Trade and the Global Recession*

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Abstract

The World Trade Organization forecasts that the volume of global trade will in 2009 exhibit its biggest contraction since World War II. This large drop in international trade is generating significant attention and concern. Given the severity of the current global recession, is international trade behaving as we would expect? Or alternatively, is international trade shrinking due to factors unique to cross border transactions per se? This paper merges an input-output framework with a structural gravity trade model in order to quantitatively answer these questions. The framework distinguishes a drop in trade resulting from a decline in the tradable good sector from a drop resulting from worsening trade frictions. We demonstrate empirically that given the geographic distribution and size of the decline in demand for manufactures, the overall decline in trade flows of manufactured goods is unexpectedly large. We use the model to solve numerically several counterfactual scenarios which give a quantitative sense for the relative importance of trade frictions and other shocks in the current recession. Our results suggest that the decline in demand for manufactures is the most important driver of the decline in manufacturing trade. An increase in trade frictions also plays an important role, but one that varies substantially across countries.

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1 Introduction

The World Trade Organization forecasts that the volume of global trade will in 2009 exhibit its biggest contraction since World War II.[1] The four panels of Figure 1 plot the average of imports and exports relative to GDP for the four largest countries in the world: U.S. Japan, China, and Germany.[2] This ratio sharply declined in the recent recession in each of these economies. Figure 2 plots the decline in an index of trade relative to GDP for the whole world since 1991. This large drop in international trade has generated significant attention and concern, even against a backdrop of plunging final demand and collapsed asset prices.

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

What is at stake in determining the culprit? Imagine that nothing unique to cross-border trade occurred. In such a scenario, trade flows would have declined from France to the U.S., but this would contain no more information than the decline in flows from Ohio to Florida. Put differently, given the severity of the recession, international trade would have behaved as expected. In this version of events, it would be crucial to understand what drove the decline in final demand for tradable goods, and international trade data could only contribute to our understanding of the cross-country transmission of the recent global recession.

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

[1] WTO Press Release 554, March 23, 2009. http://www.wto.org/english/news_e/pres09_e/pr554_e.htm

[2] Only annual figures are available for China. The 2009 point of that plot is extrapolated from the first 7 months of data.

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

This paper aims to quantitatively determine the relative contributions of these explanations, both globally and at the country level. Our tentative [pending addition of durables/non-durables, see below] conclusion is that the fall in international trade has exceeded what one would expect simply from the decline in tradables demand, and hence, does indeed reflect an independent contribution to the troubles facing the global economy. The scale of this decline, while large, is not unprecedented: when we compare these findings to calculations done on data from the Great Depression, we find that our framework implies a far more dramatic increase in trade frictions in the early 1930s.

Our analytic tool is a multi-sector model of production and trade, calibrated to detailed global data from recent quarters. We run counterfactuals to determine what the path of trade would have been without the collapse in demand for manufactures and without the increase in trade frictions. We find the collapse in demand to be the single most important factor, though both play quantitatively meaningful roles. The model further allows us to consider changes occurring only in single countries or groups of countries, and we tentatively conclude from such analyses that the increase in trade frictions was most important in trade with developing and emerging countries excluded from our primary dataset. Further, this disaggregation is very heterogenous across countries. Some countries' exports dropped due primarily to final demand for their goods, while others were hurt due primarily to trade frictions.

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

First, to see the difficulty imposed by heterogenous input-output structures, imagine a country

that produces final goods without any intermediate inputs. In such a case, any change in dollars of gross production and net imports must equal the change in dollars of final demand. Another country that uses inputs in production might require a dramatically larger change in gross production and net imports to support the same dollar decline in final demand. Relatedly if one country uses disproportionately more non-tradable intermediates in its production of tradable final goods, then the same dollar decline in final tradables demand would imply, all things equal, a disproportionately smaller decline in net imports. We solve this first problem by building a 3-sector model with a global input-output structure. Durable and non-durable manufactured goods, non-manufactured goods, and labor are combined in each sector to produce both final goods and additional intermediate inputs. Output elasticities are taken from country-specific input-output tables.

