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Trade and the Global Recession

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Abstract

The ratio of global trade to GDP declined by nearly 1/3 during the global recession of 2008-2009. This large drop in international trade has generated significant attention and concern. Given the severity of the recession, did international trade behave as we would have expected? Or alternatively, did international trade shrink due to factors unique to cross border transactions per se? This paper merges an input-output framework with a gravity trade model and solves numerically several counterfactual scenarios which give a quantitative sense for the relative importance of changes in demand, trade frictions, and other shocks in the current recession. Our results suggest that the decline in demand for manufactures was the most important driver of the decline in manufacturing trade. Changes in demand for durable manufactures alone accounted for more than 60 percent of the cross-country variation in changes in manufacturing trade/GDP. The decline in total manufacturing demand (durables and non-durables) accounted for about 70 percent of the global decline in trade/GDP. Increasing trade frictions played an important role in some countries and were insignificant in others. Globally, changing trade frictions explained about 15 percent of the decline in manufacturing trade/GDP.

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1 Introduction

According to the World Trade Organization, the value of global merchandise trade in 2009 contracted by 23 percent, four times the size of the second largest annual percentage drop since World War II. Peak to trough, estimates suggest that the ratio of global trade to GDP declined by nearly 1/3.[1] The four panels of Figure 1 plot the average of imports and exports relative to GDP for the four largest countries in the world: U.S. Japan, China, and Germany. Trade to GDP ratios sharply declined in the recent recession in each of these economies. This large drop in international trade has generated significant attention and concern, even against a backdrop of plunging final demand and collapsed asset prices.

For example, Eichengreen (2009) writes, “The collapse of trade since the summer of 2008 has been absolutely terrifying, more so insofar as we lack an adequate understanding of its causes.” *International Economy* (2009) asks in its symposium on the collapse, "World trade has been falling faster than global GDP – indeed, faster than at any time since the Great Depression. How is this possible?" Dozens of researchers posed hypotheses in Baldwin (2009), a timely and insightful collection of short essays aimed at the policy community and titled, "The Great Trade Collapse: Causes, Consequences and Prospects."

What is at stake in determining the culprit? Imagine that nothing unique to cross-border trade occurred. In such a scenario, trade flows would have declined from France to the U.S. just as there was a decline in flows from Ohio to Florida. Put differently, given the severity of the recession, international trade would have behaved as expected. In this version of events, international trade data could only contribute to our understanding of the cross-country transmission, but not the amplification, of the recent global recession.

Now, instead, imagine that an increase in international trade frictions, such as the reduced availability of trade credit or protectionist measures, were largely to blame for the decline in trade flows in the recent episode. In this scenario, in addition to the initial shock that led to a decline in

[1] The global trade index was obtained by multiplying the world trade volume index by the world trade price index available from the Netherlands Bureau for Economic Policy Analysis. This index was divided by interpolations of the world GDP series from the IMF's World Economic Outlook.

final demand, there would be negative effects from the higher prices of imported goods. The decline in international trade would be crucial to understanding the mechanics and welfare consequences of the recent recession.

This paper aims to quantitatively determine the relative contributions of these explanations, both globally and at the country level. Our [preliminary] conclusion is that the bulk of the decline in international trade is attributable to the decline in demand for tradables. Changes in demand for durable manufactures alone accounted for more than 60 percent of the cross-country variation in changes in manufacturing trade/GDP. The decline in total manufacturing demand (durables and non-durables) accounted for about 70 percent of the global decline in trade/GDP.

The total decline in trade, however, did exceed what one would expect simply from the changing patterns of demand. Hence, increasing trade frictions reflected an independent contribution to the troubles facing the global economy and played an important role in some countries, particularly in Asia. Globally, changing trade frictions explained about 15 percent of the decline in manufacturing trade/GDP. The scale of this decline, while not insignificant, is far from unprecedented: when we compare these findings to calculations done on data from the Great Depression, we find that our framework implies a far more dramatic increase in trade frictions in the early 1930s.

The spirit of our exercise is similar to that of growth accounting. One might also think of it as an analog for international trade to the "wedges" approach for business cycle accounting in Chari, Kehoe, and McGratten (2007). Just as growth accounting builds and uses a theoretical framework to decompose output growth into the growth of labor and capital inputs as well as a Solow residual term, we build and use our model to decompose changes in trade flows into changes in several factors like demand, deficits, and productivity, as well as changes in trade frictions. Closer to Chari, Kehoe, and McGratten, however, our decomposition relies on a model-based general equilibrium response to various shocks.

Our analytic tool is a multi-sector model of production and trade, calibrated to detailed global data from recent quarters. We run counterfactuals to determine what the path of trade would have been without the collapse in demand in each manufacturing sector and without the increase in

trade frictions. The model further allows us to consider changes occurring only in single countries or groups of countries. For example, the decline in durables demand in the United States alone reduced global manufacturing trade/GDP by about 2 percent, including a drop in its own manufacturing trade/GDP of about 10 percent and a corresponding 4 percent drop in Mexico. Additionally, the increase in trade frictions seen in China and Japan, two of the few countries where we estimate these increases to be large, reduced global manufacturing trade/GDP by about 3 percent. One impact of this was to deflect trade to South Korea, whose trade flows declined by less than its GDP.

In theory, the goal of our exercise is simple: we wish to tie the decline in final demand for tradable goods to the decline in trade flows in the recent global recession. So why is this exercise difficult in practice? There are three reasons: (1) countries have different input-output structures tying trade and production flows to final demand; (2) the country-level accounting must be consistent with changing patterns in bilateral trade flows; and (3) high frequency data are needed.

First, to see the difficulty imposed by heterogenous input-output structures, imagine a country that produces final goods without any intermediate inputs. In such a case, any change in dollars of gross production and net imports must equal the change in dollars of final demand. Another country that uses inputs in production might require a dramatically larger change in gross production and net imports to support the same dollar decline in final demand. Relatedly, if one country uses disproportionately more non-tradable intermediates in its production of tradable final goods, then the same dollar decline in final tradables demand would imply, all things equal, a disproportionately smaller decline in net imports. We solve this first problem by building a multi-sector model with a global input-output structure. Guided by results such as Engel and Wang (2009) and Lewis, Levchenko, and Tesar (2009) that stress the different cyclical properties of durables and non-durables (generally as well as during the recent recession), we define our sectors as durable manufacturing, non-durable manufacturing, and non-manufacturing. Output from each sector is combined with labor to produce both final goods and additional intermediate inputs in each sector. Output elasticities are taken from country-specific input-output tables.

Second, any explanation of the decline in trade must be consistent with observed patterns of bilateral trade flows. For example, one cannot "explain" a \$1 decline in exports from country A with a \$1 decline in tradable consumption in country B unless there is also a decline in trade from A to B. We solve this second problem by merging our global input-output structure with a gravity model of bilateral trade.

Third, one needs high frequency data to answer this question. The decline in trade steepened in the summer of 2008, and reversed sometime in mid-to-late 2009. Annual data would likely miss the key dynamics of the episode (and complete data for 2009 are just now starting to become available). Quarterly data would be more useful, but would still suffer from the problem that quarterly totals translated at an average exchange rate into U.S. dollars (or any common units) may differ markedly from the quarterly sum of monthly totals translated at monthly exchange rates. We solve this third problem using a procedure called "temporal disaggregation" whereby we extrapolate monthly production values from annual totals using information contained in monthly industrial production (IP) and producer price (PPI) indices, both widely available for many countries.

We calibrate our multi-country general equilibrium model to fully account for changes in macroeconomic and trade variables from the first quarter of 2008 to the first quarter of 2009. We focus on trade in the durable and non-durable manufacturing sectors. To quantify the impact of global or country-specific shocks on trade flows in our model, we run counterfactual scenarios and correlate these outcomes with what was actually observed in the data.

2 Trade Decline: Hypotheses

The shorter pieces mentioned above and other academic papers have generated several potential explanations for the decline in trade flows relative to overall economic activity. Levchenko, Lewis, and Tesar (2009), for example, uses U.S. data to show that the decline in trade is unusual relative to previous recessions. They find evidence suggesting a relative decline in demand for tradables, particularly durable goods.

Given that many economies' banking systems have been in crisis, another credible hypothesis

is that a collapse in trade credit is in large part to blame for the breakdown in trade. Amiti and Weinstein (2009) demonstrates with earlier data that the health of Japanese firms' banks significantly affected the firms' trading volumes, presumably through their role in issuing trade credit. Using U.S. trade data during the recent episode, Chor and Manova (2009) show that sectors requiring greater financing saw a greater decline in trade volume. McKinnon (2009) and Bhagwati (2009) also focus on the import of reduced trade credit availability for explaining the recent trade collapse.

In addition to the negative shock to trade credit availability, there are other explanations that suggest something unique is happening to international trade, per se. For example, there are unsettling signals that protectionist measures have and may continue to exert an extra drag on trade.[2] Brock (2009) writes, "...many political leaders find the old habits of protectionism irresistible ... This, then, is a large part of the answer to the question as to why world trade has been collapsing faster than world GDP." Another hypothesis is that, since trade flows are measured in gross rather than value added terms, a disintegration of international vertical supply chains may be driving the decline.[3] In addition, dynamics associated with the inventory cycle may be generating disproportionately severe contractions in trade as in Alessandria, Kaboski, and Midrigan (2009, 2010). All of these potential disruptions can be broadly construed as reflecting trade frictions.

Results such as Levchenko et al. and Chor and Manova only analyze U.S. data in partial equilibrium, but are able to use highly disaggregated data which allow for clean identification of various affects. We view our work as complementary to these U.S.-based empirical studies. Our framework has the benefit of being able to quantitatively evaluate hypotheses for the trade decline in a multi-country general equilibrium model.

[2] See www.globaltradealert.org for real-time tracking of protectionist measures implemented during the recent global downturn.

[3] Eichengreen (2009) writes, "The most important factor is probably the growth of global supply chains, which has magnified the impact of declining final demand on trade," and a similar hypothesis is found in Yi (2009).

3 A Framework to Analyze the Global Recession

We now turn to our general equilibrium framework, which builds upon the models of Eaton and Kortum (2002), Lucas and Alvarez (2008), and Dekle, Eaton, and Kortum (2008). Our setup is most closely related to recent work by Caliendo and Parro (2009), which uses a multi-sector generalization of these models to study the impact of NAFTA.[4] Our paper is also related to Bems, Johnson, and Yi (2010), which uses the input-output framework of Johnson and Noguera (2009) to link changes in final demand across many countries during the recent global recession to changes in trade flows throughout the global system. One crucial difference is that we endogenize changes in bilateral trade shares, an important feature to match the recent experience.

We start by describing the input-output structure. Next, we merge this with trade share equations from the class of gravity models.

3.1 Demand and Input-Output Structure

Consider a world of $i = 1, \ldots, I$ countries with constant return to scale production and perfectly competitive markets. There are three sectors j: durable manufacturing, non-durable manufacturing, and non-manufacturing. We refer to these categories with the letters D, N, and S. The variable S was chosen because "services" are a large share of non-manufacturing, though this category also includes petroleum and other raw materials. We let $\Omega = \{D, N, S\}$ denote all sectors and $\Omega_M = \{D, N\}$ the manufacturing sectors.

We only model international trade explicitly for the manufacturing sectors. Net trade in raw materials (themselves not manufactures) is exogenous in our framework. Within manufactures, we distinguish between durables and non-durables because these two groups have been characterized by shocks of different sizes, as noted in Levchenko, Lewis, and Tesar (2009).

Let Y_i^j denote country i's gross production in sector $j \in \Omega$. Country i's gross absorption of j is

[4] Their model contains significantly more sectors and input-output linkages, but unlike our work, does not seek to "account" for changes in trade patterns with various shocks.

X_i^j and $D_i^j = X_i^j - Y_i^j$ is its deficit in sector j. The overall deficit is:

$$D_i = \sum_{j \in \Omega} D_i^j,$$

while, for each $j \in \Omega$,

$$\sum_{i=1}^{I} D_i^j = 0.$$

Denoting GDP by Y_i, aggregate spending is $X_i = Y_i + D_i$. The relationship between GDP and sectoral gross outputs depends on the input-output structure, to which we now turn.

Sector outputs are used both as inputs into production and also to satisfy final demand. This round-about production structure can be modeled as a Cobb-Douglas production function. Value-added is a share β_i^j of gross production in sector j of country i, while γ_i^{jl} denotes the share of sector l in the production of intermediates for sector j, with $\sum_l \gamma_i^{jl} = 1$ for each $j \in \Omega$. We assume these parameters are fixed for each country over time, and we offer empirical support for this assumption below.

We can now express GDP as the sum of sectoral value added:

$$Y_i = \sum_{j \in \Omega} \beta_i^j Y_i^j. \tag{1}$$

We ignore capital and treat labor as perfectly mobile across sectors so that:

$$Y_i = \sum_{j \in \Omega} w_i L_i^j = w_i L_i.$$

Finally, we denote by α_i^j the share of sector j consumption in country i's aggregate final demand, so that the total demand for sector j in country i is:

$$X_i^j = \alpha_i^j X_i + \sum_{l \in \Omega} \gamma_i^{lj} (1 - \beta_i^l) Y_i^l. \tag{2}$$

To interpret (2), consider the case of durables manufacturing, $j = D$. The first term represents

the final demand for durables manufacturing as a share of total final absorption X_i. A disproportionate drop in final spending on automobiles, trucks, and tractors in country i can be captured by a decline in α_i^D. Some autos, trucks, and tractors, however, are used as inputs to make additional durable manufactures, non-durable manufactures, and even services. The demand for durable manufactures as intermediate inputs for those sectors is represented by the second term of (2). The sum of these two terms – demand for durable manufactures as final consumption and demand for durables manufactures as intermediates – generates the total demand for durable manufactures in country i, X_i^D.

It is helpful to define the 3-by-3 matrix $\mathbf{\Gamma}_i$ of input-output coefficients, with $\gamma_i^{lj}(1-\beta_i^l)$ in the l'th row and j'th column, where we've ordered the sectors as D, N, and S. We can now stack equations (2) for each value of j and write the linear system:

$$\mathbf{X}_i = \mathbf{Y}_i + \mathbf{D}_i = \boldsymbol{\alpha}_i X_i + \mathbf{\Gamma}_i^T \mathbf{Y}_i, \tag{3}$$

where $\mathbf{\Gamma}_i^T$ is the transpose of $\mathbf{\Gamma}_i$ and the boldface variables $\mathbf{X}_i$, $\mathbf{Y}_i$, $\mathbf{D}_i$, and $\boldsymbol{\alpha}_i$ are 3-by-1 vectors, with each element containing the corresponding variable for sectors D, N, and S. We can thus express production in each sector as:

$$\mathbf{Y}_i = \left(\mathbf{I} - \mathbf{\Gamma}_i^T\right)^{-1}\left(\boldsymbol{\alpha}_i X_i - \mathbf{D}_i\right). \tag{4}$$

Through the input-output structure, production in each sector depends on the entire vector of final demands across sectors, net of the vector of sectoral trade deficits.

The input-output structure also has implications for the cost of production in different sectors. We first consider the cost of inputs for each sector and then introduce a model of sectoral productivity, that, in turn, determines sectoral price levels and trade patterns for durable and non-durable manufactures.

