-based trade codes through the intermediate/final goods filter discussed in Appendix C.1. The firms' monthly trade can then be split into intermediate and final goods components. We repeat this step for years 2009, 2010, and 2011.

Using the Longitudinal Business Database, we drop inactive, ghost/deleted establishments, and establishments that are not in-scope for the Economic Census. To create the sample of manufacturing firms in the U.S., we first create a firm industry code defined as the industry encompassing the largest share of firm employment. We then drop non-manufacturing firms. Next, we merge the LBD for each year with the DCA-Bridge (see section B.1) containing multinational indicators. We then apply the rules specified above for clarifying disagreements with the DCA-based multinational indicators. After creating monthly copies of each firm, we merge by firm-month to the trade data. Missing information of trade data is altered to represent zeros. We repeat these steps for years 2009-2011, and then append the files together. Firms that do not exist in all three years are dropped from the sample.

D.1.2 GIS Mapping of Earthquake Intensity Measures to Affiliate Locations

As part of the Earthquake Hazards Program, the U.S. Geological Survey produces data and map products of the ground motion and shaking intensity following major earthquakes. The preferred measure to reflect the perceived shaking and damage distribution is the estimated "Modified Mercalli Intensity (MMI)" which is based on a relation of survey response and measured peak acceleration and velocity amplitudes. The USGS extends the raw data from geologic measurement stations and predicts values on a much finer grid using standard seismological inferences and interpolation methods. The result is a dense grid of MMI values covering the broad region affected by the seismic event. For more information on this methodology, see Wald et al. (2006).

To utilize this information, we take all Japanese addresses from the DCA/Uniworld directories that correspond to any U.S. operation via an ownership link. We geocode these addresses into latitude/longitude coordinates using the Google Geocoding API, and then compute the inverse distance-weighted mean of the relevant seismic intensity measure based on a 10km radius surrounding a given establishment. The firm identifiers within the corporate directories allow us to create firm-specific measures (average and maximum values, by manufacturing/non-manufacturing), which can then be brought into the baseline Census dataset via the bridges discussed in appendix B.1.

APPENDIX E

Other Results from Chapter One

E.1 Other Results from Chapter One

E.1.1 Alternate Specifications for Treatment Effects Regressions

Our results from section 1.3.2 are based on a sample including all Japanese multinationals in manufacturing, and therefore uses a levels specification to allow for zeros in the firm-month observations. Because larger firms exhibit greater absolute deviations from trend, this roughly amounts to weighting firms based on size, such that the results correspond to a representative firm based on the aggregate effect of the group.

To see this, and to explore how the levels specification influences our interpretation, we repeat the analysis on a subset of the firms for which we can view the percentage changes directly. Specifically, we drop any firms with zeros in any month for intermediate imports or N.A. exports during the sample, and then take logs and HP-filter each series to obtain percentage deviations from trend for each firm.[1] The results of this exercise are shown in Panel A of Figure E.1. We suppress standard errors for the sake of clarity; the drops are significant at the 95% level for between 2-4 months following the shock. If we rerun these regressions while also weighting according to the pre-shock size of firms, we obtain a picture that looks much closer to Figure 2.1, see Panel B of Figure E.1.

These results indicate that the larger firms appear to be affected the most from this shock. This could be partly a result of our proxy being less effective for smaller firms that may not engage in consistent exports to North America.

E.1.2 Bootstrapping Standard Errors

We use bootstrapping methods to compute measures of the dispersion of our point estimates. Using random sampling with replacement within each group of firms, we

[1] We re-weight the control group as described in section 1.3.1.

create 5000 new artificial samples and re-run the estimation procedure. The standard deviation of the point estimates across these bootstrap samples is shown in Table 1.4. To gain a more complete picture of the dispersion, we create density estimates for each sample of firms across the parameter space for the elasticities. These densities are shown in Figure E.2.

E.1.3 Effects on Employment and Payroll

The Standard Statistical Establishment List (SSEL) contains quarterly employment and payroll information for all employers (with some small exceptions) in the U.S. economy. This list is held separately as a single-unit(SSEL-SU) and multi-unit (SSEL-MU) file. The Report of Organization Survey (ROS) asks firms to list the establishments which report under a particular EIN, and this information is then recorded to the firm identifier on the Multi-Unit File. To build a quarterly employment series at the firm-level, we link the EIN variables on the SU file with the firm-identifier linked with each EIN on the MU file. In principle, the four quarters of payroll listed on the SSEL is combined by Census to create an annual payroll figure for each establishment, which is the value recorded in the LBD. Similarly, the employment variable corresponding to the 1st quarter (week of March 12) from the SSEL is that used by the LBD.