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

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

We calibrate our multi-country general equilibrium model to fully account for changes in macroeconomic and trade variables from the first quarter of 2008 to the first quarter of 2009. We focus on trade in the durable and non-durable manufacturing sectors. To quantify the impact of global or

country-specific shocks on trade flows in our model, we run counterfactual scenarios and correlate these outcomes with what was actually observed in the data.

The spirit of our exercise is similar to that of growth accounting.[3] Just as growth accounting builds and uses a theoretical framework to decompose output growth into the growth of labor and capital inputs as well as a Solow residual term, we build and use our model to decompose changes in trade flows into changes in several factors like demand, deficits, and productivity, as well as changes in trade frictions.

2 Trade Decline: Hypotheses

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

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

In addition to the negative shock to trade credit availability, there are other explanations that suggest something unique is happening to international trade, per se. For example, there are unsettling signals that protectionist measures have and may continue to exert an extra drag on trade.[4]

[3] One might also think of it as an analog for international trade to the "wedges" approach for business cycle accounting in Chari, Kehoe, and McGratten (2007).

[4] For example, in a session at the China Economic Summer Institute conference, panelists hypothesized that imports had plummetted, despite robust growth, due to unannounced protectionist measures associated with China's

Brock (2009) writes, "...many political leaders find the old habits of protectionism irresistable ... This, then, is a large part of the answer to the question as to why world trade has been collapsing faster than world GDP." [Add Evenett citation.] 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.[5] In addition, dynamics associated with the inventory cycle may be generating disproportionately severe contractions in trade as in Alessandria, Kaboski, and Midrigan (2009, 2010). All of these potential disruptions can be broadly construed as reflecting trade frictions.

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

3 A Framework to Analyze the Global Recession

We now turn to our general equilibrium framework, which builds upon the models of Eaton and Kortum (2002), Lucas and Alvarez (2008), and Dekle, Eaton, and Kortum (2008). Our setup is most closely related to recent work by Caliendo and Parro (2009), which uses a multi-sector generalization of these models to study the impact of NAFTA.[6] Our paper is also related to Bems, Johnson, and Yi (2010), which uses the input-output framework of Johnson and Noguera (2009) to link changes in final demand across many countries during the recent global recession to changes in trade flows throughout the global system. One crucial difference is that we endogenize changes in bilateral trade shares, an important feature to match the recent experience.

We start by describing the input-output structure. Next, we merge this with trade share

stimulus package.

[5] 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).

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

equations from the class of gravity models.

3.1 Demand and Input-Output Structure

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

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

Let Y_i^j denote country i's gross production in sector $j \in \Omega$. Country i's gross absorption of j is X_i^j and $D_i^j = X_i^j - Y_i^j$ is its deficit in sector j. The overall deficit is:

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

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

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

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

Sector outputs are used both as inputs into production and also to satisfy final demand. This round-about production structure can be modeled as a Cobb-Douglas production function. Value-added is a share β_i^j of gross production in sector j of country i, while γ_i^{jl} denotes the share of sector

l in the production of intermediates for sector j, with $\sum_l \gamma_i^{jl} = 1$ for each $j \in \Omega$. We assume these parameters are fixed for each country over time, and we offer empirical support for this assumption below.

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

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

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

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

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

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

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

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

system:

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

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. We can thus express production in each sector as:

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

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

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

For now we take wages w_i and sectoral prices, p_i^l for $l \in \Omega$, as given. Labor and intermediates are aggregated in a Cobb-Douglas production function for input bundles used to produce sector j output.[7] The minimized cost of a bundle of inputs used by sector $j \in \Omega$ producers is thus:

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

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

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

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

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

we get:

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

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

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

for $j \in \Omega_M$. Here

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

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

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

3.2 International Trade

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

$$Y^j_i = \sum_{n=1}^{I} \pi^j_{ni} X^j_n. \tag{7}$$

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

Durable and non-durable manufactures consist of disjoint unit measures of differentiated goods, indexed by z^j.[8] We denote country i's efficiency making good z^j in sector j as $a^j_i(z^j)$. The cost of producing good z^j in sector j in country i is thus $c^j_i/a^j_i(z^j)$, where c^j_i is the cost of an input bundle, given by (6).