For now we take wages w_i and sectoral prices, p_i^l for $l \in \Omega$, as given. Labor and intermediates are aggregated in a Cobb-Douglas production function for input bundles used to produce sector j

output.[5] The minimized cost of a bundle of inputs used by sector $j \in \Omega$ producers is thus:

$$c_i^j = w_i^{\beta_i^j} \prod_{l \in \Omega} \left(p_i^l\right)^{\gamma_i^{jl}(1-\beta_i^j)}. \tag{5}$$

As noted above, we do not explicitly model trade in sector S. Instead we simply specify productivity for that sector as a_i^S so that $p_i^S = c_i^S / a_i^S$. Taking into account round-about production we get:

$$p_i^S = \left(\frac{1}{a_i^S} w_i^{\beta_i^S} \prod_{l \in \Omega_M} \left(p_i^l\right)^{\gamma_i^{Sl}(1-\beta_i^S)} \right)^{\frac{1}{1-\gamma_i^{SS}(1-\beta_i^S)}}.$$

We can substitute this expression for the price of services back into the cost functions expressions (5) for $j \in \Omega_M$. We are essentially looking at the manufacturing sectors as if they had integrated the production of all service-sector intermediates into their operations. After some algebra we can write the resulting expression for the cost of an input bundle in a way that brings out the parallels to (5):

$$c_i^j = \frac{1}{a_i^{jS}} w_i^{\widetilde{\beta}_i^j} \prod_{l \in \Omega_M} \left(p_i^l\right)^{\widetilde{\gamma}_i^{jl}(1-\widetilde{\beta}_i^j)}, \tag{6}$$

for $j \in \Omega_M$. Here, the productivity term is

$$a_i^{jS} = \left(a_i^S\right)^{\gamma_i^{jS}(1-\beta_i^j)/[1-\gamma_i^{SS}(1-\beta_i^S)]},$$

while the input-output parameters become

$$\widetilde{\beta}_i^j = \beta_i^j + \frac{\gamma_i^{jS}(1-\beta_i^j)\beta_i^S}{1-\gamma_i^{SS}(1-\beta_i^S)},$$

[5] To avoid uninteresting constants in the cost functions that follow, we specify this Cobb-Douglas function as:

$$B_i^j = \left(\beta_i^j l_i^j\right)^{\beta_i^j} \prod_{k \in \Omega} \left(\left[\gamma_i^{jk}(1-\beta_i^j)\right] y_i^{jk} \right)^{\gamma_i^{jk}(1-\beta_i^j)},$$

where B_i^j are sector-j input bundles, l_i^j is labor input in sector j, and y_i^{jk} is sector-k intermediate input used in sector-j production. We later introduce country-by-industry specific productivity terms that absorb any economic implications of this parameterization.

and

$$\widetilde{\gamma}_i^{jl} = \gamma_i^{jl} + \gamma_i^{jS} \frac{\gamma_i^{Sl}(1-\beta_i^S) + \gamma_i^{jl}\beta_i^S}{1-\gamma_i^{SS}(1-\beta_i^S) - \gamma_i^{jS}\beta_i^S}.$$

The term a_i^{jS} captures the pecuniary spillover from service-sector productivity to sector j costs. The parameter $\widetilde{\beta}_i^j$ is the share of value added used directly in sector j as well as the value added embodied in service-sector intermediates used by sector j. The share of manufacturing intermediates is $1-\widetilde{\beta}_i^j$, with $\widetilde{\gamma}_i^{jl}$ representing the share of manufacturing sector l intermediates among those used by sector j (again with production of service-sector inputs integrated into these manufacturing sectors). As expected,

$$\sum_{l\in\Omega_M} \widetilde{\gamma}_i^{jl} = 1.$$

3.2 International Trade

Any country's production in each sector $j \in \Omega_M$ must be absorbed by demand from other countries or from itself. Define π_{ni}^j as the share of country n's expenditures on goods in sector j purchased from country i. Thus, we require:

$$Y_i^j = \sum_{n=1}^{I} \pi_{ni}^j X_n^j. \tag{7}$$

To complete the picture, we next detail the production technology across countries, which leads to an expression for trade shares.

Durable and non-durable manufactures consist of disjoint unit measures of differentiated goods, indexed by z^j.[6] We denote country i's efficiency making good z^j in sector j as $a_i^j(z^j)$. The cost of producing good z^j in sector j in country i is thus $c_i^j/a_i^j(z^j)$, where c_i^j is the cost of an input bundle, given by (6).

With the standard "iceberg" assumption about trade, delivering one unit of a good in sector j from country i to country n requires shipping $d_{ni}^j \geq 1$ units, with $d_{ii}^j = 1$ for all $j \in \Omega_M$. Thus, a

[6] We put a sector specific superscript on the index to make it clear that there is no connection between goods in different sectors that happen to have the same index. On the other hand, goods from different countries in the same sector with the same index are perfect substitutes.

unit of good z^j in sector j in country n from country i costs:

$$p_{ni}^j(z^j) = c_i^j d_{ni}^j / a_i^j(z^j).$$

Country i's efficiency $a_i^j(z^j)$ in making good z^j in sector j can be treated as a random variable with distribution: $F_i^j(a) = \Pr[a_i^j(z^j) \leq a] = e^{-T_i^j a^{-\theta^j}}$, which is drawn independently across i and j. Here $T_i^j > 0$ is a parameter that reflects country i's overall efficiency in producing any good in sector j and θ^j is an inverse measure of the dispersion of efficiencies. The implied distribution of $p_{ni}^j(z^j)$ is:

$$\Pr[p_{ni}^j(z^j) \leq p] = \Pr\left[a_i^j(z^j) \geq \frac{c_i^j d_{ni}^j}{p}\right] = 1 - e^{-T_i^j (c_i^j d_{ni}^j)^{-\theta^j} p^{\theta^j}}.$$

Buyers in destination n buy each manufacturing good z^j in sectors $j \in \Omega_M$ from the cheapest source. We assume that the individual manufacturing goods, whether used as intermediates or in final demand, combine with constant elasticity $\sigma^j > 0$.

As detailed in Eaton and Kortum (2002), we then compute the price index by integrating over the prices of individual goods to get:

$$p_n^j = \varphi^j \left[\sum_{i=1}^{I} T_i^j \left(c_i^j d_{ni}^j\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{8}$$

where φ^j is a function of θ^j and σ^j, requiring $\theta^j > (\sigma^j - 1)$. Substituting (6) into (8), we get:

$$p_n^j = \varphi^j \left[\sum_{i=1}^{I} A_i^j \left(w_i^{\beta_i^j} \left(p_i^j\right)^{\gamma_i^{jj} \; 1-\beta_i^j} \left(p_i^l\right)^{\gamma_i^{jl} \; 1-\beta_i^j} d_{ni}^j\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{9}$$

where $l \neq j$ is the other manufacturing sector and

$$A_i^j = \left(a_i^{jS}\right)^{\theta^j} T_i^j$$

captures the combined effect on costs of better technology in manufacturing sector j and cost reductions brought about by productivity gains in the services sector. Expression (9) links sector-j

prices in country n to the prices of labor and intermediates around the world.

Finally, imposing that each destination purchases each differentiated good z^j from the lowest cost source, and invoking the law of large numbers, leads to an expression for sector-j trade shares that takes the form:

$$\pi_{ni}^j = \frac{T_i^j \left[c_i^j d_{ni}^j\right]^{-\theta^j}}{\sum_{k=1}^I T_k^j \left[c_k^j d_{nk}^j\right]^{-\theta^j}} \tag{10}$$

$$= \frac{A_i^j \left[w_i^{\beta_i^j} \left(p_i^j\right)^{\gamma_i^{jj} \; 1-\beta_i^j} \quad \left(p_i^l\right)^{\gamma_i^{jl} \; 1-\beta_i^j} \quad d_{ni}^j\right]^{-\theta^j}}{\sum_{k=1}^I A_k^j \left[w_k^{\beta_k^j} \left(p_k^j\right)^{\gamma_k^{jj} \; 1-\beta_i^j} \quad \left(p_k^l\right)^{\gamma_k^{jl} \; 1-\beta_k^j} \quad d_{nk}^j\right]^{-\theta^j}}. \tag{11}$$

World equilibrium is a set of wages w_i and, for sectors $j \in \Omega_M$, deficits D_i^j and price levels p_i^j that solve equations (3), (7), (9), and (11) given labor endowments L_i, and deficits, D_i and D_i^S. World GDP is the numeraire.

4 Monthly Data on Trade and Production

As described above, one challenge in studying the recent trade decline is the need for high-frequency data. We need such data both because the decline sharpened in the middle of 2008, and also because translating production flows into a common currency is problematic at an annual or quarterly frequency.

Trade flow data are easily found at a monthly frequency – we use monthly bilateral trade flows from the Global Trade Atlas Database. These data are not seasonally adjusted and are provided in dollars. We aggregate appropriate 2-digit HS categories to generate the total bilateral and multilateral trade flows in each manufacturing sector.

Production data are a bit trickier. A limited number of countries, such as the United States, report monthly estimates of the level of manufacturing production, but such data are generally not available. The difficulty, then, is in finding a suitable way to disaggregate these annual totals into

internally consistent monthly values, as well as to generate out-of-sample predictions that reflect all up-to-date information for the months subsequent to the previous year's end.[7]

4.1 Temporal Disaggregation

Appendix B details our econometric procedure for disaggregating and extrapolating the annual production data in country i using the estimated relationship with several high frequency variables.[8] To build intuition for the procedure, think of a linear regression between the annual gross production of manufacturers and the annual sum of the monthly totals of the high frequency variables. At its most basic, Chow and Lin (1971) uses the coefficient estimates from such a regression to generate predicted monthly values. Next, the Chow-Lin procedure would distribute the regression residuals equally to each of these monthly predicted values for any given year. This procedure creates an internally consistent monthly series that sums up to the actual annual data. However, it generally creates artificial jumps from December to January since the corrections for residuals are different only from year to year. Our procedure makes two additional changes to this basic structure.

First, we follow Fernandez (1981) and allow for serial correlation in the monthly residuals, which eliminates spurious jumps between the last period of one year and the first of the next. Second, we follow Di Fonzi (2002) in adjusting the data so the procedure works for a log-linear, rather than linear, relationship. The monthly indicators used are the index of industrial production (IP) and the producer price index (PPI), so a relationship in logs is clearly most sensible. IP and PPI are available for the vast majority of large countries and are released with a very short time lag.

[Note: We we ultimately do this in two ways, first with the procedure automatically picking the beta coefficients for the relationship between production and IP/PPI and a second in which we automatically set these beta values to equal 1. The results below are generated from a mix of these procedure types, and figure notes clarify which. Future drafts will use one and reference the other as a robustness check. The two procedures do not appear to produce important differences,

[7] This problem, referred to in the econometrics and forecasting literature as temporal disaggregation, was studied as early as the 1950s by, among others, Milton Friedman. See Friedman (1962).

[8] The procedure was adapted from the code in Quilis, Enrique. "A Matlab Library of Temporal Disaggregation and Interpolation Methods: Summary," 2006.

but we will formally check this in future drafts.]

4.2 Disaggregating Manufacturing Sub-Categories

To actually implement this procedure in our multi-sector model and with our data, we first need IP and PPI indices at the sector level. Some countries explicitly offer these indices for durable and non-durable manufacturing production, while others produce the indices separately for capital goods, consumer durables, consumer non-durables, and intermediate goods. [There are some exceptions and we will offer further details in an appendix in the next draft on how we use these sub-categories to form durables and non-durable manufacturing. For now, a weighted average of capital goods, consumer durables, and intermediates are used for durables, while a weighted average of consumer non-durables and intermediates are used for non-durables. We will have the capacity to also disaggregate intermediates.]

We concord International Standard Industrial Classification (ISIC Rev. 3) 2-digit manufacturing production data to the appropriate sector definition (whatever is required to match the IP/PPI indices) so we have annual totals for each of these categories.[9] Our definition of manufacturing comprises ISIC industries 15 through 36 excluding 23 (petroleum). We further divide goods into the above sub-categories using the U.S. import end use classification. Harmonized System (HS) trade data are simultaneously mapped into the end use classification using a concordance from the U.S. Census Bureau and into the ISIC classification using the concordances from the World Bank's World Integrated Trade Solution (WITS) website. World trade volumes at the 6-digit level for 2007-2008 are again used to estimate what proportion of each ISIC classification belongs in each of the categories.

We then apply our procedure to generate monthly series of these disaggregated categories and from these, obtain a monthly series of the share of durables in manufacturing. Given the highest quality production data from these databases are for the total manufacturing sector, we then multiply these shares by total manufacturing production, which is interpolated in exactly the same

[9] Occasionally, a 2-digit sector will be dropped for one year, so we impute an alternative series where production levels are "grown" backward from the more recent and most complete data, only using the growth rates from categories reported in both years.

way but with IP/PPI indices for the whole of manufacturing. After all this, we then have monthly series for durable and non-durable manufacturing production which are consistent with annual (and implied monthly) levels of total manufacturing production in the data.

The annual data on manufacturing production used in the procedure are from the OECD Structural Analysis Database (STAN) and the United Nations National Accounts and Industrial Statistics Database (UNIDO). For China, Chang-Tai Hsieh provided us with cross-tabs from 4-digit manufacturing production data from the census of manufacturing production. We used these data to determine the durables/non-durables split and got manufacturing totals from http://chinadataonline.org. Monthly data on the manufacturing industrial production and producer price indices are primarily from the OECD Main Economic Indicators Database (MEI) and the Economist Intelligence Unit (EIU) Database. The exceptions here are Argentina, Chile, China, and Thailand. Data for these countries are from Argentina's National Institute of Statistics and Census (INE), the Federation of Chilean Industry (SOFOFA), chinadataonline.org, and the Bank of Thailand. Monthly data on these indices for manufacturing sub-categories, such as capital goods, are obtained from Datastream.

To check the quality of the procedure, we compared the monthly fitted series produced using this algorithm and the actual monthly data released by the U.S. Census Bureau on the value of shipments in durable and non-durable manufacturing. The U.S. monthly data are collected as part of the M3 manufacturing survey.[10] In the main paper, our monthly series will sum to the annual production totals found in the UN and OECD data, but for this test of the algorithm, we re-run the procedure using annual totals from the M3 survey. Though M3 data are available through 2009, we only use annual totals for 1995-2007 to ensure the procedure uses the same amount of data as other countries in our sample. We test both our procedure which endogenously selects the relationship between annual production and the monthly indicators as well as that in which we set the relationship equal to one.

Appendix Figure B1 demonstrates that both procedures do an excellent job of matching move-

[10] The monthly totals are extrapolated from a sampling procedure that covers a majority of manufacturers with $500 million or more in annual shipments as well as selected smaller companies in certain industries. See http://www.census.gov/indicator/www/m3/m3desc.pdf for additional details.

ments in the time series for non-durables, including during the out-of-sample decline during the recent recession. Our "Beta equals 1" procedure also does an excellent job both in-sample and out-of sample, though the endogenous beta procedure does underestimate the durables decline somewhat during the recent recession. Both procedures are likely successful enough to serve our purposes, but in future drafts we will formally compare all results using the two procedures.[11]

4.3 Concordances Linking Trade and Production

A many-to-many concordance was constructed to link the 2-digit harmonized system (HS) trade data to the International Standard Industrial Classification (ISIC) codes used in the production data. We start by downloading the mapping of 6-digit HS codes (including all revisions) to ISIC codes from the WITS website. This concordance was then merged with data on the volume of world trade at the 6-digit level for 2007-2008, from COMTRADE data, also accessed through WITS. We estimate the proportion of each HS 2-digit code that belongs in each ISIC category using these detailed worldwide trade weights. Then we can use the same concordance in the last step to map production and trade to our sectors $j \in \Omega_M$.

4.4 Input-Output Coefficients

The input-output coefficients – β_i^j and γ_i^{jl} – were calculated from the 2009 edition of the OECD's country tables. We concord and combine the 48 sectors used in these tables to form input-output tables for the three sectors $j \in \Omega$. Table 1 shows how we classified these 48 sectors into durables, non-durables, and non-manufactures. To determine β_i^j, we divide the total value added in sector j of country i by that sector's total output. To determine the values for γ_i^{jl}, we divide total spending in country i by sector j on inputs from sector l and divide this by that sector's total intermediate use at basic prices (i.e. net of taxes on products).

The OECD input-output tables are often available for the same countries for multiple years. In such cases, we use the most recent year of data available. Figure 2 includes examples of the input-

[11] Further, we note that there are essentially no large in-sample deviations, implying that once annual data is available, both procedures will do an extremely good job.

output coefficients for several large economies for both 2000 and 2005. First, one notes that there are important differences in the levels of these coefficients across countries. For example, China's value added in durable manufacturing is significantly lower than the U.K.'s (i.e. $\beta^D_{China} < \beta^D_{U.K.}$). Further, the time series information provides empirical support for our assumption that these technological parameters are fixed over time. For example, the share of non-durables in the production of non-durable intermediates in the United States ($\gamma^{NN}_{U.S.}$) was 39.5 percent in 2000 and 37.8 percent in 2005. There are a few exceptions, but this degree of stability in the time series is highly representative.

4.5 Additional Macro Data

Exchange rates to translate local currency production values into dollars (to match the dollar-denominated trade flows) are from the OECD.Stat database and from the International Financial Statistics database from the IMF. Other standard data used in the paper, such as quarterly GDP and deficits, are taken from the EIU. Trade and production data are translated using exchange rates at the monthly frequency before being combined to form the quarterly aggregates we use in our regressions and counterfactuals.

5 The Four Shocks in the System

Trade flows for each sector in our model are driven entirely by four categories of shocks to the system – demand shocks, deficit shocks, productivity shocks, and trade friction shocks. We emphasize, however, that while we derived our system from a particular model, these shocks are consistent with a variety of different structural interpretations.

5.1 Interpreting the Shocks

The first category of shocks in our model is the country-specific share of final demand that is for goods of type j, α^j_i. Fluctuations in α^j_i are consistent with any changes in the domestic absorption of good j that are not attributable to the current production of intermediate inputs. For example, non-homothetic preferences over consumption may imply a relative decline in final consumption

demand for durables during recessions. In our model, this type of effect – such as a particularly severe reduction in the purchase of automobiles – would manifest as a decline in α_i^D. Similarly, any shocks which reduce final investment activity would map to a change α_i^D because that term reflects the purchase of machinery or capital goods that are not used up in the production of intermediates. A reduction in durable inventories, since inventories have not yet been used up in the production of intermediates, will also produce a decline in α_i^D.