Once we merge the SSEL-based data with quarterly employment and payroll to the LBD for a particular year, we conduct a series of reviews to ensure that the annual payroll (and 1st quarter employment) roughly align. Any establishments with disagreements between the SSEL-based payroll and LBD-based payroll such that the ratio was greater than 2 or less than 0.6 were dropped.

After these modifications were made, the remainder of the data construction was similar to that in section D.1. We merge multinational indicators from the DCA, drop non-manufacturing firms, append the 2009, 2010, and 2011 files together, and keep only those firms that exist in each year. Using the same set of firms as a control group as specified in section 1.3.1, we run the following regression:

$$\Delta \text{emp}_{j,t} = \sum_{i=-3}^{3} \gamma_i E_i + \sum_{i=-3}^{3} \beta_i E_i D_{j,i} + u_{j,t} \tag{E.1}$$

where $\Delta \text{emp}_{j,t} \equiv ln(\text{emp}_{j,t}/\text{emp}_{j,t-4})$, where $\text{emp}_{j,t}$ indicates employment at firm j in quarter t. We also re-run the equation specified in equation E.1 using payroll $pay_{j,t}$ as the dependent variable (where $\Delta \text{pay}_{j,t} \equiv ln(\text{pay}_{j,t}/\text{pay}_{j,t-4})$. The qualitative results are shown in table E.1.

E.1.4 Effects on Unit Values (Prices) of Trade

The LFTTD contains information on quantities as well as values for each trade transaction, recorded at a highly disaggregated product definition (HS 10 digit). This allows for the construction of unit values (prices) for each firm-product-month observation, which allows for an analysis of price movements surrounding the Tōhoku event.

The majority of the data construction is identical to that in section D.1, however there are a number of modifications. First, we drop all transactions with missing or imputed quantities in the LFTTD, and then aggregate to the Firm-HS10-month frequency, separately for each type of trade transaction: 1) Related-Party imports from Japan; 2) Non Related-Party imports from Japan; 3) Related-Party exports to Canada/Mexico; and 4) Non Related-Party exports to Canada/Mexico. Next, we select only those firms identified as manufacturing in the LBD. We keep the related-party and arms-length transactions separate as one may expect these prices to behave differently following a shock. As above, we keep only manufacturing firms, append the annual files together, and then select only those firms identified as a multinational in either 2009, 2010, or 2011.

At the product level, there is little reason to suspect trends or seasonal variation over this short of a time period. Moreover, there is no concern here about accounting for zeros in the data. As such we take a firm j's imports (exports) of product p in month t, and run the following specification in logs ($\mathrm{m}_{p,j,t} = log(\mathrm{M}_{p,j,t})$:

$$\mathrm{m}_{p,j,t} = \alpha_{pj} + \sum_{i=-19}^{9} \gamma_i E_i + \sum_{i=-19}^{9} \beta_i E_i D_{j,i} + u_{j,t} \tag{E.2}$$

where α_{pj} are firmXproduct fixed-effects, γ_i are monthly fixed effects (with the dummy variable $E_i's$ corresponding to each calendar month), and $u_{j,t}$ are random effects. The variables $D_{j,t}$ are dummy variables equal to one if the firm is owned by a Japanese parent company.

A qualitative version of the results is shown in Table E.2.

E.1.5 Ward's Automotive Data

Ward's electronic databank offers a variety of data products for the global automotive industry at a monthly frequency. We obtain Japanese production (by model), North American production (by plant and model), U.S. inventory (by model), and North American sales (by model) all for the period January 2000 to December 2012. The inventory and sales data also contain the country of origin, so one can separate out these variables based on whether a particular model was imported vs domestically-produced. The series cover the universe of the assembly operations of finished cars and light trucks. Unfortunately, there is no information on input shipments.