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

$$p^j_{ni}(z^j) = c^j_i d^j_{ni}/a^j_i(z^j).$$

Country i's efficiency $a^j_i(z^j)$ in making good z^j in sector j can be treated as a random variable with distribution: $F^j_i(a) = \Pr[a^j_i(z^j) \leq a] = e^{-T^j_i a^{-\theta^j}}$, which is drawn independently across i and j. Here $T^j_i > 0$ is a parameter that reflects country i's overall efficiency in producing any good in sector j and θ^j is an inverse measure of the dispersion of efficiencies. The implied distribution of $p^j_{ni}(z^j)$ is:

$$\Pr[p^j_{ni}(z^j) \leq p] = \Pr\left[a^j_i(z^j) \geq \frac{c^j_i d^j_{ni}}{p}\right] = 1 - e^{-T^j_i (c^j_i d^j_{ni})^{-\theta^j} p^{\theta^j}}.$$

Buyers in destination n buy each manufacturing good z^j in sectors $j \in \Omega_M$ from the cheapest source. We assume that the individual manufacturing goods, whether used as intermediates or in

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

final demand, combine with constant elasticity $\sigma^j > 0$.

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

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

where φ^j is a function of θ^j and σ^j, requiring $\theta^j > (\sigma^j - 1)$. To simplify the expressions that follow, we define price indices for the intermediates used by sector j in country i:

$$q_i^j = \prod_{l \in \Omega_M} \left(p_i^l \right)^{\widetilde{\gamma}_i^{jl}}. \tag{9}$$

Substituting (9) into (6), and the resulting expression into (8), we get:

$$p_n^j = \varphi^j \left[\sum_{i=1}^{I} A_i^j \left(w_i^{\widetilde{\beta}_i^j} \left(q_i^j \right)^{1-\widetilde{\beta}_i^j} d_{ni}^j \right)^{-\theta^j} \right]^{-1/\theta^j}, \tag{10}$$

where

$$A_i^j = \left(\widetilde{a}_i^j \right)^{\theta^j} T_i^j$$

captures the combined effect on costs of better technology in manufacturing sector j and cost reductions brought about by productivity gains in the services sector. Expression (10) links sector-j prices in country n to the prices of labor and intermediates around the world.

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

that takes the form:

$$\pi_{ni}^{j} = \frac{T_i^j \left[c_i^j d_{ni}^j\right]^{-\theta^j}}{\sum_{k=1}^{I} T_k^j \left[c_k^j d_{nk}^j\right]^{-\theta^j}} \tag{11}$$

$$= \frac{A_i^j \left[w_i^{\widetilde{\beta}_i^j} \left(q_i^j\right)^{1-\widetilde{\beta}_i^j} d_{ni}^j\right]^{-\theta^j}}{\sum_{k=1}^{I} A_k^j \left[w_k^{\widetilde{\beta}_k^j} \left(q_k^j\right)^{1-\widetilde{\beta}_k^j} d_{nk}^j\right]^{-\theta^j}}. \tag{12}$$

We derived the price index (10) and trade share expression (12) from a particular Ricardian model, but emphasize that any model generating these two aggregate equations would be equally valid in the analysis that follows. For instance, Appendix A shows that these expressions emerge in, among others, the Armington (1969) model elaborated in Anderson and Van Wincoop (2003), the Krugman (1980) model implemented in Redding and Venables (2004), the Ricardian model of Eaton and Kortum (2002), and the Melitz (2003) model expanded in Chaney (2008).[9]

World equilibrium is a set of wages w_i and, for sectors $j \in \Omega_M$, deficits D_i^j and price levels p_i^j that solve equations (3), (7), (9), (10), and (12) given labor endowments L_i, and deficits, D_i and D_i^S. World GDP is the numeraire.