The second category of shocks in our model is deficits. In particular, equilibrium is a function of each country's overall deficit D_i and its non-manufacturing deficit D_i^S. Of our four categories of shocks, this is the only one without flexible interpretation.

The third and fourth categories of shocks are productivity and trade friction shocks and are isomorphic to many different structural representations. We derived the price index (9) and trade share expression (11) from a particular Ricardian model, but emphasize that any model generating these two aggregate equations would be equally valid in our analysis. For instance, Appendix A shows that these expressions emerge in, among others, the Armington (1969) model elaborated in Anderson and Van Wincoop (2003), the Krugman (1980) model implemented in Redding and Venables (2004), the Ricardian model of Eaton and Kortum (2002), and the Melitz (2003) model expanded in Chaney (2008).[12] In the Armington setup, for example, one would simply re-interpret shocks to A_i^j as preference shocks for that country's goods. For instance, a world-wide decline in demand for cars produced in Japan would map to a reduction in A_{JPN}^D in our framework.

Finally, the shocks d_{ni}^j can be interpreted as trade frictions in the broadest sense possible. Anything causing an increase in home-bias, or a reduction in absorption of imports relative to absorption of domestic production, will map in our framework to a change in d_{ni}^j. The simplest examples of such shocks would be changes in shipping costs (relative to domestic shipping costs), changes in tariffs, and changes in non-tariff trade barriers, such as the so-called "Buy America" provision in the U.S. fiscal stimulus package. Difficulties in obtaining trade finance relative to other types of credit, as in Amiti and Weinstein (2009), would also influence the d_{ni}^j term in our model.

[12]The deep similarity in the predicted trade patterns from such seemingly disparate models is striking and is the subject of Arkolakis, Costinot, and Rodriguez-Clare (2009).

Even the highly plausible scenario where importers reduce inventories in recessions more than the average firm (because importing has additional fixed costs), as detailed in the model of Alessandria, Kaboski, and Midrigan (2010), would map to a change in d^j_{ni}.[13]

These four categories of shocks can be divided into two types. The first two – demand and deficit shocks – are readily observable in the data, while the second two – productivity and trade frictions – must be taken implicitly from the data based on relationships in the model. To better characterize the recent decline in trade flows, we now separately show what has happened in recent years to these shocks.

5.2 Measuring Manufacturing Demand

We start with the first two categories of shocks, which can be readily observed or computed from the data. The first one, the demand for durable and non-durable goods as a share of final demand, can be calculated using (4) as the first two elements of the vector $\boldsymbol{\alpha}_i$:

$$\boldsymbol{\alpha}_i = \frac{1}{X_i} \left(\mathbf{X}_i - \boldsymbol{\Gamma}_i \mathbf{Y}_i \right),$$

where data for all the right hand side terms have been described above.[14] Figure 3 plots the paths of α_i^D and α_i^N for four large countries since 2000. The dashed vertical lines on the right of the plot correspond to the period starting in the first quarter of 2008 and ending in the first quarter of 2009. We highlight this window because that will be the period we use for our counterfactual analyses. The recent recession has led to a steep decline in final demand for manufactures in all these countries, with a particularly steep decline in durables (the blue line).

[13] To reiterate, if there is a uniform reduction in inventories – whether the goods are imported or not – this will appear in our model as a decline in demand for that sector. A disproportionately large decline in imported good inventories, howver, would appear in our framework as an increase in trade frictions.

[14] The one element not explicitly described above, service sector production, is imputed as: $Y_i^S = (Y_i - \beta_i^D Y_i^D - \beta_i^N Y_i^N)/\beta_i^S$, as implied by (1).

5.3 Measuring Deficits

Similarly, deficits changed dramatically over this period. Figure 4 shows overall and non-manufacturing trade deficits for these same countries (plus China). The U.S.'s overall deficit's sharp reduction is balanced by reduced surpluses from countries like Japan, Germany, and China.

5.4 Measuring Trade Frictions with the Head-Ries Index

Trade frictions are not as easily measured as the macro aggregates above. Hence, in this section, we derive the Head-Ries index, an inverse measure of trade frictions implied by our trade share equation (11), or any gravity model. The index will be an easily measurable object that reflects changes in trade frictions and is invariant to the scale of tradable good demand or the relative size and productivity of trading partners. Head and Ries (2001) uses this expression – equation (8) in the paper – to measure the border effect on trade between the U.S. and Canada for several manufacturing industries. Jacks, Meissner, and Novy (2009) studies a very similar object for a span of over 100 years to analyze long-term changes in trade frictions.

Denote country n's spending on manufactures of type j from country i by X^j_{ni}, measured in U.S. Dollars. All variables are indexed by time (other than the elasticity θ^j), though we generally omit this from our notation. We have:

$$\frac{X^j_{ni}}{X^j_{nn}} = \frac{\pi^j_{ni}}{\pi^j_{nn}} = \frac{T^j_i \left[c^j_i d^j_{ni}\right]^{-\theta^j}}{T^j_n \left[c^j_n\right]^{-\theta^j}}, \tag{12}$$

where we normalize $d^j_{nn} = 1$. Domestic absorption of goods of type j, X^j_{nn}, is equal to gross production less exports: $X^j_{nn} = Y^j_n - \sum_{i=1}^{I} X^j_{in}$.[15]

Multiplying (12) by the parallel expression for what i buys from n in sector j and taking the

[15] Grouping together country-level terms as $S^j_i = T^j_i \left(c^j_i\right)^{-\theta^j}$ and taking logs of both sides of (12), we could run a regression at date t on country fixed effects. We might do this hoping to sweep out the components S^j_i so that we would be left with $\left(d^j_{ni}\right)^{-\theta^j}$, which is the object we would like to input into our analysis. Such a procedure would be misleading, however, due to a fundamental identification problem. For any set of parameters $\left\{S^j_i, d^j_{ni}\right\}$ we can fit the same data with another set of parameters $\left\{\widetilde{S}^j_i, \widetilde{d}^j_{ni}\right\}$ where:

$$\widetilde{S}^j_i = \phi^j_i S^j_i,$$

square root, we generate:

$$\Theta_{ni}^{j} = \left(\frac{X_{ni}^{j}}{X_{nn}^{j}} \frac{X_{in}^{j}}{X_{ii}^{j}} \right)^{1/2} = \left[d_{ni}^{j} d_{in}^{j} \right]^{-\theta^{j}/2}. \tag{13}$$

This index implies that, for given trade costs, the product of bilateral trade flows in both directions should be a fixed share of the product of the countries' domestic absorption of tradable goods.

This index will change only in response to movements in the cost of trade. Other measures which might have been used to capture these movements include "openness" indices, similar to the left-hand side of (12), or the summation of bilateral trade flows relative to the summation of any pair of countries' final demands. These other measures, however, have the disadvantage of being unable to isolate trade frictions.

To characterize historical trends in trade frictions at the country level, we apply a regression framework to these bilateral indices. We start with the assumption that each directional transport cost reflects aggregate (η^{j}), exporter (δ^{j}), and importer (μ^{j}) components that change over time, as well as a bilateral term (γ_{ni}^{j}) that is fixed, and finally a shock (ϵ_{ni}^{j}):

$$d_{ni}^{j}(t) = e^{\eta^{j}(t) + \delta_{n}^{j}(t) + \mu_{i}^{j}(t) + \gamma_{ni}^{j} + \epsilon_{ni}^{j}(t)}. \tag{14}$$

We think of the exporter effect δ^{j} as reflecting, for example, the difficulties potentially imposed on exporting firms in obtaining trade credit and the importer effect μ captures, for example, an import tariff. Equations (13) and (14) imply:

$$\ln \Theta_{ni}^{j}(t) = \frac{\theta^{j}}{2} \ln \left(d_{ni}^{j}(t) d_{in}^{j}(t) \right) = \theta^{j} \eta^{j}(t) + \theta^{j} \gamma_{ni}^{j} + \frac{\theta^{j}}{2} (\delta + \mu)_{n}^{j}(t) + \frac{\theta^{j}}{2} (\delta + \mu)_{i}^{j}(t) + \frac{\theta^{j}}{2} (\epsilon_{ni} + \epsilon_{in})(t),$$

and

$$\widetilde{d}_{ni}^{j} = \left[\frac{\phi_{i}^{j}}{\phi_{n}^{j}} \right]^{1/\theta^{j}} \widetilde{d}_{ni}^{j}.$$

The problem is that there are no restrictions on ϕ_{i}^{j}, so this procedure would be unable to determine whether the d_{ni}^{j} changed or the S_{i}^{j} changed. Going back to the primitives of the model, any change in trade shares can be explained by an infinite number of combinations of changes in $\{T_{i}^{j}\}$ and $\{d_{ni}^{j}\}$. There is hope, however. Notice that if we multiply d_{ni}^{j} by d_{in}^{j}, the ambiguity goes away. This fact is the key motivation for our use of the Head-Ries index.

which shows that, even though there might be distinct importer and exporter frictions, we can only learn about their combination ($\beta_n^j = \theta^j \left(\delta_n^j + \mu_n^j\right)/2$) when looking at an individual Head-Ries index, since importers and exporters enter the index calculation symmetrically. To extract these distinct effects, we estimate the pooled regression for all i, n, and t:

$$\ln \Theta_{ni}^j(t) = \beta_n^j(t) + \beta_i^j(t) + \gamma_{ni}^j + \varepsilon_{ni}^j(t). \tag{15}$$

We do this separately for each manufacturing industry, $j = D, N$. Note that each regression contains only N country dummy variables each period, any given observation will be influenced by two of these country dummies, and each dummy represents the sum of the trade frictions experienced by that country's exporters and importers.

Figures 5 and 6 plot the four-quarter moving average of the country-time effects β_i^j from a weighted estimation of (15) for selected countries. We use a moving average due to the strong seasonal effects in the data. The coefficients are normalized to zero in the first quarter of 2000 and in some cases extend through the second quarter of 2009. The country-time effects act proportionately on the Head-Ries indices for all bilateral pairs involving any given country. For instance, if the series for country i increases from 0 to 0.1, it implies that the index would increase 10 percent for all pairs in which i is an exporter or an importer.

Looking at Figure 5, we see examples of countries where the recession did not bring with it marked declines in trade frictions. Only a small share, if any, of the large declines in trade flows for Germany, the U.S., France, and Italy should, according to this measure, be attributed to declining trade frictions. Figure 6, by contrast, includes only countries for which there is a steeper increase in trade frictions (a decline in the index) during the recession. These countries include Japan, China, Austria, and Canada, among others not shown. One important conclusion, thus, is that while there is evidence of a potentially important contribution from trade frictions to the trade collapse, this contribution appears to be quite heterogenous across countries.

The implied changes in trade frictions for durable and non-durables need not be the same for any given bilateral trading pair. First, this may reflect differences in the within-country trade

costs for the two types of goods. Given we normalize $d_{ii}^j = 1$ for all countries and sectors, changes in international trade costs must interpreted as relative to domestic trade costs. Different modes of transport for durable and non-durable goods, for example, could generate different changes in within-country trade costs across the sectors. Further, the elasticities, θ^j, may be different across sectors, and since the Head-Ries index includes this term, similar proportional changes in trade costs can generate different magnitude fluctuations of the Head-Ries index across sectors. Finally, each of the possible stories driving changes in trade frictions, such as difficulties in acquiring trade financing, could plausibly differ across sectors. For example, if one sector is performing worse than another – due to differences in the demand shocks α^j, say – there might be differential increases in the higher cost of trade credit.

5.5 Measuring Trade Frictions During the Great Depression

To check the ability of the Head-Ries index to pick up changes in trade frictions, as well as to give a benchmark for the scale of any such changes, we calculate (13) using data from the Great Depression, which also coincided with a major collapse in trade. The lack of availability of data on bilateral manufacturing trade restricts our analysis to flows between the United States and 8 trading partners: Austria, Canada, Finland, Germany, Japan, Spain, Sweden, and the United Kingdom. We obtained data on bilateral and multilateral manufacturing trade as well as exchange rates for 1926-1937 from the annual *Foreign Commerce Yearbooks*, published by the U.S. Department of Commerce.[16] The gross value of manufacturing, required for the denominator of (13), were obtained from a variety of country-specific sources.[17] The U.S. ratio of gross output to value added in manufacturing, found in Carter (2006), was applied to foreign manufacturing value added when

[16] Total U.S. multilateral manufacturing imports and exports were taken from Carter et al. (2006).

[17] Where needed, U.S. Department of Commerce (1968) was used to convert currency or physical units into U.S. dollars. Austria: Bundesamt fur Statistik (1927-1936) was used to obtain product-specific production data, either in hundreds of Austrian schilling or in kilograms. Canada: Value of manufacturing data were available in U.S. dollars from Urquhart (1983). Germany: Data were obtained from Statistishen Reichsamt (1931, 1935, 1940). Finland, Japan, Spain, and Sweden: Value added in manufacturing, in local currency units, were taken from Smits (2009). Peru: Output data in Peruvian pounds and soles obtained from Ministerio de Hacienda y Comercio (1939). United Kingdom: Data were obtained from United Kingdom Board of Trade (1938). These annual numbers combined less frequent results from the censuses in 1924, 1930, and 1935, with industrial production data, taken yearly, from 1927-1937.

output data were unavailable.

The bilateral trade and the manufacturing totals often reflect changing availability of data for disaggregated categories. For example, one year's total growth may reflect both 20% growth in Paper Products as well as the initial measurement (relative to previous missing values) of Transportation Equipment. Since inspection suggests that such missing values do not simply reflect zero values, we calculate year-to-year growth rates using only the common set of recorded goods. For manufacturing production, we not only need the growth rate, but the level also matters because we subtract the level of exports to measure absorption. We apply the growth rate backwards from the most complete, typically also the most recent, series value.

[Future drafts will present these results. Our preliminary analysis suggests the HR drops dramatically in all these countries starting in about 1930, corroborating our results here.]

6 Calibration

Having set up the model, discussed the four categories of shocks that can change trade flows, and given historical context on the path of these shocks, we now calibrate the model to perfectly match the period from the first quarter of 2008 to the first quarter of 2009. The calibration exercise only includes a balanced panel of countries for which we have data on imports from and exports to all other included countries. After constructing trade, production, GDP, deficit, and input-output information for each country, and balancing this panel, we are left with a dataset containing complete data for 20 countries [This number should increase to about 25-30 in future drafts] responsible for about 75 percent of global manufacturing trade and global GDP.[18] We use all available countries for which we have the data with the only exceptions being Belgium and the Netherlands [Explain other omissions here]. They are omitted because their manufacturing exports often exceed their manufacturing production (due to re-exports), and our framework is not capable of handling this situation. Table 2 lists the included countries, shares in trade, and shares in global GDP, before and after the crisis, as well as a residual category "rest of world."

[18] These shares are highly similar before and after the crisis, suggesting we have a representative sample in terms of the declines in trade and output.

First, we re-formulate the model in a notation that makes it easier to think about this four-quarter change. Next we describe how we parameterize the model.

6.1 Change Formulation

For any time-varying variable x in the model we denote its beginning-of-period value as x and its end-of-period value as x', with the "change" over the period denoted $\hat{x} = x'/x$. In our counterfactuals, this means x would be the variable's value in the first quarter of 2008, x' would be the value in the first quarter of 2009, and $\hat{x}$ would be the gross change in that variable over that four quarter period. We will take the labor force as fixed so that $Y_i' = \hat{w}_i Y_i$.

In terms of changes, the goods market clearing conditions (7) become:

$$\left(Y_i^j\right)' = \sum_{n=1}^{I} \left(\pi_{ni}^j\right)' \left(X_n^j\right)', \tag{16}$$

while sectoral demand (3) becomes:

$$\mathbf{X}_i' = \boldsymbol{\alpha}_i' \left(\hat{w}_i Y_i + D_i'\right) + \boldsymbol{\Gamma}_i^T \mathbf{Y}_i'. \tag{17}$$

The price equations (9) become:

$$\widehat{p}_n^j = \left(\sum_{i=1}^{I} \pi_{ni}^j \widehat{A}_i^j \widehat{w}_i^{-\theta^j \beta_i^j} \left(\widehat{p}_i^j\right)^{-\phi_i^{jj} \theta^j (1-\beta_i^j)} \left(\widehat{p}_i^l\right)^{-\phi_i^{jl} \theta^j (1-\beta_i^j)} \left(\widehat{d}_{ni}^j\right)^{-\theta^j} \right)^{-1/\theta^j}, \tag{18}$$

where $l \neq j$ is the other manufacturing sector. The trade share equations (11) become:

$$\widehat{\pi}_{ni}^j = \frac{\widehat{A}_i^j \widehat{w}_i^{-\theta^j \beta_i^j} \left(\widehat{p}_i^j\right)^{-\phi_i^{jj} \theta^j (1-\beta_i^j)} \left(\widehat{p}_i^l\right)^{-\phi_i^{jl} \theta^j (1-\beta_i^j)} \left(\widehat{d}_{ni}^j\right)^{-\theta^j}}{\left(\widehat{p}_n^j\right)^{-\theta^j}}. \tag{19}$$

Equations (16), (17), (18), and (19) determine the changes in endogenous variables implied by a given set of shocks. We solve this set of equations for: (i) $I-1$ changes in wages $\hat{w}_i$, (ii) $I-1$ sectoral deficits $\left(D_i^D\right)'$ and $\left(D_i^N\right)' = D_i' - \left(D_i^D\right)' - \left(D_i^S\right)'$, (iii) I changes in durable manufacturing

prices $\hat{p}_i^D$, and (iv) I changes in non-durable manufacturing prices $\hat{p}_i^N$. Beginning-of-period trade shares and GDPs are used to calibrate the model. The forcing variables are the changes in demand $\widehat{\alpha}_i^D$ and $\widehat{\alpha}_i^N$ (determining $\boldsymbol{\alpha}_i'$ given $\boldsymbol{\alpha}_i$), changes in trade frictions $\left(\hat{d}_{ni}^D\right)^{-\theta^D}$ and $\left(\hat{d}_{ni}^N\right)^{-\theta^N}$, changes in productivities $\hat{A}_i^D$ and $\hat{A}_i^N$, and end-of-period deficits $D_i^{S'}$ and D_i'.

