Complementarities in Multinational Production and Business Cycle Dynamics*

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PRELIMINARY

Abstract

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 (2014), 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.

JEL Codes: F10, F12, F23, F41, F44

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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, Flaaen, and Pandalai-Nayar (2014)) 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

[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 A.

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 (2014) — 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 (1992)) 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 (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 co-movement 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

[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.

are accounted for separately. Moreover, Cravino and Levchenko (2014) document positive comovement 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 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.

2.1 Households

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

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

subject to

$$\rho_D^H\left(s^t\right)y^H\left(s^t\right)+\rho_X^F\left(s^t\right)y_X^F\left(s^t\right)+\rho_M^F\left(s^t\right)y_M^F\left(s^t\right)+I^H\left(s^t\right)+\sum_{s_{t+1}|s^t}q\left(s^t,s_{t+1}\right)b^H\left(s^t,s_{t+1}\right)$$
$$=w^H\left(s^t\right)L^H\left(s^t\right)+R^H\left(s^t\right)K^H\left(s^t\right)+b^H\left(s^t\right)+\Pi^H\left(s^t\right), \tag{2}$$

$$K^H\left(s^{t+1}\right)=(1-\delta)K^H\left(s^t\right)+I^H\left(s^t\right), \tag{3}$$

$$Y^H\left(s^t\right)=\left(\left(y_D^H\left(s^t\right)\right)^{\frac{\varepsilon-1}{\varepsilon}}+Z_X\left(\tau^{-1}y_X^F\left(s^t\right)\right)^{\frac{\varepsilon-1}{\varepsilon}}+Z_M\left(y_M^F\left(s^t\right)\right)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{4}$$

$$Y^H\left(s^t\right)=C^H\left(s^t\right)+I^H\left(s^t\right)+\Xi^H\left(s^t\right). \tag{5}$$

and a no-Ponzi game condition. Equation (2) is the household's budget constraint and (3) is the standard capital accumulation equation. Relationship (4) is a CES aggregator used to combine goods purchased from home domestic firms, foreign exporters, and foreign multinationals into the final good $Y^H\left(s^t\right)$ which, as equation (5) shows, is used for consumption, investment, as well as adjustment costs $\Xi^H\left(s^t\right)$ (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, $K^H\left(s^t\right)$ denotes the capital stock, $w^H\left(s^t\right)$ the real wage, $R^H\left(s^t\right)$ the real rental rate, and $q\left(s^t\right)$ 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 Firms

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

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

$$y_{D,t}^H = A_t^H \left(k_{D,t}^H\right)^\alpha \left(l_{D,t}^H\right)^{1-\alpha}, \tag{6}$$
$$y_{X,t}^H = A_t^H \left(k_{X,t}^H\right)^\alpha \left(l_{X,t}^H\right)^{1-\alpha}. \tag{7}$$

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

$$x_{\iota,t}^H = A_t^H \left(k_{\iota,t}^H\right)^\alpha \left(l_{\iota,t}^H\right)^{1-\alpha}. \tag{8}$$

and combined with an intermediate $A_t^F \left(k_{M,t}^H\right)^\alpha \left(l_{M,t}^H\right)^{1-\alpha}$ 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

$$y_{M,t}^H = \left(\mu^{\frac{1}{\psi}} \left(A_t^F \left(k_{M,t}^H\right)^\alpha \left(l_{M,t}^H\right)^{1-\alpha}\right)^{\frac{\psi-1}{\psi}} + (1-\mu)^{\frac{1}{\psi}} \left(\frac{y_{\iota,t}^H}{\tau}\right)^{\frac{\psi-1}{\psi}}\right)^{\frac{\psi}{\psi-1}}. \tag{9}$$

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, $l_{s,t}^H$ and $k_{s,t}^H$, $s \in \{D, X, M, \iota\}$, denote capital and labor. A_t^H (A_t^F) is the productivity of the home (foreign) country.