4 Monthly Data on Trade and Production

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

Trade flow data are easily found at a monthly frequency – we use monthly bilateral trade flows from the Global Trade Atlas Database. These data are not seasonally adjusted and are provided

[9] For example, in the Armington setup, one would simply re-interpret shocks to A_i^j as preference shocks for that country's goods. Relatedly, in Redding and Venables' (2004) implementation of Krugman (1980), θ^j would be interpretted as a function of the elasticity of substitution across differentiated goods within sector j. This deep similarity in the predicted trade patterns from such seemingly disparate models is striking and is the subject of Arkolakis, Costinot, and Rodriguez-Clare (2009).

in dollars. We aggregate appropriate 2-digit HS categories to generate the total bilateral and multilateral trade flows in each manufacturing sector.

Production data is a bit trickier. A limited number of countries, such as the United States, report monthly estimates of the level of manufacturing production, but such data are generally not available. The difficulty, then, is in finding a suitable way to disaggregate these annual totals into internally consistent monthly values, as well as to generate out-of-sample predictions that reflect all up-to-date information for the months subsequent to the previous year's end.[10]

4.1 Temporal Disaggregation

Appendix B details our econometric procedure for disaggregating and extrapolating the annual production data in country i using the estimated relationship with several high frequency variables.[11] To build intuition for the procedure, think of a linear regression between the annual gross production of manufacturers and the annual sum of the monthly totals of the high frequency variables. At its most basic, Chow and Lin (1971) uses the coefficient estimates from such a regression to generate predicted monthly values. Next, the Chow-Lin procedure would distribute the regression residuals equally to each of these monthly predicted values for any given year. This procedure creates an internally consistent monthly series that sums up to the actual annual data. However, it generally creates artificial jumps from December to January since the corrections for residuals are different only from year to year. Our procedure makes two additional changes to this basic structure.

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

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

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

available for the vast majority of large countries and are released with a very short time lag.

[Note: We we ultimately do this in two ways, first with the procedure automatically picking the beta coefficients for the relationship between production and IP/PPI and a second in which we automatically set these beta values to equal 1. The 2-sector results below are generated from the first procedure and the 3-sector results below are generated from a mix of the first and second (the notes from the figures specify which). The two procedures do not appear to produce important differences, but we will formally check this in future drafts.]

4.2 Disaggregating Manufacturing Sub-Categories

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

We concord International Standard Industrial Classification (ISIC Rev. 3) 2-digit manufacturing production data to the appropriate sector definition (whatever is required to match the IP/PPI indices) so we have annual totals for each of these categories.[12] Our definition of manufacturing comprises ISIC industries 15 through 36 excluding 23 (petroleum). We further divide goods into the above sub-categories using the U.S. import end use classification. Harmonized System (HS) trade data is 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

[12] 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.

of each ISIC classification belongs in each of the categories.

We then apply our procedure to generate monthly series of these disaggregated categories and from these, obtain a monthly series of the share of durables in manufacturing. Given the highest quality production data from these databases is for the total manufacturing sector, we then multiply these shares by total manufacturing production, which is interpolated in exactly the same way but with IP/PPI indices for the whole of manufacturing. After all this, we then have monthly series for durable and non-durable manufacturing production which are consistent with annual (and implied monthly) levels of total manufacturing production in the data.

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

To check the quality of the procedure, we compared the monthly fitted series produced using this algorithm and the actual monthly data released by the U.S. Census Bureau on the value of shippments in durables, non-durables, and total manufacturing. The U.S. monthly data are collected as part of the M3 manufacturing survey.[13] By construction, our monthly series will sum to the annual manufacturing production totals found in the UN and OECD data. For the U.S., this total differed in 1995 from the total implied by the M3 data by about 3 percent. In Appendix

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

Figure B1, we scale our series by this 3 percent number and compare how well the procedure tracks the monthly M3 data series both before 2007, when totals are constrained to equal the annual sums, and after 2007 when the series is extrapolated exclusively from information in the IP and PPI series. Looking at the top panel, one sees that the procedure does an excellent job of matching movements in the time series, both when allowing the procedure to estimate the elasticity between high and low-frequency series as well as when manually setting the elasticitiy (referred to as "Beta" in the plots) equal to 1.

