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ABSTRACT

Global trade fell 30 percent relative to GDP during the Great Recession of 2008-2009. Did this collapse result from factors impeding international transactions or did it simply reflect the greater severity of the recession in highly traded sectors? We answer this question with detailed international data, interpreted within a general-equilibrium trade model. Counterfactual simulations of the model show that a shift in spending away from manufactures, particularly durables, accounts for more than 80 percent of the drop in trade/GDP. Increased trade impediments reduced trade in some countries, but globally the impact of these changes largely cancels out.

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1 Introduction

Global trade plunged by nearly 30 percent relative to GDP during the Great Recession of 2008-2009. The four panels of Figure 1 plot the average of imports and exports relative to GDP for the four largest economies in the world: the United States, Japan, China, and Germany. Trade/GDP fell sharply in each of these countries since 2008. This large drop in international trade has generated significant attention and concern. 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."[1]

Given traded goods sectors such as durable manufactures are procyclical, one explanation is that trade fell relative to GDP due to the changing composition of global output in the recession. Another is that increasing trade frictions at the international border, broadly defined, might be the culprit. This paper investigates the relative contributions of these two hypotheses, both globally and at the country level.

Our conclusion is that the bulk of the decline in international trade is attributable to the decline in the share of demand for tradables. Changes in demand for durable manufactures alone accounted for about 65 percent of the cross-country variation in changes in manufacturing trade/GDP from the first quarter of 2008 to the first quarter of 2009, four quarters encompassing the steep decline in trade. The decline in total manufacturing demand (durables and non-durables) accounted for more than 80 percent of the global decline in trade/GDP in 2008 and 2009.

The decline in trade for some countries (and between some country pairs) did exceed what one would expect simply from the changing composition of demand. Hence, increasing trade frictions independently contributed to the troubles facing the global economy and played an important role in some countries, particularly China and Japan. Our calculations suggest, however, that other countries saw reductions in trade frictions over this period. Globally, these effects largely cancel out. When we perform related calculations on data from the Great Depression, we find very different evidence, suggesting a dramatic increase in trade frictions for the United States in the early 1930s.

Our analytic tool for this investigation is a multi-sector model of production and trade,

[1] *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 pose various hypotheses in Baldwin (2009).

calibrated to sectoral data on output and bilateral trade from recent quarters. We run counterfactuals to determine what the path of trade would have been without the shift in demand away from the manufacturing sectors and without the increase in trade frictions.[2] Our approach also allows us to decompose the extent to which what happened to an individual country was the consequence of (i) shocks hitting it directly and (ii) shocks hitting other countries transmitted to it through trade.

We proceed as follows. The next section reviews some major explanations that have been offered for the recent trade collapse. Section 3 reviews some basic evidence on what happened to trade and manufacturing production over the recent period. Section 4 presents a framework to make use of this evidence to quantify the contributions of various shocks to the collapse of GDP. Section 5 explains how we take this framework to the data. We then, in Section 6, decompose what happened through the examination of various counterfactuals in which various shocks are suppressed. As a final exercise, in Section 7 we compare the recent experience to the declines in trade during the 2001 U.S. recession and during the great Great Depression. Section 8 concludes.

2 Trade Decline: Hypotheses

The literature offers various explanations for the decline in trade flows relative to overall economic activity. Levchenko et al. (2010) use U.S. data to show that the recent decline in trade is large relative to previous recessions. They document the relative decline in demand for tradables, particularly durable goods.[3]

Bems et al. (2010) combine Leontief preferences and technologies with the input-output structure from Johnson and Noguera (2009) to link changes in final demand during the recent recession to changes in trade flows throughout the global system. This work suggests that the changing composition of GDP can largely account for the decline in trade relative to GDP.[4]

[2] Just as growth accounting uses a theoretical framework to decompose output growth into the growth of labor and capital inputs as well as the Solow residual, we use our model to decompose changes in trade flows into factors such as changes in trade frictions and the composition of demand. Closer to Chari et al. (2007) "wedges" approach to business cycle accounting, our decomposition relies on model-based general equilibrium counterfactual responses to various shocks.

[3] Engel and Wang (2009) also stress the different cyclical properties of durables and non-durables, both generally as well as during the recent recession.

[4] A pair of firm-level analyses for European countries support the view that a shift in the composition

Other work suggests that trade frictions or phenomena that increase home-bias, are of first-order importance. For instance, given that many economies' banking systems have been in crisis, one leading hypothesis is that a collapse in trade credit has contributed to the breakdown in trade. Amiti and Weinstein (2010) demonstrate that the health of Japanese firms' banks significantly affected the firms' export activity, 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 role of reduced trade credit availability in explaining the recent trade collapse.

Others note that protectionist measures have exerted an extra drag on trade. 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. 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). In addition, dynamics associated with the inventory cycle may be generating disproportionately severe contractions in trade, as in Alessandria et al. (2010a, 2010b). Finally, fiscal stimulus measures implemented worldwide may be home-biased due to political pressures on government purchases. All of these potential disruptions can be broadly construed as reflecting international trade frictions, where some factor is directly affecting goods which cross the international border per se.

Papers such as Levchenko et al., Chor and Manova, and Amiti and Weinstein analyze data from a single country in partial equilibrium, but they are able to use highly disaggregated data which allow for clean identification of various effects. We view our work as complementary to these country-specific empirical studies. Our framework has the benefit of being able to evaluate hypotheses for the trade decline in a multi-country quantitative

of demand, rather than a collapse of trade credit or of global supply chains, was behind the decline in trade. Behrens et al. (2010), looking at the imports and exports of Belgian firms, find that trade in consumer durables and in capital goods fell much more than in other products, while financial factors and participation in supply chains affected domestic and foreign activity in proportion. Bricongne et al. (2010), looking at exports of French firms, find that those involved in durable goods were much more affected by the crisis, although they also find that dependence on external finance mattered.

general equilibrium model.

3 A First Look at the Data

Before turning to our analytic framework for disentangling the forces driving the decline in trade, we look at some of the key variables to see how much of what happened during the Great Recession represents a departure from previous experience.[5] We first look at how trade relative to GDP relates to real GDP growth over the last 50 years. We then turn to how spending on manufactures, which constitute the major component of trade for most OECD countries, varies with GDP over the same period. Finally, we look at the relationship between trade in manufactures and manufacturing production over the last decade. These relationships in the raw data lie underneath the results of our subsequent calibration exercise.

3.1 Trade and GDP

Is the decline in trade relative to GDP during the Great Recession anomalous or just the manifestation of a business cycle regularity? To get a handle on the answer, Figure 2 plots four-quarter changes in non-oil imports relative to GDP against the change in real GDP for the United States, Japan, China, and Germany from the first quarter of 1960 (1960:Q1) through 2009:Q4.[6] The Great Recession observations appear as solid squares and the others as hollow circles. We include regression lines based on the observations prior to the Great Recession. Note that, for the United States and Germany, the slope of the line is distinctly positive and that the observations for the Great Recession lie close to the regression line based on the prior period. They are, of course, at the lower left-hand tail, reflecting the fact that the Great Recession was the worst recession in the period. For Japan and China, however, there is little or no relationship between imports and GDP in the earlier years. So the decline in trade/GDP that these countries experienced during the Great Recession

[5] Appendix A describes the data used throughout the paper. We take most data, such as input-output elasticities, monthly trade flows, and annual production levels, directly from international sources. In addition, we construct our own monthly indicators for industrial production and producer prices in the durable and non-durable sectors by taking a weighted average of the equivalent indicators from more disaggregated sectors. Finally, we use a procedure, described in Appendix A, called temporal disaggregation, to extract internally-consistent monthly production data using these monthly indicators and annual production data.

[6] Throughout this paper, we deal with seasonality by examining four-quarter changes in the data. Due to data limitations, China's plot is of manufacturing imports relative to GDP (and is manufacturing production relative to GDP in Appendix Figure 1).

represents a departure from previous patterns.

3.2 Manufacturing and GDP

To consider the potential role of composition effects, we similarly examine the four-quarter changes in the share of spending on manufactures relative to changes in real GDP for the same four countries over the same period, separating the Great Recession from other observations as above.[7] For all four countries the slope, based on the earlier period, is positive, with the Great Recession observations not appearing anomalous.

3.3 Trade and Manufacturing Production: The Head-Ries Index

For some countries, at least, a decline in trade and a decline in spending on manufactures are symptomatic of a recession. To what extent did trade in manufactures decline by more than what we would expect given the decline in spending on manufactures? To get some handle on the answer we calculate an indicator of trade frictions between individual country pairs. To our knowledge the indicator first appears in Head and Ries (2001), so we refer to it as the Head-Ries index.

The index can be derived from a standard gravity equation of the form:

$$X_{ni} = \kappa \frac{Z_n^I Z_i^E}{\tau_{ni}},$$

where Z_n^I is a vector of destination characteristics, Z_i^E a vector of source characteristics (where GDP is often used for each), and $\tau_{ni} \geq 1$ an indicator of the frictions thwarting exports from i to n (often proxied by distance). Assume that the relationship applies to home sales X_{ii} as well, with $\tau_{ii} = 1$. Then the Head-Ries index for trade between i and n is given by:

$$\Theta_{ni} = \left(\frac{X_{ni}}{X_{nn}} \frac{X_{in}}{X_{ii}} \right)^{1/2} = (\tau_{ni}\tau_{in})^{-1/2}. \quad (1)$$

Note that this measure extracts (inversely) the pure trade friction component of the gravity equation (although it can't distinguish directional elements in them).[8] We calculate the

[7] These relationships are plotted in Appendix Figure 1.

[8] The index is invariant to scale or to the relative size and productivity of trading partners, unlike simpler measures such as the ratio of imports or exports to production. Head and Ries (2001) use the index, equation (8) in their paper, to measure the border effect on trade between the United States and Canada for several

index separately for durable and non-durable manufactures by using trade data to obtain X_{ni} for $n \neq i$ and data on production and exports to calculate X_{ii} over the period 2000:Q1 through 2009:Q4 for the 22 countries listed in Table 1.[9]

Figure 3 plots the six bilateral Head-Ries indices involving the United States, Japan, China, and Germany, separating durables and non-durables.[10] If trade frictions increased during the Great Recession then we should notice a decline in the index during the last several quarters. The results are mixed. In the relationships in which Germany participates there is no notable decline, with the index for non-durables sometimes rising. For these relationships the recession seemed to apply to domestic activity (the denominator of (1)) as much or more than to foreign transactions (the numerator of (1)). For some of the relationships involving China or Japan, however, the indices decline markedly starting in 2008.

Figure 4 summarizes the trend in trade frictions at the country level. We estimate country-time fixed effects from a pooled regression of $\ln \Theta_{ni}$, weighting observations by the value of the numerator of (1) in 2008:Q1 in order to emphasize more important trading partners. Consistent with plots of the bilateral relationships, we see that the recession did not imply large increases in trade frictions for the United States and Germany, while there is a steep increase in trade frictions for Japan and China. Looking across all the countries in our data, the time fixed effects decreased in exactly half of them for durable manufacturing and slightly less than half for non-durable manufacturing between 2008:Q1 and 2009:Q1. Our conclusion is that changes in trade frictions appear to be quite heterogenous across countries, and are often relatively muted.

These simple summary relationships suggest that both a general decline in spending on manufactures and, for at least some countries, an increase in trade frictions, may account for the trade collapse. To assess the quantitative contribution of each, as well as of other potential factors, we turn to our framework for combining these different sources of information into a model.

manufacturing industries. Jacks et al. (2009) study a very similar object for a span of over 100 years to analyze long-term changes in trade frictions. Also see Anderson and Yotov (2009) for related estimates of bilateral trade frictions.

[9] Country n's purchases of domesticly produced goods, X_{nn}, is equal to gross production less exports: $X_{nn} = Y_n - \sum_{i \neq n} X_{in}$.

[10] In order to minimize seasonal effects, Figure 3 as well as Figure 4 below plot four-quarter moving averages.

4 A Framework to Analyze the Global Recession

Our general equilibrium framework builds on Eaton and Kortum (2002), Lucas and Alvarez (2008), and Dekle et al. (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.

We start by describing the input-output structure. Next, we merge this structure with a model of bilateral trade. We treat some parameters of the model as fixed over time while allowing others to vary, but for ease of exposition, we omit time subscripts until that distinction becomes relevant.

4.1 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 indexed by j: durable manufacturing ($j = D$), non-durable manufacturing ($j = N$), and non-manufacturing ($j = S$). The label S was chosen because "services" are a large share of non-manufacturing, although our category also includes agriculture, petroleum and other raw materials. We let $\Omega = \{D, N, S\}$ denote all sectors and $\Omega_M = \{D, N\}$ denote the manufacturing sectors.

We model international trade explicitly only for the manufacturing sectors. Net trade in the S sector 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 documented in Levchenko et al. (2009).

Let Y_i^j denote country i's gross production in sector $j \in \Omega$, X_i^j its gross absorption of j, and $D_i^j = X_i^j - Y_i^j$ its deficit in j. Country i's 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^F, aggregate final spending is $X_i^F = Y_i^F + D_i$. The relationship between GDP and sectoral gross outputs depends on the input-output structure, to which we now

turn.

Sectoral outputs are used both as inputs into production and to satisfy final demand. We assume a Cobb-Douglas aggregator of sectoral inputs.[11] 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 intermediates used by sector j, with $\sum_l \gamma_i^{jl} = 1$ for each $j \in \Omega$.[12]

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

$$Y_i^F = \sum_{j \in \Omega} \beta_i^j Y_i^j. \tag{2}$$

We assume a single factor, which we call labor, treating it as perfectly mobile across sectors.[13] Hence:

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

Finally, we denote by α_i^j the share of sector $j's$ output in country i's aggregate final demand. Total spending on sector j output in country i is thus:

$$X_i^j = \alpha_i^j X_i^F + \sum_{l \in \Omega} \gamma_i^{lj} (1 - \beta_i^l) Y_i^l. \tag{3}$$

To interpret (3), consider the case of durables manufacturing, $j = D$. The first term on the right-hand side represents the final demand for durables. A decline in α_i^D represents a disproportionate drop in final spending on durables in country i (whether purchased by consumers or by firms as investment goods). The second term captures demand for durable manufactures as intermediate inputs. The total demand for durable manufactures in country i, X_i^D, is just their sum.

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

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

$$B_i^j = \left(\frac{l_i^j}{\beta_i^j} \right)^{\beta_i^j} \prod_{l \in \Omega} \left(\frac{y_i^{jl}}{\gamma_i^{jl}(1 - \beta_i^j)} \right)^{\gamma_i^{jl}(1 - \beta_i^j)},$$

where B_i^j are input bundles used to produce sector j output. Here l_i^j is labor input in sector j, and y_i^{jl} is sector-l intermediate input used in sector-j production.

[12] Input-output tables offer support for our Cobb-Douglas assumption. Appendix Figure 2 shows that the β and γ values in several large economies remained quite stable from 2000 to 2005.

[13] Our analysis could be interpreted as allowing for an arbitrary number of sectorally-mobile factors as long as factor intensity doesn't differ across sectors.

and j'th column, where we've ordered the sectors as D, N, and S. We can now stack equations (3) for each value of j and write the linear system:

$$\mathbf{X}_i = \mathbf{Y}_i + \mathbf{D}_i = \boldsymbol{\alpha}_i X_i^F + \boldsymbol{\Gamma}_i^T \mathbf{Y}_i, \tag{4}$$

where $\boldsymbol{\Gamma}_i^T$ is the transpose of $\boldsymbol{\Gamma}_i$ 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.

For now we take wages w_i and sectoral prices p_i^l for $l \in \Omega$, as given. The Cobb-Douglas aggregator implies that a bundle of inputs used in sector $j \in \Omega$ costs:

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

4.2 Folding Non-Manufacturing into Manufacturing

As noted above, we do not explicitly model trade in sector S. We now reformulate the model so that the S sector equilibrates only in the background, allowing us to focus on equilibrium in durables D and non-durables N.

We specify country i's labor productivity in sector S as A_i^S, so that $p_i^S = c_i^S / A_i^S$. Taking into account round-about production, the price of services in country i is:

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

Substituting this expression for the price of non-manufactures back into the cost functions expressions (5) for $j \in \Omega_M$, we can treat the manufacturing sectors as if they had integrated the production of all non-manufacturing intermediates into their operations. Some algebra shows that an input bundle in sector j, parallel to (5), costs:

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

for $j \in \Omega_M$, where 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:

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

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 non-manufacturing 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 non-manufacturing 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, where:

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

Substituting out the non-manufacturing sector leaves, in place of (3), two sectoral demand equations for each country, one for each $j \in \Omega_M$:

$$X_i^j = \widetilde{\alpha}_i^j(w_iL_i + D_i) - \delta_i^j D_i^S + \sum_{l\in\Omega_M}\widetilde{\gamma}_i^{lj}(1-\widetilde{\beta}_i^l)Y_i^l, \tag{7}$$

where

$$\delta_i^j = \frac{\gamma_i^{Sj}(1-\beta_i^S)}{1-\gamma_i^{SS}(1-\beta_i^S)},$$

and

$$\widetilde{\alpha}_i^j = \alpha_i^j + \delta_i^j\alpha_i^S. \tag{8}$$

All that remains of the non-manufacturing sector is its trade deficit, which we treat as exogenous. Thus, in the remainder of the paper, j refers to $j \in \Omega_M$.

4.3 International Trade

Any country's production in either manufacturing sector 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. Then:

$$Y_i^j = \sum_{n=1}^{I} \pi_{ni}^j X_n^j. \tag{9}$$

We adopt the framework in Eaton and Kortum (2002) to model the determinants of π_{ni}^j.