Domestic firms Perfectly competitive domestic firms choose $l_{D,t}^H$ and $k_{D,t}^H$ so as to maximize

$$E_0 \sum_{t=0}^{\infty} m_{0,t}^H \left\{\rho_{D,t}^H y_{D,t}^H - w_t^H l_{D,t}^H - R_t^H k_{D,t}^H - \xi_L\left(l_{D,t}^H, l_{D,t-1}^H\right) - \xi_K\left(k_{D,t}^H, k_{D,t-1}^H\right)\right\} \tag{10}$$

[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.

subject to equation (6). Here, $m_{0,t}^H$ denotes the stochastic discount factor and ξ_K and ξ_L are the firm-specific adjustment costs for capital and labor.

Exporters Exporting firms solve

$$\max_{l_{X,t}^H, k_{X,t}^H} E_0 \sum_{t=0}^{\infty} m_{0,t}^H \left\{ Q_t \rho_{X,t}^H y_{X,t}^H - w_t^H l_{X,t}^H - R_t^H k_{X,t}^H - \xi_L \left(l_{X,t}^H, l_{X,t-1}^H \right) - \xi_K \left(k_{X,t}^H, k_{X,t-1}^H \right) \right\} \quad (11)$$

subject to the equation (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 $l_{\iota,t}^H$ and rent capital $k_{\iota,t}^H$ to produce the intermediate $y_{\iota,t}^H$ which it sells to the foreign assembling firm. The affiliate abroad hires foreign labor $l_{M,t}^H$ at wage w_t^F, rents foreign capital $k_{M,t}^H$ at rental rate R_t^F and uses the intermediate $y_{\iota,t}^H$ (after paying transport costs τ). The home multinationals' optimization problem can be conveniently broken into two parts. In the source country they solve

$$\max_{l_{\iota,t}^H, k_{\iota,t}^H} E_0 \sum_{t=0}^{\infty} m_{0,t}^H \left\{ Q_t \rho_{\iota,t}^H y_{\iota,t}^H - w_t^H l_{\iota,t}^H - R_t^H k_{\iota,t}^H - \xi_L \left(l_{\iota,t}^H, l_{\iota,t-1}^H \right) - \xi_K \left(k_{\iota,t}^H, k_{\iota,t-1}^H \right) \right\} \quad (12)$$

subject to equation (8). Similarly, in the destination country they solve

$$\max_{l_{M,t}^H, k_{M,t}^H} E_0 \sum_{t=0}^{\infty} m_{0,t}^H Q_t \left\{ \rho_{M,t}^H y_{M,t}^H - w_t^F l_{M,t}^H - R_t^F k_{M,t}^H - \rho_{\iota,t}^H y_{\iota,t}^H - \xi_L \left(l_{M,t}^H, l_{M,t-1}^H \right) - \xi_K \left(k_{M,t}^H, k_{M,t-1}^H \right) \right\} \quad (13)$$

subject to equation (9).

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

$$\begin{pmatrix} A_t^H \\ A_t^F \end{pmatrix} = \begin{pmatrix} \varrho^H & a_H^F \\ a_F^H & \varrho^F \end{pmatrix} \begin{pmatrix} A_{t-1}^H \\ A_{t-1}^F \end{pmatrix} + \begin{pmatrix} \varepsilon_t^H \\ \varepsilon_t^F \end{pmatrix}, \quad (14)$$

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_H^F and a_F^H. Furthermore, simultaneous innovations can be captured in the covariance matrix of $\left(\varepsilon_t^H, \varepsilon_t^F\right)$.

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

$$\Xi_t^H = \sum_{s \in \{D,X,\iota\}} \left[\xi_L\left(l_{s,t}^H, l_{s,t-1}^H\right) + \xi_K\left(l_{s,t}^H, l_{s,t-1}^H\right)\right] + \xi_L\left(l_{M,t}^F, l_{M,t-1}^F\right) + \xi_K\left(l_{M,t}^F, l_{M,t-1}^F\right), \qquad (15)$$

which enters the material balance (5). To complete the model, we state the market clearing conditions. Labor and capital market clearing in the home country require that