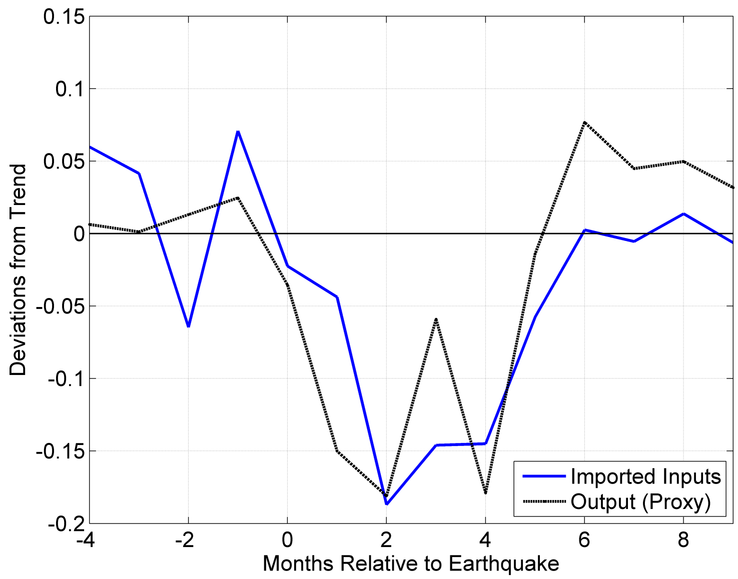
For the plant-level analysis of production, the base sample consists of 167 plants active at some point during 2000-2012. We remove plants that were not continuously in operation during the period 2009-2012, and combine several plants that are recorded separately in the data, but are in effect the same plant. After these modifications, the sample reduces to 62 plants, 22 of which are owned by a Japanese parent. The average monthly production in the three months preceding the shock is 12,904 for Japanese plants, and 14,903 for Non-Japanese plants. The specification is identical to that in section 1.3.1:

$$Q_{i,t} = \alpha_0 + \alpha_i + \sum_{p=-14}^{9} \gamma_p E_p + \sum_{p=-14}^{9} \beta_p E_p \text{JPN}_{i,p} + u_{i,t} \tag{E.3}$$

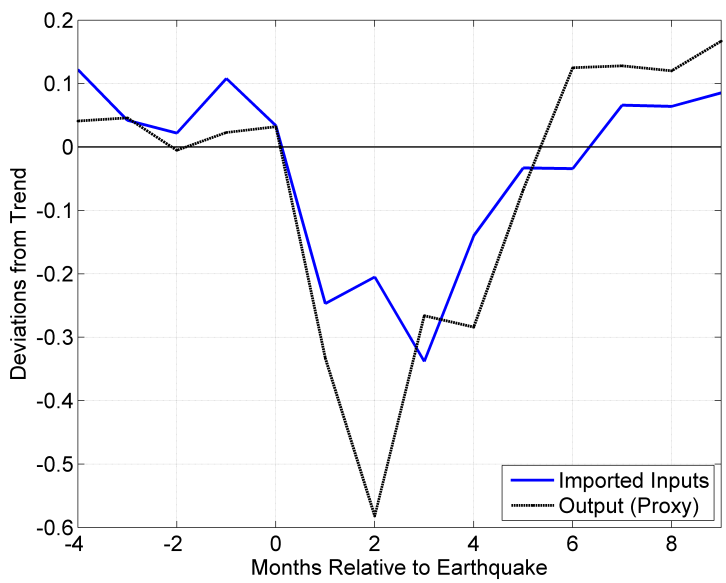
where here the variable $Q_{i,t}$ is auto production by plant i in month t, after removing a plant-specific trend though March 2011. Because these plants can be tracked with some confidence back in time, it is reasonable here to remove seasonality directly, rather than assume a shared seasonal component between the treated and control groups as in section 1.3.2. We use the X12-ARIMA model, provided by the National Bank of Belgium, and apply it to each series before correcting for trend. The results for the Japanese plants are mostly similar, as shown in table E.3.

Figure E.1: Relative Inputs and Output (Proxy) of Japanese Firms (Reduced Sample) Logged, HP-Filtered