Changes in trade frictions and changes in productivity are intimately connected. We can bring out this connection, and reveal the logic of our calibration of the model, by combining trade friction shocks and productivity shocks in the term:

$$\delta_{ni}^j = \frac{\Phi_i^j}{\Phi_n^j}\left(\widehat{d}_{ni}^j\right)^{-\theta^j}, \tag{20}$$

where the Φ_i^j represent productivity changes through:

$$\widehat{A}_i^j = \left(\Phi_i^j\right)^{1-\gamma_i^{jj}(1-\beta_i^j)}\left(\Phi_i^l\right)^{-\frac{\theta^j}{\theta^l}\gamma_i^{jl}(1-\beta_i^j)}. \tag{21}$$

In this reparameterization (16) and (17) remain unchanged while (18) becomes:

$$\widehat{q}_n^j = \left(\sum_{i=1}^{I}\pi_{ni}^j\widehat{w}_i^{-\theta^j\beta_i^j}\left(\widehat{q}_i^j\right)^{-\gamma_i^{jj}\theta^j(1-\beta_i^j)}\left(\widehat{q}_i^l\right)^{-\gamma_i^{jl}\theta^j(1-\beta_i^j)}\delta_{ni}^j\right)^{-1/\theta^j}, \tag{22}$$

and (19) becomes:

$$\widehat{\pi}_{ni}^j = \frac{\widehat{w}_i^{-\theta^j\beta_i^j}\left(\widehat{q}_i^j\right)^{-\gamma_i^{jj}\theta^j(1-\beta_i^j)}\left(\widehat{q}_i^l\right)^{-\gamma_i^{jl}\theta^j(1-\beta_i^j)}\delta_{ni}^j}{\left(\widehat{q}_n^j\right)^{-\theta^j}}. \tag{23}$$

Note that productivity changes do not enter directly into (22) or (23).

The solution to (16), (17), (22), and (23) is also the solution to (16), (17), (18), and (19), with

$$\widehat{p}_i^j = \left(\Phi_i^j\right)^{-1/\theta^j}\widehat{q}_i^j. \tag{24}$$

To see why, substitute (20) into (22) to get:

$$\widehat{q}_n^j = \left(\sum_{i=1}^{I} \pi_{ni}^j \widehat{w}_i^{-\theta^j \beta_i^j} \left(\widehat{q}_i^j\right)^{-\gamma_i^{jj}\theta^j(1-\beta_i^j)} \left(\widehat{q}_i^l\right)^{-\gamma_i^{jl}\theta^j(1-\beta_i^j)} \frac{\Phi_i^j}{\Phi_n^j} \left(\widehat{d}_{ni}^j\right)^{-\theta^j} \right)^{-1/\theta^j}.$$

Grouping terms, the left hand side becomes $\left(\Phi_n^j\right)^{-1/\theta^j} \widehat{q}_n^j$, the price terms on the right hand side become $\left(\Phi_i^j\right)^{-1/\theta^j} \widehat{q}_i^j$, and this leaves a remaining term on the right hand side equal to $\left(\Phi_i^j\right)^{1-\gamma_i^{jj}(1-\beta_i^j)} \left(\Phi_i^l\right)^{-\frac{\theta^j}{\theta^l}\gamma_i^{jl}(1-\beta_i^j)}$. This expression then replicates (18) after substituting in (24) and (21). Similarly, substituting (20) into (23), applying (24) and (21), yields (19). The implication of this result is that to solve the model for changes in wages and trade shares, all we need is δ_{ni}^j rather than $\left(\widehat{d}_{ni}^j\right)^{-\theta^j}$ and $\widehat{A}_i^j$ separately. We can later decompose the contribution of trade friction and productivity shocks using additional restrictions or data.

6.2 Parameter Values and Shocks

We start by setting $\theta^D = \theta^N = 2$. This value between the smaller values typically used in the open-economy macro literature and the larger values used in Eaton and Kortum (2002). We have described earlier our procedure for backing out $\hat{\alpha}_i^D$, $\hat{\alpha}_i^N$, and end of period deficits D_i' and $\left(D_i^S\right)'$.[19]

We now turn to the calibration of the δ_{ni}^j. Start by dividing both sides of equation (23) by π_{ni}^j to get an expression for $\hat{\pi}_{ni}^j$. Dividing by the corresponding expression for $\hat{\pi}_{ii}^j$ gives:

$$\delta_{ni}^j = \frac{\hat{\pi}_{ni}^j}{\hat{\pi}_{ii}^j} \left(\frac{\widehat{q}_i^j}{\widehat{q}_n^j} \right)^{\theta^j}. \tag{25}$$

We can then use (23) (for $n = i$) and (22) to get:

$$\hat{\pi}_{ii}^j = \widehat{w}_i^{-\theta^j \beta_i^j} \left(\widehat{q}_i^j\right)^{\theta^j \left[1-\gamma_i^{jj}(1-\beta_i^j)\right]} \left(\widehat{q}_i^l\right)^{-\theta^j \gamma_i^{jl}(1-\beta_i^j)}, \tag{26}$$

where $l \neq j$ is the other manufacturing sector. Combining these equations for the two manufacturing

[19] Due to the lack of data on quarterly manufacturing production in the "Rest of World", we set Y_{world}^M such that $\hat{\alpha}_{ROW}$ equals the GDP-weighted average of the $\hat{\alpha}$ values across all our other countries.

sectors, and rearranging yields:

$$\left(\widehat{q}_i^j\right)^{\theta^j} = \left(\hat{\pi}_{ii}^j \widehat{w}_i^{\theta^j \beta_i^j}\right)^{\frac{1-\widetilde{\gamma}_i^{ll}(1-\widetilde{\beta}_i^l)}{\Delta_i}} \left(\hat{\pi}_{ii}^l \widehat{w}_i^{\theta^l \beta_i^l}\right)^{\frac{\theta^j \widetilde{\gamma}_i^{jl}(1-\widetilde{\beta}_i^j)}{\theta^l \Delta_i}},$$

where

$$\Delta_i = \prod_{l \in \Omega_M} \left(1 - \widetilde{\gamma}_i^{ll}(1 - \widetilde{\beta}_i^l)\right) - \prod_{l,j \in \Omega_M, l \neq j} \widetilde{\gamma}_i^{lj}(1 - \widetilde{\beta}_i^l).$$

These expressions for price changes can be plugged into (25) to get:

$$\delta_{ni}^j = \frac{\hat{\pi}_{ni}^j}{\hat{\pi}_{ii}^j} \frac{\left(\hat{\pi}_{ii}^j \widehat{w}_i^{\theta^j \beta_i^j}\right)^{\frac{1-\widetilde{\gamma}_i^{ll}(1-\widetilde{\beta}_i^l)}{\Delta_i}} \left(\hat{\pi}_{ii}^l \widehat{w}_i^{\theta^l \beta_i^l}\right)^{\frac{\theta^j \widetilde{\gamma}_i^{jl}(1-\widetilde{\beta}_i^j)}{\theta^l \Delta_i}}}{\left(\hat{\pi}_{nn}^j \widehat{w}_n^{\theta^j \beta_n^j}\right)^{\frac{1-\widetilde{\gamma}_n^{ll}(1-\widetilde{\beta}_n^l)}{\Delta_n}} \left(\hat{\pi}_{nn}^l \widehat{w}_n^{\theta^l \beta_n^l}\right)^{\frac{\theta^j \widetilde{\gamma}_n^{jl}(1-\widetilde{\beta}_n^j)}{\theta^l \Delta_n}}}. \tag{27}$$

To go any further, we need to separate out productivity changes from changes in trade frictions. We proceed in two ways. First, we solve for the set of productivity changes that maximizes the symmetry in the resulting changes in trade frictions. Second [TBD], we use data on price changes to back out productivity from a relationship implied by the model.

Starting with the first method, since the Head-Ries index is $\Theta_{ni}^j = \left[d_{ni}^j d_{in}^j\right]^{-\theta^j/2}$, imposing $d_{ni}^j = d_{in}^j$ implies, in changes, $\widehat{\Theta}_{ni}^j = \left(\widehat{d}_{ni}^j\right)^{-\theta^j} = \left(\widehat{d}_{in}^j\right)^{-\theta^j}$. Combining with (20), and allowing for deviations μ_{ni}^j around symmetry, we get:

$$\frac{\widehat{\Theta}_{ni}^j}{\delta_{ni}^j} = \frac{\Phi_n^j}{\Phi_i^j} e^{\mu_{ni}^j}.$$

Taking logs gives our estimating equation:

$$\ln(\widehat{\Theta}_{ni}^j / \delta_{ni}^j) = \ln(\Phi_n^j) - \ln(\Phi_i^j) + \mu_{ni}^j. \tag{28}$$

The left-hand side can be calculated from our data, while for the right-hand side we estimate the coefficients on a set of N dummy variables, one for each country. For each (n, i) observation, there

are two non-zero dummy values. The first, corresponding to country n, takes a value of (+1), while the second, corresponding to country i, takes a value of (−1). We estimate Φ_i^j by exponentiating the coefficients (for each sector j) on the dummy variables for country i, with "Rest of World" dropped (since a common scalar won't change anything). Finally, to recover changes in sectoral productivity, we substitute these estimates into (21).

The second method uses data on sectoral price changes by country. In parallel to the derivation of (25) we use (19) to obtain:

$$\left(\widehat{d}_{ni}^j\right)^{-\theta^j} = \frac{\hat{\pi}_{ni}^j}{\hat{\pi}_{ii}^j}\left(\frac{\widehat{p}_i^j}{\widehat{p}_n^j}\right)^{\theta^j},$$

so that

$$\frac{\Phi_i^j}{\Phi_n^j} = \delta_{ni}^j \frac{\hat{\pi}_{ii}^j}{\hat{\pi}_{ni}^j}\left(\frac{\widehat{p}_n^j}{\widehat{p}_i^j}\right)^{\theta^j}.$$

The four panels in Figure 7 plot on the y-axis the changes in the durables and non-durables demand shocks and the overall and non-manufacturing deficits. The change in trade to GDP ratios during the crisis are plotted along the x-axis. Figure 8 shows changes in the durable and non-durable productivity terms, estimated under various assumptions for the parameters θ^j. Finally, the two panels of Figure 9 contains histograms of the durable and non-durable trade friction changes, raised to the $-\theta^j$ power: $\left(\widehat{d}_{ni}^j\right)^{-\theta^j}$.[20] The histograms exclude the largest and smallest 5 percentile values (generally small country-pair outliers).[21]

Table 3 list the combined impact of all the shocks that characterize the recession on imports and exports relative to GDP for all the countries in our calibration. Globally, trade declined by 21 percent relative to GDP, with durables dropping by 24 percent and non-durables dropping by 13 percent.

[20] Since this function, rather than the trade frictions themselves, is what can be identified in the above procedures, we report and consider counterfactual shocks only to this object. If one wishes to apply the particular structural interpretation that the friction is a tariff, for instance, she might choose a value for the parameter θ^j and back out $\widehat{d}_{ni}^j$. As discussed above, however, these trade frictions will pick up a broad class of shocks impacting the degree of home bias. Hence, we only report results for the integrated object $\left(\widehat{d}_{ni}^j\right)^{-\theta^j}$.

[21] It is again worth noting that our measure of trade frictions must be interpreted as *relative* to domestic trade costs.

7 Counterfactuals

We now discuss our counterfactual exercises. Given values for the changes in the forcing variables we solve (16), (18), and (19), using an algorithm adapted from Dekle, Eaton, and Kortum (2008). Throughout, we take world GDP, measured in U.S. dollars, as given. It is our numeraire and, hence, we will have nothing to say about the drop in world GDP over the past year. Formally, we could express every nominal variable in the model as a fraction of world GDP.[22] In the results that follow we treat all end-of-period deficits as exogenous, so that wage changes are endogenous. In future drafts we will consider a case of exogenous wage changes and endogenous end-of-period manufacturing deficits.

7.1 Decomposing Changes Across Countries

We start with counterfactuals that consider the country-level trade flows implied by a given configuration of the four shocks. It will be convenient to define the set of all shocks:

$$\Xi' = \left\{ \left\{ \widehat{\alpha}_i^D \right\}, \left\{ \widehat{\alpha}_i^N \right\}, \left\{ \widehat{D}_i \right\}, \left\{ \widehat{D}_i^S \right\}, \left\{ \widehat{d}_{ni}^D \right\}, \left\{ \widehat{d}_{ni}^N \right\}, \left\{ \widehat{A}_i^D \right\}, \left\{ \widehat{A}_i^S \right\} \right\},$$

for all countries $i, n \in I$.[23]

For any given set of shocks Ξ, we can solve our model to generate changes in all values and flows in the global system, relative to the baseline period in 2008. For example, if we solve the model with all shocks in Ξ' equal to one, implying the shocks did not change at all relative to the first quarter of 2008, the model would generate outcome variables (such as production, trade, GDP, etc.) precisely equal to those seen in the first quarter of 2008, as if the recession never occurred. If, on the other hand, we solve the model with the set of shocks $\Xi' = data$, where "*data*" means that the shock values are as given in the previous tables and plots, the model would generate values precisely equal to those seen in the first quarter of 2009. Define these two special cases of the shock

[22] In practice, the issue of numeraire arises in two places. First, the end-of-period deficits that we feed the model need to be divided by a factor equal to the change in world GDP over the period, $\hat{Y}$. Similarly, country-specific changes in GDP $\hat{Y}_i$, used to measure changes in wages $\widehat{w}_i$, also need to be divided by $\hat{Y}$.

[23] We note that while we write $\widehat{D}_i^S$ and $\widehat{D}_i$, we really only need information on $\left(D_i^S\right)'$and $\left(D_i^S\right)'$, and so do not run into problems if $\widehat{D}_i^S$ and $\widehat{D}_i$ are undefined because initial deficits are zero.

matrices as Ξ^{08} and Ξ^{09}, respectively.

Next, write the gross change in any particular outcome variable ξ for country i as $\widehat{\xi}_i(\Xi') = \xi'_i/\xi_i^{08}$ to represent its value when the system is solved using the set of shocks Ξ' relative to the value that was observed before the recessions. For example, if ξ_i is country i's overall trade to GDP ratio, then $\widehat{\xi}_i(\Xi^{09})$ is the gross percentage change in trade to GDP observed over the crisis in that country. (Note that by definition, $\widehat{\xi}_i(\Xi^{08}) = 1$, for any variable ξ_i.)