$$L_t^H = l_{D,t}^H + l_{X,t}^H + l_{\iota,t}^H + l_{M,t}^F \qquad (16)$$

and

$$K_{t-1}^H = k_{D,t}^H + k_{X,t}^H + k_{\iota,t}^H + k_{M,t}^F. \qquad (17)$$

Finally, the bond market clearing condition is

$$b_t^H + b_t^F = 0. \qquad (18)$$

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 $C^i(\Omega_t)$, $L^i(\Omega_t)$, $I^i(\Omega_t)$, $Y^i(\Omega_t)$, $y_s^i(\Omega_t)$, $s \in \{D, X, \iota, M\}$, firms' factor inputs $l_s^i(\Omega_t)$, $k_s^i(\Omega_t)$, $s \in \{D, X, \iota, M\}$, goods prices $\rho_s^i(\Omega_t)$, $s \in \{D, X, \iota, M\}$, wages $w^i(\Omega_t)$, rental rates $R^i(\Omega_t)$, and a real exchange rate $Q(\Omega_t)$ such that the following conditions are satisfied.

1. Taking prices as given, $C^i(\Omega_t)$, $L^i(\Omega_t)$, $I^i(\Omega_t)$, $Y^i(\Omega_t)$, $y_s^i(\Omega_t)$, $s \in \{D, X, \iota, M\}$ solve the household's problem as described in equations (1) to (5).

2. Taking prices as given, $l_s^i(\Omega_t)$, $k_s^i(\Omega_t)$, $s \in \{D, X, \iota, M\}$ solves the firms' optimization problems as described in (10) to (13) subject to the respective production functions (6) to (9).

3. All markets clear, that is, equations (15) to (18) hold.

4. The exogenous process for the evolution of technology is given in (14).

The next section discusses the calibration.

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 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 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 ($\varepsilon^H,\ \varepsilon^F$) is set to that used in Backus, Kehoe, and Kydland (1992) (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 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 (2014) 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 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 (2014) for details).

The production elasticity of substitution ψ is a critical parameter in governing the 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 (2014)) 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

[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).

specifications

$$\xi_L\left(l_{s,t}^i, l_{s,t-1}^i\right) = \frac{\zeta^L}{2} l_{s,t-1}^i \left(\frac{l_{s,t}^i}{l_{s,t-1}^i} - 1\right)^2, \; \xi_K\left(k_{s,t}^i, k_{s,t-1}^i\right) = \frac{\zeta^K}{2} k_{s,t-1}^i \left(\frac{k_{s,t}^i}{k_{s,t-1}^i} - 1\right)^2 \tag{19}$$

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.

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.

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 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 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 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 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).

[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.

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 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 3 and Figure 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 4 illustrates the strength of spillovers to home GDP across the various versions of the model discussed in the paper.

4.3 Capturing Firm Behavior following the Tōhoku Earthquake

Upon comparing Figures 2 and 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 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 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).

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.

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

[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

$$\tilde{A}_t^H + \alpha\tilde{l}_{M,t}^F + (1-\alpha)\,\tilde{k}_{M,t}^F = \tilde{y}_{\iota,t}^F. \tag{20}$$

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.

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.

References

Ambler, Steve, Emanuela Cardia, and Christian Zimmerman. 2002. "International Transmission of the Business Cycle in a Multi-Sector Model." *European Economic Review* 46 (2):273–300.

Arkolakis, Costas and Ananth Ramanarayanan. 2009. "Vertical Specialization and International Business Cycle Synchronization." *Scandinavian Journal of Economics* 111 (4):655–680.

Backus, David K., Patrick J. Kehoe, and Finn E. Kydland. 1992. "International Real Business Cycles." *Journal of Political Economy* 100 (4):745–775.

Baxter, Marianne and Mario J. Crucini. 1995. "Business Cycles and the Asset Structure of Foreign Trade." *International Economic Review* 36 (4):821–854.

Bems, Rudolf and Robert C. Johnson. 2014. "International Prices and Demand for Value Added with Global Supply Chains." Working paper.

Blasnik, Michael. 2010. "RECLINK: A Stata Module to Probabilistically Match Records." Working paper.