A. No Size-Weighting



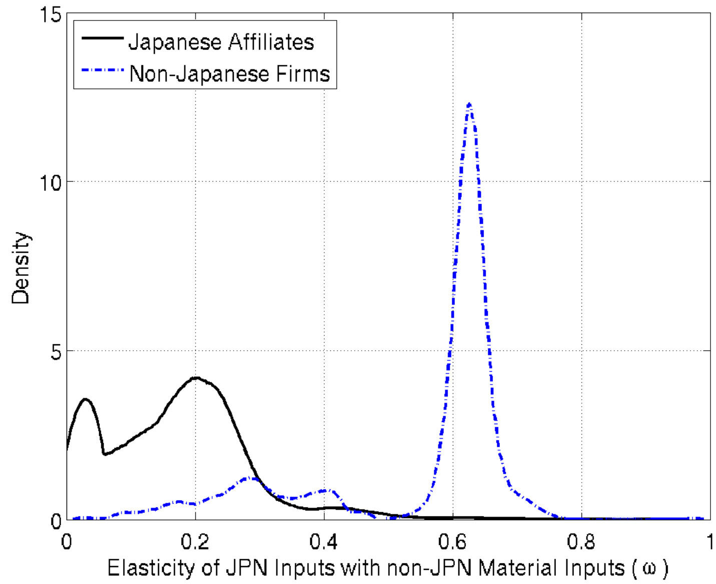
B. Size-Weighted



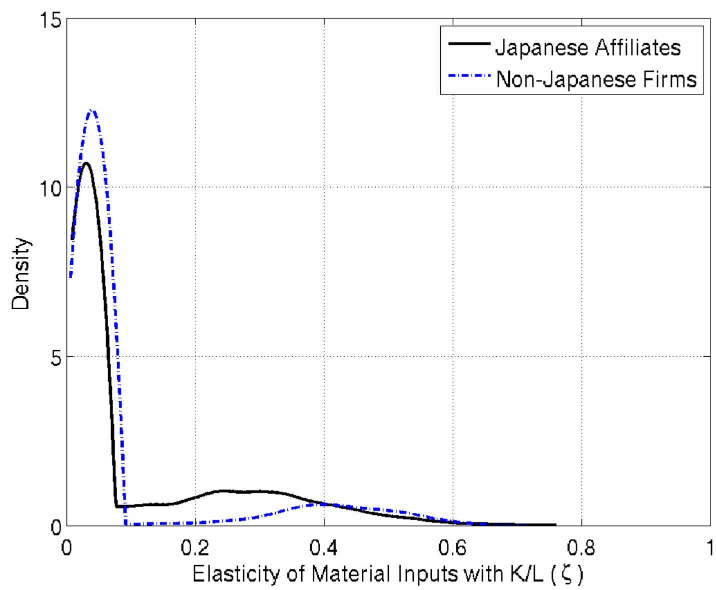
Source: LFTTD-DCA-UBP as explained in text.
These figures report the relative percentage deviations from trend of Japanese affiliates relative to a control group of other multinational firms. The values are coefficient estimates taken from an interaction of a Japanese-firm dummy with a monthly dummy – additional baseline monthly dummies remove seasonal effects. These results reflect a reduced sample with no firm-month zeros in imported inputs or N.A. exports. The data is logged, and HP-filtered using a monthly smoothing parameter.

Figure E.2: Density Estimates of Elasticities Across Bootstrap Samples

A. Materials Elasticity (ω)



B. Materials-Capital/Labor Elasticity (ζ)



Source: LFTTD-DCA-UBP as explained in text.

Table E.1: Dynamic Treatment Effects: Quarterly Employment/Payroll Surrounding Tōhoku Event

	Log 4-Quarter Difference	
	Employment	Payroll
Independent Variables	(1)	(2)
Q2_2010 (t=-3)	pos***	pos***
Q3_2010 (t=-2)	pos***	pos***
Q4_2010 (t=-1)	pos***	pos***
Q1_2011 (t=0)	pos***	pos***
Q2_2011 (t=1)	pos***	pos***
Q3_2011 (t=2)	pos***	pos***
Q4_2011 (t=3)	pos***	pos***
JPNxQ2_2010 (t=-3)	neg	neg
JPNxQ3_2010 (t=-2)	neg	neg
JPNxQ4_2010 (t=-1)	neg	neg
JPNxQ1_2011 (t=0)	neg	neg
JPNxQ2_2011 (t=1)	neg	neg
JPNxQ3_2011 (t=2)	neg	neg
JPNxQ4_2011 (t=3)	neg	pos
constant	neg***	neg***
Firm Fixed Effects	Yes	Yes
Observations		
R-squared		