To create a measure comparing the extent of cross-country changes in any variable ξ induced by any set of shocks Ξ' relative to what occurred over the crisis, we define:

$$\upsilon(\Xi') = \sum_i^I w_i \left(\widehat{\xi}_i(\Xi') - \widehat{\xi}_i(\Xi^{09})\right)^2,$$

which is a weighted sum of squared errors of the vector $\widehat{\boldsymbol{\xi}}(\Xi')$ around the vector $\widehat{\boldsymbol{\xi}}\left(\Xi^{09}\right)$, with each element's deviation weighted by w_i, with $\sum_i w_i = 1$. For instance, if ξ is the trade to GDP ratio, then the measure $\upsilon\left(\Xi^{08}\right)$ gives the total amount of change in country-level trade to GDP ratios that occurred during the recession. Finally, to measure the share of total changes in ξ over the recession that are captured by a set of shocks Ξ', we define:

$$\mathbb{V}(\Xi') = 1 - \frac{\upsilon(\Xi')}{\upsilon(\Xi^{08})}.$$

Consider the question of whether changes in country's non-manufacturing trade deficits are very important for understanding the pattern of changes in trade to GDP observed over the recession. To answer this, we input the shock matrix $\Xi' = \left\{1_{Ix1}, 1_{Ix1}, 1_{Ix1}, \left\{\widehat{D}_i^S\right\}, 1_{Ix1}, 1_{Ix1}, 1_{Ix1}, 1_{Ix1}\right\}$ and generate the counterfactual vector of changes in trade to GDP ratios. The x-axis in the top-left plot of Figure 10 plots the vector $\widehat{\boldsymbol{\xi}}\left(\Xi^{09}\right)$, while the y-axis plots the vector $\widehat{\boldsymbol{\xi}}(\Xi')$.[24] If all the points were on the 45 degree line, it would indicate that the observed changes in the non-manufacturing deficits alone can fully explain the changes in global trade shares during the recession. In such a case, $\mathbb{V}(\Xi')$ would equal 1. As is easy to see, however, the counterfactual did little to align the

[24] The plots actual show the net rates of change, that is, $\widehat{\boldsymbol{\xi}}(\Xi) - 1$.

points along the 45 degree line and, using shares of pre-recession global trade as our weights, we calculate $\mathbb{V}(\Xi') = 0.03$. It is in this sense that the figure's subtitle says "Share of Trade-Weighted Variance Explained: 3%" and that we say the non-manufacturing deficit shocks can explain very little of the recent trade decline.[25]

Figures 10 and 11 include plots of various counterfactual scenarios, simulated with only one shock at a time. The most notable results – the shocks with greatest explanatory power – are the durable demand shocks on the bottom left panel of Figure 10 and the durable trade friction shocks on the top left panel of Figure 11. The durable demand shocks, on their own, explain 61 percent of the trade-weighted variance and the durable friction shocks, own their own, explain 37 percent.

Figure 12 considers various combinations of shocks and demonstrates that, for example, both manufacturing shocks together explain 68 percent of the variation and all trade friction and productivity shocks together explain 39 percent of the variation. As shown in the bottom right panel of Figure 12, when all shocks are implemented, they perfectly explain changes in the economic system. This is, of course, true by construction.

7.2 Decomposing the Global Trade Decline

Next, in Table 4, we consider these results at the global level. The country values mirror the values that appeared in the previous plots, but the boldface line labeled "World" gives the implied global change in imports and exports. We saw in Table 3 that trade dropped 21 percent relative to world economic activity in the recession. Compared to this 21 percent, Table 4 shows that a 14 percent decline is generated from a counterfactual recession in which manufacturing demand dropped as it did but with no other shocks.[26] Table 5 shows that a counterfactual recession in which the only change is the shock to trade frictions produces a 3 percent decline in global trade. In this sense, we conclude that the demand decline is the most salient single factor, responsible for nearly 70 percent of the drop, though changes in trade frictions were also contributors responsible for about

[25] Note that this calculation can very well be negative. We would expect this with any shock that pushes the vector of outcome variables even further away from the post-recession data.

[26] It is somewhat misleading to say manufacturing demand "dropped" since this experiment does include several countries where it increased.

15 percent of the drop.[27]

7.3 Other Counterfactuals

Given the heterogeneity in the shocks impacting countries in the recent recession, we also consider counterfactuals run at the country- or region-level. As an example, imagine one wants to know the global impact of the decline in durables demand in the U.S. The top panel of Table 6 shows simulated trade flows at the country and global level (for selected countries) when the only shock we introduce into the system is $\widehat{\alpha}_{US}^{D}$. The impact of this single shock on the world is large – it reduces global durables trade by about 3 percent relative to GDP. One also notes the impact of geography. Mexico and Canada are impacted very significantly, while Germany, for example, is relatively insulated.

The bottom panel of Table 6 shows an alternative exercise where the only shocks introduced are the changes in trade frictions observed in China and Japan. These reduce total global trade by about 3 percent relative to GDP, but also have interesting cross-country implications. For example, the counterfactual produces trade diversion as manifest in the increase in South Korea's trade to GDP ratio.

8 Conclusion

A prominent characteristic of the recent global recession was a large and rapid drop in trade relative to economic activity. Motivated by these dramatic changes in the cross-country pattern of trade, production, and GDP, we build an accounting framework relating them to shocks to demand, trade frictions, deficits, and productivities across several sectors. Applying our framework to the recent recession, we find that the bulk of the decline in trade/GDP can be explained by the shocks to manufacturing demand, with a particularly important role for the shocks to durable manufacturing demand. We do observe that trade fell by more than what would be predicted by demand shocks

[27] Note that the contributions of each of the individual shocks are not orthogonal and hence do not sum to 100 percent. These percentages, 70 and 15, correspond to each shock's share of the sum of single shock contributions: i.e. $0.70 = \mathbb{V}\left(\Xi^{demand}\right) / \sum_{m\in\{shocks\}} \mathbb{V}\left(\Xi^{m}\right)$.

alone, and hence estimate a secondary, but still moderate, contribution from trade frictions.

One benefit of our approach is its generality. For example, our demand shocks are isomorphic to changes in inventories or non-homotheticities in consumption. Our productivity shocks can also be interpreted as preference shocks. Our trade friction shocks encompass tariff and non-tariff barriers or trade financing costs. These isomorphisms in the framework allow us to match data for many sectors and countries without tying the results to a particular structural model. One of the goals of our analysis is to guide the construction of more detailed models which endogenize these shocks.

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Tables

Durable Manufacturing

(1) Wood and products of wood and cork
(2) Other non-metallic mineral products
(3) Iron & steel
(4) Non-ferrous metals
(5) Fabricated metal products, except machinery & equipment
(6) Machinery & equipment, nec
(7) Office, accounting & computing machinery
(8) Electrical machinery & apparatus, nec
(9) Radio, television & communication equipment
(10) Medical, precision & optical instruments
(11) Motor vehicles, trailers & semi-trailers
(12) Building & repairing of ships & boats
(13) Aircraft & spacecraft
(14) Railroad equipment & transport equip n.e.c.
(15) 50 percent of: Manufacturing nec; recycling (include Furniture)

Non-Durable Manufacturing

(1) Food products, beverages and tobacco
(2) Textiles, textile products, leather and footwear
(3) Pulp, paper, paper products, printing and publishing
(4) Chemicals excluding pharmaceuticals
(5) Pharmaceuticals
(6) Rubber & plastics products
(7) 50 percent of: Manufacturing nec; recycling (include Furniture)

Non-Manufacturing

(1) Agriculture, hunting, forestry and fishing
(2) Mining and quarrying (energy)
(3) Mining and quarrying (non-energy)
(4) Coke, refined petroleum products and nuclear fuel
(5) Production, collection and distribution of electricity
(6) Manufacture of gas; distribution of gaseous fuels through mains
(7) Steam and hot water supply
(8) Collection, purification and distribution of water
(9) Construction
(10) Wholesale & retail trade; repairs
(11) Hotels & restaurants
(12) Land transport; transport via pipelines
(13) Water transport
(14) Air transport
(15) Supporting and auxiliary transport activities; activities of travel agencies
(16) Post & telecommunications
(17) Finance & insurance
(18) Real estate activities
(19) Renting of machinery & equipment
(20) Computer & related activities
(21) Research & development
(22) Other Business Activities
(23) Public admin. & defence; compulsory social security
(24) Education
(25) Health & social work
(26) Other community, social & personal services
(27) Private households with employed persons & extra-territorial organisations & bodies

Table 1: Sector definitions in the OECD Input-Output tables

Notes:

Country	Share of Global GDP in USD (Percent)		Share of Global Exports (Percent)		Share of Global Imports (Percent)	
	2008:Q1	2009:Q2	2008:Q1	2009:Q2	2008:Q1	2009:Q2
Austria	0.7	0.6	1.7	1.6	1.5	1.5
Canada	2.6	2.2	2.7	2.6	3.2	3.4
Chile	0.3	0.3	0.4	0.4	0.3	0.4
China	6.6	7.9	12.6	14.1	7.3	7.5
Denmark	0.6	0.5	0.9	1.0	0.9	1.0
Finland	0.5	0.4	0.9	0.7	0.7	0.6
France	4.8	4.5	5.4	5.2	5.5	5.6
Germany	6.2	5.6	13.4	13.0	9.2	9.8
Greece	0.6	0.6	0.2	0.2	0.6	0.7
Hungary	0.3	0.2	1.0	0.9	0.9	0.8
Italy	3.9	3.6	4.8	4.6	4.0	3.9
Japan	8.1	9.4	7.2	6.0	4.0	4.4
Mexico	1.8	1.5	2.2	2.4	2.5	2.6
Norway	0.8	0.6	0.4	0.5	0.8	0.7
Portugal	0.4	0.4	0.5	0.5	0.7	0.7
South Korea	1.8	1.3	3.6	3.9	2.6	2.5
Spain	2.7	2.5	2.4	2.1	3.3	2.7
Sweden	0.8	0.7	1.6	1.4	1.4	1.2
United Kingdom	4.7	3.6	3.8	3.6	5.1	4.9
United States	23.7	25.8	10.2	11.3	14.4	15.2
Rest of World	28.3	27.7	23.9	24.2	30.9	30.0

Table 2: Country Coverage in Data

Notes:

	No Recession	Recession (First Quarter 2009)					
Shocks:	None	All Shocks Introduced					
		Exports / GDP			Imports / GDP		
	All Vars	All	Durables	Non-Durables	All	Durables	Non-Durables
World	**1.00**	**0.79**	**0.76**	**0.87**	**0.79**	**0.76**	**0.87**
Austria	1.00	0.78	0.74	0.90	0.84	0.81	0.93
Canada	1.00	0.88	0.82	1.02	0.98	0.92	1.13
Chile	1.00	0.87	0.72	1.21	1.09	1.07	1.12
China	1.00	0.74	0.72	0.79	0.67	0.67	0.68
Denmark	1.00	0.91	0.84	0.98	0.89	0.86	0.94
Finland	1.00	0.71	0.68	0.78	0.76	0.71	0.89
France	1.00	0.80	0.75	0.89	0.86	0.82	0.94
Germany	1.00	0.84	0.81	0.94	0.92	0.89	0.99
Greece	1.00	0.81	0.73	0.88	0.88	0.86	0.91
Hungary	1.00	0.86	0.83	1.00	0.84	0.79	0.97
Italy	1.00	0.80	0.77	0.87	0.81	0.75	0.92
Japan	1.00	0.56	0.55	0.65	0.75	0.67	0.89
Mexico	1.00	1.06	1.03	1.20	1.02	1.02	1.04
Norway	1.00	1.01	0.98	1.08	0.91	0.86	1.06
Portugal	1.00	0.77	0.71	0.86	0.83	0.77	0.91
South Korea	1.00	1.15	1.16	1.11	1.03	1.02	1.05
Spain	1.00	0.76	0.69	0.86	0.70	0.63	0.83
Sweden	1.00	0.86	0.79	1.03	0.88	0.81	1.03
United Kingdom	1.00	0.98	0.90	1.13	0.97	0.89	1.13
United States	1.00	0.80	0.79	0.84	0.77	0.73	0.87
Rest of World	1.00	0.82	0.76	0.91	0.79	0.76	0.85

Table 3: Imports/GDP and Exports/GDP over Recession

Notes: All variables expressed relative to global GDP. Calculations using $\beta = 1$ restricted interpolations and extrapolations.

	No Recession	Demand Shocks Only					
Shocks:	None	Durable and Non-Durable Demand Shocks Introduced					
		Exports / GDP			Imports / GDP		
	All Vars	All	Durables	Non-Durables	All	Durables	Non-Durables
World	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Austria	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Canada	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Denmark	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Finland	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
France	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Germany	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Greece	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hungary	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Italy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Japan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mexico	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Norway	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Portugal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Spain	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sweden	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
United Kingdom	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
United States	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rest of World	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4: Counterfactual Results with Demand Shocks Only

Notes: $\theta^D = \theta^N = 2$.All variables expressed relative to global GDP. Calculations using $\beta = 1$ restricted interpolations and extrapolations.

	No Recession	Trade Frictions Only					
Shocks:	None	Durable and Non-Durable Trade Frictions Introduced					
		Exports / GDP			Imports / GDP		
	All Vars	All	Durables	Non-Durables	All	Durables	Non-Durables
World	**1.00**	**0.97**	**0.95**	**1.02**	**0.97**	**0.95**	**1.02**
Austria	1.00	0.94	0.85	1.18	0.92	0.89	0.99
Canada	1.00	0.99	0.96	1.05	0.99	0.99	1.00
Chile	1.00	0.88	0.76	1.15	0.85	0.80	0.92
China	1.00	0.91	0.91	0.91	0.83	0.82	0.84
Denmark	1.00	1.03	0.91	1.16	1.03	0.99	1.09
Finland	1.00	0.96	0.92	1.08	0.94	0.93	0.98
France	1.00	1.02	0.94	1.17	1.02	0.97	1.13
Germany	1.00	1.02	1.01	1.05	1.04	1.03	1.07
Greece	1.00	1.07	1.08	1.06	1.03	1.00	1.07
Hungary	1.00	1.06	1.15	0.72	1.07	1.09	1.02
Italy	1.00	1.01	1.00	1.04	1.02	0.99	1.05
Japan	1.00	0.93	0.94	0.92	0.86	0.83	0.93
Mexico	1.00	0.97	0.91	1.35	0.98	0.94	1.07
Norway	1.00	1.04	1.04	1.05	1.01	0.98	1.10
Portugal	1.00	0.96	0.90	1.06	0.98	0.94	1.05
South Korea	1.00	1.08	1.12	0.92	1.13	1.17	1.04
Spain	1.00	0.93	0.89	0.98	0.95	0.93	1.00
Sweden	1.00	0.97	0.88	1.19	0.95	0.91	1.05
United Kingdom	1.00	1.01	0.96	1.10	1.01	0.97	1.07
United States	1.00	0.97	0.96	1.01	0.98	0.95	1.06
Rest of World	1.00	0.94	0.90	1.00	0.96	0.94	1.00

Table 5: Counterfactual Results with Trade Friction Shocks Only

Notes: $\theta^D = \theta^N = 2$.All variables expressed relative to global GDP. Calculations using $\beta = 1$ restricted interpolations and extrapolations.

	No Recession	Only U.S. Durables Demand Shock					
Shocks:	None	Durable Demand Shock for U.S. Introduced					
		Exports / GDP			Imports / GDP		
	All Vars	All	Durables	Non-Durables	All	Durables	Non-Durables
World	**1.00**	**0.98**	**0.97**	**1.00**	**0.98**	**0.97**	**1.00**
Canada	1.00	0.97	0.93	1.07	0.98	0.97	0.98
China	1.00	1.00	0.99	1.03	0.99	0.99	0.99
Germany	1.00	1.00	1.00	1.01	1.00	1.00	1.00
Japan	1.00	1.00	0.99	1.03	0.98	0.98	0.99
Mexico	1.00	0.96	0.94	1.09	0.97	0.98	0.96
South Korea	1.00	1.00	0.99	1.02	0.99	0.99	0.99
United Kingdom	1.00	0.99	0.99	1.01	1.00	1.00	1.00
United States	1.00	0.89	0.89	0.89	0.91	0.86	1.05
Rest of World	1.00	0.99	0.98	1.02	1.00	0.99	1.00

	No Recession	Only Trade Friction Shocks in China and Japan					
Shocks:	None	Both Trade Frictions Shocks in China and Japan					
		Exports / GDP			Imports / GDP		
	All Vars	All	Durables	Non-Durables	All	Durables	Non-Durables
World	**1.00**	**0.97**	**0.97**	**0.98**	**0.97**	**0.97**	**0.98**
Canada	1.00	1.01	1.02	0.98	1.00	1.01	1.00
China	1.00	0.91	0.90	0.94	0.83	0.82	0.84
Germany	1.00	1.00	1.00	0.99	1.00	1.00	1.01
Japan	1.00	0.93	0.93	0.94	0.86	0.83	0.92
Mexico	1.00	1.00	1.00	1.00	1.00	1.00	1.00
South Korea	1.00	1.02	1.03	1.01	1.03	1.05	0.97
United Kingdom	1.00	1.00	1.00	1.00	1.00	1.00	1.01
United States	1.00	0.98	0.98	0.97	0.98	0.98	1.00
Rest of World	1.00	0.95	0.94	0.98	0.96	0.96	0.97

Table 6: Country/Region-specific Counterfactuals

Notes: $\theta^D = \theta^N = 2$.All variables expressed relative to global GDP. Calculations using $\beta = 1$ restricted interpolations and extrapolations.