Bloom, Nicholas. 2009. "The Impact of Uncertainty Shocks." *Econometrica* 77 (3):623–685.

Boehm, Christoph, Aaron Flaaen, and Nitya Pandalai-Nayar. 2014. "Input Linkages and the Transmission of Shocks: Firm Level Evidence from the 2011 Tōhoku Earthquake." Working paper, University of Michigan.

Burstein, Ariel, Christopher Kurz, and Linda Tesar. 2008. "International Trade, Production Sharing and the Transmission of Business Cycles." *Journal of Monetary Economics* 44 (4):775–795.

Cravino, Javier and Andrei Levchenko. 2014. "Multinational Firms and International Business Cycle Transmission." Working paper, University of Michigan.

di Giovanni, Julian and Andrei Levchenko. 2010. "Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement." *American Economic Journal: Macroeconomics* 1 (1):95–124.

Engel, Charles and Jian Wang. 2011. "International Trade in Durable Goods: Understanding Volatility, Cyclicality, and Elasticities." *Journal of International Economics* 83 (1):37–52.

Flaaen, Aaron. 2013a. "Constructing a Bridge Between the LexisNexis Directory of Corporate Affiliations and the U.S. Business Register." Working paper, University of Michigan.

———. 2013b. "Multinational Firms in Context." Working paper, University of Michigan.

Frankel, Jeffrey A. and Andrew K. Rose. 1998. "The Endogeneity of the Optimum Currency Area Criteria." *Economic Journal* 108 (449):1009–1025.

Heathcote, Jonathan and Fabrizio Perri. 2002. “Financial Autarky and International Business Cycles.” *Journal of Monetary Economics* 49:601–627.

Imbs, Jean. 2004. “Trade, Finance, Specialization, and Synchronization.” *Review of Economics and Statistics* 86 (3):723–734.

Johnson, Robert C. 2014. “Trade in Intermediate Inputs and Business Cycle Comovement.” *American Economic Journal: Macroeconomics* 6 (4):39–83.

Kleinert, Jörn, Julien Martin, and Farid Toubal. 2014. “The Few Leading the Many: Foreign Affiliates and Business Cycle Comovement.” *American Economic Journal: Macroeconomics* forthcoming.

Kose, M. Ayhan and Kei-Mu Yi. 2006. “Can the Standard International Business Cycle Model Explain the Relation Between Trade and Comovement?” *Journal of International Economics* 68:267–295.

Ohanian, Lee E. and Andrea Raffo. 2012. “Aggregate Hours Worked in OECD Countries: New Measurement and Implications for Business Cycles.” *Journal of Monetary Economics* 59:40–56.

Peek, Joe and Eric S. Rosengren. 1997. “The International Transmission of Financial Shocks: The Case of Japan.” *American Economic Review* 87 (4):495–505.

———. 2000. “Collateral Damage: Effects of the Japanese Bank Crisis on Real Activity in the United States.” *American Economic Review* 90 (1):30–45.

Pierce, Justin and Peter Schott. 2012. “A Concordance Between U.S. Harmonized System Codes and SIC/NAICS Product Classes and Industries.” *Journal of Economic and Social Measurement* 37 (1-2):61–96.

Wasi, Nada and Aaron Flaaen. 2014. “Record Linkage Using Stata: Pre-Processing, Linking and Reviewing Utilities.” Working paper, University of Michigan.

Table 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 (1992), modified for a monthly frequency, unless specified otherwise in the text. The baseline value for ψ is taken from Boehm, Flaaen, and Pandalai-Nayar (2014). 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: 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 A. 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.