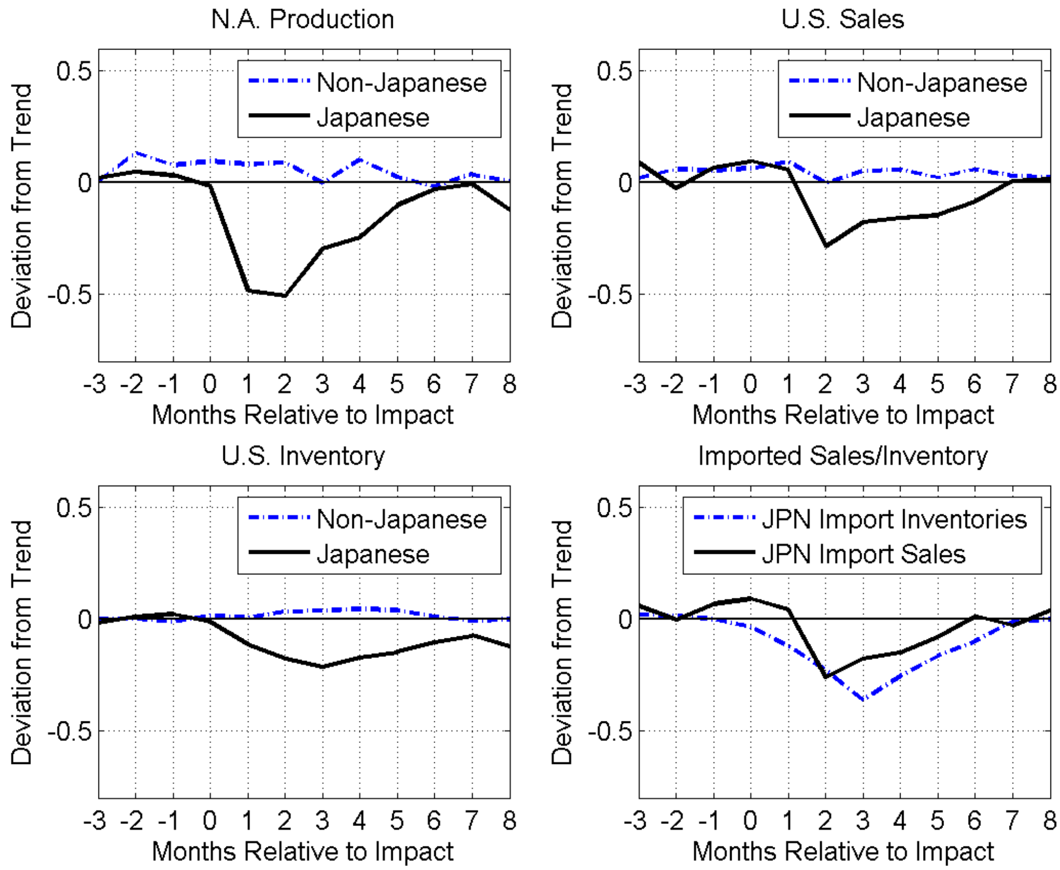
Source: SSEL and DCA as explained in the text.
Robust standard errors (clustered at the firmXProduct level) pertaining to each sign coefficient are indicated by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.
This table reports qualitative features of firm employment and firm payroll in the quarters surrounding the Tōhoku earthquake and tsunami. The first set of coefficients correspond to quarter dummies, whereas the second set (JPNx) correspond to the interaction of a Japanese firm dummy with quarter dummies. See equation E.1 in the text. The dependent variable is the four-quarter log difference of employment (payroll).

Table E.2: Dynamic Treatment Effects: Unit Values of Trade

	Log Unit-Value of:			
	JPN Imports		N.A. Exports	
	Intra-Firm	Arms-Length	Intra-Firm	Arms-Length
Independent Variables	(1)	(2)	(3)	(4)
Sep 2010 (t=-6)	neg**	pos	pos*	pos
Oct 2010 (t=-5)	pos	neg	pos**	pos
Nov 2010 (t=-4)	pos	pos	pos**	pos
Dec 2010 (t=-3)	pos	neg	pos	pos
Jan 2011 (t=-2)	neg	pos	neg	pos
Feb 2011 (t=-1)	pos	neg	pos**	pos
Mar 2011 (t=0)	neg	pos	pos	pos
Apr 2011 (t=1)	pos	pos	pos	pos
May 2011 (t=2)	neg	pos	neg	pos**
Jun 2011 (t=3)	pos**	neg	pos**	neg
Jul 2011 (t=4)	neg	neg	pos	neg
Aug 2011 (t=5)	pos	pos	neg	pos
Sep 2011 (t=6)	pos	pos	pos	pos**
Oct 2011 (t=7)	neg	neg	pos	pos
Nov 2011 (t=8)	pos	neg	pos	neg
Dec 2011 (t=9)	neg	pos	pos**	pos
JPNxSep 2010 (t=-6)	pos**	neg*	neg**	neg
JPNxOct 2010 (t=-5)	neg*	pos	pos	pos
JPNxNov 2010 (t=-4)	neg	pos	neg	neg
JPNxDec 2010 (t=-3)	neg	neg*	pos	pos
JPNxJan 2011 (t=-2)	pos	neg	neg	neg
JPNxFeb 2011 (t=-1)	neg	pos	pos	pos**
JPNxMar 2011 (t=0)	pos	pos	neg	neg
JPNxApr 2011 (t=1)	neg	pos	neg	neg
JPNxMay 2011 (t=2)	pos	neg	pos	neg
JPNxJun 2011 (t=3)	neg	pos*	neg	neg
JPNxJul 2011 (t=4)	pos	neg	pos	neg
JPNxAug 2011 (t=5)	neg*	neg*	neg	pos
JPNxSep 2011 (t=6)	neg	neg	neg	neg
JPNxOct 2011 (t=7)	pos	neg	neg	neg
JPNxNov 2011 (t=8)	neg	neg	neg	pos
JPNxDec 2011 (t=9)	neg	neg	pos	neg
constant	pos	neg	neg	neg
FirmXProduct Fixed Effect	Yes	Yes	Yes	Yes