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

Making the standard iceberg assumption about trade costs, that delivering one unit of a good in sector j from country i to country n requires shipping $d_{ni}^j \geq 1$ units, with $d_{ii}^j = 1$, the unit price faced by buyers in country n for good z^j imported from i is:

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

Each country purchases each differentiated good z^j from the lowest cost source, hence the price actually paid in country n for this good is:

$$p_n(z^j) = \min_k \left\{ p_{nk}(z^j) \right\}.$$

Country i's efficiency $a_i(z^j)$ in making good z^j is the realization of a random variable with distribution: $F_i^j(a) = \Pr[a_i(z^j) \leq a] = e^{-T_i^j a^{-\theta^j}}$, drawn independently across i and z^j. Here $T_i^j > 0$ is a parameter that reflects country i's overall efficiency in producing any good z^j. The average efficiency in sector j of country i is proportional to $\left(T_i^j\right)^{1/\theta^j}$. The parameter θ^j is an inverse measure of the dispersion of efficiencies.

We assume that the individual manufacturing goods, whether used as intermediates or in final demand, are combined in a constant-elasticity-of-substitution aggregator, with elasticity $\sigma^j > 0$. Integrating over the prices of individual goods in sector j gives the price index:

$$p_n^j = \varphi^j \left[\sum_{i=1}^{I} T_i^j \left(c_i^j d_{ni}^j \right)^{-\theta^j} \right]^{-1/\theta^j}, \tag{10}$$

where φ^j is a function of θ^j and σ^j, requiring $\theta^j > (\sigma^j - 1)$. Substituting (6) into (10), we

get:

$$p_n^j = \varphi^j \left[\sum_{i=1}^{I} \left(w_i^{\widetilde{\beta}_i^j} \left(p_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)} \left(p_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)} \frac{d_{ni}^j}{A_i^j} \right)^{-\theta^j} \right]^{-1/\theta^j}, \tag{11}$$

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

$$A_i^j = A_i^{jS} \left(T_i^j\right)^{1/\theta^j},$$

captures the combined effect on costs of technology in manufacturing sector j and productivity in sector S on the price index for good j. Expression (11) links sector-j prices in country n to the prices of labor and intermediates around the world.

Finally, we get an expression for the trade shares in sector j:

$$\pi_{ni}^j = \frac{T_i^j \left(c_i^j d_{ni}^j\right)^{-\theta^j}}{\sum_{k=1}^{I} T_k^j \left(c_k^j d_{nk}^j\right)^{-\theta^j}},$$

where trade flows in sector j from i to n are $X_{ni}^j = \pi_{ni}^j X_n^j$.[14] We can use (10) and (6) to rewrite the trade-share expression as:

$$\pi_{ni}^j = \left[w_i^{\widetilde{\beta}_i^j} \left(p_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)} \left(p_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)} \frac{\varphi^j d_{ni}^j}{A_i^j p_n^j} \right]^{-\theta^j}. \tag{12}$$

4.4 Global Equilibrium

We can now express the conditions for global equilibrium. Substituting (9) into (7) we obtain input-output equations linking spending in each manufacturing sector around the world:

$$X_i^j = \widetilde{\alpha}_i^j (w_i L_i + D_i) - \delta_i^j D_i^S + \sum_{l \in \Omega_M} \widetilde{\gamma}_i^{lj} (1 - \widetilde{\beta}_i^l) \left(\sum_{n=1}^{I} \pi_{ni}^l X_n^l \right). \tag{13}$$

Summing (9) across the two manufacturing sectors gives market clearing equations for each country:

$$X_i^D + X_i^N - (D_i - D_i^S) = \sum_{l \in \Omega_M} \sum_{n=1}^{I} \pi_{ni}^l X_n^l. \tag{14}$$

[14] This expression gives back the Head-Ries index (1) by setting $\tau_{ni} = (d_{ni})^{\theta}$.

Following Alvarez and Lucas (2007), we make world GDP numeraire. The model accounts for country-level GDP relative to the global total. Given the shares of final demand α_i^j, deficits D_i and D_i^S, trade frictions d_{ni}^j, productivity terms A_i^j, labor forces L_i, and the parameters θ^j, β_i^j, and γ_i^{jl} for each country $i = 1, ..., I$ and for manufacturing sector j, the equilibrium is a set of wages w_i, spending levels X_i^j, price levels p_i^j, and trade shares π_{ni}^j that solve equations (11), (12), (13), and (14). Production, deficits, and employment by country for each sector j are then given by (9).

4.5 The Model's Four Shocks

We now turn to how we account for changes in trade/GDP over the recent period. We treat the distribution parameters θ^j, the value-added shares β_i^j, and the input-output coefficients γ_i^{jl} as fixed over time. We then attribute changes in equilibrium outcomes to four types of shocks which we treat as exogenous: (i) shocks to sector j's share in the final spending of country i, α_i^j, (ii) shocks to the frictions in exporting goods of type j from i to n, d_{ni}^j, (iii) shocks to country i's productivity in sector j, A_i^j, and (iv) changes in country i's overall and non-manufacturing deficits D_i and D_i^S.[15]

The first category of shocks are to the shares α_i^j of final demand spent on sector-j goods in country i. For example, (i) consumers putting off buying cars, (ii) firms postponing investment, or (iii) a reduction in durable inventories would appear as declines in the α_i^D's. The hypothesis that shifts in the patterns of overall demand during the Great Recession led to the trade collapse attributes it to a drop in the α_i^j's.

The second set of shocks are to trade frictions d_{ni}^j. Anything causing a reduction in absorption of imports relative to absorption of domestic production map into an increase in the d_{ni}^j's. Examples are (i) hikes in the cost of shipping cross-country (relative to shipping domestically), (ii) tariff increases, (iii) the "Buy America" provision in the U.S. fiscal stimulus

[15] We relate the trade shocks and productivity shocks to the price index (11) and trade share expression (12) from the Ricardian model developed above. But any model generating these two aggregate equations would work for our analysis. These same 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). 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 change in the taste for cars produced in Japan would map into a reduction in Japan's durable-good productivity in our framework. Arkolakis et al. (2009) emphasize the striking similarity in the trade patterns implied by such seemingly disparate models.

package, (iv) difficulties in obtaining trade finance relative to other types of credit, as in Amiti and Weinstein (2010) and Chor and Manova (2009), and (v) greater adjustment of inventories of imports relative to those of domestically-produced goods, as in Alessandria et al. (2010b).[16]

The third set of shocks A_i^j relate to each country's productivity in durables and in non-durables (taking into account the effects of changes in productivity in non-manufacturing through the input-output structure). Note that d_{ni}^j and A_i^j enter both (11) and (12) as a ratio to each other. Hence a decrease in d_{ni}^j or an increase in A_i^j have the same effect in reducing the price index in a destination market n or increasing the trade share of country i at destination n. To separate the effect of A_i^j we use our normalization that $d_{ii}^j = 1$ for all i, so that trade frictions don't appear in the relationship:

$$\pi_{ii}^j = \left[w_i^{\widetilde{\beta}_i^j} \left(p_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)} \left(p_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)} \frac{\varphi^j}{A_i^j p_i^j} \right]^{-\theta^j}. \tag{15}$$

Given prices, an increase in A_i^j raises the share of goods that country i buys from itself as well as what other countries buy from it. A drop in d_{ni}^j for $n \neq i$ just increases what country n buys from it.

The final set of shocks in our model are the deficits. In particular, equilibrium is a function of each country's overall deficit D_i and its non-manufacturing deficit D_i^S. Since our model is static, it doesn't incorporate the intertemporal trade-offs that determine deficits. Hence we simply feed in the deficits that actually occurred.

The demand shocks and trade friction shocks correspond to the two types of explanations that have been given for the decline in trade relative to GDP. We have no reason to think that productivity shocks or deficits had a systematic effect on what happened to trade relative to GDP during the Great Recession (and we find that they mostly don't) but we need to take them into account to calculate the general equilibrium of the world economy. To economize on the parameter values and data that we need to calibrate our model, we reformulate it in terms of changes over time.

[16] In contrast, a drop in overall manufacturing inventories, regardless of source, will appear as a decline in α_i^j.

4.6 The Model in Changes

Denote the beginning-of-period or baseline value of any time-varying variable as x and its end-of-period or counterfactual value as x', with the change over the period (or counterfactual change) denoted $\hat{x} = x'/x$. Since output is payment to labor, $Y_i^F = w_i L_i$, the assumption that labor supplies are fixed implies that $\left(Y_i^F\right)' = \hat{w}_i Y_i^F$. (As we discuss below, little changes if instead we take into account the actual changes in L_i.)

In terms of counterfactual levels and changes, the global input-output equations (13), for sectors $j \in \Omega_M$ and countries $i = 1, 2, ..., I$, become:

$$\left(X_i^j\right)' = \left(\widetilde{\alpha}_i^j\right)' \left(\hat{w}_i Y_i^F + D_i'\right) - \delta_i^j \left(D_i^S\right)' + \sum_{l \in \Omega_M} \widetilde{\gamma}_i^{lj} (1 - \widetilde{\beta}_i^l) \left[\sum_{n=1}^{I} \left(\pi_{ni}^l\right)' \left(X_n^l\right)'\right]. \tag{16}$$

The global market clearing conditions (14) become:

$$\left(X_i^D\right)' + \left(X_i^N\right)' - \left[D_i' - \left(D_i^S\right)'\right] = \sum_{n=1}^{I} \left[\left(\pi_{ni}^D\right)' \left(X_n^D\right)' + \left(\pi_{ni}^N\right)' \left(X_n^N\right)'\right], \tag{17}$$

while the price equations (11) become:

$$\hat{p}_n^j = \left[\sum_{i=1}^{I} \pi_{ni}^j \hat{w}_i^{-\theta^j \widetilde{\beta}_i^j} \left(\hat{p}_i^j\right)^{-\theta^j \widetilde{\gamma}_i^{jj} (1 - \widetilde{\beta}_i^j)} \left(\hat{p}_i^l\right)^{-\theta^j \widetilde{\gamma}_i^{jl} (1 - \widetilde{\beta}_i^j)} \left(\frac{\hat{d}_{ni}^j}{\hat{A}_i^j}\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{18}$$

where $l \neq j$ is the other manufacturing sector. The trade share equations (12) become:

$$\left(\pi_{ni}^j\right)' = \pi_{ni}^j \hat{w}_i^{-\theta^j \widetilde{\beta}_i^j} \left(\hat{p}_i^j\right)^{-\theta^j \widetilde{\gamma}_i^{jj} (1 - \widetilde{\beta}_i^j)} \left(\hat{p}_i^l\right)^{-\theta^j \widetilde{\gamma}_i^{jl} (1 - \widetilde{\beta}_i^j)} \left(\frac{\hat{d}_{ni}^j}{\hat{A}_i^j \hat{p}_n^j}\right)^{-\theta^j}. \tag{19}$$

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) changes in wages $\hat{w}_i$, (ii) counterfactual levels of spending $(X_i^j)'$, (iii) changes in prices $\hat{p}_i^j$, and (iv) counterfactual trade shares $\left(\pi_{ni}^j\right)'$. The forcing variables are the end-of-period or counterfactual demand composition shocks $\left(\widetilde{\alpha}_i^j\right)'$ and deficits $\left(D_i^S\right)'$ and D_i', as well as changes in in trade frictions $\hat{d}_{ni}^j$ and productivities $\hat{A}_i^j$.[17] We use actual baseline trade shares π_{ni}^j and GDP's Y_i^F to cali-

[17] As described in Appendix B, equilibrium outcomes for everything but price changes are invariant to labor-

brate the model. The only parameters required are the θ^j's and the input-output coefficients underlying the $\widetilde{\beta}_i^l$'s and the $\widetilde{\gamma}_i^{jl}$'s.

We solve the system as follows. Given a vector of possible wage changes $\widehat{w}_i$'s, we solve (18) for price changes $\hat{p}_i^j$'s. Wage and price changes then imply counterfactual trade shares $\left(\pi_{ni}^j\right)'$ via (19). Given counterfactual trade shares and wage changes, we solve (16) as a linear system for counterfactual levels of spending $\left(X_i^j\right)'$. If these levels of spending satisfy (17), then we have an equilibrium. If not, we adjust wage changes according to where there is excess demand (with world GDP fixed) and return to (18). Appendix C describes the details of the solution algorithm.[18]

5 Backing Out the Shocks

In the previous section we described how to solve for changes in the equilibrium outcomes (wages, spending, prices, and trade shares) given the four types of shocks. We now invert this relationship to back out the shocks from observed outcomes. We use a panel of 22 countries for which we have data on input-output structure, production, and exports, as well as a residual category ROW, for "Rest of World." In 2008 our 22 countries account for about 75 percent of global manufacturing trade and of world GDP. Table 1 lists the countries, their shares of global GDP and global trade, and trade/GDP.[19] We work at a quarterly frequency, sometimes aggregating up from monthly data.[20] We set $\theta^D = \theta^N = 2$, a value between the smaller values typically used in the open-economy macro literature and the larger values used in Eaton and Kortum (2002).[21] Below, we go through how we back out the four types of shocks and provide some evidence on each.

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augmenting productivity shocks, i.e. $\hat{A}_i^j = \lambda^{\widetilde{\beta}_i^j}$ for some $\lambda > 0$. Such shocks lead to price changes equal to $1/\lambda$. Furthermore, equilibrium outcomes are invariant to shocks to non-manufacturing sector productivity, given $\hat{A}_i^j$. These configurations of productivity shocks affect welfare, but are irrelevant to the model's implications for international trade.

[18] Given the solution, we can calculate counterfactual manufacturing production as the difference between manufacturing absorption $\left(X_i^D\right)' + \left(X_i^S\right)'$ and the manufacturing deficit $D_i' - \left(D_i^S\right)'$. We can then use equation (9), as it applies to the counterfactual levels, to solve separetely for durable and non-durable output.

[19] Here and for the rest of the paper, we use the term "trade" to refer to the average of imports and exports of manufactured goods.

[20] Appendix A describes our sources and procedures to generate our dataset.

[21] Our qualitative conclusion that demand shocks were the primary driver of the decline in trade/GDP are robust to alternative choices for θ^D and θ^N.

5.1 Demand

We extract the vector of demand shocks for country i, $\boldsymbol{\alpha}_i$, from data on absorption by sector $\mathbf{X}_i$, output by sector $\mathbf{Y}_i$, final spending X_i^F, and the input-output coefficients determining Γ_i through a manipulation of (4):[22]

$$\boldsymbol{\alpha}_i = \frac{1}{X_i^F}\left(\mathbf{X}_i - \boldsymbol{\Gamma}_i^T \mathbf{Y}_i\right). \tag{20}$$

Figure 5 plots the paths of α_i^D and α_i^N for four large countries since 2000, with the dashed vertical lines highlighting 2008:Q1 to 2009:Q1. The recent recession accompanied a steep decline in the share of final demand for manufactures in all these countries, particularly for durables. For most countries this share begins to increase again toward the end of 2009. We use beginning-of-period values as α_i^j and end-of-period values as $\left(\alpha_i^j\right)'$.[23]

5.2 Trade Deficits

Overall and non-manufacturing trade deficits D_i and D_i^S enter the model in equations (16) and (17). We take them directly from the data, calculating the deficits for ROW to make the global deficits zero.

Deficits changed dramatically over the recession. Figure 6 shows overall and non-manufacturing trade deficits for several major countries. The sharp reduction in the overall U.S. trade deficit during the recession is balanced by reduced surpluses for Japan, Germany, and China. As with demand shocks, in solving the model in terms of changes we use beginning-of-period values as D_i and D_i^S and end-of-period values as $(D_i)'$ and $\left(D_i^S\right)'$.

[22] We impute non-manufacturing production as: $Y_i^S = (Y_i^F - \beta_i^D Y_i^D - \beta_i^N Y_i^N)/\beta_i^S$ from (2). For ROW, we first need to construct sectoral production for $j \in \Omega_M$. We start by averaging sectoral value added as a fraction of GDP $\beta_i^j Y_i^j / Y_i^F$ across the 22 countries in our sample. We then multiply the result by Y_{ROW}^F to estimate value added by sector for ROW. We divide by β_{ROW}^j to estimate Y_{ROW}^j, where we take β_{ROW}^j as the median value of β_i^j across the 22 countries in our sample.

[23] We insert these demand shocks and input-output coefficients into (8) to construct the $\widetilde{\alpha}_i^j$ in equation (16). In the counterfactuals that follow we perturb $\left(\alpha_i^D\right)'$ and $\left(\alpha_i^N\right)'$ (with $\left(\alpha_i^S\right)' = 1 - \left(\alpha_i^D\right)' - \left(\alpha_i^N\right)'$ calculated as a residual) in constructing $\left(\widetilde{\alpha}_i^j\right)'$.

5.3 Productivity

To retrieve productivity shocks we express (15) in terms of changes and rearrange to get:

$$\hat{A}_i^j = \left(\hat{\pi}_{ii}^j\right)^{1/\theta^j} \hat{w}_i^{\widetilde{\beta}_i^j} \left(\hat{p}_i^j\right)^{\widetilde{\gamma}_i^{jj}(1-\widetilde{\beta}_i^j)-1} \left(\hat{p}_i^l\right)^{\widetilde{\gamma}_i^{jl}(1-\widetilde{\beta}_i^j)}. \tag{21}$$

For $\hat{\pi}_{ii}^j$ we simply use the change in home share in demand for country i in absorption of good j. Since in our model GDP is simply $w_i L_i$ and we treat L_i as fixed, we use the change in country i's GDP to infer $\widehat{w}_i$.[24] Finally, we use the sectoral PPI data described in Appendix A to infer the $\widehat{p}_i^j$.