Figures

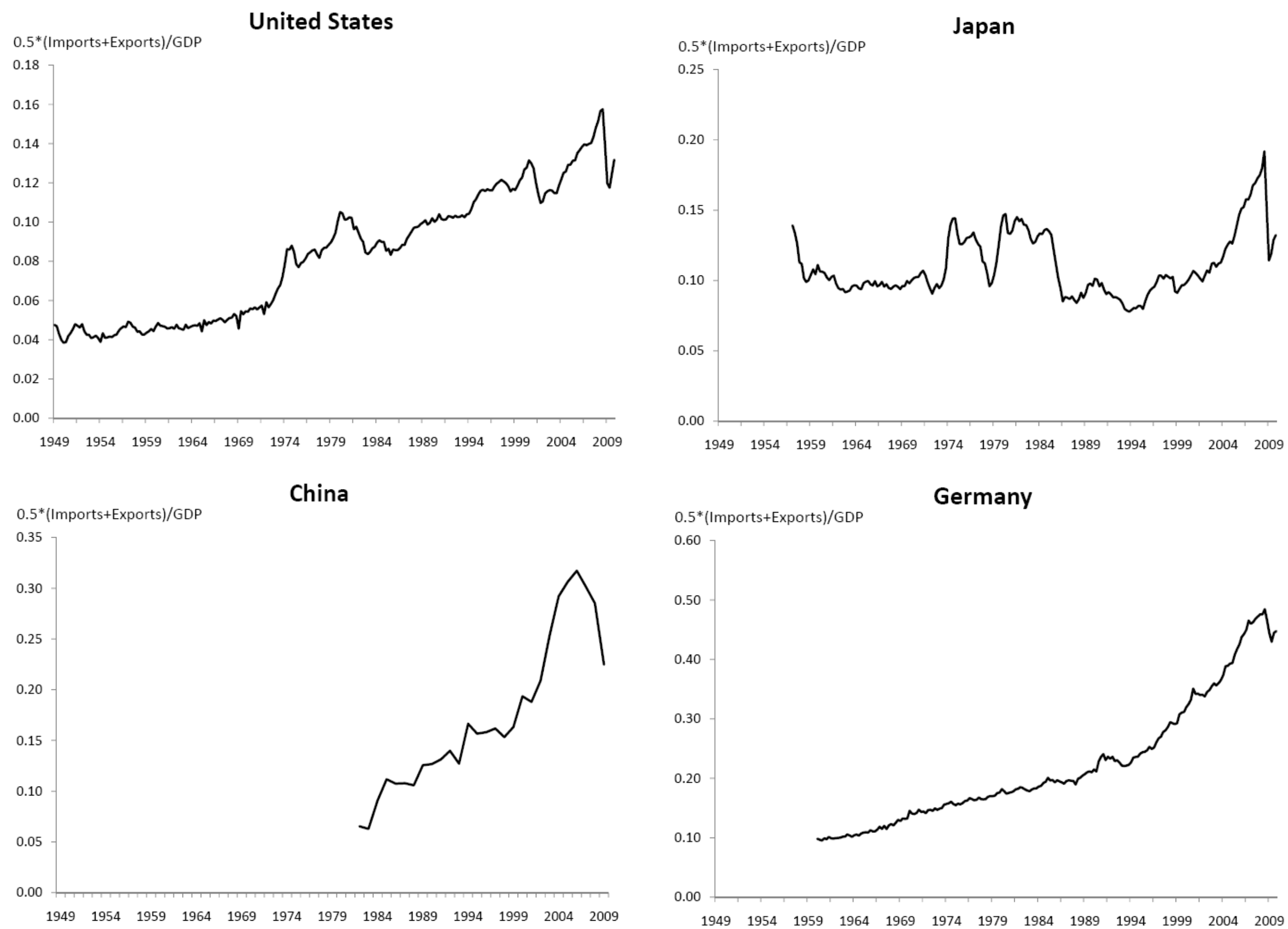


Figure 1: Trade as a Share of Output in the Four Largest Economies

Notes: All data through the end of 2009. United States quarterly data taken from BEA national accounts. Japan quarterly data taken from IMF's IFS database. Germany's quarterly data taken from Source.OECD database. China data only available annually. China's data taken from IFS through 2008. 2009 Trade data for taken from WTO database and GDP estimate from IMF's WEO for China. Trade for United States, Germany, and Japan is goods and services, China is just goods.

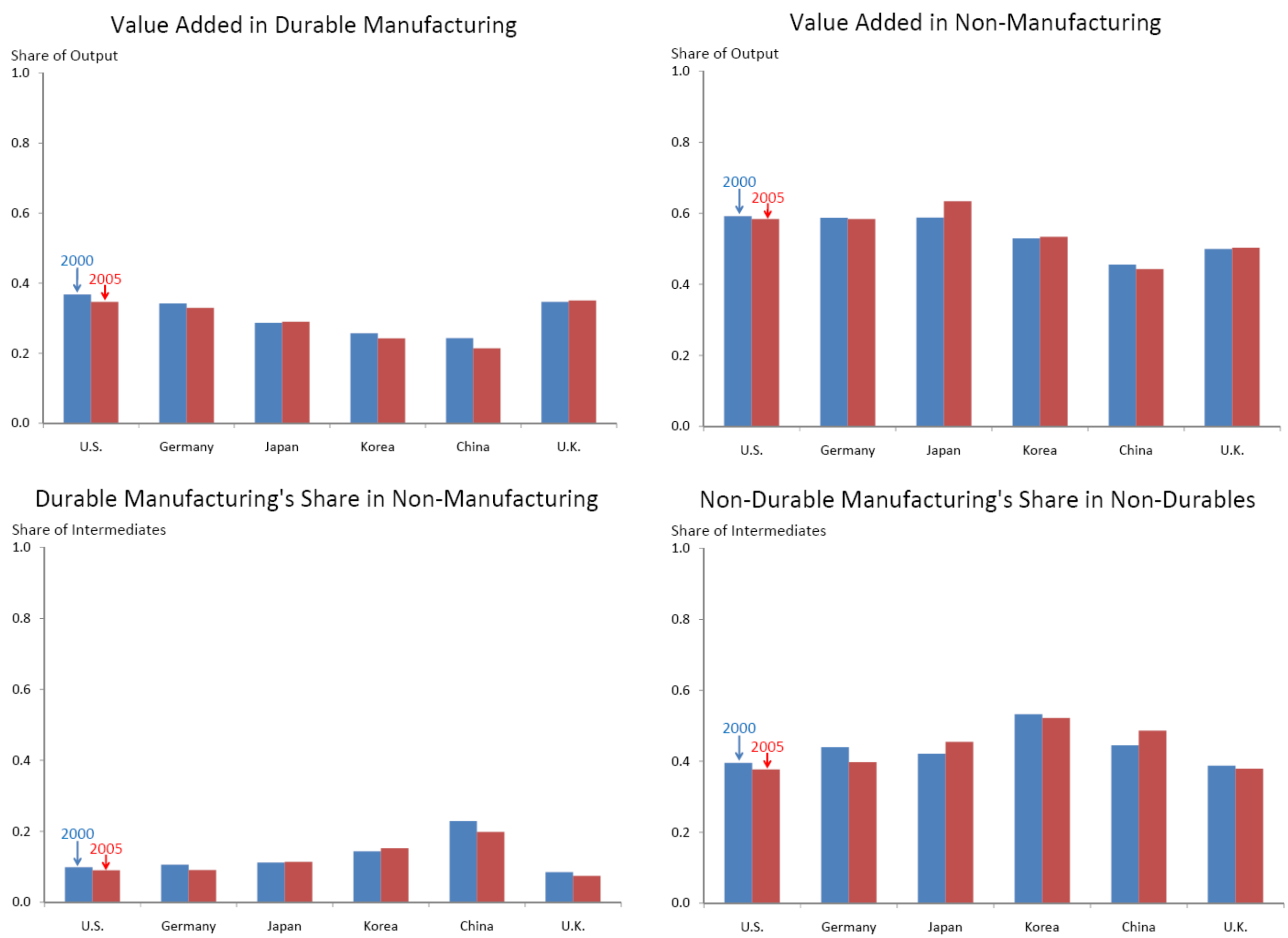


Figure 2: Sample Input-Output Coefficients (β_i^D, β_i^N, γ_i^{ND}, and γ_i^{NN})

Notes: Input-Output coefficients taken from OECD input-Output database, version 2009. See Table 1 for sectoral definitions.

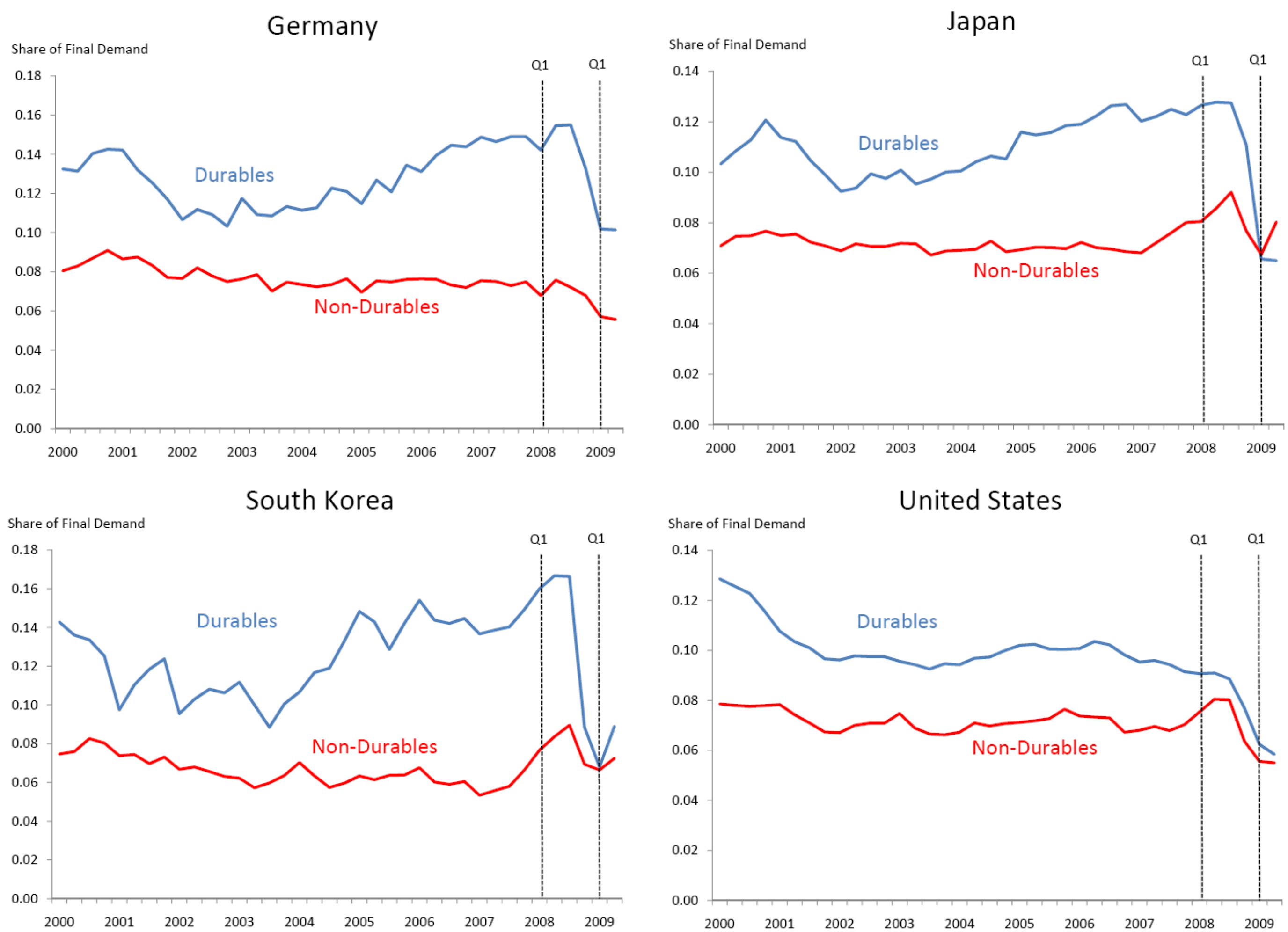


Figure 3: Shares of Manufacturing in Final Demand

Notes: Generated using interpolation procedure with elasticities set to equal one.

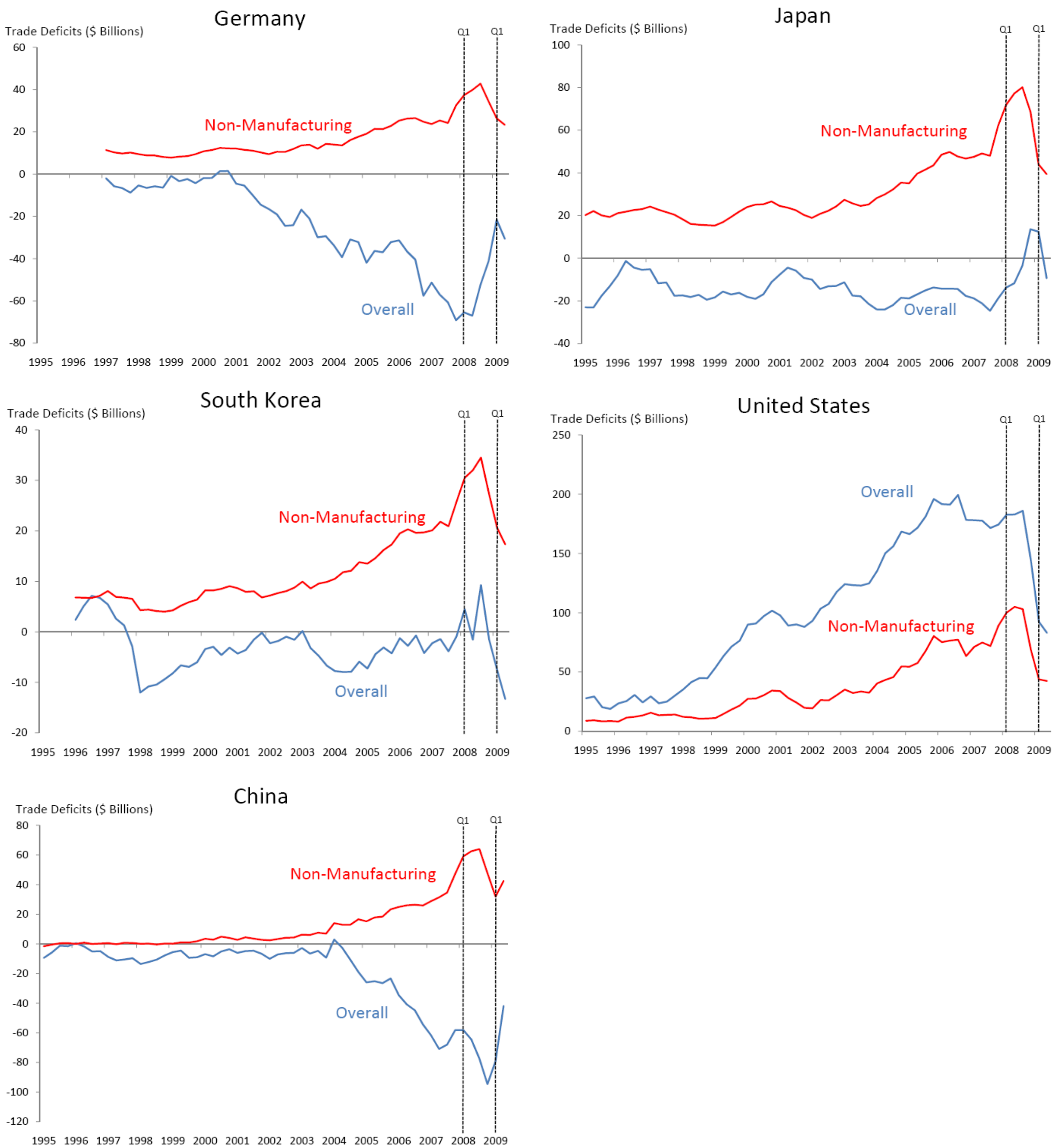


Figure 4: Manufacturing Trade Deficits

Notes:

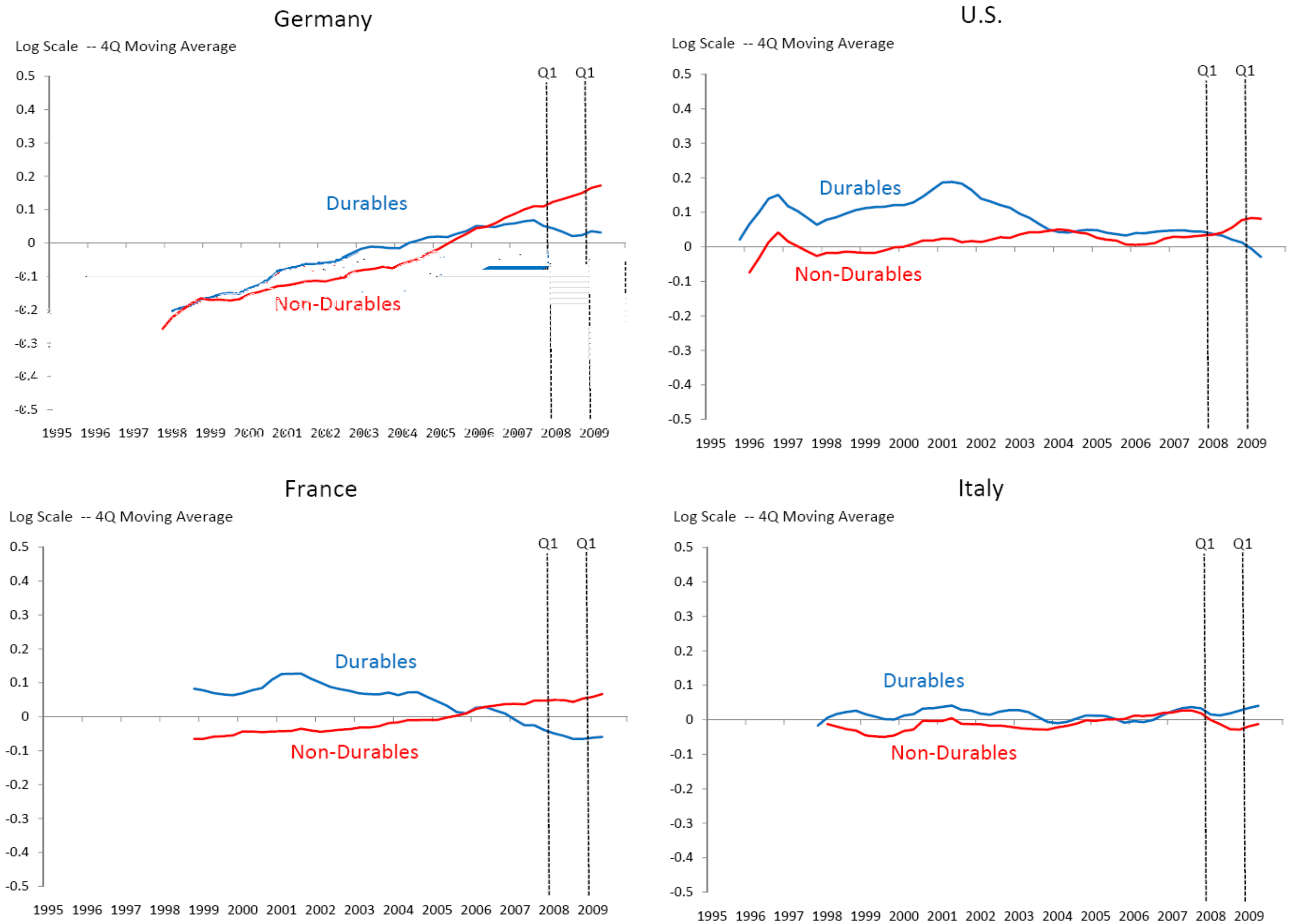


Figure 5: Countries without Large Negative Shock to Trade Frictions

Notes: Generated using interpolation procedure with endogenous elasticites.

Figure 6: Countries with Large Negative Shock to Trade Frictions

Notes: Generated using interpolation procedure with endogenous elasticites.

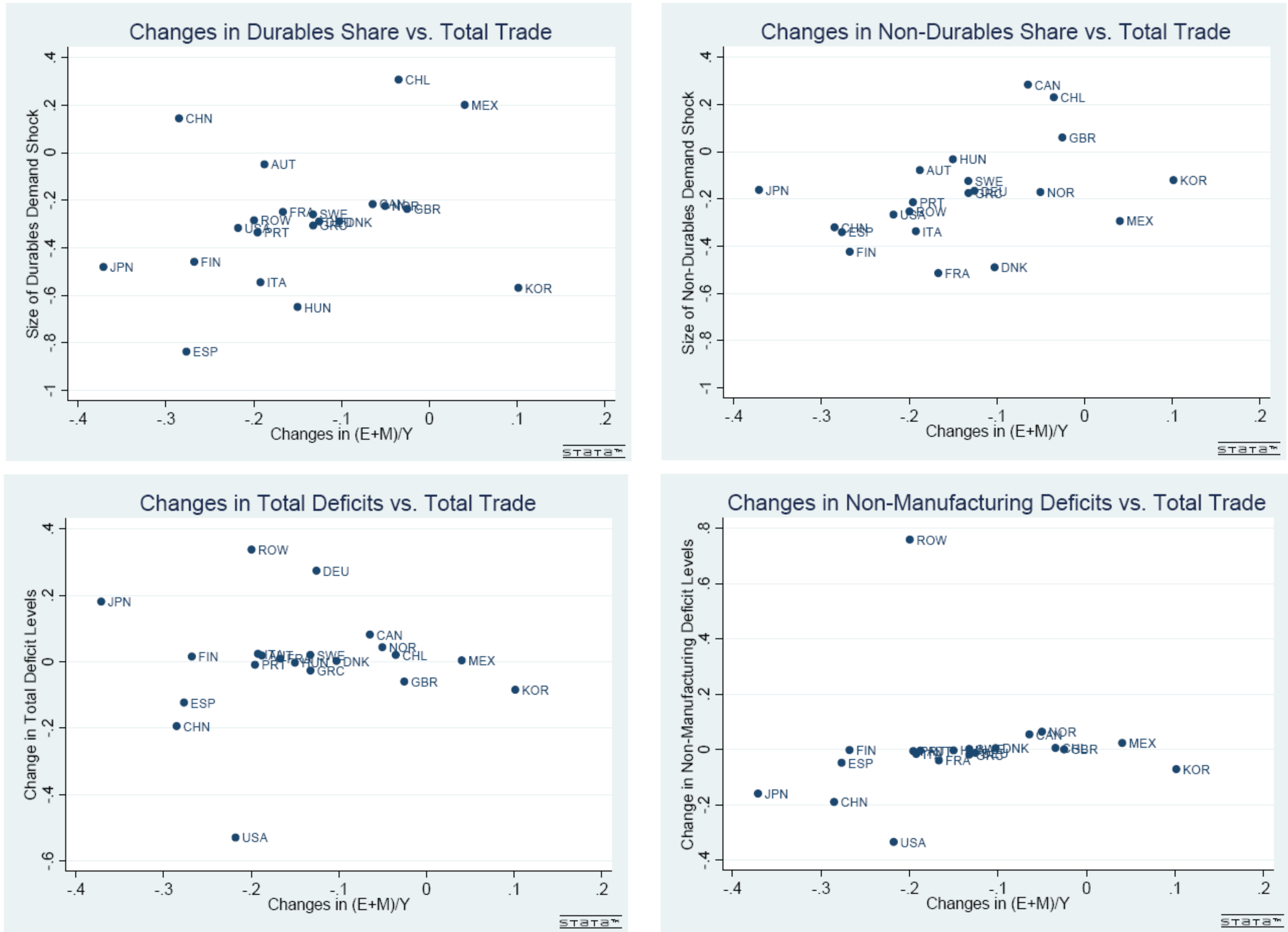


Figure 7: Demand, Deficit Shocks, and Trade from 2008:Q1 to 2009:Q1

Notes: Changes in deficit levels are relative to global GDP.

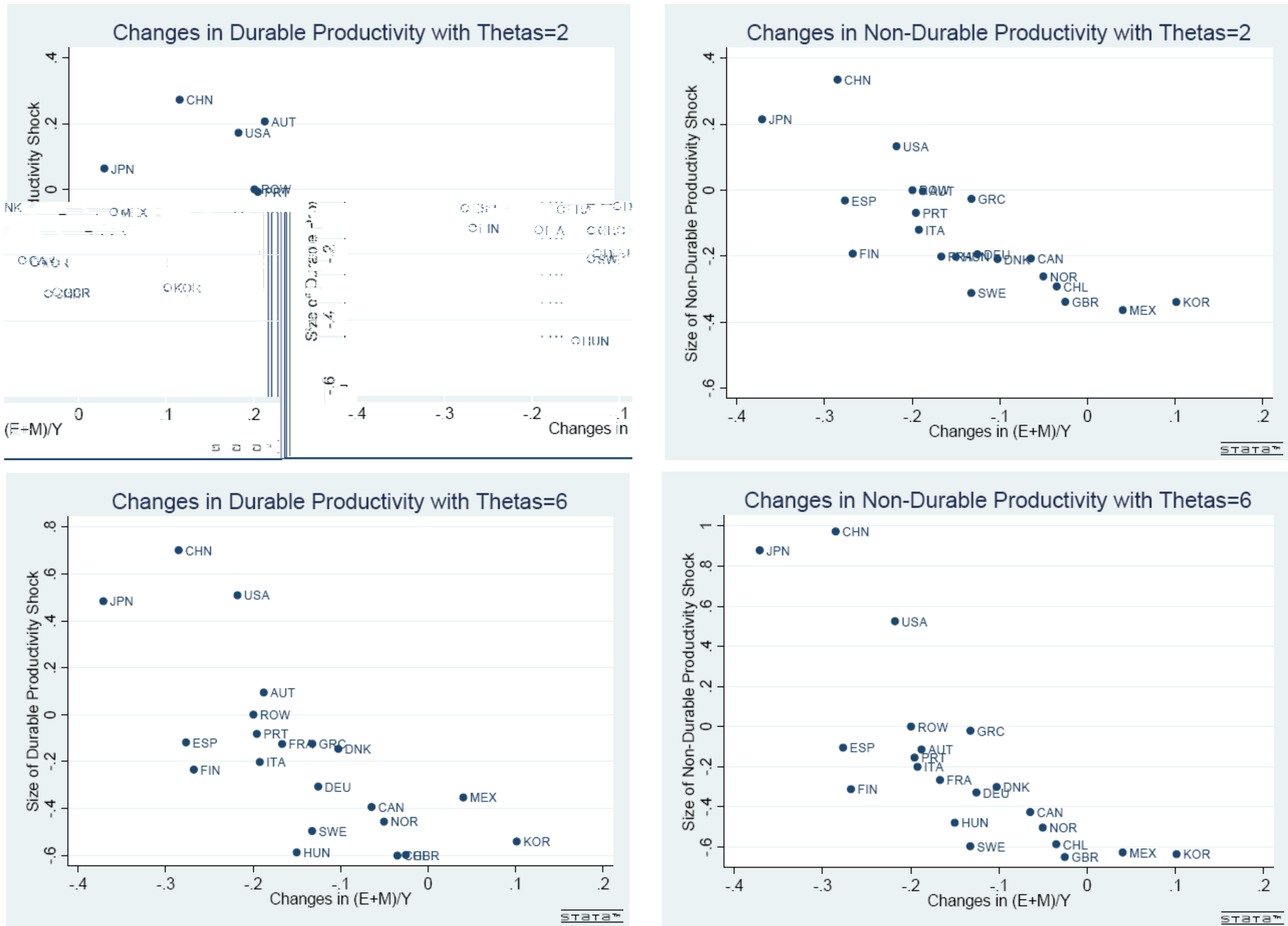
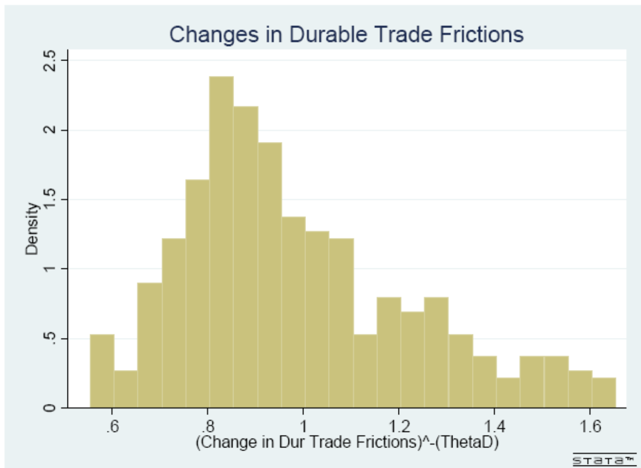


Figure 8: Shocks to Productivity and Trade from 2008:Q1 to 2009:Q1

Notes:



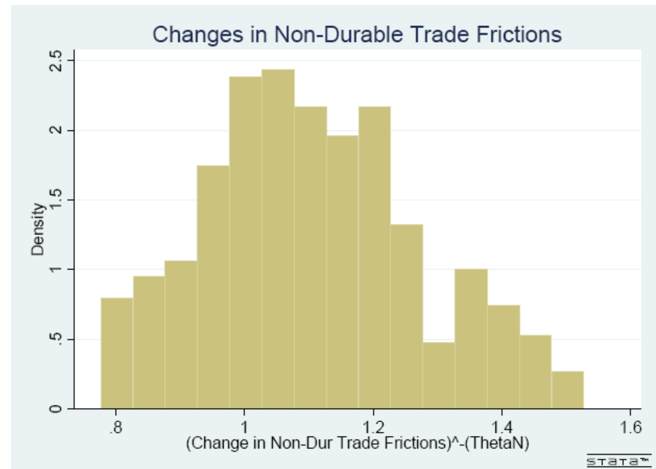


Figure 9: Shocks to Bilateral Trade Frictions from 2008:Q1 to 2009:Q1

Notes: Histograms exclude largest and smallest 5 percentile shocks

Figure 10: Explanatory Power of Deficit and Demand Shocks

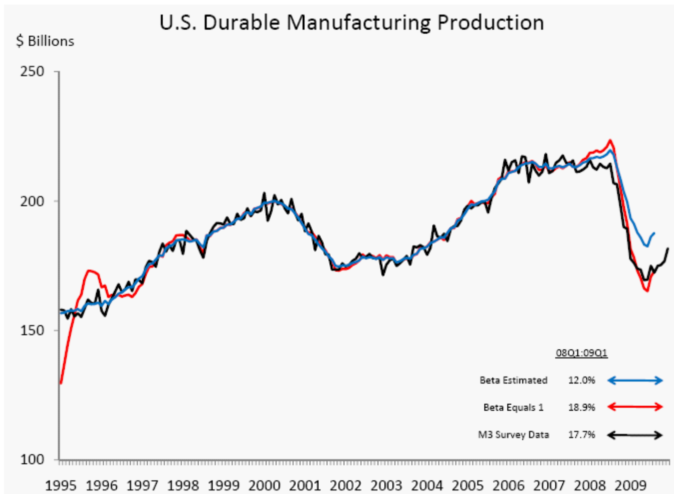
Notes: $\theta^D = \theta^N = 2$

Figure 11: Explanatory Power of Trade Friction and Productivity Shocks

Notes: $\theta^D = \theta^N = 2$

Figure 12: Explanatory Power of Combinations of Shocks

Notes: $\theta^D = \theta^N = 2$



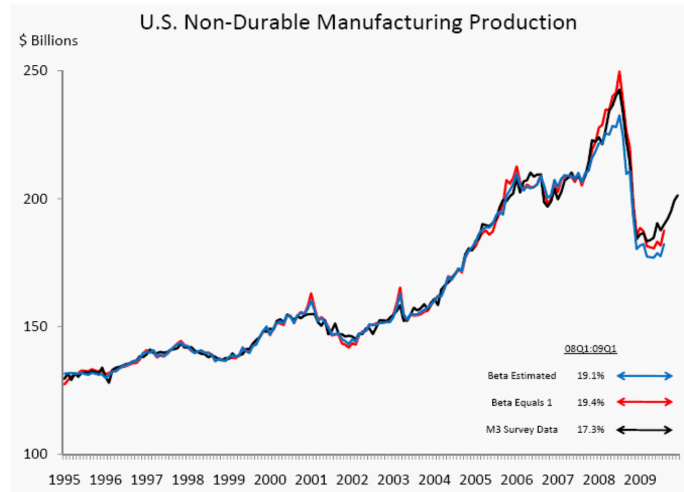


Figure B1: Checking Accuracy of Temporal Disaggregation Procedure for U.S.

Notes: Checking procedure with durable (AMDMVS) and non-durable (AMNMVS) series from Federal Reserve M3 survey (note this is different source from analysis in paper). Annual totals included from 1995-2007 only, even though data starts earlier and is available through 2009, to mirror extent of data used for other countries.

Appendix A: Derivations of Expression (11)

In this appendix, we demonstrate that one can derive the Head-Ries index from many classes of trade models, such as a structure with Armington preferences, as in Anderson and van Wincoop (2003), monopolistic competition as in Redding and Venables (2004), the Ricardian structure in Eaton and Kortum (2002), or monopolistic competition with heterogeneous producers, as in Melitz (2003) and Chaney (2008). To do so, we need only show that each theory of international trade lead to a bilateral import share equation with the same form as equation (11). From there, the derivation of (13) follows exactly as in Section 2. This implies that for the first sections of the paper, we need not specify a particular trade structure, so long as it is in this larger set of models.