Source: LFTTD, DCA, and UBP as explained in the text.
Robust standard errors (clustered at the firmXProduct level) pertaining to each sign coefficient are indicated by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.
This table reports qualitative features of the unit values of trade surrounding the 2011 Tōhoku earthquake and tsunami. The first set of coefficients correspond to monthly dummies, whereas the second set (JPNx) correspond to the interaction of a Japanese firm dummy with monthly dummies. See equation E.2.

Figure E.3: Automotive Production, Inventory, Sales by Firm Type, Distributed Lag Model



Source: Ward's Automotive Database
This figure reports North American production, and U.S. sales and inventory data according to firm type: Japanese and non-Japanese firms. The values are coefficient estimates taken from a distributed lag model, exploiting time-series variation only. The underlying series have been seasonally adjusted, logged, and HP-Filtered Standard errors are suppressed in the interests of clarity. The Japanese automakers are Honda, Mazda, Mitsubishi, Nissan, Toyota, and Subaru.

Table E.3: Dynamic Treatment Effects: N.A. Automotive Production

VARS	(1) Prod	(2) Prod	VARS (cont'd)	(1) Prod (cont'd)	(2) Prod (cont'd)
Nov.2010 (t=-4)	91.06	17.78	JPNxNov.2010	-195.8	-341.7
	(649.9)	(608.8)		(841.9)	(799.2)
Dec.2010 (t=-3)	-1,973***	310.3	JPNxDec.2010	-385.0	-408.3
	(467.5)	(497.5)		(736.5)	(706.4)
Jan.2011 (t=-2)	-611.5	1,083*	JPNxJan.2011	781.0	-1,092
	(637.3)	(618.7)		(792.1)	(804.6)
Feb.2011 (t=-1)	694.9*	756.3*	JPNxFeb.2011	-1,142	-1,210*
	(401.9)	(394.7)		(696.2)	(666.8)
Mar.2011 (t=0)	4,356***	1,483***	JPNxMar.2011	-3,515***	-2,592***
	(524.9)	(389.1)		(812.0)	(842.7)
Apr.2011 (t=1)	-216.2	305.5	JPNxApr.2011	-6,239***	-6,099***
	(707.7)	(620.4)		(1,303)	(1,282)
May.2011 (t=2)	1,584***	799.1	JPNxMay.2011	-7,244***	-6,625***
	(525.4)	(511.3)		(1,651)	(1,740)
Jun.2011 (t=3)	1,366**	-499.3	JPNxJun.2011	-4,564***	-3,423**
	(623.6)	(594.9)		(1,248)	(1,320)
Jul.2011 (t=4)	-4,512***	123.3	JPNxJul.2011	-2,143	-3,723***
	(878.4)	(606.2)		(1,430)	(1,045)
Aug.2011 (t=5)	685.6	-1,323**	JPNxAug.2011	-1,275	-1,108
	(744.0)	(648.1)		(970.8)	(1,012)
Sep.2011 (t=6)	-836.5	-1,895***	JPNxSep.2011	-359.4	40.37
	(663.7)	(641.5)		(930.7)	(959.8)
Oct.2011 (t=7)	-338.0	-1,434**	JPNxOct.2011	93.27	-265.4
	(662.3)	(632.4)		(885.6)	(785.8)
Nov.2011 (t=8)	-1,393**	-1,443**	JPNxNov.2011	-1,318	-2,059*
	(582.8)	(601.2)		(1,159)	(1,183)
Dec.2011 (t=9)	-4,511***	-1,619**	JPNxDec.2011	759.1	24.95
	(774.4)	(655.5)		(1,105)	(803.9)
Constant				-1,535***	-1,683***
				(89.30)	(91.95)
Plant Fixed Effects				Yes	Yes
Remove Plant-Specific Pre-Shock Trend				Yes	Yes
Remove Seasonal Component				No	Yes
Observations				2,976	2,976
R-squared				0.260	0.272

Source: Ward's Automotive Yearbook

Robust standard errors (clustered at the plant level) in parentheses. *** p<0.01, ** p<0.05, * p<0.1 .