Figure 7 presents the productivity shocks, by sector, for the four large economies over 2000-2009. Note that the Great Recession is characterized by noticeable drops in productivity in Germany and Japan and by continuing productivity growth in China.

5.4 Trade Frictions

To get the $\widehat{d}_{ni}^j$ we divide both sides of (19) by π_{ni}^j to get $\hat{\pi}_{ni}^j$. Dividing by the corresponding expression for $\hat{\pi}_{ii}^j$ and rearranging yields:

$$\left(\hat{d}_{ni}^j\right)^{-\theta^j} = \frac{\hat{\pi}_{ni}^j}{\hat{\pi}_{ii}^j} \left(\frac{\hat{p}_i^j}{\hat{p}_n^j}\right)^{\theta^j}. \tag{22}$$

We implement this equation using data on the changes in trade shares $\hat{\pi}_{ni}^j$ and changes in sectoral PPI's.[25]

Note that the geometric mean of $\left(\hat{d}_{ni}^j\right)^{-\theta^j}$ and $\left(\hat{d}_{in}^j\right)^{-\theta^j}$ as calculated in (22), yields the

[24] We have examined for several countries how our productivity measures would differ if we take into account employment changes. While there is more productivity growth in the earlier period there is little that changes during the Great Recession. Except for the different inference about productivity shocks, taking into account employment changes makes no difference for the rest of our analysis. These results are available by request from the authors.

[25] We need data on the price indices to separate changes in productivity and in trade frictions. We do not need these price data to back out the demand shocks (or, of course, the deficits). Appendix B shows an alternative decomposition into demand shocks, deficits, and a third shock which is a complicated combination of the sectoral productivity and trade friction shocks. This third shock can be backed out without making use of price data. We didn't pursue this alternative decomposition because it doesn't isolate the trade friction shocks that we are interested in. We emphasize, though, that what we have to say about the contribution of demand shocks and deficits, as well as the combined contribution of trade frictions and productivity shocks, to the Great Recession doesn't rely on these price data. Price data only affect how we disentangle trade friction and productivity shocks.

formula for the change in the Head-Ries index (1). Thus, the plots of the Head-Ries indices summarize the behavior of the trade-friction shocks. Figures 3 and 4 reveal that evidence on trade frictions is a mixed bag.[26] The heterogeneity across country pairs makes it hard to determine their importance. To quantify their contribution, we turn to counterfactual exercises that map the various shocks into the outcomes of interest.

6 Counterfactuals

Our counterfactual simulations measure the contribution of various subsets of the shocks to the decline in trade over the Great Recession. To proceed, we define the set of all shocks, in terms of changes, as:

$$\widehat{s} = \left\{ \left\{ \widehat{\alpha}_i^j \right\}, \left\{ \widehat{D}_i, \widehat{D}_i^S \right\}, \left\{ \widehat{d}_{ni}^j \right\}, \left\{ \widehat{A}_i^j \right\} \right\},$$

for all countries $i, n \in I$ and sectors $j \in \Omega_M$.[27] For any given four-quarter period and any given set of shocks $\widehat{s}$, we can solve equations (16), (17), (18), and (19) for changes over that period in the endogenous variables (production, trade, and GDP).

While we can perform counterfactuals using any values of $\widehat{s}$ that we want, we limit ourselves to either the actual values backed out from the data or else the value 1, eliminating any contribution from that shock. At one extreme, setting all elements in $\widehat{s}$ to 1, meaning that all shocks are constant over the period, delivers the outcome of no change. At the other, setting all the elements in $\widehat{s}$ equal to the values backed out from the data delivers the outcome that actually happened. More interesting are the cases in between in which a subset of shocks take on the values backed out from the data, with the others set to 1. Such a counterfactual isolates the contribution of that subset of shocks to what happened.[28]

We decompose the shocks in two different ways. First, to assess the role of each set of shocks for the trade collapse, we solve the model setting one type of shock (either $\left\{ \widehat{\alpha}_i^j \right\}, \left\{ \widehat{D}_i, \widehat{D}_i^S \right\}, \left\{ \widehat{d}_{ni}^j \right\}$, or $\left\{ \widehat{A}_i^j \right\}$) equal to the values backed out from the data for all

[26] Appendix Figure 4 presents histograms of trade-friction shocks across all country pairs constructed according to equation (22). Over the period 2008:Q1 to 2009:Q1 most of the mass in the distributions lies below one, indicating that trade frictions typically increased over this period.

[27] For notational consistency with the other shocks we write $\widehat{D}_i^S$ and $\widehat{D}_i$. The cases of $D_i^S = 0$ or $D_i = 0$ raise no problems since all that matters for computing counterfactuals is $\left(D_i^S\right)'$ and D_i'.

[28] Because of the non-linearity of the model, the contributions of individual shocks to a change needn't add up to the actual change. Since a "change" means the ratio of the counterfactual value to its baseline value, "adding up" means summing the logarithms of such ratios.

countries, with all the other three types of shocks set to 1. We further differentiate between shocks to the durables and non-durables sectors. The solution tells us how much trade relative to GDP would have fallen if only that one type of shock had occurred.

Second, to assess the role of international interactions, we ask how much various outcomes for each country were the consequence of shocks transmitted to it through the re-equilibration of world markets versus shocks it experienced directly. Denote the shocks in which country i appears as $\widehat{s}_i$ and the shocks in which it does not appear as $\widehat{s}_{-i}$. We first solve the model setting $\widehat{s}_{-i}$ to the shocks backed out from the data and $\widehat{s}_i$ to 1. We then do the reverse. The first exercise tells us what just foreign shocks would have done and the second what just domestic shocks would have done.

6.1 Accounting for Trade/GDP: 2006-2009

We start by considering a series of four-quarter changes, beginning with 2006:Q1 to 2007:Q1 and ending with 2008:Q4 to 2009:Q4. We run the model for each of these four-quarter periods (twelve in total). Figure 8 plots the results at the global level, with the ending quarter on the x-axis and the change in trade/GDP from the same quarter the previous year (with 1 indicating no change) on the y-axis.[29]

The boldface black line labeled "Data" plots the actual changes (what emerges setting all shocks to those backed out from the data). After modest growth through 2007, global manufacturing trade/GDP was essentially unchanged until the fourth quarter of 2008, when it dropped to nearly 10 percent below its value four quarters earlier. By the first and second quarters of 2009, world trade/GDP was about 20 percent below its level four quarters earlier. By the end of 2009, trade/GDP was at about the level of four-quarters before, as the black line approaches 1.

What would have happened to this ratio with shocks only to demand? For each of the 12 year-to-year changes, we input the shock matrix $\widehat{s} = \left\{\left\{\widehat{\alpha}_i^j\right\}, 1, 1, 1, 1, 1, 1\right\}$ and generate the counterfactual change in trade/GDP. The solid red line plots this counterfactual. Note that the demand shocks alone capture the magnitude of the decline in trade/GDP across all the recent four-quarter windows, accounting for more than 80 percent of the decline in global trade/GDP during the recession.

[29] While we plot the overlapping four-quarter changes as a continuous line, the changes are not cumulative. We calculate each four-quarter change independently and plot each value on its own.

When we perform this exercise allowing only for productivity shocks, trade friction shocks, or deficit shocks, the implied changes in global trade/GDP are quite small, so that the lines remain close to 1. Hence no other set of shocks, on their own, comes close to matching the actual pattern of decline in global trade/GDP.

We now turn to the experience of individual countries. Heterogeneity in the Head-Ries indices reported above suggests that trade friction shocks may have played a significant role in reducing trade/GDP in some countries. In Figure 9, we plot the results of our counterfactual exercise separately for the four largest economies. The United States and Germany largely mirror the results for global trade, with demand shocks explaining most of the changes in trade/GDP. For Japan, the actual declines in trade/GDP significantly exceed the contribution from demand shocks alone in the depths of the recession. No single set of shocks on their own account for a majority of these declines. In China, the decline in trade/GDP started earlier and, like Japan, no single set of shocks explain it. For both Japan and China, the trade friction shocks are arguably the largest contributors.

6.2 Focusing on 2008:Q1 to 2009:Q1

To get a better sense for the experiences across all countries, we now focus on 2008:Q1 to 2009:Q1, which captures the precipitous decline in trade in the Great Recession. Table 2 shows the combined impact on trade/GDP for each country for each of our counterfactual exercises in which all shocks are set to 1 except for (in separate columns): (i) demand shocks, (ii) trade friction shocks, (iii) productivity shocks, and (iv) the deficits.[30]

To quantify these results we introduce a measure of a counterfactual's contribution to a change over the period. Writing the actual change in trade/GDP for country i as $\widehat{x}_i$ and its counterfactual change, given a particular set of counterfactual shocks $\widehat{s}$, as $\widehat{x}_i(\widehat{s})$ we first construct:

$$\upsilon\left(\widehat{s}\right) = \sum_{i}^{I} w_i \left[\widehat{x}_i(\widehat{s}) - \widehat{x}_i\right]^2,$$

where the weights w_i are country i's share of world trade in 2008:Q1 (as shown in Table 1). An important feature of this measure is that it does not net out the mean value of the deviation. We then express this deviation relative to the deviations in the data from

[30] The top row, in boldface and labeled "World," shows the change in global trade to GDP plotted in Figure 8 (the "09:Q1" data points).

a scenario of no change, $\upsilon(\iota)$, where ι is a vector of 1's. Thus, our final measure of the contribution of $\widehat{s}$ is:

$$\mathbb{V}(\widehat{s}) = 1 - \frac{\upsilon(\widehat{s})}{\upsilon(\iota)}. \tag{23}$$

This measure appears as the "share of trade-weighted variance explained" in the last row of Table 2 for each of the global counterfactuals.[31] The demand shocks contribute the most to explaining the decline in trade/GDP over 2008:Q1 to 2009:Q1.

Of the large contribution of demand shocks, the decline in demand for durables makes a contribution of 64 percent. Figure 10 illustrates this result, along with several other counterfactuals. For each counterfactual exercise $\widehat{s}$, the x-axis in each panel in Figure 10 shows $\widehat{x}_i$ while the y-axis shows $\widehat{x}_i(\widehat{s})$.

Using only the $\widehat{s}$ backed out from the data, all points line up on the 45 degree, shown in the lower-right quadrant. For this case, $\upsilon(\widehat{s})$ equals zero and $\mathbb{V}(\widehat{s})$ equals 1. The upper-left quadrant of Figure 10 shows what happens with only the actual changes in non-manufacturing deficits. Countries remain far from the 45 degree line, indicating that shocks to deficits had little to do with the decline in trade/GDP (contributing only 5 percent). The upper-right quadrant shows the counterfactual involving only trade-friction shocks. They capture much of the decline for some countries but only contribute 9 to 17 percent overall. The lower-left quadrant shows the results with only the shocks to durable demand in the data. They account well for the overall pattern, contributing 64 percent, but do a poor job for a handful of countries.

We have run counterfactuals involving many other combinations of shocks, reporting results in Appendix Table 3. A general finding is that no combination of shocks accounts for a large fraction of the decline in trade/GDP unless it includes the actual shocks to durable demand.

6.3 The Global Trading System as a Transmitter of the Recession

How much did shocks from individual countries affect other countries throughout the world? As an example, consider the global impact of the negative shocks to demand for durable

[31] We provide a range for the contribution of trade frictions since it is sensitive to the inclusion of ROW for which we have little in the way of direct measures. The higher number drops observation for ROW while the lower value includes it. A particular $\widehat{s}$ can move trade/GDP in the opposite direction from what happened, implying a negative value of $\mathbb{V}(\widehat{s})$.

and non-durable manufactures just in the United States, with all other shocks set to 1. The penultimate column of Table 2 shows simulated trade/GDP at the global and country level when the only shocks we introduce into the system are $\{\widehat{\alpha}^j_{US}\}$. The impact of these shocks on the world is large: They reduces global trade by about 3 percent relative to GDP. One also sees the impact of geography. Mexico and Canada are affected very significantly, while Germany, for example, is relatively insulated.

The last column of Table 2 shows an alternative exercise in which the only shocks are to trade frictions involving China and Japan. Global trade also falls by about 3 percent relative to GDP, but trade diversion leads to trade increases for some countries, such as South Korea.

More generally, we can ask how much the fate of each country, in terms of trade/GDP, its relative GDP, and manufacturing/GDP, was the consequence of shocks at home versus those transmitted to it through the trading system from other countries. Table 3 includes three columns for each of the objects trade/GDP, GDP, and production. The first of the three columns reports what actually happened to each of these magnitudes during the recession for each of our countries i. The second column then reports what would have happened if the only shocks in the system were shocks from other countries $\widehat{s}_{-i}$ (i.e., row i corresponds to a counterfactual that eliminates all shocks containing an i subscript). Finally, the third column reports the impact if the only shocks were those that directly hit each country, $\widehat{s}_i$. For the United States, for example, the decline in trade/GDP by a factor of 0.78 would have been a modest 0.95 in the absence of direct shocks but what happened at home by itself would have implied a larger drop by a factor of 0.85. Note that the United States actually experienced an increase in its relative GDP during the period. This positive outcome was totally the result of domestic shocks which more than offset negative ones from abroad. Similarly, the drop in manufacturing production (relative to global GDP) by a factor of 0.93 was totally the consequence of foreign factors which more than offset the effect of domestic shocks. The country for which domestic factors had the greatest expansionary effect is China, where they overwhelmed the negative effect of foreign factors on each of these magnitudes.[32]

[32]Note that domestic shocks tended to mitigate the effect of foreign shocks on relative GDP. The reason is that the major shock hitting most countries was a shift away from spending on manufactures toward spending on services. Since services are more intensive in domestic labor as opposed to foreign labor (through imported intermediates), the effect on domestic GDP is generally positive.

7 The 2001 Recession and the Great Depression

We perform our counterfactuals for the period surrounding the last U.S. recession in 2001 (dropping a few of our 22 countries for which we lack data). Figure 11 shows that in the four quarters leading up to 2001:Q1, global trade/GDP increased at an annual rate of about 5 percent, with this growth predominantly due to reduced trade frictions. The subsequent decline in trade/GDP coinciding with the recession was much milder than in 2008, but was similar in that it can be almost entirely explained by demand shocks, with the other three types of shock contributing roughly zero. After the recession ended in mid-2002, trade/GDP resumed its secular growth, again explained by declines in trade frictions.

Another major trade collapse occurred during the Great Depression. Observers such as Irwin (1998) attribute this earlier collapse to increased trade frictions. We have sufficient Depression-era data to construct Head-Ries indices (1) for the bilateral trade between the United States and eight partners: Austria, Canada, Finland, Germany, Japan, Spain, Sweden, and the United Kingdom. Appendix A describes our data. Figure 12 compares a simple average of these Head-Ries indices from the Great Depression (seen in the solid line and corresponding to the lower x-axis) with the equivalent simple average of Head-Ries indices from the Great Recession (the dotted line which corresponds to the upper x-axis). Because of data limitations, these indices are annual rather than quarterly, and pool durables and non-durables.

Consistent with our results above, the average Head-Ries index for the recent recession declines only slightly in 2008 and 2009 relative to 2007. In contrast, the solid line plunges by nearly 50 percent in the years following 1930 and finishes 1937 below its pre-depression value. Data limitations prevent us from running our counterfactuals for the Depression, but the large drops in the Head-Ries index suggest that we would attribute much more of the decline in trade to increases in trade frictions in the Great Depression. An explanation for the difference with the Great Recession is that the world trading system is now better equipped to resist protectionist pressure.

8 Conclusion

A prominent characteristic of the recent global recession was a large and rapid drop in trade relative to GDP. To delve into these dramatic changes in patterns of trade, production, and GDP, we build an accounting framework relating them to shocks to the composition of demand, trade frictions, deficits, and productivities across several sectors. Applying our framework to the recent recession, we find that shocks to manufacturing demand, particularly for durables, account for the bulk of the decline in trade/GDP. The trade declines in China and Japan, however, reflect a moderate contribution from increased trade frictions.

We developed this approach with the recent recession in mind. We anticipate, however, that the framework can be applied quite generally to study the geography of global booms and busts.

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Tables

Country	Share of Global GDP (percent)	Share of Global Trade (percent)	Trade / GDP (percent)
Austria	0.7	1.6	40.7
Canada	2.6	2.9	20.0
China	6.6	9.6	26.6
Czech Republic	0.4	1.3	64.5
Denmark	0.6	0.9	28.2
Finland	0.5	0.8	30.4
France	4.9	5.3	19.8
Germany	6.3	11.0	32.1
Greece	0.6	0.4	12.2
Hungary	0.3	0.9	65.5
India	2.2	1.2	10.3
Italy	3.9	4.3	19.9
Japan	8.2	5.4	12.1
Mexico	1.9	2.3	22.3
Poland	0.9	1.6	32.0
Romania	0.3	0.5	28.8
Slovakia	0.1	0.6	73.6
South Korea	1.8	3.0	30.7
Spain	2.7	2.7	18.4
Sweden	0.8	1.5	32.1
United Kingdom	4.8	4.3	16.5
United States	23.9	11.9	9.1
ROW	25.1	26.0	18.9

Table 1: Summary Statistics (2008:Q1) for Countries in Dataset

Notes: Quarterly GDP for ROW calculated by assuming constant quarterly growth between annual figures from the IMF World Economic Outlook Database. Exports and imports for ROW taken by subtracting in-sample bilateral trade totals from in-sample countries' multilateral trade figures.