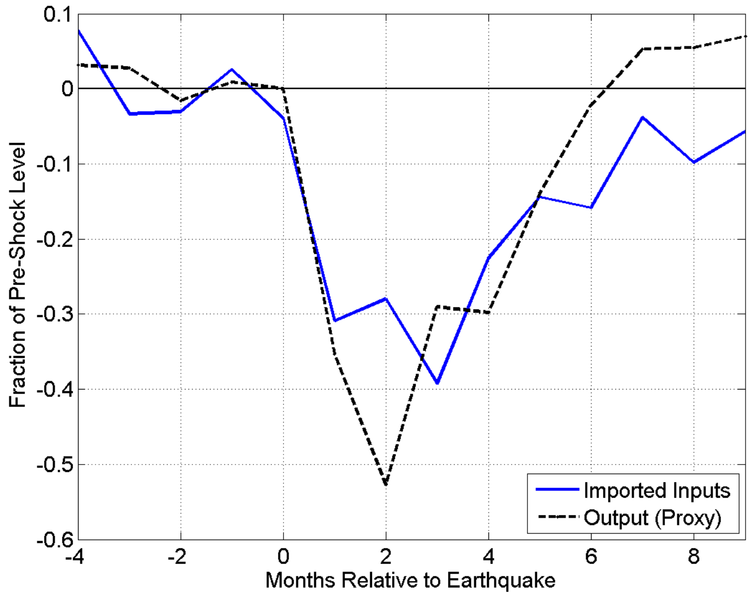
[1]Monthly data for GDP corresponds to gross output, rather than value-added.

Table 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 1: Relative Imported Inputs and Output (Proxy) of Japanese Firms: Fraction of Pre-Shock Level



Source: Boehm, Flaaen, and Pandalai-Nayar (2014).
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 (2014) for details.

Figure 2: Impulse Response: Negative TFP Shock in Home: Baseline Model

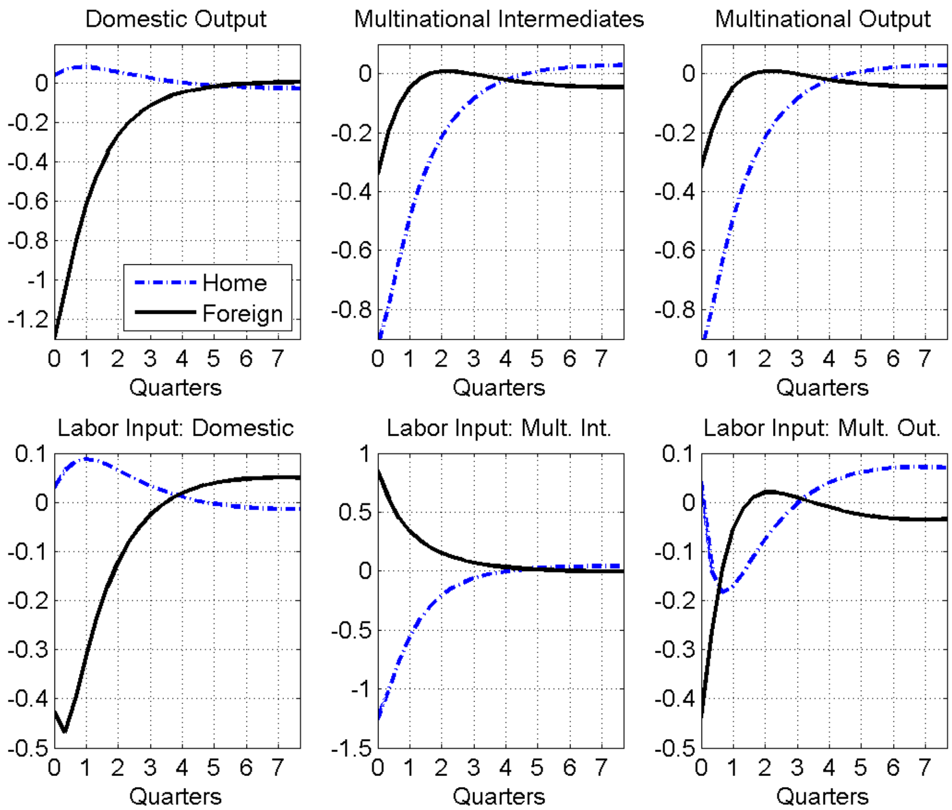


Figure 3: Impulse Response: Negative TFP Shock in Home: No Adjustment Costs Model