APPENDIX F

Country-Level Correlations

F.1 Country-Level Correlations

F.1.1 Quarterly Data

Data are taken from the International Financial Statistics of the International Monetary Fund (IMF). The series used in these calculations are nominal GDP, GDP deflator, world GDP, private and public consumption, gross fixed capital formation, and goods/services exports and imports, all at a quarterly frequency. We retain all countries in the OECD for which we have high-quality data going back to at least 1980. (Korea joined the OECD in 1996.) We deflate nominal GDP using the country-level GDP deflator, log each series, and then use a Hodrick-Prescott filter with a smoothing parameter of 1600.

Table F.1: Country-Level Correlations by Period: Quarterly Frequency

Country	Correlation of Country Real GDP with: U.S. GDP		World GDP	
	1980-1995	1995-2010	1980-1995	1995-2010
United States	1.00	1.00	0.28	0.71
Australia	0.62	0.49	0.10	0.31
Austria	-0.07	0.75	0.45	0.65
Belgium	0.23	0.78	0.52	0.70
Canada	0.81	0.84	0.13	0.64
Denmark	0.34	0.80	0.11	0.72
Finland	0.26	0.82	0.11	0.75
France	-0.07	0.80	0.46	0.74
Germany	-0.12	0.72	0.48	0.77
Italy	0.29	0.65	0.48	0.69
Japan	0.07	0.71	0.50	0.68
Korea, Rep.	0.02	0.17	-0.02	0.39
Netherlands	0.60	0.73	0.48	0.77
Norway	0.49	0.43	0.29	0.49
Spain	-0.02	0.66	0.46	0.67
Sweden	0.41	0.86	0.22	0.67
Switzerland	0.40	0.74	0.41	0.76
United Kingdom	0.47	0.80	-0.11	0.64
Median	**0.29**	**0.74**	**0.35**	**0.68**
Average	0.28	0.69	0.30	0.65

Source: International Financial Statistics, IMF.
GDP is deflated using the country GDP deflator. All reported numbers are based on correlations from the logged, HP-filtered series (smoothing parameter of 1600) relative to the equivalent series for the United States.

Table F.2: Country-Level Correlations by Period: Quarterly Frequency

	Correlation of Country-Level Variable with Equivalent U.S. Variable:					
	Real Cons.	Real Inv.	Total Hours	Real Cons.	Real Inv.	Total Hours
	1980-1995			1995-2010		
United States	1.00	1.00	1.00	1.00	1.00	1.00
Australia	0.02	0.58	0.63	0.05	0.14	0.50
Austria	-0.10	0.10	-0.07	0.45	0.69	0.45
Belgium	-0.37	0.16	–	0.36	0.76	–
Canada	0.67	0.51	0.75	-0.20	0.72	0.72
Denmark	0.29	0.35	–	0.36	0.66	–
Finland	-0.15	0.06	0.41	0.36	0.74	0.60
France	-0.61	-0.14	0.26	0.64	0.77	0.52
Germany	-0.29	-0.10	0.30	0.46	0.66	0.66
Italy	-0.04	0.07	-0.41	0.76	0.65	0.57
Japan	-0.13	-0.09	0.05	0.58	0.71	0.55
Korea, Rep.	-0.22	-0.08	-0.03	0.19	-0.08	-0.12
Netherlands	0.39	0.41	–	0.46	0.56	–
Norway	0.26	0.21	0.06	-0.59	0.28	0.44
Spain	-0.36	-0.25	–	0.77	0.86	–
Sweden	-0.10	0.21	0.51	0.74	0.78	0.71
Switzerland	0.13	0.25	–	0.16	0.73	–
United Kingdom	0.45	0.46	0.79	0.80	0.70	0.65
Median	**-0.10**	**0.16**	**0.28**	**0.45**	**0.70**	**0.56**
Average	-0.01	0.16	0.27	0.37	0.61	0.52

Notes: Data on consumption and investment are taken from the International Financial Statistics, IMF. Data on total hours worked come from Ohanian and Raffo (2012). Total hours is defined as (Empl*Hours)/(Pop*365*14). Consumption and investment are deflated using the country GDP deflator. All reported numbers are based on correlations from the logged, HP-filtered series (smoothing parameter of 1600) relative to the equivalent series for the United States.