		Change (2009:Q1/2008:Q1) in Trade / GDP in Various Counterfactuals:							
	Trade / GDP in 2008:Q1 (percent)	No Change (No Shocks)	Actual Change (All Shocks)	Demand Shocks Only	Trade Friction Shocks Only	Productivity Shocks Only	Deficit Shocks Only	U.S. Demand Shocks Only	China/Japan Trade Friction Shocks Only
World	**18.2**	**1.00**	**0.81**	**0.85**	**0.99**	**0.99**	**0.99**	**0.97**	**0.97**
Austria	40.7	1.00	0.80	0.96	0.94	0.97	0.95	1.00	1.00
Canada	20.0	1.00	0.94	0.91	1.02	1.03	0.99	0.97	1.01
China	26.6	1.00	0.72	0.95	0.87	0.89	1.00	1.00	0.86
Czech Republic	64.5	1.00	0.80	0.79	1.06	1.00	0.98	1.00	1.01
Denmark	28.2	1.00	0.90	0.87	1.02	1.01	1.01	1.00	1.00
Finland	30.4	1.00	0.74	0.81	0.99	1.01	0.95	1.00	1.01
France	19.8	1.00	0.86	0.82	1.08	1.00	0.98	1.00	1.01
Germany	32.1	1.00	0.88	0.89	1.05	1.03	0.94	1.00	1.01
Greece	12.2	1.00	0.89	0.85	1.06	1.01	0.98	1.00	1.01
Hungary	65.5	1.00	0.85	0.83	1.11	0.91	0.99	1.00	1.01
India	10.3	1.00	1.04	0.94	1.15	0.98	0.99	0.99	1.00
Italy	19.9	1.00	0.82	0.79	1.05	1.01	0.98	1.00	1.01
Japan	12.1	1.00	0.64	0.86	0.83	1.04	0.89	0.99	0.84
Mexico	22.3	1.00	1.03	0.89	1.20	0.95	1.03	0.96	1.02
Poland	32.0	1.00	0.90	0.83	1.08	0.98	1.02	1.00	1.02
Romania	28.8	1.00	0.83	0.81	0.98	1.00	1.04	1.00	1.00
Slovakia	73.6	1.00	0.76	0.74	1.04	1.04	0.98	1.00	1.00
South Korea	30.7	1.00	1.10	0.85	1.26	1.05	0.99	1.00	1.12
Spain	18.4	1.00	0.73	0.74	0.96	0.98	1.03	1.00	0.99
Sweden	32.1	1.00	0.88	0.86	1.05	1.02	0.97	1.00	1.02
United Kingdom	16.5	1.00	0.98	0.90	1.05	1.02	1.02	0.99	1.01
United States	9.1	1.00	0.78	0.83	0.99	0.96	1.01	0.87	0.97
ROW	18.9	1.00	0.87	0.83	1.02	1.01	1.02	0.99	0.98
Share of Trade-Weighted Variance Explained (percent):		0	100	65	9 to 17	12	10		

Table 2: Trade/GDP over the Great Recession

Notes: Growth in all variables is expressed relative to global GDP.

	Trade / GDP			GDP			Production		
	Actual (2008:Q1/ 2009:Q1)	Counterfactual (All Shocks From Other Countries)	Counterfactual (Only Shocks For This Country)	Actual (2008:Q1/ 2009:Q1)	Counterfactual (All Shocks From Other Countries)	Counterfactual (Only Shocks For This Country)	Actual (2008:Q1/ 2009:Q1)	Counterfactual (All Shocks From Other Countries)	Counterfactual (Only Shocks For This Country)
Austria	0.80	0.98	0.84	0.96	0.82	1.18	0.86	0.83	1.05
Canada	0.94	1.03	0.97	0.87	0.91	0.95	0.78	0.90	0.87
China	0.72	0.93	0.74	1.23	0.92	1.40	1.19	0.92	1.35
Czech Republic	0.80	1.00	0.82	0.90	0.79	1.15	0.70	0.81	0.86
Denmark	0.90	0.99	0.91	0.95	0.88	1.15	0.84	0.87	1.02
Finland	0.74	1.00	0.76	0.92	0.81	1.13	0.68	0.84	0.82
France	0.86	1.00	0.90	0.96	0.84	1.14	0.75	0.84	0.90
Germany	0.88	1.02	0.89	0.93	0.83	1.14	0.77	0.86	0.91
Greece	0.89	1.01	0.93	0.98	0.90	1.10	0.77	0.85	0.92
Hungary	0.85	1.03	0.86	0.83	0.78	1.06	0.70	0.81	0.88
India	1.04	0.99	1.09	0.96	0.87	1.11	0.93	0.86	1.08
Italy	0.82	1.00	0.85	0.95	0.84	1.14	0.71	0.85	0.85
Japan	0.64	0.95	0.67	1.16	0.91	1.32	0.84	0.91	0.95
Mexico	1.03	1.05	1.03	0.83	0.90	0.91	0.81	0.91	0.90
Poland	0.90	1.01	0.95	0.83	0.79	1.01	0.73	0.79	0.89
Romania	0.83	0.95	0.88	0.88	0.85	1.04	0.81	0.81	0.99
Slovakia	0.76	0.98	0.77	1.01	0.85	1.31	0.71	0.84	0.92
South Korea	1.10	1.08	1.13	0.75	0.83	0.88	0.67	0.88	0.76
Spain	0.73	0.94	0.78	0.96	0.86	1.13	0.74	0.84	0.88
Sweden	0.88	1.02	0.90	0.81	0.81	0.98	0.67	0.83	0.80
United Kingdom	0.98	1.01	1.04	0.78	0.84	0.92	0.73	0.82	0.88
United States	0.78	0.95	0.85	1.11	0.93	1.21	0.93	0.93	1.02
ROW	0.87	0.99	0.90	0.93	0.90	1.03	0.79	0.90	0.87

Table 3: Impact of Direct and Indirect Shocks

Notes: Growth in all variables is expressed relative to global GDP. In "counterfactuals with all shocks from other countries," we set any shock directly involving the row country equal to 1 (i.e. no change from 2008:Q1), and keep all other shocks. "Counterfactual with only shocks for this country" do the opposite.

Figures

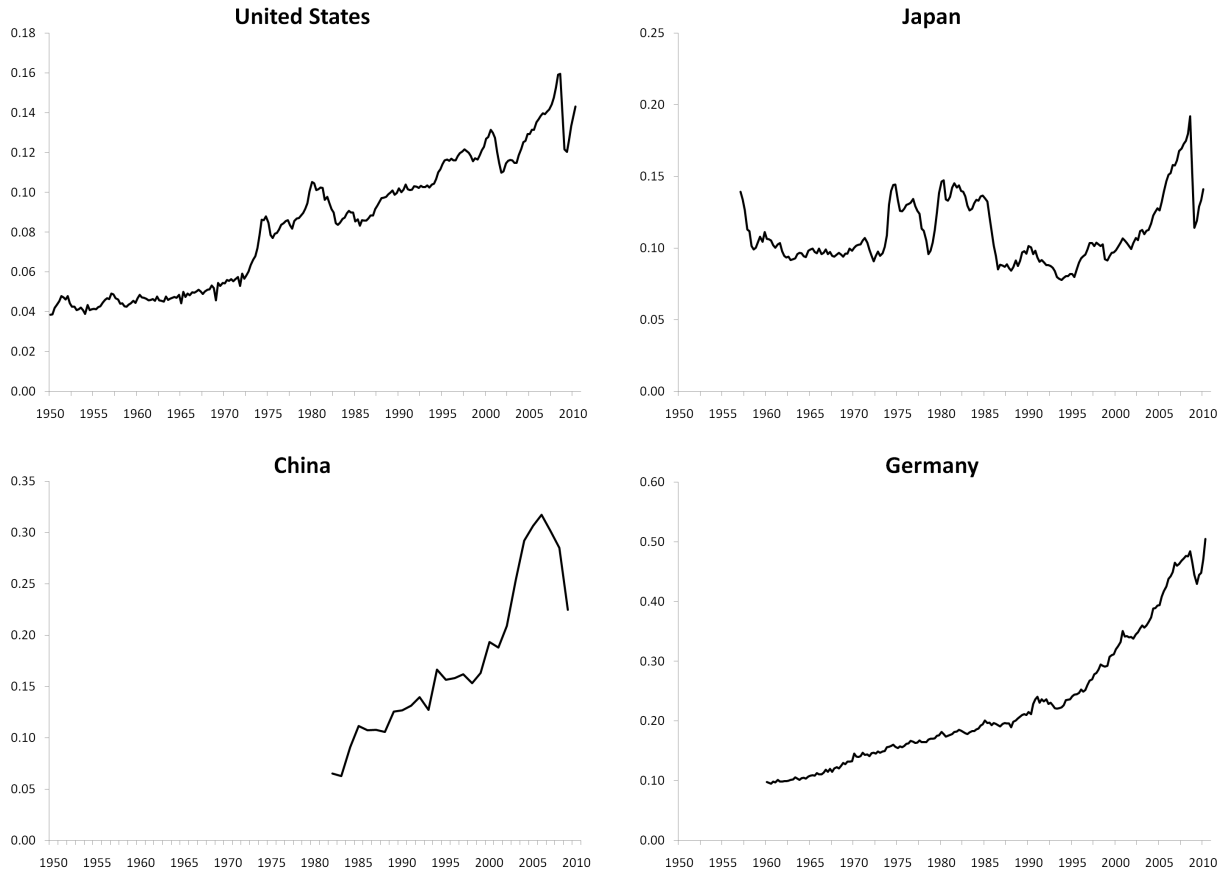

Figure 1: Trade / GDP in the Four Largest Economies

Notes: All data are through the end of 2009. "Trade" refers to (exports+imports)/2 of all goods and services. This figure is the only part of our paper that includes trade in oil. United States' quarterly data are taken from BEA national accounts. Japan's quarterly data are taken from the IMF's IFS database. Germany's quarterly data are taken from Source.OECD database. China's data are only available annually. We obtain data on China up to 2008 from IFS. China's trade data for 2009 come from the WTO, while the estimate of 2009 GDP is from the IMF's WEO. Trade for United States, Germany, and Japan is goods and services, China is just goods. We note that each of the four figures is plotted with a different scale for the vertical axis.

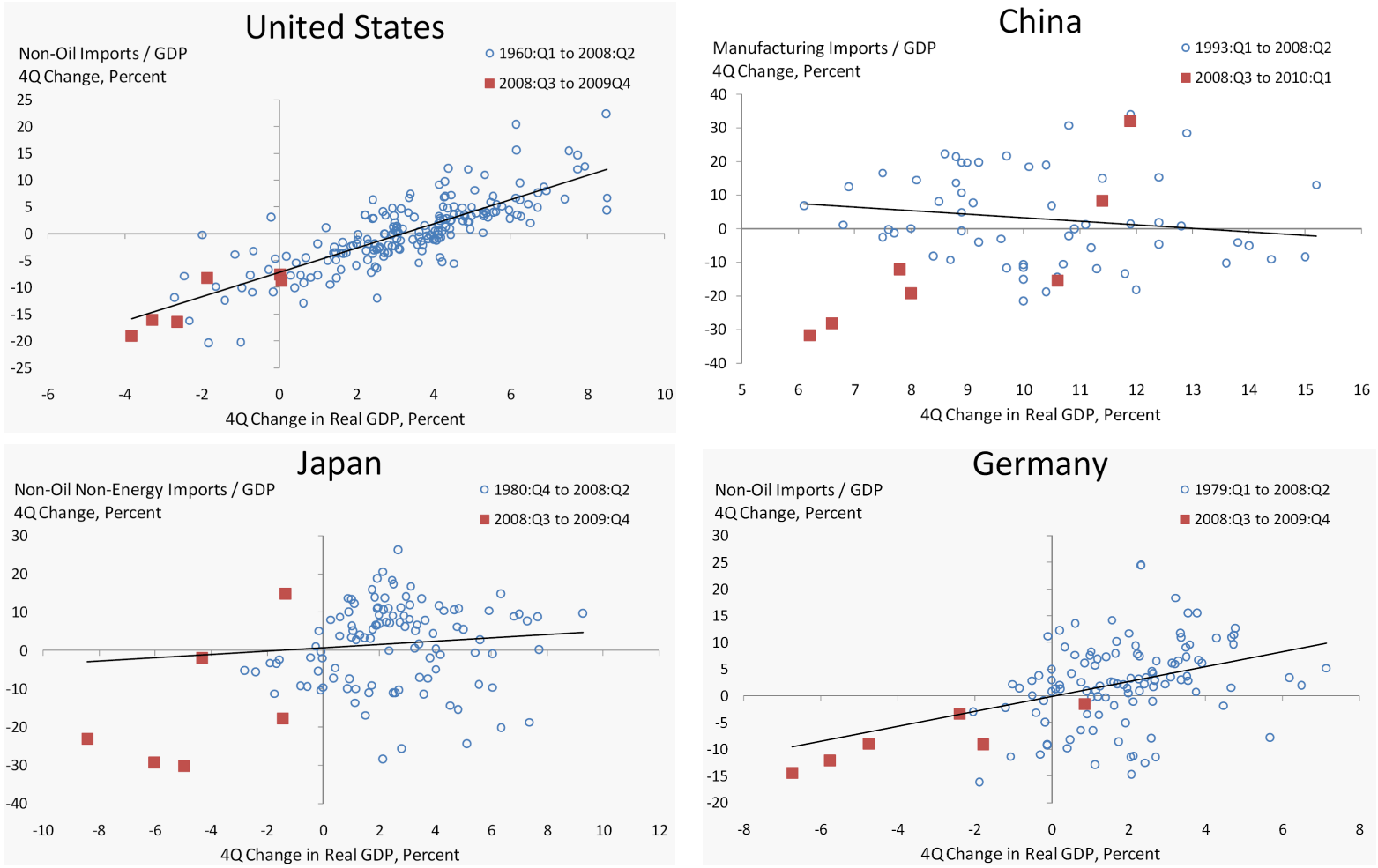

Figure 2: The Cyclical Properties of Trade in Selected Countries

Notes: For the United States, Japan, and Germany, non-oil imports are total imports less imports of petroleum, petroleum products, crude, and partly refined petroleum. For China, manufacturing imports are imports of manufactured goods. All series are from Datastream. We note that each of the four figures is plotted with a different scale for the vertical and horizontal axes.

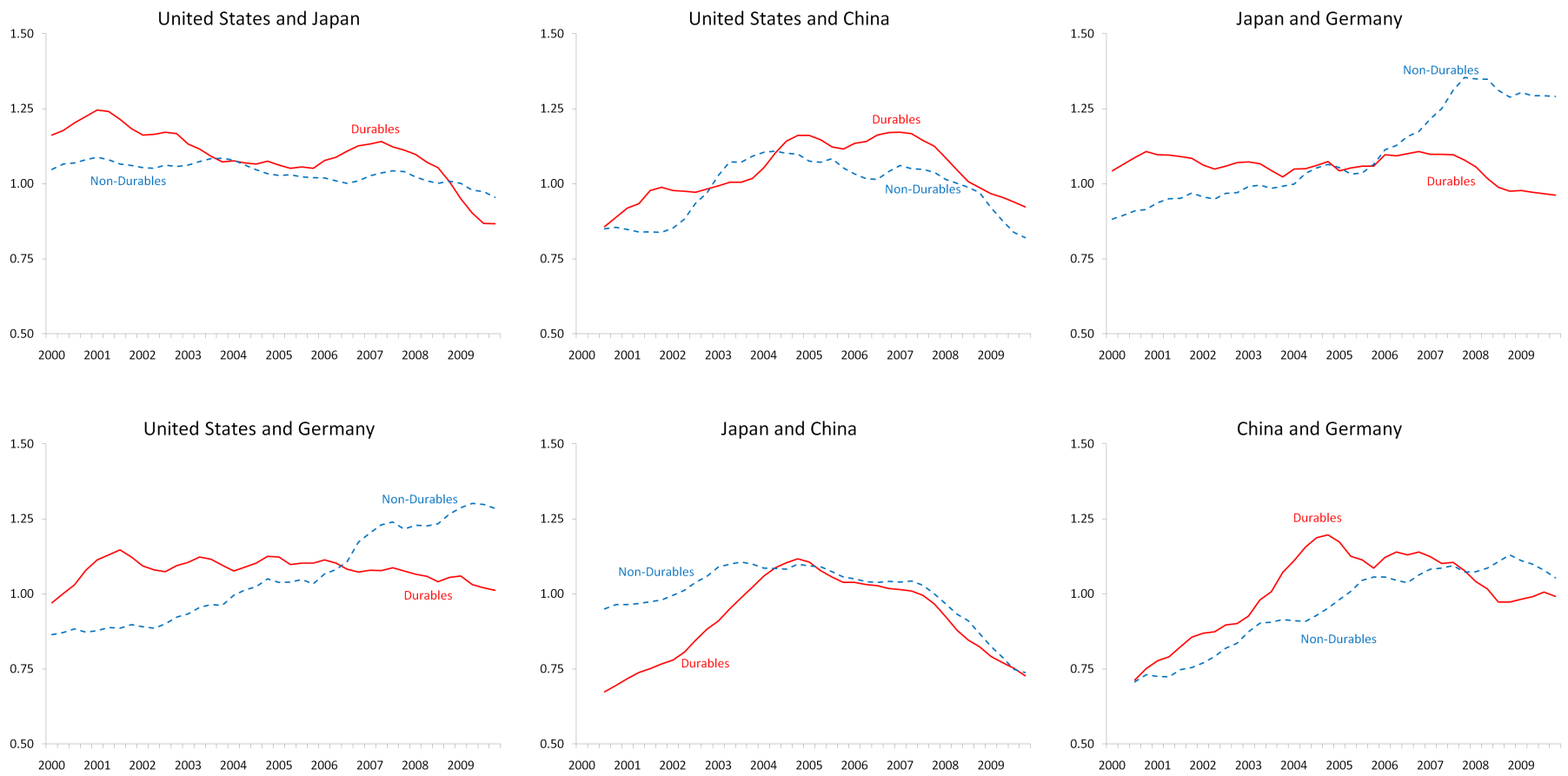

Figure 3: Head-Ries Indices: Selected Bilaterals

Notes: Head-Ries Indices (1) calculated for all bilateral combinations involving the United States, Japan, China, and Germany using manufacturing trade and production data separately in the durable and non-durable sectors. The indices are scaled to 2005:Q1=1 and plotted in 4-quarter moving averages to eliminate seasonal effects.