1. Consider the model of Armington (1969), as implemented in Anderson and van Wincoop (2003). Consumers in country n maximize:

$$\left(\sum_i \beta_i^{(1-\sigma)/\sigma} c_{ni}^{(\sigma-1)/\sigma}\right)^{\sigma/(\sigma-1)},$$

subject to the budget constraint $\sum_i p_{ni} c_{ni} = y_n$, where σ is a preference parameter representing the elasticity of substitution across goods produced in different countries, $\beta_i > 0$ is a parameter capturing the desirability of of country i's goods, y_n is the nominal income of country n, and p_{ni} and c_{ni} are the price and quantity of the traded good supplied by country i to country n. In their setup, prices reflect a producer-specific cost and a bilateral-specific trade cost: $p_{ni} = p_i t_{ni}$. Solving for the nominal demand of country i for goods from country j then yields their equation (6):

$$x_{ni} = \left(\frac{\beta_i p_i t_{ni}}{P_n}\right)^{1-\sigma} y_n,$$

where $P_n = \left[\sum_k \left(\beta_k p_k t_{nk}\right)^{1-\sigma}\right]^{1/(1-\sigma)}$ is the price index of country n. Substituting this definition and with goods markets clearing, $y_n = \sum_j x_{nj}$, we obtain:

$$\pi_{ni} = \frac{x_{ni}}{\sum_j x_{nj}} = \frac{\left(\beta_i p_i t_{ni}\right)^{1-\sigma}}{\sum_k \left(\beta_k p_k t_{nk}\right)^{1-\sigma}}.$$

Relabeling $\theta = \sigma - 1$ and $T_i = \beta_i^{-\theta}$, we recover an expression equivalent to (11).

2. Consider the model of Krugman (1980), as implemented in Redding and Venables (2004). Like Anderson and van Wincoop, they use a constant elasticity formulation, but they include a fixed cost for firms operating in each country. They express, in their equation (9), the total value of imports to country n from i:

$$x_{ni} = \left(n_i p_i^{1-\sigma}\right) t_{ni}^{1-\sigma} \left(E_n G_n^{\sigma-1}\right),$$

where they refer to $\left(E_n G_n^{\sigma-1}\right)$ as the "market capacity" of the importing country n because it refers to the size of n's market, the number of competing firms that can cover the fixed cost of operation, and the level of competition as summarized by the price index G. They refer to the term $\left(n_i p_i^{1-\sigma}\right)$ as the "supply capacity" of the exporting country i, because fixing the market capacity, the volume of sales is linearly homogeneous in that term. Finally, $T_{ni}^{1-\sigma}$ is the iceberg trade cost for shipping from i to n. Hence, this model too leads to an expression:

$$\pi_{ni} = \frac{x_{ni}}{\sum_j x_{nj}} = \frac{\left(n_i p_i^{1-\sigma}\right) T_{ni}^{1-\sigma}}{\sum_k \left(n_k p_k^{1-\sigma}\right) T_{nk}^{1-\sigma}}.$$

Again, this expression can be relabeled and made equivalent to (11).

3. Consider the competitive model of Eaton and Kortum (2002), where θ and T_i are parameters of a Fréchet distribution of producer efficiency capturing, respectively, heterogeneity across producers (inversely) and country i's absolute advantage. The property of this distribution is such that the probability that country i is the lowest price (production plus transport costs) provider of a good to

country n is an expression identical to (11), their equation (8). Given that average expenditure per good in their model does not vary by source and invoking the low of large numbers, it follows that this probability is equivalent to the trade share.

4. Consider Chaney (2008), which builds on Melitz (2003). Firm productivities are distributed Pareto with shape parameter γ and in addition to iceberg costs τ_{ni}, to sell in market n also requires employing f_{ni} units of local labor. This leads to an expression for total imports by country n from country i, his equation (10) (where we've dropped sectoral terms indexed by h):

$$x_{ni} = \frac{Y_i Y_n}{Y} \theta_n^{\gamma} w_i^{-\gamma} \tau_{ni}^{-\gamma} f_{ni}^{-[\gamma/(\sigma-1)-1]},$$

where notation is similar to the examples above, and θ_n measures what he refers to as country n's "remoteness" from the rest of the world. Summing this over all bilaterals implies:

$$\pi_{ni} = \frac{x_{ni}}{\sum_j x_{nj}} = \frac{Y_i w_i^{-\gamma} \left(\tau_{ni} f_{ni}^{[1/(\sigma-1)-1/\gamma]}\right)^{-\gamma}}{\sum_k Y_k w_k^{-\gamma} \left(\tau_{nk} f_{nk}^{[1/(\sigma-1)-1/\gamma]}\right)^{-\gamma}},$$

which, again, is clearly in the same form as (11).

Appendix B: Temporal Disaggregation Procedure

In this appendix, we describe the procedure used to generate an estimate of the monthly series for gross manufacturing production $Y^M(t)$ when we only have the annual totals for this series:

$$\overline{Y}^M(\tau) = \sum_{t=12(\tau-1)+1}^{12\tau} Y^M(t), \tag{29}$$

where $\tau = 1..T$ denotes the year and $t = 1..12T$ denotes the month. Consider related series Z_q where $q = 1..Q$ that are available at a monthly frequency and contain information on the underlying gross production series. Examples of Z_q are industrial production (IP), the producer price index (PPI), the exchange rate (ER), and potential combinations of these series. Represent the related series data in a $(12T)$-by-Q matrix Z with elements $\{z_{tq}\}$.

Write the annual data in vector form as $\overline{Y}^M = [\overline{Y}_1^M, .., \overline{Y}_T^M]'$, and the estimates for $Y^M(t)$ in vector form as $\widehat{Y^M} = [\widehat{Y_1^M}, .., \widehat{Y_{12T}^M}]'$. Assume a linear relationship between the related series and series we wish to estimate:

$$Y^M = Z\beta + \varepsilon \tag{30}$$

where $\beta = [\beta_1, .., \beta_q]'$ and ε is a random vector with mean 0 and covariance matrix $E[\varepsilon\varepsilon'] = \Omega$. We can write (30) as:

$$\overline{Y}^M = B'Y^M = B'Z\beta + B'\varepsilon,$$

where

$$B = I_T \otimes \Psi,$$

and I_T is the T-by-T identity matrix and Ψ is a 12-by-1 column vector of ones. Hence, $\widehat{\beta}$ and $\widehat{Y^M}$ can be obtained using GLS as:

$$\begin{aligned} \widehat{\beta} &= [Z'B(B'\Omega B)^{-1}B'Z]^{-1}Z'B\,(B'\Omega B)^{-1}\,\overline{Y}^M \\ \widehat{Y^M} &= Z\widehat{\beta} + \Omega B(B'\Omega B)^{-1}[\overline{Y}^M - B'Z\widehat{\beta}] \end{aligned} \tag{31}$$

Consider the simplest assumption that there is no serial correlation and equal variance in the monthly residuals, or $\Omega = \sigma^2 I_{12T}$. Then, equation (31) simplifies to:

$$\widehat{Y^M} = Z\widehat{\beta} + B[\overline{Y}^M - B'Z\widehat{\beta}]\frac{1}{12}$$

because $(B'B)^{-1} = 1/12$. This implies that the annual discrepancy $B'\varepsilon$ be distributed evenly across each month of that year. Given the failure of the zero serial correlation assumption in the data, this would create obvious and spurious discontinuities near the beginning and end of each year.

We now follow Fernandez (1981) and consider a similar procedure, but with a transformation designed to transform a model with serially correlated residuals into one with classical properties, and then to apply a procedure similar to the one above, to deal with the disaggregation of annual values. Consider the case where the error term from equation (30) followed a random walk:

$$\varepsilon_t = \varepsilon_{t-1} + \mu_t,$$

where μ_t has no serial correlation, zero mean, and constant variance σ^2. Consider the first difference transformation D:

$$D_{12T\text{-by-}12T} = \begin{bmatrix} 1 & 0 & 0 & . & 0 & 0 \\ -1 & 1 & 0 & . & 0 & 0 \\ 0 & -1 & 1 & . & 0 & 0 \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ 0 & 0 & 0 & . & -1 & 1 \end{bmatrix}.$$

One can premultiply the error in equation (30) by this matrix to generate: $DY^M - DZ\beta$, which converts the both left and right hand sides of the model into first-difference form, with the exception being the first terms given the upper left hand element equals one. With these first-differenced series, we can re-write the

model as:

$$D\overline{Y}^M = DZ\beta + D\varepsilon.$$

Note that $\Omega = E[D\varepsilon\varepsilon' D'] = E[\mu\mu'] = \sigma^2 I_{12T}$, so errors in this reformulated model have classical properties. Fernandez shows that the expression for the best linear estimator in this context is the same as (31), but with $\Omega = (D'D)^{-1}$:

$$\begin{aligned} \widehat{\beta} &= [Z'B(B'(D'D)^{-1}B)^{-1}B'Z]^{-1}Z'B\left(B'(D'D)^{-1}B\right)^{-1}\overline{Y}^M \\ \widehat{Y^M} &= Z\widehat{\beta} + (D'D)^{-1}B(B'(D'D)^{-1}B)^{-1}[\overline{Y}^M - B'Z\widehat{\beta}] \end{aligned} \tag{32}$$

The relationship (30) is written in levels, but it is clearly more appropriate for our purposes to write the relationship between production and production indicators in log-levels, such that a given percentage change in one variable leads to a percentage change in the other:

$$\ln Y^M = (\ln Z)\,\beta + \varepsilon. \tag{33}$$

This can be somewhat difficult to handle in the above framework, however, because the sum of the log of monthly totals will not equal the log of the annual total when the adding-up constrain does hold in levels. We deal with this by running the algorithm on annual data that has been converted such that the sum of fitted monthly data will approximate the original annual levels. This cannot be achieved exactly, so a second-stage procedure is then implemented to distribute the residuals across the months and ensure the aggregation constraints bind exactly.

Following Di Fonzi (2002), we consider the first order Taylor series approximation of $\ln Y^M$ around the log of the arithmetic average for the monthly totals, $\ln(\overline{Y}^M/12)$. We write:

$$\ln Y^M = \widetilde{Y^M} \approx \ln\frac{\overline{Y}^M}{12} + \frac{12}{\overline{Y}^M}\left(Y^M - \frac{\overline{Y}^M}{12}\right) = \ln\overline{Y}^M - \ln 12 + 12\frac{Y^M}{\overline{Y}^M} - 1.$$

Summing this expression up over the twelve months, we get:

$$\sum_{j=1}^{12}\widetilde{Y_j^M} = 12\ln\overline{Y}^M - 12\ln 12.$$

Hence, we can follow the above procedure, except we replace the left hand size of (33) with $\widetilde{Y^M} = 12\ln\overline{Y}^M - 12\ln 12$ and the right hand size with $\sum_{j=1}^{12}\ln Z_j$.

This approximation should come close to satisfying the temporal aggregation constraints, but will fail to do so exactly. Hence, the final step is to adjust the estimates following Denton (1971). Denoting the initial fitted values as $\widehat{Y^M}$ and the residuals $\overline{Y}^M - \sum_{t=1}^{12}\widehat{Y_t^M} = R$ (in vector form), we make the final adjustment:

$$\widehat{Y^{M*}} = \widehat{Y^M} + (D'D)^{-1}B'(B(D'D)^{-1}B')^{-1}R.$$

Appendix C: Solving for the Equilibrium

In this appendix, we explain in more detail how we solve for the system's equilibrium. First we plug (**??**) into (18) and then, given a vector of wage changes $\widehat{\boldsymbol{w}}$, we solve (18) and (19) jointly for changes in trade shares and prices. Denote the solution for changes in trade shares by $\pi^j_{ni}(\widehat{w}) = \left(\pi^j_{ni}\right)'$.

Second, we can substitute the service sector out of equation (3) to get

$$\begin{bmatrix} \left(X^D_i\right)' \\ \left(X^N_i\right)' \end{bmatrix} = \widetilde{\boldsymbol{\alpha}}'_i \left(Y'_i + D'_i\right) - \boldsymbol{\delta}_i \left(D^S_i\right)' + \widetilde{\boldsymbol{\Gamma}}^T_i \begin{bmatrix} \left(Y^D_i\right)' \\ \left(Y^N_i\right)' \end{bmatrix}, \tag{34}$$

where the 2 by 1 vector $\widetilde{\boldsymbol{\alpha}}_i$ has elements

$$\left(\widetilde{\alpha}^j_i\right)' = \left(\alpha^j_i\right)' + \left(\alpha^S_i\right)' \delta^j_i,$$

the 2 by 1 vector $\boldsymbol{\delta}_i$ has elements

$$\delta^j_i = \frac{\gamma^{Sj}_i (1-\beta^S_i)}{1-\gamma^{SS}_i (1-\beta^S_i)},$$

and the 2 by 2 matrix $\widetilde{\boldsymbol{\Gamma}}_i$ contains

$$\widetilde{\gamma}^{jl}_i (1-\widetilde{\beta}^j_i)$$

in its j'th row and l'th column for all $j, l \in \Omega_M$.

Third, we follow the approach of Caliendo and Parro (2009) and substitute (16) into the right hand side of (34). Given wage changes, we obtain a linear system in the $\left(X^j_i\right)'$'s by stacking (34) across all countries:

$$\mathbb{X}' = (\widetilde{\boldsymbol{\alpha}}\mathbf{X})' - \left(\delta \mathbb{D}^S\right)' + \widetilde{\boldsymbol{\Gamma}}^T \left[\boldsymbol{\Pi}(\widehat{w})\right]^T \mathbb{X}'.$$

Here

$$\mathbb{X}' = \left[\left(X^D_1\right)', \left(X^D_2\right)', ..., \left(X^D_I\right)', \left(X^N_1\right)', \left(X^N_2\right)', ..., \left(X^N_I\right)'\right]^T,$$

$$(\widetilde{\boldsymbol{\alpha}}\mathbf{X})' = \left[\left(\widetilde{\alpha}^D_1 X_1\right)', \left(\widetilde{\alpha}^D_2 X_2\right)', ..., \left(\widetilde{\alpha}^D_I X_I\right)', \left(\widetilde{\alpha}^N_1 X_1\right)', \left(\widetilde{\alpha}^N_2 X_2\right)', ..., \left(\widetilde{\alpha}^N_I X_I\right)'\right]^T,$$

with

$$\left(\widetilde{\alpha}^j_i X_i\right)' = \left(\widetilde{\alpha}^j_i\right)' \left(\hat{w}_i Y_i + D'_i\right),$$

$$\left(\delta \mathbb{D}^S\right)' = \left[\delta^D_1 \left(D^S_1\right)', \delta^D_2 \left(D^S_2\right)', ..., \delta^D_I \left(D^S_I\right)', \delta^N_1 \left(D^S_1\right)', \delta^N_2 \left(D^S_2\right)', ..., \delta^N_I \left(D^S_I\right)'\right]^T,$$

$$\widetilde{\boldsymbol{\Gamma}} = \begin{bmatrix} \widetilde{\gamma}^{DD}_1 (1-\widetilde{\beta}^D_1) & 0 & 0 & \widetilde{\gamma}^{DN}_1 (1-\widetilde{\beta}^D_1) & 0 & 0 \\ 0 & \ddots & 0 & 0 & \ddots & 0 \\ 0 & 0 & \widetilde{\gamma}^{DD}_I (1-\widetilde{\beta}^D_I) & 0 & 0 & \widetilde{\gamma}^{DN}_I (1-\widetilde{\beta}^D_I) \\ \widetilde{\gamma}^{ND}_1 (1-\widetilde{\beta}^N_1) & 0 & 0 & \widetilde{\gamma}^{NN}_1 (1-\widetilde{\beta}^N_1) & 0 & 0 \\ 0 & \ddots & 0 & 0 & \ddots & 0 \\ 0 & 0 & \widetilde{\gamma}^{ND}_I (1-\widetilde{\beta}^N_I) & 0 & 0 & \widetilde{\gamma}^{NN}_I (1-\widetilde{\beta}^N_I) \end{bmatrix},$$

and

$$\boldsymbol{\Pi}(\widehat{w}) = \begin{bmatrix} \Pi^D(\widehat{w}) & 0 \\ 0 & \Pi^N(\widehat{w}) \end{bmatrix},$$

where $\left(\Pi^j\right)'(\widehat{w})$ has $\pi^j_{ni}(\widehat{w})$ in its n'th row and i'th column. We can denote the solution by

$$\mathbb{X}(\widehat{w}) = \left[\boldsymbol{I} - \widetilde{\boldsymbol{\Gamma}}^T \left[\boldsymbol{\Pi}(\widehat{w})\right]^T\right]^{-1} \left[(\widetilde{\boldsymbol{\alpha}}\boldsymbol{X})' - \left(\delta \mathbb{D}^S\right)'\right],$$

where the elements of $\mathbb{X}(\widehat{w})$ are $X^j_i(\widehat{w}) = \left(X^j_i\right)'$.

Finally, summing up (16) over $j \in \Omega_M$ yields

$$X^D_i(\widehat{w}) + X^N_i(\widehat{w}) - \left(D'_i - \left(D^S_i\right)'\right) = \sum_{n=1}^{I} \pi^D_{ni}(\widehat{w}) X^D_n(\widehat{w}) + \sum_{n=1}^{I} \pi^N_{ni}(\widehat{w}) X^N_n(\widehat{w}). \tag{35}$$

This non-linear system of equations can be solved for the $I - 1$ changes in wages.