Table F.3: Country-Level Correlations by Period: Quarterly Frequency

	Correlation of Country Real GDP with:					
	Real Exports	Real Imports	Real NX/GDP	Real Exports	Real Imports	Real NX/GDP
	1980-1995			1995-2010		
Australia	0.38	0.68	-0.43	-0.17	0.23	-0.40
Austria	0.52	0.46	-0.07	0.88	0.86	0.28
Belgium	0.52	0.58	-0.09	0.88	0.86	-0.24
Canada	0.77	0.80	-0.22	0.85	0.80	0.48
Denmark	-0.08	0.32	-0.62	0.84	0.89	-0.17
Finland	0.20	0.52	-0.37	0.85	0.83	0.33
France	0.51	0.64	-0.27	0.84	0.88	-0.54
Germany	0.12	0.63	-0.72	0.89	0.81	0.29
Italy	0.15	0.43	-0.35	0.96	0.91	-0.09
Japan	0.60	0.65	-0.36	0.89	0.86	0.11
Korea, Rep.	0.23	0.14	0.17	-0.34	0.49	-0.81
Netherlands	0.43	0.54	-0.23	0.77	0.80	0.17
Norway	0.14	0.48	-0.13	0.54	0.58	0.17
Spain	-0.01	0.51	-0.44	0.72	0.80	-0.74
Sweden	0.50	0.52	0.03	0.84	0.83	0.13
Switzerland	0.71	0.82	-0.55	0.92	0.86	0.29
United Kingdom	0.45	0.64	-0.53	0.38	0.50	-0.33
United States	0.35	0.80	-0.51	0.84	0.87	-0.74
Median	**0.41**	**0.56**	**-0.35**	**0.84**	**0.83**	**0.01**
Average	0.36	0.56	-0.32	0.69	0.76	-0.10

Source: International Financial Statistics, IMF.
Each series is deflated using the country GDP deflator. All reported numbers are based on correlations from the logged, HP-filtered (smoothing parameter of 1600) series.

F.1.2 Monthly Data

Data are taken from SourceOECD. We retain all countries in the OECD for which we have high-quality data going back to at least 1980. (Australia, Italy, Korea, and Switzerland do not report monthly industrial production to the OECD. There exists no information on monthly trade for Greece and Mexico.) We deflate the trade data using the relevant CPI index for each country. Correlations are based on series that have been logged, and HP-filtered using a smoothing parameter of 14,400.

Table F.4: Country-Level Correlations by Period: Monthly Frequency

Correlation of Country Real Industrial Production with U.S. Real Industrial Production		
	1980-1995	1995-2010
United States	1.00	1.00
Austria	0.26	0.71
Belgium	0.12	0.68
Canada	0.85	0.81
Denmark	0.10	0.51
Finland	0.24	0.78
France	0.17	0.86
Germany	0.10	0.78
Greece	0.08	0.45
Ireland	0.38	0.20
Japan	0.38	0.81
Luxembourg	0.30	0.65
Mexico	0.22	0.71
Netherlands	0.31	0.79
Norway	0.06	0.54
Portugal	-0.18	0.39
Spain	0.14	0.69
Sweden	0.26	0.83
United Kingdom	0.39	0.81
Median	**0.23**	**0.71**
Average	0.23	0.67

Source: OECD
All reported numbers are based on correlations from the logged, HP-filtered (smoothing parameter of 14,400) series, relative to the equivalent series for the United States.

Table F.5: Country-Level Correlations by Period: Monthly Frequency

Correlation with Country-Level Real Industrial Production		
	Real Exports	Real Imports
Austria	0.47	0.50
Belgium	0.42	0.49
Canada	0.53	0.37
Denmark	0.29	0.33
Finland	0.58	0.64
France	0.41	0.48
Germany	0.58	0.61
Greece	–	–
Ireland	0.24	0.16
Japan	0.75	0.76
Luxembourg	0.53	0.46
Mexico	–	–
Netherlands	0.56	0.58
Norway	0.27	0.40
Portugal	0.33	0.33
Spain	0.38	0.49
Sweden	0.58	0.60
United Kingdom	0.56	0.63
United States	0.64	0.69
Median	**0.53**	**0.49**
Average	0.48	0.50

Source: OECD.
Each series is deflated using the country CPI Index. All reported numbers are based on correlations from the logged, HP-filtered (smoothing parameter of 14,400) series.