Figure 4: Head-Ries Indices: Selected Country Components

Notes: These plots show country-time fixed effects from weighted regressions of the logged bilateral Head-Ries Indices (1) calculated using manufacturing trade and production data separately in the durable and non-durable sectors. The fixed effects are exponentiated, scaled to 2005:Q1=1, and plotted in 4-quarter moving averages to eliminate seasonal effects.

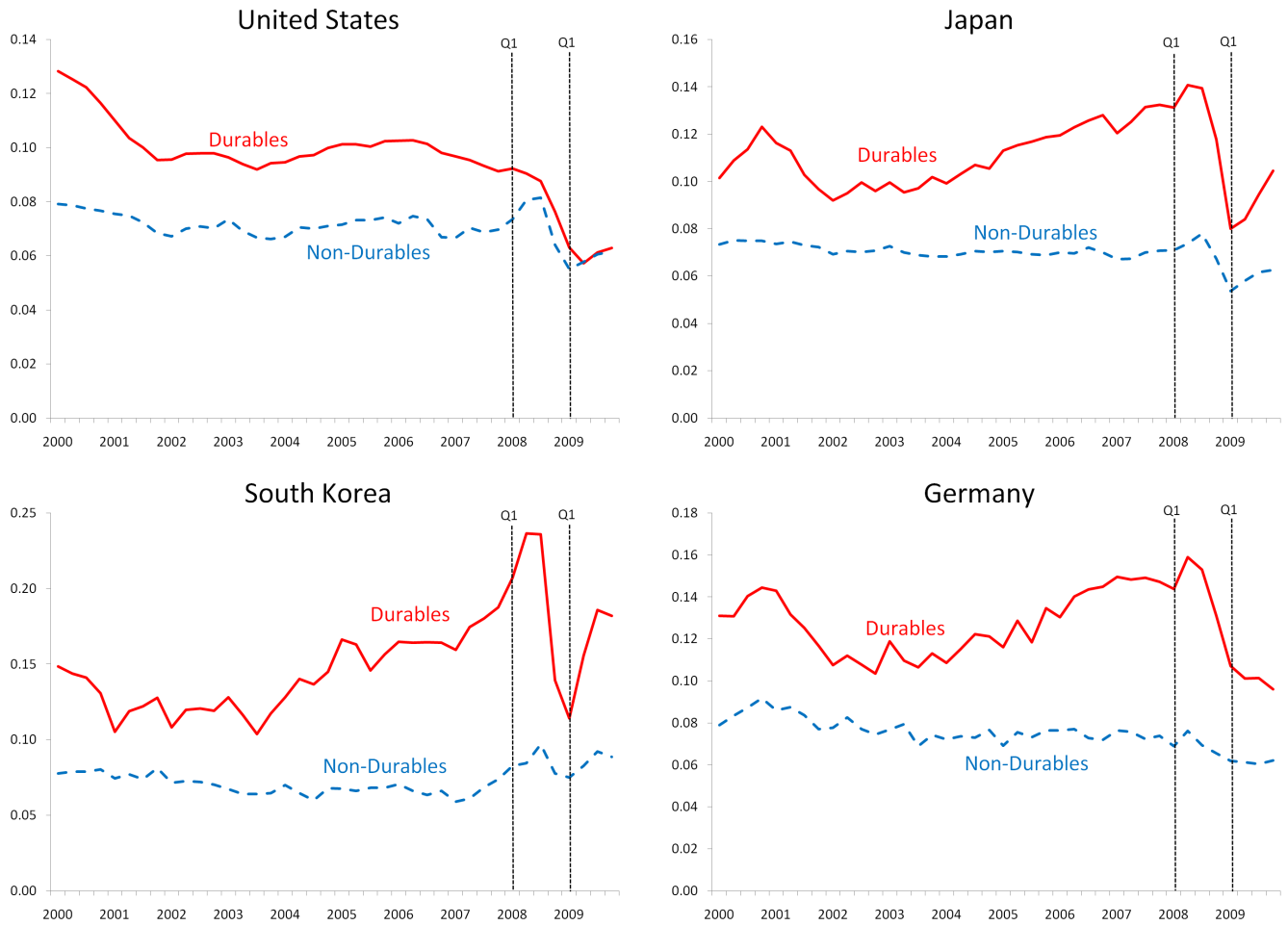

Figure 5: Shares of Manufacturing in Final Demand

Notes: These plots are generated using the relationship (20) from input-output coefficients and data on total absorption and production. We show South Korea (where we have typically shown China) because our assumption of fixed input-output coefficients is clearly violated in China when we go back before 2005 and the share becomes negative. This has no impact on our counterfactual exercise, though, and simply limits our ability to show a long history of the α's. This problem only arises in our dataset with China. We note that each of the four figures is plotted with a different scale for the vertical axes.

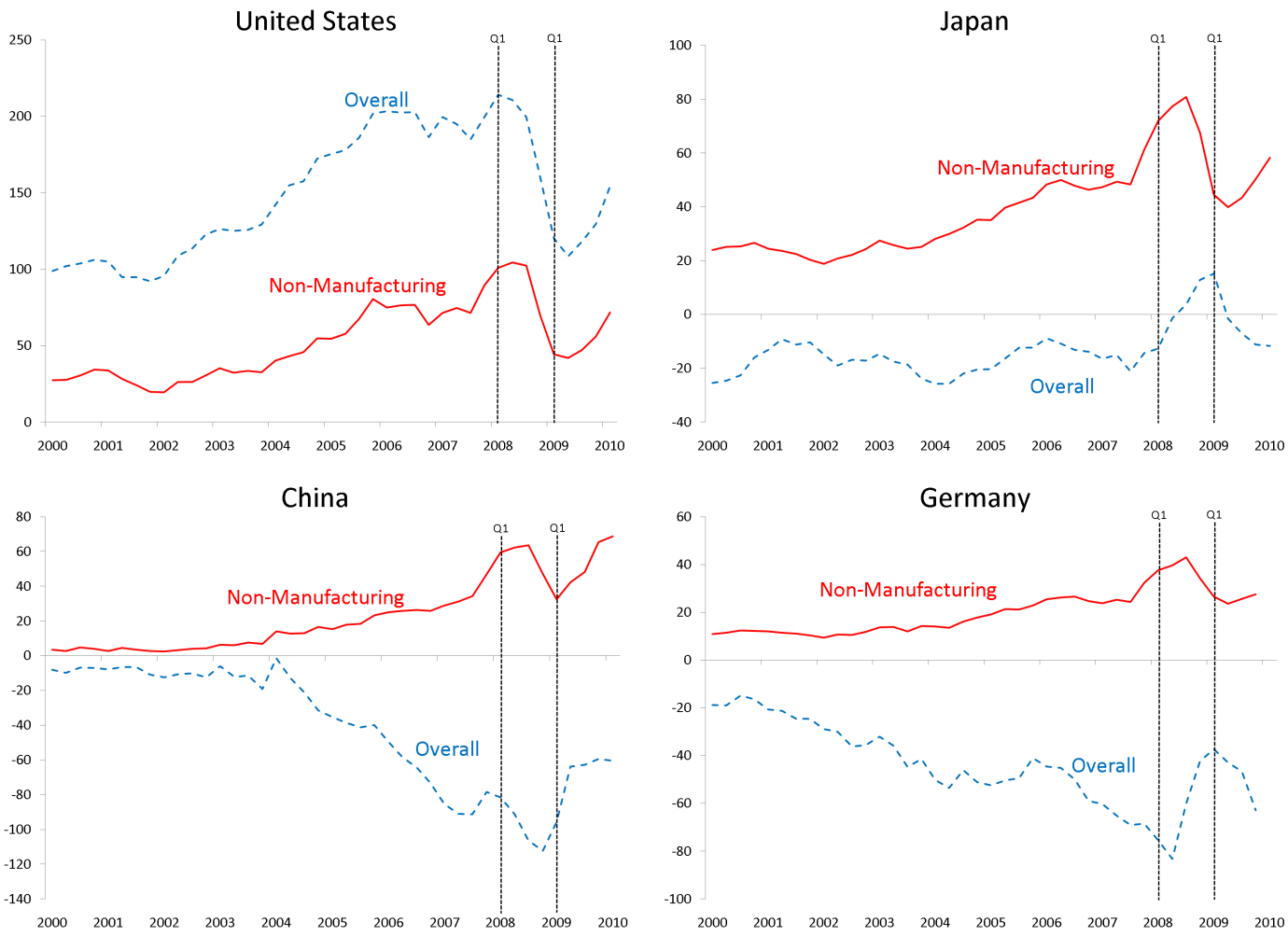

Figure 6: Trade Deficits: Overall and Non-Manufacturing

Notes: Deficits defined as imports less exports and measured in billions of U.S. dollars. "Overall" deficit refers to the sum of durable manufacturing, non-durable manufacturing, and non-manufacturing sectors. We note that each of the four figures is plotted with a different scale for the vertical axis.

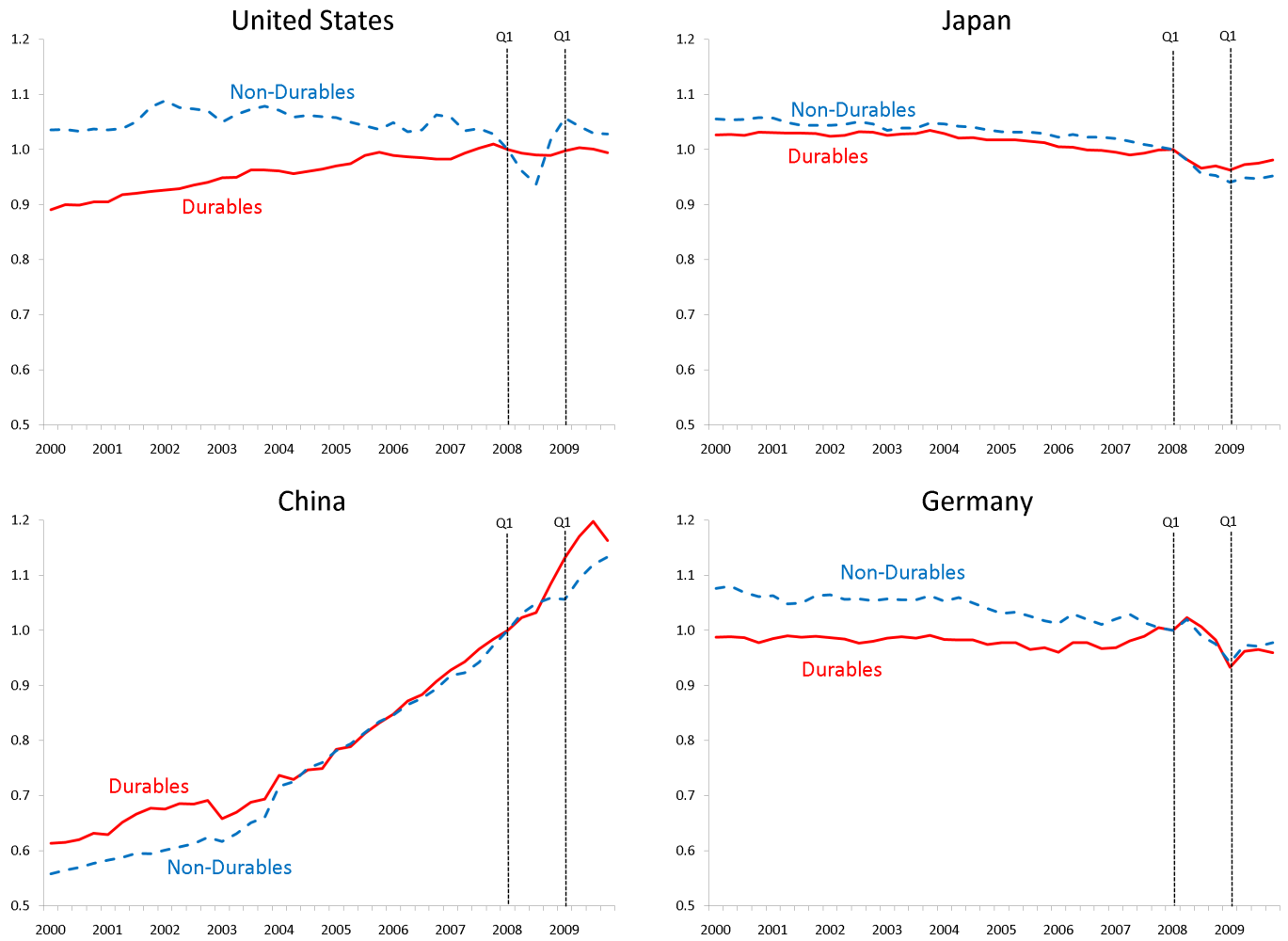

Figure 7: Manufacturing Productivities

Notes: These plots show an index of productivity levels, scaled to 2008:Q1=1, whose changes are the shocks to productivity measured according to (21).

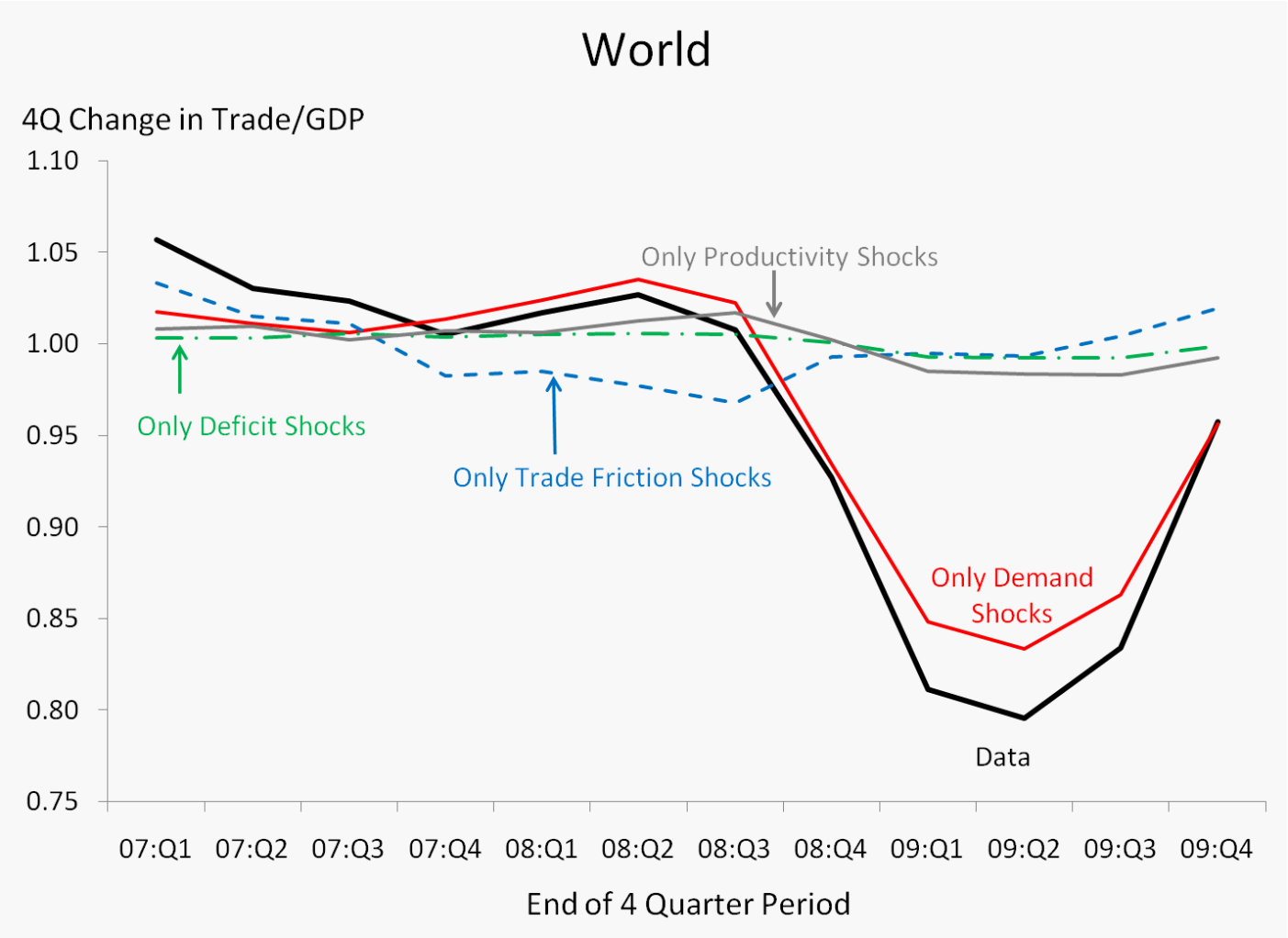

Figure 8: Global Trade/GDP in Data and Counterfactuals for the Great Recession

Notes: Growth in all variables is expressed relative to global GDP. Each point on the x-axis corresponds to growth over the 4-quarters preceding that period. The plot is therefore a series of 4-quarter static counterfactuals, connected together. The values near 1.00 toward the end of the plot thus indicate that global trade/GDP stabilized by 2009:Q4, not that it had recovered to the pre-crisis level.