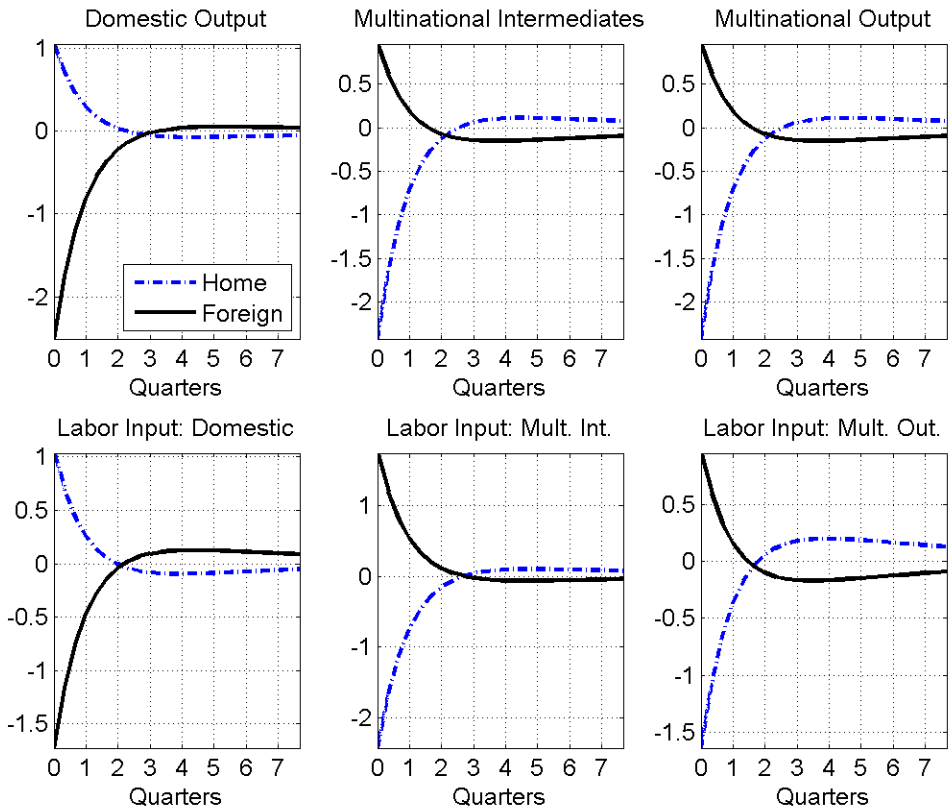


Figure 4: Impulse Response: Home Country Spillovers Following Shock in Foreign

GDP (Value-Added) in Home by Model Type

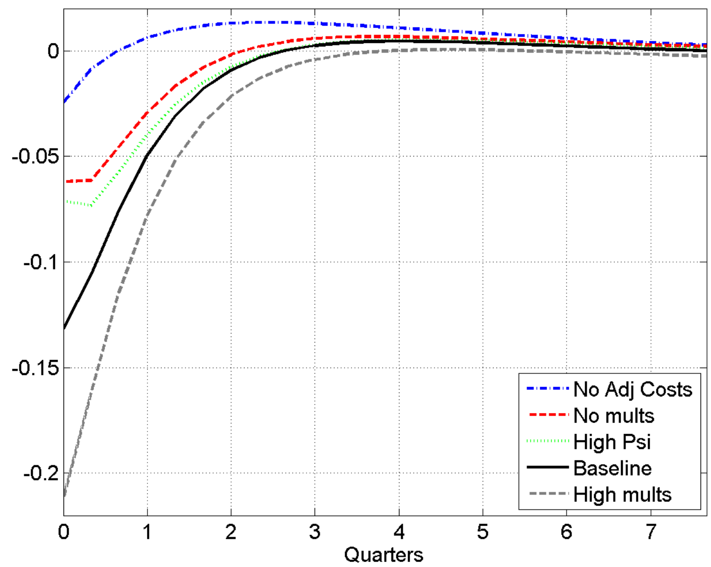
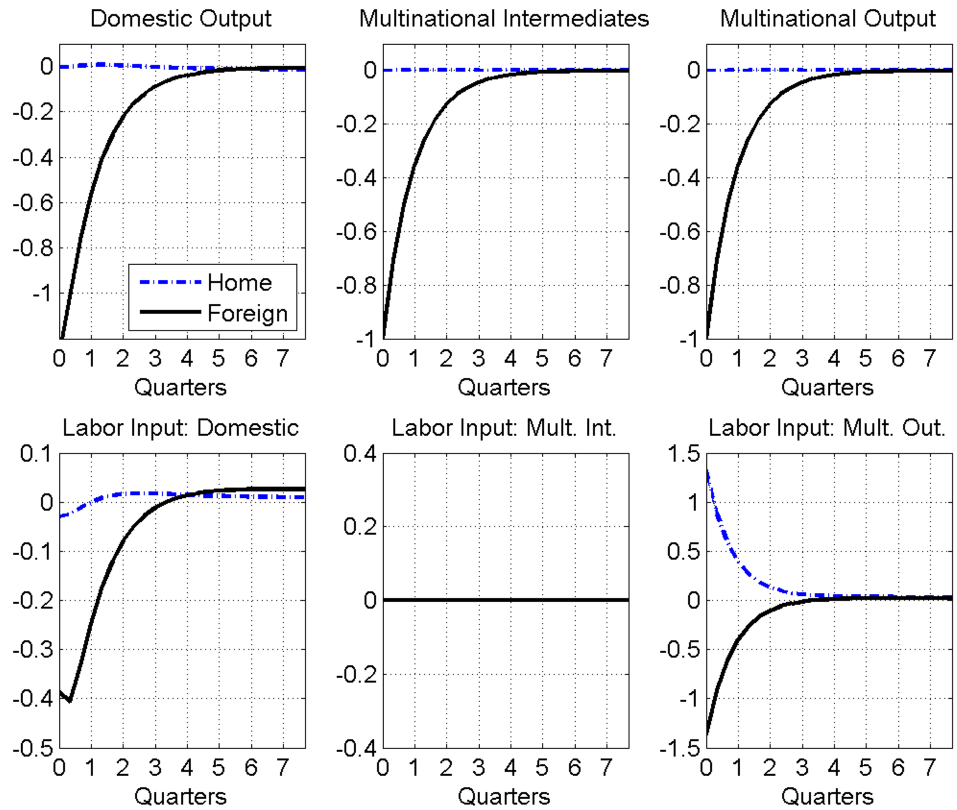


Figure 5: Impulse Response: Negative TFP Shock in Home: Infinite Adjustment Costs in Intermediate Production



A Data Appendix: Country-Level Correlations

A.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 A1: Country-Level Correlations by Period: Quarterly Frequency

	Correlation of Country Real GDP with:			
Country	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 A2: Country-Level Correlations by Period: Quarterly Frequency

	Correlation of Country-Level Variable with Equivalent U.S. Variable:					
	Real Consumption	Real Investment	Total Hours	Real Consumption	Real Investment	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 A3: 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.

A.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 A4: 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.

B Data Appendix: Census Data Supplements

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.

Table A5: 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.

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.[8] 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

[8]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.

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.

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.[9]

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 A6 for a summary of the establishment-level match rate statistics by year and type of firm. Table A7 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.[10]

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

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

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

DCA-based multinational indicators and aggregating to the (Census-based) firm level. There are three potential cases:[11]

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

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.

B.2 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.[12] Disentangling whether an imported product is used as an

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

[12] 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).

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.[13] 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.

B.2.1 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.

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:

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

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

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 A8 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.[14] 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.

B.2.2 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

[14] 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.

(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. [15] 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:

$$\left.\begin{aligned} M_{ij}^{\text{int}} &= \sum_{p \notin P_j} M_{ipj} \\ M_{ij}^{\text{fin}} &= \sum_{p \in P_j} M_{ipj} \end{aligned}\right\} \qquad \text{where} \qquad P_j = \{p \mid S_{pj} \geq W\}\,. \tag{A1}$$

The bottom section of Table A8 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.

[15] 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.

Table A6: 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 A7: 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.

Table A8: 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