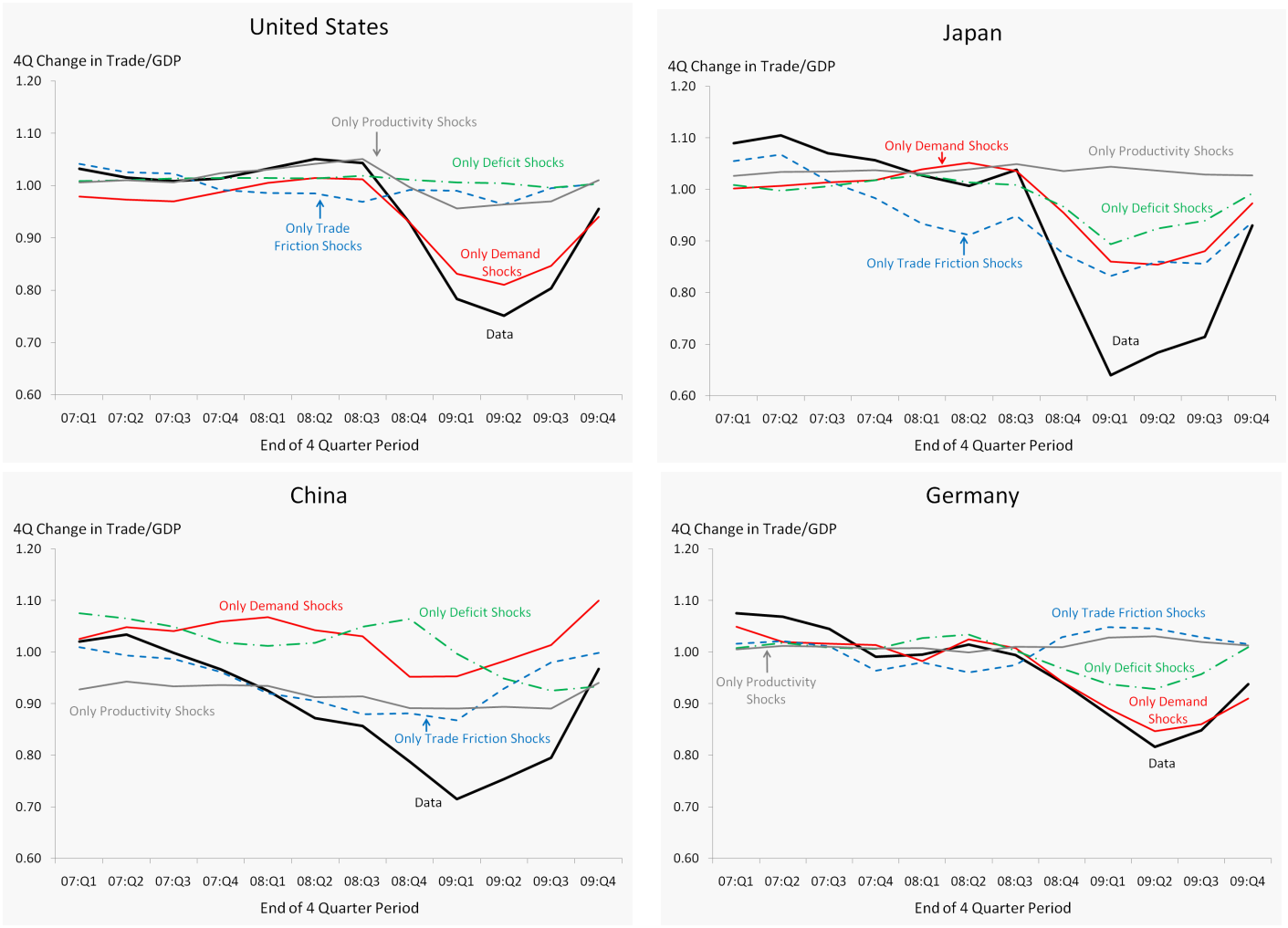

Figure 9: Country Trade/GDP Across Many Four-Quarter Periods in Data and Counterfactuals

Notes: Growth in all variables is expressed relative to global GDP. Each point on the x-axis corresponds to growth over the 4-quarters preceding that period. The plot is therefore a series of 4-quarter static counterfactuals, connected together.

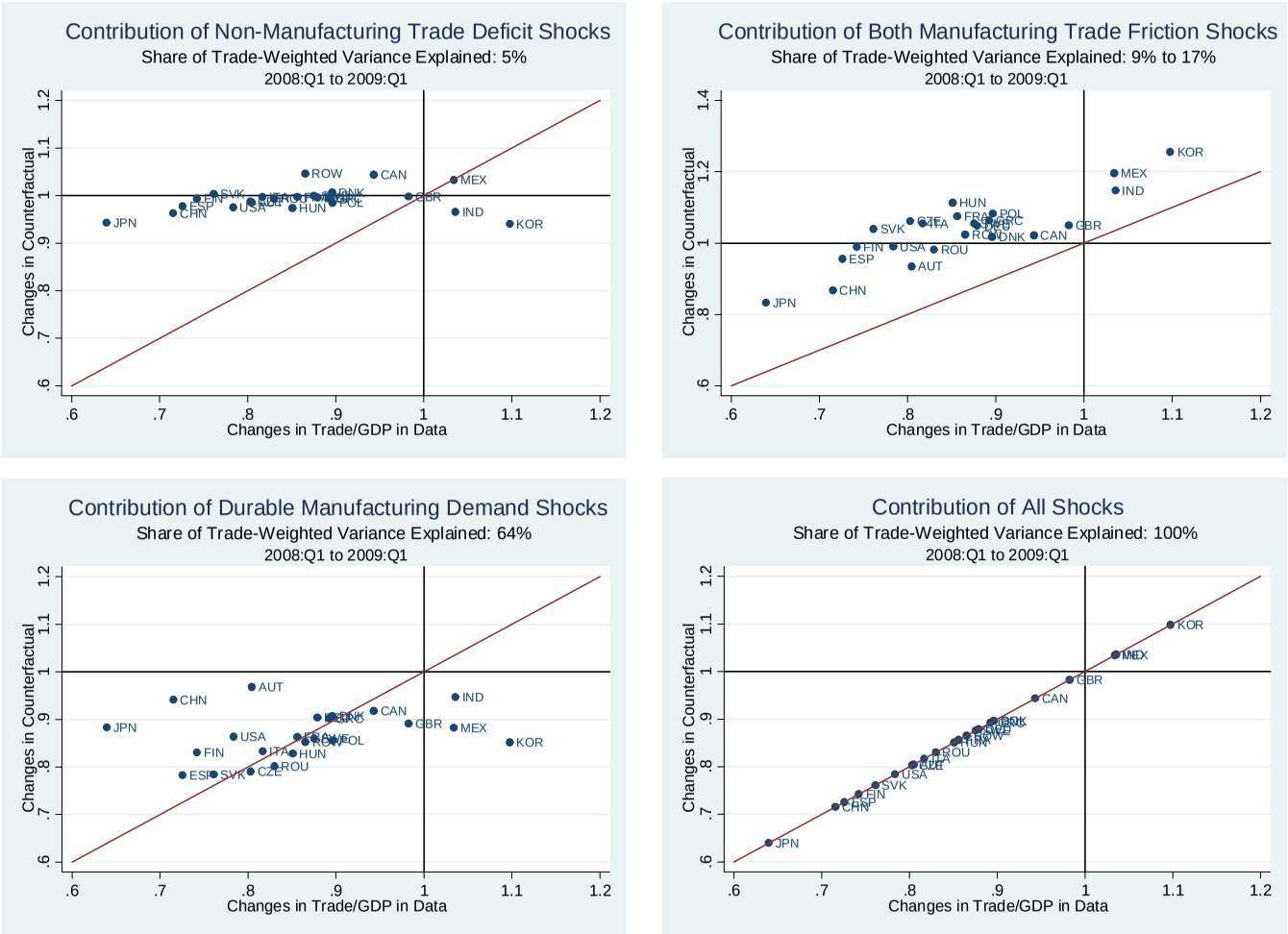

Figure 10: Cross-Sectional Explanatory Power of Various Shocks, 2008:Q1 to 2009:Q1

Notes: These plots compare the patterns in trade/GDP generated by various combinations of shocks to what was observed in the data from 2008:Q1 to 2009:Q1. Growth in all variables is expressed relative to global GDP. The ability of each counterfactual to explain the trade patterns observed in the data is summarized by the statistic (23), where a large value implies a better fit.

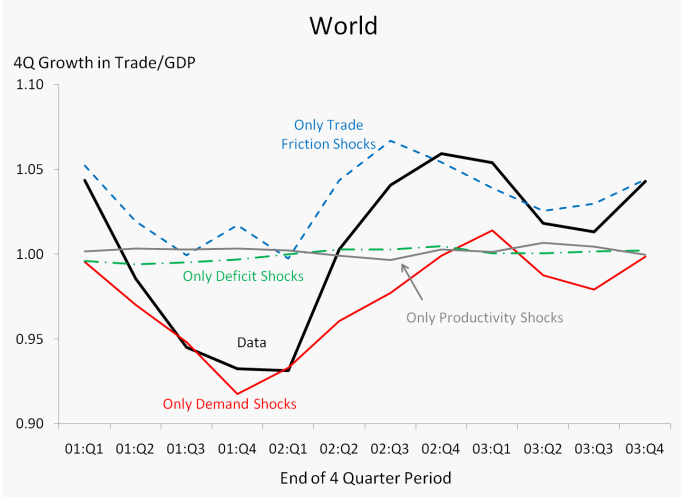

Figure 11: Global Trade/GDP in Data and Counterfactuals for the 2001 Recession
Notes: Growth in all variables is expressed relative to global GDP. Each point on the x-axis corresponds to growth over the 4-quarters preceding that period. The plot is therefore a series of 4-quarter static counterfactuals, connected together.

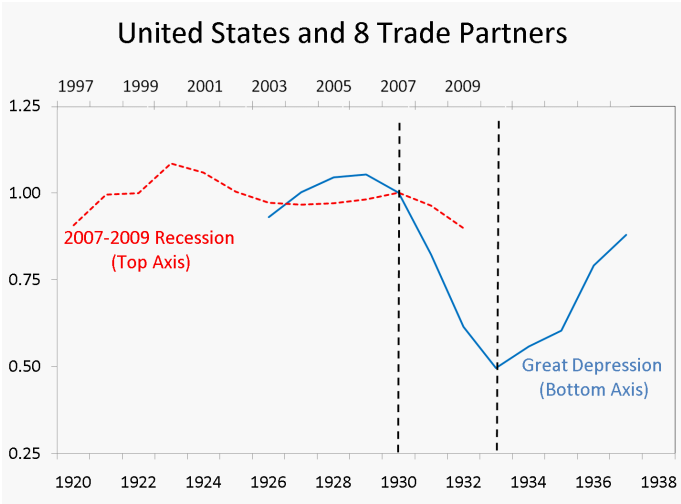

Figure 12: Head-Ries Indices: Great Recession vs. Great Depression
Notes: We plot the simple average of normalized bilateral Head-Ries indices for the United States and Austria, Canada, Germany, Spain, Finland, the United Kingdom, Japan, and Sweden. Unlike the other Head-Ries indices, these are done using annual data on all of manufacturing. See Appendix A for details on the construction of the dataset.

Appendices

Appendix A: Data Sources and Related Procedures

In this appendix, we first detail our sources for trade, production, input-output, and macroeconomic data. We omit countries lacking adequate data and retain 22 countries in our dataset. We next describe the construction of sectoral industrial production and producer price indices and the temporal disaggregation procedure that uses these indices along with annual data to generate monthly production values for each manufacturing sector. Finally, we list the data sources and procedures used to calculate the Head-Ries indices for Great Depression-era data.

Trade Data

We use monthly bilateral trade data from the Global Trade Atlas Database. These data are not seasonally adjusted and are in dollars. We aggregate 2-digit harmonized system (HS) categories to generate bilateral and multilateral trade flows in each manufacturing sector. We calculate global trade/GDP, referred to in the introduction, by multiplying the world trade volume index by the world trade price index available from the Netherlands Bureau for Economic Policy Analysis and then dividing by our own estimations of world GDP.

Concordances Linking Trade and Production

A concordance was constructed to link the 2-digit 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 to ISIC codes from the World Bank's World Integrated Trade Solution (WITS) website. This concordance was then merged with COMTRADE data on the volume of world trade at the 6-digit level for 2007-2008. 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 $j \in \Omega_M$. Appendix Table 2 shows levels of exports/GDP and imports/GDP, separately for each sector and country, for 2008:Q1 and 2009:Q1.

Input-Output Coefficients

We calculate the input-output coefficients – β_i^j and γ_i^{jl} – from the 2009 edition of the OECD's country tables.[33] We use the most recent input-output table available for each country. We concord the 48 sectors used in these tables to form input-output tables for the three sectors $j \in \Omega$. Appendix 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).

Additional Macro Data

Exchange rates to translate local currency values into dollars are from the OECD.Stat database and from the IMF's International Financial Statistics database. Other standard data used in the paper, such as quarterly GDP and trade deficits, are from the Economist Intelligence Unit (EIU). Trade and production data are translated using exchange rates at the monthly frequency.

IP and PPI Indices by Sector

We need sectoral IP and PPI indices to generate monthly production levels for durables and non-durables. The exact methodology used to construct the series depended on what series were available on Datastream, as this was not consistent across countries. Three different methodologies were used.

For some countries, Datastream contains IP or PPI series on durable manufacturing and non-durable manufacturing. Included in this category for IP are Canada, China, and the United States. Included in this category for PPI are China and the United States. For China the series are actually "Heavy Industry" and "Light Industry." The key difference appears to be that one group of non-durable manufactures, chemicals, is included in heavy industry.

Next, there are several countries for which Datastream contains IP or PPI series for capital goods, durable consumer goods, non-durable consumer goods, and intermediate goods. We classify capital goods as durable, but need to be able to decompose the intermediate goods into durable goods (such as metals) and non-durable goods (such as paper). The presence of more detailed manufacturing industry data allows us to do this using regression

[33] The only exception is China's input-output table, which was obtained from Robert Feenstra.

analysis. We regress monthly log-changes in intermediate goods IP or PPI series on log changes for underlying manufacturing industry series to reveal the composition of the intermediate series and exclude countries for which there is not a good fit. The regression results give us estimates of the industry composition of intermediate goods manufacturing, and we combine this with our industry concordances to generate durable and non-durable intermediate goods IP or PPI series. We then combine all the more aggregated categories, using their weights in production from the annual data, to generate indices for overall durables and non-durables. This methodology applies to the construction of our IP and PPI series for Austria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Romania, Slovakia, South Korea, Spain, Sweden, and the United Kingdom.

There are some countries with IP or PPI data for multiple manufacturing industries together with aggregate manufacturing (or occasionally, total industry IP or PPI). We use similar regression analysis to ascertain the industry composition of the broad measure, and then use our data on the durable and non-durable composition of each of these industries to construct aggregate durable and non-durable series. When the regression analysis does not yield a good fit (judged by a high R-squared and coefficients that sum close to 1), we do not include that country. This procedure was used for India, Japan, Mexico and Poland.

We also require IP and PPI indices for overall manufacturing. These monthly data for China were found at chinadataonline.com, and for the other countries were downloaded from the OECD Main Economic Indicators Database (MEI) and the EIU Database. Finally, we estimate changes in the PPI indices for our ROW category ($\hat{p}^j_{ROW}$) as an average of the $\hat{p}^j_i$ across the 22 countries in our sample.

Annual Production by Sector

In addition to monthly IP and PPI indices, we need annual production levels for each sector and for overall manufacturing. These annual data are taken 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 multiplied these shares by the manufacturing total from http://chinadataonline.org.

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) to get annual totals for each of these categories.[34] Our definition of manufacturing consists of ISIC industries 15 through 36, excluding 23 (petroleum). We further divide goods into capital goods, durable consumer goods, non-durable consumer goods, durable intermediate goods, and non-durable intermediate goods 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 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.

Temporal Disaggregation

Monthly manufacturing production level data are not available for most countries we study. However, annual data are available for all of these countries. We use monthly IP and PPI indices to disaggregate annual production levels into internally consistent monthly production values and out-of-sample predictions reflecting all available monthly information. This problem, referred to as temporal disaggregation, was studied from the 1950's by, among others, Milton Friedman (see Friedman, 1962).

We disaggregate and extrapolate annual production data in country i and sector j into monthly data using an adaptation of the Chow-Lin procedure (Chow and Lin, 1971). The first step of the procedure requires an elasticity between the monthly production data and the corresponding IP and PPI indices. Our baseline procedure assumes that both of these elasticities equals one, and as a robustness check, we also estimate these elasticities from a regression of annual production levels on the appropriately accumulated sum of the monthly indicators. The next step uses the assumed or estimated elasticity to generate predicted monthly values for the level of production. Generally, there will be a gap between the actual annual production level and the sum of the 12 predicted monthly values. The Chow-Lin procedure apportions this gap equally to each monthly predicted value. This creates an internally consistent monthly series that sums to the actual annual data, but generally creates artificial jumps from December to January due to residual corrections being identical within years and different across years. Hence, we instead follow Fernandez (1981) and redistribute the gap in a way that allows for serial correlation in the monthly residuals and

[34] 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.

eliminates these spurious jumps. We also follow Di Fonzi (2002) in treating the relationship between annual production levels and monthly IP and PPI indices as a log-linear rather than linear relationship. Exact details of our procedures are available from the authors on request.[35]

We run this procedure for the two manufacturing sectors separately, as well as for total manufacturing, which has the highest quality production data. Hence, we multiply the sector shares of manufacturing implied in our estimates by the overall manufacturing number. In the end, we have monthly series for durable and non-durable manufacturing production which are consistent with published annual (and implied monthly) levels of total manufacturing production in each country.

As a quality check, we compare our monthly fitted series to actual monthly U.S. Census Bureau data for the values of durable and non-durable manufacturing shipments (the United States is among the few countries with such monthly data). The U.S. monthly data are collected in the M3 manufacturing survey. For this quality test only, we re-run both procedures using annual totals from the M3 survey. Though M3 data are available through 2009, we only use data for 1995-2007 – the same amount of data we have for most other countries. Appendix Figure A2 shows that both procedures do an excellent job of matching movements in the non-durables series, including the out-of-sample decline in production during the Great Recession. Our baseline "Beta equals 1" procedure also does an excellent job for durables, though our procedure with estimated elasticities understates to some degree the decline in durables production during the Great Recession. We therefore use the baseline procedure for all results in the text. We checked all results using the estimated coefficients. Both procedures yield similar global results.

Calculating Head-Ries Indices During the Great Depression

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. Total U.S. multilateral manufacturing imports and exports were taken from Carter et al. (2006). The gross value of manufacturing, required for the denominator of (1), were obtained from a variety of country-specific sources.[36] The U.S. ratio of

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

[36] Where needed, U.S. Department of Commerce (1968) was used to translate 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

gross output to value added in manufacturing, found in Carter (2006), was applied to foreign manufacturing value added when 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.

Appendix B: Trade Frictions and Productivity

Her we show how the productivity and trade friction shocks can be combined into a single shock. Start with the price and trade-share equations

$$p_n^j = \varphi^j \left[\sum_{i=1}^{I} \left(w_i^{\widetilde{\beta}_i^j} \left(p_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)} \left(p_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)} \frac{d_{ni}^j}{A_i^j} \right)^{-\theta^j} \right]^{-1/\theta^j}, \tag{24}$$

$$\pi_{ni}^j = \left[w_i^{\widetilde{\beta}_i^j} \left(p_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)} \left(p_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)} \frac{\varphi^j d_{ni}^j}{A_i^j p_n^j} \right]^{-\theta^j}. \tag{25}$$

Both equation depend on the trade-friction shock and the productivity shock only through the combined shock

$$\lambda_{ni}^j = \frac{d_{ni}^j}{A_i^j}.$$

From (12) we get

$$\frac{\pi_{ni}^j}{\pi_{ii}^j} = \left(d_{ni}^j \frac{p_i^j}{p_n^j} \right)^{-\theta^j},$$

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.

hence we can back out the trade friction as

$$d_{ni}^{j} = \left(\frac{\pi_{ni}^{j}}{\pi_{ii}^{j}} \right)^{-1/\theta^{j}} \frac{p_{n}^{j}}{p_{i}^{j}}.$$

We can also rearrange (12) for $n = i$ to solve for productivity

$$A_{i}^{j} = \varphi^{j} w_{i}^{\widetilde{\beta}_{i}^{j}} \left(p_{i}^{j}\right)^{\widetilde{\gamma}_{i}^{jj}\left(1-\widetilde{\beta}_{i}^{j}\right)-1} \left(p_{i}^{l}\right)^{\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)} \left(\pi_{ii}^{j}\right)^{1/\theta^{j}}.$$

We can thus back out the combined shock as

$$\lambda_{ni}^{j} = \frac{\left(\pi_{ni}^{j}\right)^{-1/\theta^{j}} p_{n}^{j}}{\varphi^{j} w_{i}^{\widetilde{\beta}_{i}^{j}} \left(p_{i}^{j}\right)^{\widetilde{\gamma}_{i}^{jj}\left(1-\widetilde{\beta}_{i}^{j}\right)} \left(p_{i}^{l}\right)^{\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)}}$$

Notice that each individual shock as well as the combined shock all require price data.

We'll now try to derive an alternative to the combined shock that serves the same purpose but that can be backed out without the use of price data. Define a variable related to the price

$$q_{i}^{j} = p_{i}^{j} \left[\left(A_{i}^{j}\right)^{1-\widetilde{\gamma}_{i}^{jj}\left(1-\widetilde{\beta}_{i}^{j}\right)} \left(A_{i}^{l}\right)^{\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)} \right]^{1/\Delta_{i}} \tag{26}$$

and a variable capturing the combined shock

$$\delta_{ni}^{j} = \frac{\left[\left(A_{n}^{j}\right)^{1-\widetilde{\gamma}_{n}^{jj}\left(1-\widetilde{\beta}_{n}^{j}\right)} \left(A_{n}^{l}\right)^{\widetilde{\gamma}_{n}^{jl}\left(1-\widetilde{\beta}_{n}^{j}\right)} \right]^{1/\Delta_{n}}}{\left[\left(A_{i}^{j}\right)^{1-\widetilde{\gamma}_{i}^{jj}\left(1-\widetilde{\beta}_{i}^{j}\right)} \left(A_{i}^{l}\right)^{\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)} \right]^{1/\Delta_{i}}} d_{ni}^{j}, \tag{27}$$

where

$$\Delta_{i} = \left(1 - \widetilde{\gamma}_{i}^{jj}(1-\widetilde{\beta}_{i}^{j})\right)\left(1 - \widetilde{\gamma}_{i}^{ll}(1-\widetilde{\beta}_{i}^{l})\right) - \widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)\widetilde{\gamma}_{i}^{lj}\left(1-\widetilde{\beta}_{i}^{l}\right).$$

This new price term and combined shock satisfy

$$q_{n}^{j} = \varphi^{j} \left[\sum_{i=1}^{I} \left(w_{i}^{\widetilde{\beta}_{i}^{j}} \left(q_{i}^{j}\right)^{\widetilde{\gamma}_{i}^{jj}\left(1-\widetilde{\beta}_{i}^{j}\right)} \left(q_{i}^{l}\right)^{\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)} \delta_{ni}^{j} \right)^{-\theta^{j}} \right]^{-1/\theta^{j}} \tag{28}$$

and

$$\pi_{ni}^{j} = \left[w_{i}^{\widetilde{\beta}_{i}^{j}} \left(q_{i}^{j}\right)^{\widetilde{\gamma}_{i}^{jj}\left(1-\widetilde{\beta}_{i}^{j}\right)} \left(q_{i}^{l}\right)^{\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)} \frac{\varphi^{j}\delta_{ni}^{j}}{q_{n}^{j}} \right]^{-\theta^{j}}. \tag{29}$$

Thus, the implication for trade shares given wages is the same as in the original parameter-

ization.

First, we want to show that substituting (26) and (27) into (24) and (12) yields (28) and (29). It is sufficient to show that (26) and (27) imply

$$w_i^{\widetilde{\beta}_i^j}\left(p_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)}\left(p_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}\frac{\varphi^j d_{ni}^j}{A_i^j p_n^j}=w_i^{\widetilde{\beta}_i^j}\left(q_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)}\left(q_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}\frac{\varphi^j\delta_{ni}^j}{q_n^j} \tag{30}$$

or

$$\left(A_i^j\right)^{-1}=\left(q_i^j/p_i^j\right)^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)}\left(q_i^l/p_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}\frac{\delta_{ni}^j/d_{ni}^j}{q_n^j/p_n^j}. \tag{31}$$

Substituting (26) and (27) into the right hand side of (31) we get the simplification

$$\left(A_i^j\right)^{-\Delta_i}=\left[\left(A_i^j\right)^{1-\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)}\left(A_i^l\right)^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}\right]^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)-1}\left[\left(A_i^l\right)^{1-\widetilde{\gamma}_i^{ll}\left(1-\widetilde{\beta}_i^l\right)}\left(A_i^j\right)^{\widetilde{\gamma}_i^{lj}\left(1-\widetilde{\beta}_i^l\right)}\right]^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}$$

or

$$\left(A_i^j\right)^{-\Delta_i}=\left[\left(A_i^j\right)^{1-\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)}\right]^{\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)-1}\left[\left(A_i^j\right)^{\widetilde{\gamma}_i^{lj}\left(1-\widetilde{\beta}_i^l\right)}\right]^{\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}$$

which follows from the definition of Δ_i.

Next, we want to show that δ_{ni}^j can be backed out without data on prices. From (29) we have

$$\left(\delta_{ni}^j\right)^{-\theta^j}=\frac{\pi_{ni}^j}{\pi_{ii}^j}\left(\frac{q_i^j}{q_n^j}\right)^{\theta^j}$$

To get at the q's, evaluate (29) at $n=i$ to get

$$\pi_{ii}^j w_i^{\theta^j\widetilde{\beta}_i^j}\left(\varphi^j\right)^{\theta^j}=\left(q_i^j\right)^{\theta^j\left[1-\widetilde{\gamma}_i^{jj}\left(1-\widetilde{\beta}_i^j\right)\right]}\left(q_i^l\right)^{-\theta^j\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}$$

and

$$\pi_{ii}^l w_i^{\theta^l\widetilde{\beta}_i^l}\left(\varphi^l\right)^{\theta^l}=\left(q_i^l\right)^{\theta^l\left[1-\widetilde{\gamma}_i^{ll}\left(1-\widetilde{\beta}_i^l\right)\right]}\left(q_i^j\right)^{-\theta^l\widetilde{\gamma}_i^{lj}\left(1-\widetilde{\beta}_i^l\right)}.$$

We can solve these equations for

$$\left(q_i^j\right)^{\theta^j}=\left(\pi_{ii}^j w_i^{\theta^j\widetilde{\beta}_i^j}\left(\varphi^j\right)^{\theta^j}\right)^{\frac{1-\widetilde{\gamma}_i^{ll}\left(1-\widetilde{\beta}_i^l\right)}{\Delta_i}}\left(\pi_{ii}^l w_i^{\theta^l\widetilde{\beta}_i^l}\left(\varphi^l\right)^{\theta^l}\right)^{\frac{\theta^j\widetilde{\gamma}_i^{jl}\left(1-\widetilde{\beta}_i^j\right)}{\theta^l\Delta_i}}.$$

Thus

$$\left(\delta_{ni}^{j}\right)^{-\theta^{j}}=\frac{\pi_{ni}^{j}}{\pi_{ii}^{j}}\frac{\left(\pi_{ii}^{j}w_{i}^{\theta^{j}\widetilde{\beta}_{i}^{j}}\left(\varphi^{j}\right)^{\theta^{j}}\right)^{\frac{1-\widetilde{\gamma}_{i}^{ll}\left(1-\widetilde{\beta}_{i}^{l}\right)}{\Delta_{i}}}\left(\pi_{ii}^{l}w_{i}^{\theta^{l}\widetilde{\beta}_{i}^{l}}\left(\varphi^{l}\right)^{\theta^{l}}\right)^{\frac{\theta^{j}\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)}{\theta^{l}\Delta_{i}}}}{\left(\pi_{nn}^{j}w_{n}^{\theta^{j}\widetilde{\beta}_{n}^{j}}\left(\varphi^{j}\right)^{\theta^{j}}\right)^{\frac{1-\widetilde{\gamma}_{n}^{ll}\left(1-\widetilde{\beta}_{n}^{l}\right)}{\Delta_{n}}}\left(\pi_{nn}^{l}w_{n}^{\theta^{l}\widetilde{\beta}_{n}^{l}}\left(\varphi^{l}\right)^{\theta^{l}}\right)^{\frac{\theta^{j}\widetilde{\gamma}_{n}^{jl}\left(1-\widetilde{\beta}_{n}^{j}\right)}{\theta^{l}\Delta_{n}}}}.$$

In terms of changes:

$$\left(\widehat{\delta}_{ni}^{j}\right)^{-\theta^{j}}=\frac{\widehat{\pi}_{ni}^{j}}{\widehat{\pi}_{ii}^{j}}\frac{\left(\widehat{\pi}_{ii}^{j}\widehat{w}_{i}^{\theta^{j}\widetilde{\beta}_{i}^{j}}\right)^{\frac{1-\widetilde{\gamma}_{i}^{ll}\left(1-\widetilde{\beta}_{i}^{l}\right)}{\Delta_{i}}}\left(\widehat{\pi}_{ii}^{l}\widehat{w}_{i}^{\theta^{l}\widetilde{\beta}_{i}^{l}}\right)^{\frac{\theta^{j}\widetilde{\gamma}_{i}^{jl}\left(1-\widetilde{\beta}_{i}^{j}\right)}{\theta^{l}\Delta_{i}}}}{\left(\widehat{\pi}_{nn}^{j}\widehat{w}_{n}^{\theta^{j}\widetilde{\beta}_{n}^{j}}\right)^{\frac{1-\widetilde{\gamma}_{n}^{ll}\left(1-\widetilde{\beta}_{n}^{l}\right)}{\Delta_{n}}}\left(\widehat{\pi}_{nn}^{l}\widehat{w}_{n}^{\theta^{l}\widetilde{\beta}_{n}^{l}}\right)^{\frac{\theta^{j}\widetilde{\gamma}_{n}^{jl}\left(1-\widetilde{\beta}_{n}^{j}\right)}{\theta^{l}\Delta_{n}}}}.$$

Note that we can infer $\widehat{\delta}$ from input-output coefficients and data on changes in trade shares and GDP without any price data. Hence there is an alternative decomposition into the same $\widehat{\alpha}$'s and $\widehat{D}$'s as above and $\widehat{\delta}$'s not requiring price data. The contributions of the first two would be the same in our analysis above.

Appendix C: Solving for the Equilibrium

In this appendix, we explain in more detail how we solve for the system's equilibrium. 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 $\pi_{ni}^{j}(\widehat{w})=\left(\pi_{ni}^{j}\right)'$.

Second, we can substitute the non-manufacturing sector out of equation (4) to get

$$\left[\begin{array}{c}\left(X_{i}^{D}\right)'\\ \left(X_{i}^{N}\right)'\end{array}\right]=\widetilde{\boldsymbol{\alpha}}_{i}'\left(\left(Y_{i}^{F}\right)'+D_{i}'\right)-\boldsymbol{\delta}_{i}\left(D_{i}^{S}\right)'+\widetilde{\boldsymbol{\Gamma}}_{i}^{T}\left[\begin{array}{c}\left(Y_{i}^{D}\right)'\\ \left(Y_{i}^{N}\right)'\end{array}\right], \tag{D1}$$

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

$$\left(\widetilde{\alpha}_{i}^{j}\right)'=\left(\alpha_{i}^{j}\right)'+\left(\alpha_{i}^{S}\right)'\delta_{i}^{j},$$

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

$$\delta_{i}^{j}=\frac{\gamma_{i}^{Sj}(1-\beta_{i}^{S})}{1-\gamma_{i}^{SS}(1-\beta_{i}^{S})},$$

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

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

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

Third, we note that

$$\left(Y_i^j\right)' = \sum_{n=1}^{I} \left(\pi_{ni}^j\right)' \left(X_n^j\right)'. \tag{32}$$

Following Caliendo and Parro (2009), we can substitute this expression into the right hand side of (D1). Given wage changes, we obtain a linear system in the $\left(X_i^j\right)'$s by stacking (D1) across all countries:

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

Here

$$\mathbb{X}' = \left[\left(X_1^D\right)', \left(X_2^D\right)', ..., \left(X_I^D\right)', \left(X_1^N\right)', \left(X_2^N\right)', ..., \left(X_I^N\right)'\right]^T,$$

$$(\widetilde{\boldsymbol{\alpha}}\boldsymbol{X})' = \left[\left(\widetilde{\alpha}_1^D X_1^F\right)', \left(\widetilde{\alpha}_2^D X_2^F\right)', ..., \left(\widetilde{\alpha}_I^D X_I^F\right)', \left(\widetilde{\alpha}_1^N X_1^F\right)', \left(\widetilde{\alpha}_2^N X_2^F\right)', ..., \left(\widetilde{\alpha}_I^N X_I^F\right)'\right]^T,$$

with

$$\left(\widetilde{\alpha}_i^j X_i^F\right)' = \left(\widetilde{\alpha}_i^j\right)' \left(\widehat{w}_i Y_i^F + D_i'\right),$$

$$\left(\delta\mathbb{D}^S\right)' = \left[\delta_1^D \left(D_1^S\right)', \delta_2^D \left(D_2^S\right)', ..., \delta_I^D \left(D_I^S\right)', \delta_1^N \left(D_1^S\right)', \delta_2^N \left(D_2^S\right)', ..., \delta_I^N \left(D_I^S\right)'\right]^T,$$

$$\widetilde{\mathbf{\Gamma}} = \begin{bmatrix} \widetilde{\gamma}_1^{DD}(1-\widetilde{\beta}_1^D) & 0 & 0 & \widetilde{\gamma}_1^{DN}(1-\widetilde{\beta}_1^D) & 0 & 0 \\ 0 & \ddots & 0 & 0 & \ddots & 0 \\ 0 & 0 & \widetilde{\gamma}_I^{DD}(1-\widetilde{\beta}_I^D) & 0 & 0 & \widetilde{\gamma}_I^{DN}(1-\widetilde{\beta}_I^D) \\ \widetilde{\gamma}_1^{ND}(1-\widetilde{\beta}_1^N) & 0 & 0 & \widetilde{\gamma}_1^{NN}(1-\widetilde{\beta}_1^N) & 0 & 0 \\ 0 & \ddots & 0 & 0 & \ddots & 0 \\ 0 & 0 & \widetilde{\gamma}_I^{ND}(1-\widetilde{\beta}_I^N) & 0 & 0 & \widetilde{\gamma}_I^{NN}(1-\widetilde{\beta}_I^N) \end{bmatrix},$$

and

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

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

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

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

Finally, summing up (32) over $j \in \Omega_M$ yields

$$X_i^D(\widehat{w}) + X_i^N(\widehat{w}) - \left(D_i' - \left(D_i^S\right)'\right) = \sum_{n=1}^{I} \pi_{ni}^D(\widehat{w}) X_n^D(\widehat{w}) + \sum_{n=1}^{I} \pi_{ni}^N(\widehat{w}) X_n^N(\widehat{w}). \qquad \text{(D2)}$$

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

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Appendix 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

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

Notes: Authors' classifications of the 48 sectors included in the OECD input-output tables, with one sector ("Manufacturing nec; recycling (include Furniture)") split evenly between durables and non-durables.

	2008:Q1 Values of:						Change (2009:Q1/2008:Q1) in:					
	Exports / GDP			Imports / GDP			Exports / GDP			Imports / GDP		
	All (percent)	Durables (percent)	Non-Durables (percent)	All (percent)	Durables (percent)	Non-Durables (percent)	All	Durables	Non-Durables	All	Durables	Non-Durables
World	**18.2**	**12.7**	**5.5**	**18.2**	**12.7**	**5.5**	**0.81**	**0.78**	**0.89**	**0.81**	**0.78**	**0.89**
Austria	43.0	31.0	12.0	38.4	26.3	12.1	0.78	0.73	0.89	0.84	0.80	0.92
Canada	18.5	13.0	5.5	21.6	15.6	5.9	0.89	0.83	1.03	0.99	0.93	1.14
China	33.8	24.5	9.3	19.5	14.5	5.0	0.74	0.72	0.79	0.67	0.67	0.68
Czech Republic	68.1	54.9	13.2	60.9	44.4	16.5	0.80	0.79	0.87	0.80	0.76	0.90
Denmark	28.4	15.2	13.2	28.1	17.5	10.6	0.90	0.84	0.97	0.89	0.86	0.94
Finland	34.2	24.4	9.8	26.7	19.4	7.3	0.72	0.69	0.79	0.77	0.72	0.91
France	19.6	12.1	7.5	19.9	12.7	7.2	0.83	0.79	0.89	0.88	0.85	0.94
Germany	38.1	27.5	10.6	26.1	17.4	8.6	0.85	0.81	0.95	0.92	0.89	0.99
Greece	5.6	2.6	3.0	18.8	10.7	8.1	0.84	0.75	0.91	0.91	0.88	0.94
Hungary	68.4	54.3	14.1	62.6	47.2	15.4	0.86	0.83	0.99	0.84	0.80	0.96
India	9.2	4.7	4.5	11.3	8.1	3.2	1.02	1.13	0.90	1.05	1.05	1.04
Italy	21.8	14.4	7.4	18.1	11.2	6.9	0.81	0.78	0.88	0.82	0.76	0.93
Japan	15.5	13.3	2.2	8.6	5.5	3.1	0.57	0.56	0.66	0.76	0.68	0.91
Mexico	20.9	17.7	3.2	23.7	17.1	6.6	1.05	1.03	1.19	1.02	1.01	1.03
Poland	30.7	22.0	8.7	33.4	22.3	11.0	0.93	0.90	1.00	0.87	0.82	0.96
Romania	21.2	14.5	6.7	36.4	24.5	11.9	0.92	0.93	0.90	0.78	0.67	0.99
Slovakia	75.6	61.3	14.3	71.6	53.2	18.4	0.75	0.74	0.80	0.77	0.72	0.91
South Korea	35.8	29.2	6.6	25.7	18.9	6.9	1.15	1.16	1.11	1.03	1.02	1.05
Spain	15.5	9.7	5.7	21.3	13.7	7.6	0.76	0.70	0.86	0.70	0.63	0.83
Sweden	35.1	25.2	9.8	29.1	20.3	8.8	0.86	0.79	1.04	0.89	0.82	1.05
United Kingdom	14.0	9.2	4.8	19.0	12.5	6.6	0.98	0.90	1.14	0.98	0.90	1.14
United States	7.5	5.4	2.1	10.7	7.6	3.0	0.81	0.79	0.84	0.77	0.73	0.87
ROW	16.4	10.2	6.2	21.4	15.5	5.9	0.88	0.82	0.98	0.85	0.83	0.92

Appendix Table 2: Changes in Sectoral and Total Imports/GDP and Exports/GDP from 2008:Q1 to 2009:Q1

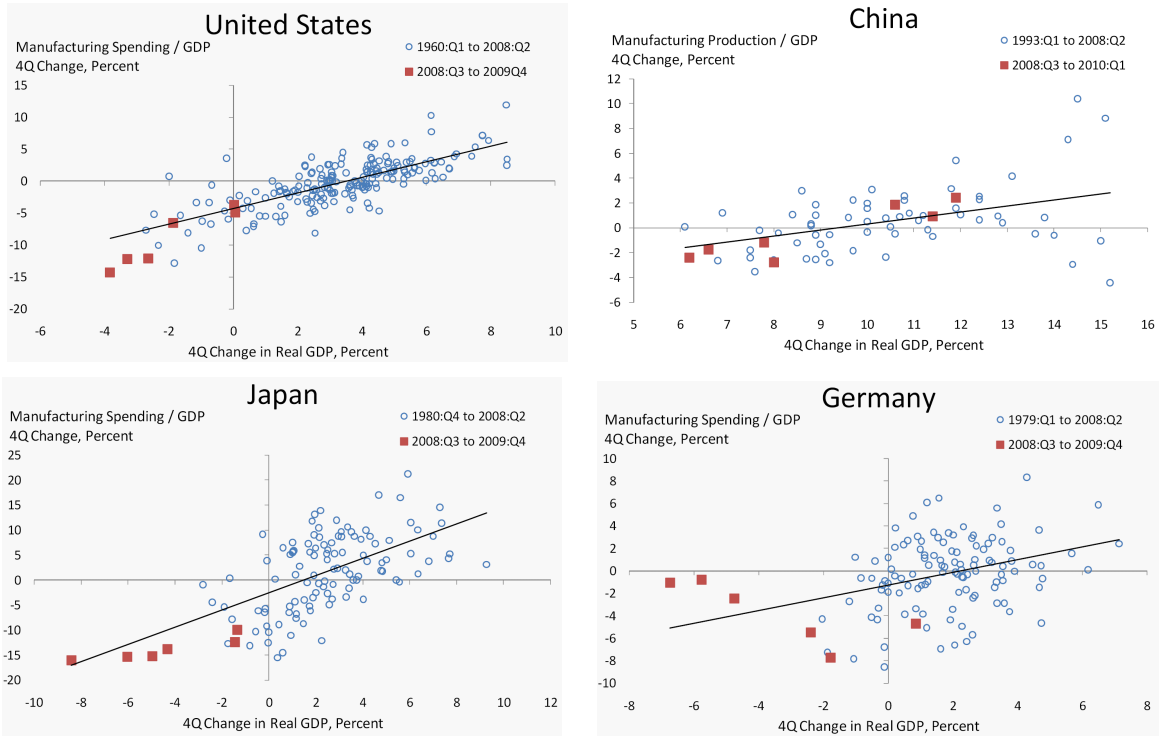
Notes: Growth in all variables is expressed relative to global GDP. "Imports" and "Exports" refer only to manufacturing trade (omitting, for example, oil). Gross growth rates on right side of chart compare the realized values in 2009:Q1 compared to 2008:Q1.

Shock:	Demand Shocks		Trade Frictions		Deficit Shocks		Prod. Shocks		Share of Trade-Weighted Variance Explained
Sector:	Durables	Non-Durables	Durables	Non-Durables	Durables	Non-Durables	Durables	Non-Durables	
	("X" Indicates Shocks are Included)								(2008:Q1 to 2009:Q1)
	X								0.64
		X							0.17
			X						0.07 to 0.13
				X					0.08 to 0.12
					X				0.05
						X			-0.01
							X		0.11
								X	0.01
	X	X							0.65
			X	X					0.09 to 0.17
					X	X			0.10
							X	X	0.12
	X	X			X	X			0.71
	X	X					X	X	0.74
			X	X			X	X	0.18 to 0.26
	X	X	X	X	X	X	X	X	1.00

Appendix Table 3: Cross-Sectional Explanatory Power of Combinations of Shocks, 2008:Q1 to 2009:Q1

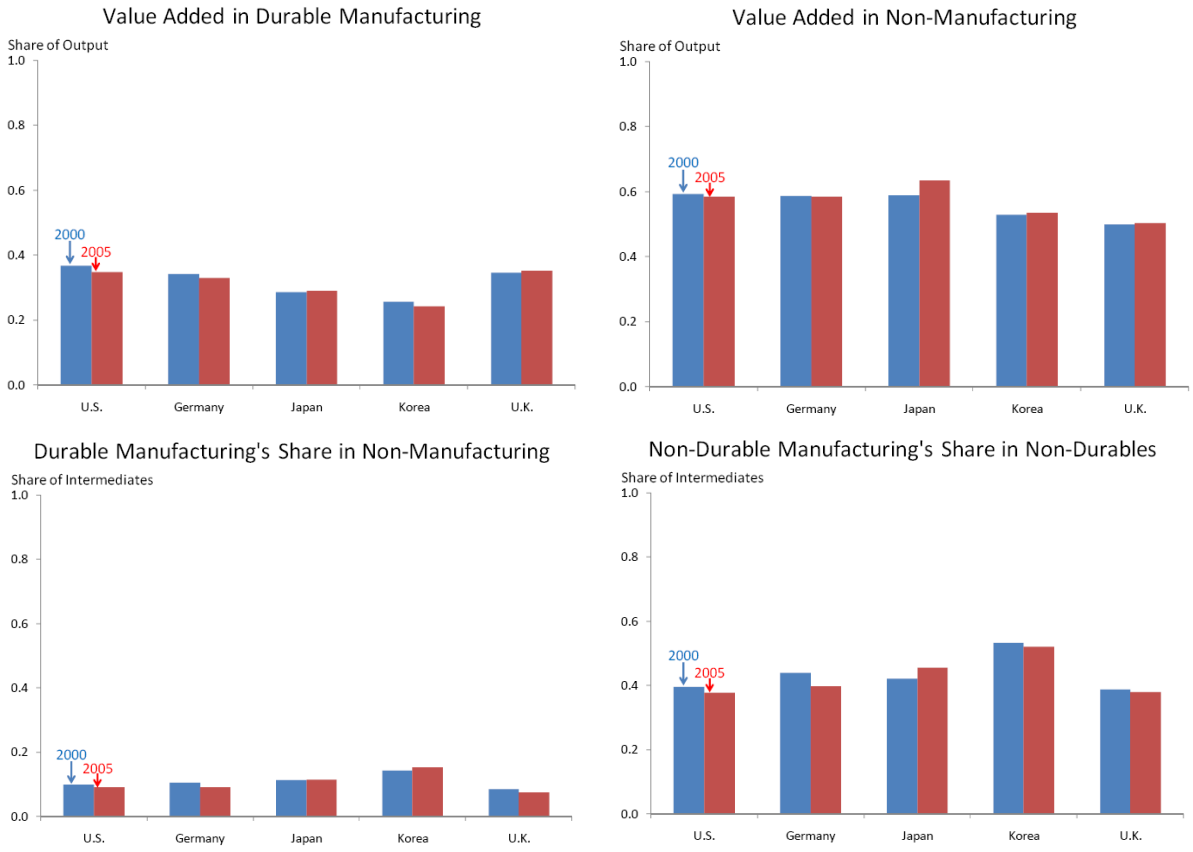
Notes: Ranges for share of variance explained reflect differential treatment of ROW, as described in the text. These ranges are only given for counterfactuals involving trade friction shocks, since these are the only shocks that directly involve both ROW and other countries in the data. Those counterfactuals are most sensitive to assumptions used to construct ROW.

Appendix Figures



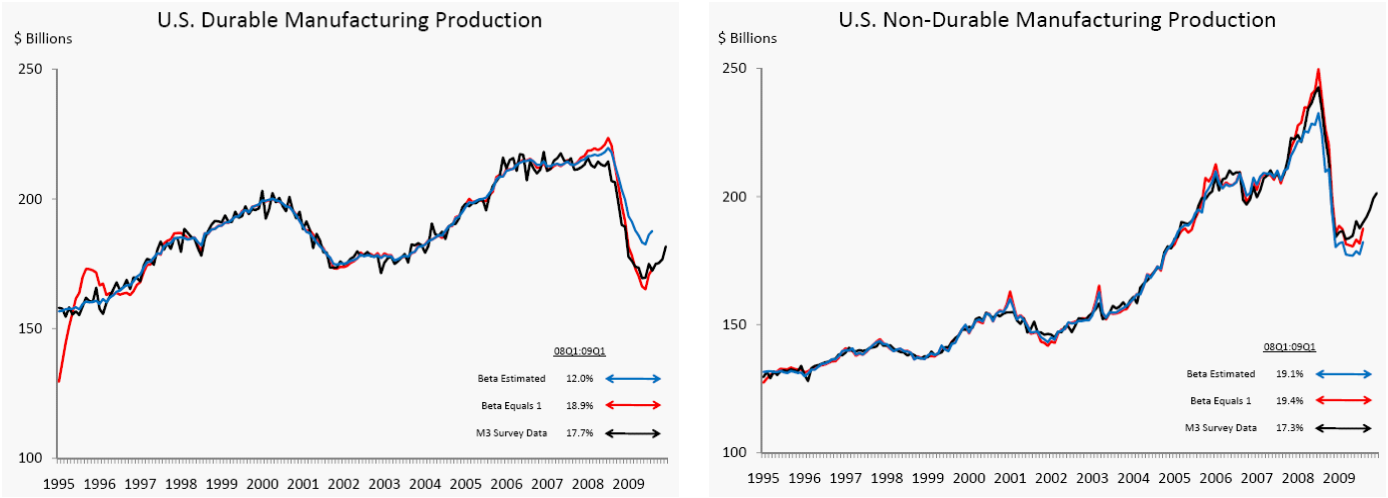
Appendix Figure 1: The Cyclical Properties of Tradable-Sector Activity in Selected Countries

Notes: For the United States, manufacturing spending is the sum of non-farm non-financial business capital spending, personal consumption expenditures on durables, and half of personal consumption expenditures on non-durables (only half because it includes some non-manufactures and services). For Japan, manufacturing spending is the sum of business expenditure on new plant and equipment, household expenditure on durable goods, and household expenditure on semi-durables For China, manufacturing production is the GDP of secondary industry. For Germany, growth in manufacturing spending to GDP is one third of the growth rate of machinery and equipment investment to GDP plus two-thirds of the growth rate of retail sales including motor vehicles and petrol to GDP. All series are from Datastream. We note that each of the four figures is plotted with a different scale for the vertical and horizontal axes.



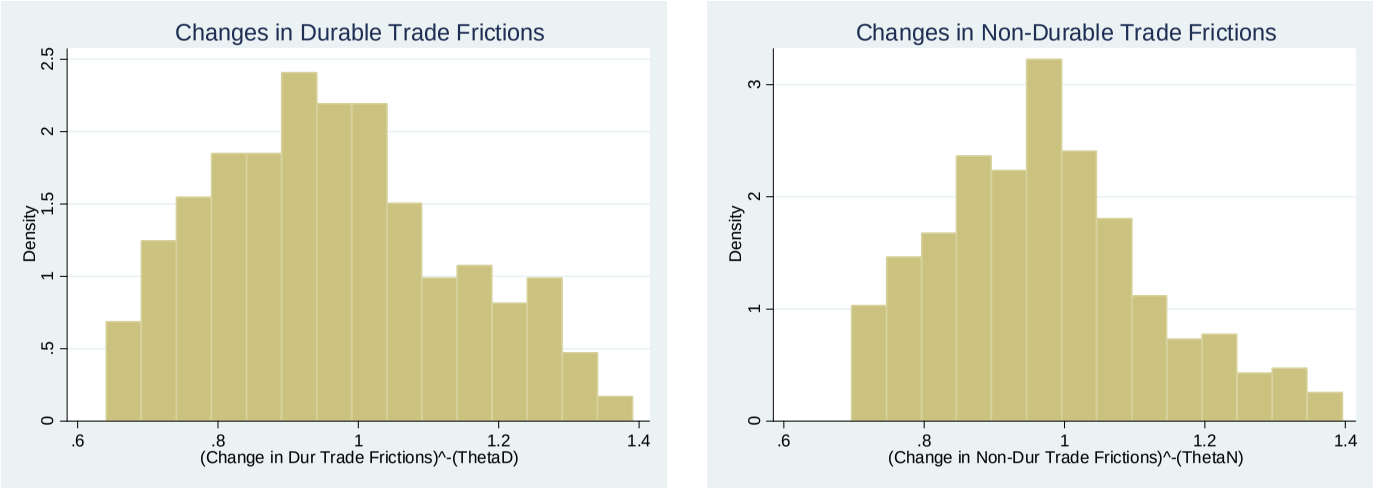
Appendix Figure 2: Sample Input-Output Coefficients (β_i^D, β_i^N, γ_i^{ND}, and γ_i^{NN})

Notes: Input-Output coefficients calculated from OECD input-Output database, version 2009. See Appendix Table 1 for sectoral definitions. γ Coefficients calculated as spending by one sector on another's output divided by total input purchases at basic prices (i.e. net of taxes on products).



Appendix Figure 3: Checking Accuracy of Temporal Disaggregation Procedure for United States

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 Figure 4: Shocks to Bilateral Trade Frictions from 2008:Q1 to 2009:Q1

Notes: Histogram plots $\left(\hat{d}_{ni}^{j}\right)^{-\theta^{j}}$ for each sector j during the period 2008:Q1 to 2009:Q1. Note that values less than 1 imply an increase in trade frictions. the largest and smallest 5 percentile shocks (generally between small countries) are excluded.