The bottom panels of Appendix Figure B1 show the same comparison but done separately for durables and non-durables. Here there are clearly discrepancies which, given the better fit at the total manufacturing level, imply either different categorizations of manufacturing industries or different implied growth rates in those industries. To the extent our production classifications line up more closely with our trade classifications than does the one used in the M3 survey, the discrepancies do not matter – what is most important is for a consistent sector definition across trade and production flows. Unfortunately, the level of production itself can matter for our results, and in future drafts we can test the sensitivity to errors in production levels. We suspect, however, that levels differences are not nearly as important as the high frequency changes in the series, particularly over the recent period we are focusing on. Hence, we find it highly encouraging that our estimates of the 4-quarter production decline ending in Q1 of 2009 – shown in the bottom-right of the plots – are within a few percentage points of the M3 decline for both durables and non-durables.

4.3 Concordances Linking Trade and Production

A many-to-many concordance was constructed to link the 2-digit harmonized system (HS) trade data to the International Standard Industrial Classification (ISIC) codes used in the production data. We start by downloading the mapping of 6-digit HS codes (including all revisions) to ISIC codes from the World Bank's World Integrated Trade Solution (WITS) website. This concordances was then merged with data on the volume of world trade at the 6-digit level for 2007-2008, from

COMTRADE data, also accessed through WITS. We estimate the proportion of each HS 2-digit code that belongs in each ISIC category using these detailed worldwide trade weights. Then we can use the same concordance in the last step to map production and trade to our sectors $j \in \Omega_M$.

4.4 Input-Output Coefficients

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

The OECD input-output tables are often available for the same countries for multiple years. In such cases, we use the most recent year of data available. Figure 3 includes examples of the input-output coefficients for several large economies for both 2000 and 2005. First, one notes that there are important differences in the levels of these coefficients across countries. For example, China's value added in durable manufacturing is significantly lower than the U.K.'s (i.e. $\beta_{China}^D < \beta_{U.K.}^D$. Further, the time series information provides empirical support for our assumption that these technological parameters are fixed over time. For example, the share of non-durables in the production of non-durable intermediates in the United States ($\gamma_{U.S.}^{NN}$) was 39.5 percent in 2000 and 37.8 percent in 2005. There are a few exceptions, but this degree of stability in the time series is highly representative. [Future versions will include a table listing these coefficients.]

4.5 Additional Macro Data

Exchange rates to translate local currency production values into dollars (to match the dollar-denominated trade flows) are from the OECD Stat database and from the International Financial Statistics database from the IMF. Other standard data used in the paper, such as quarterly GDP and deficits, are taken from the EIU. Trade and production data are converted using exchange rates

at the monthly frequency before being combined to form the quarterly aggregates we use in our regressions and counterfactuals.

5 The Four Shocks in the System

Trade flows for each sector in our model are driven entirely by four categories of shocks to the system – demand shocks, deficit shocks, productivity shocks, and trade friction shocks. First, there is the country-specific share of final demand that is for goods of type j, α_i^j. The hypothesis that the decline in trade relative to GDP is entirely due to the disproportionate slowdown in durable and non-durable manufacturing corresponds to asserting that α^D and α^N shocks are the only determinants of recent changes in trade. Second, trade deficits, D_i^D, D_i^N, and D_i^S, can of course change trade patters. Third, changes in the productivity (or if interpreted in the Armington model, the preference) parameter in each manufacturing sector, A_i^D and A_i^N, will change trade flows. Finally, bilateral trade frictions in each manufacturing sector, d_{ni}^D and d_{ni}^N, are the fourth force that can impact trade. The hypothesis that trade credit rationing, protectionism, or any trade friction is the primary driver of the trade collapse implies that shocks to the d_{ni}^j's are of first-order importance.

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

5.1 Durable and Non-Durable Manufacturing Demand

We start with the first two categories of shocks, which can be readily observed or computed from the data. The first one, the demand for durable and non-durable goods as a share of final demand,

can be calculated using (4) as the first two elements of the vector $\boldsymbol{\alpha}_i$:

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

where data for all the right hand side terms have been described above.[14] Figure 4 plots the paths of α_i^D and α_i^N for four large countries since 2000 [MORE COUNTRIES WILL SHORTLY BE ADDED]. The dashed vertical lines on the right of the plot correspond to the period starting in the first quarter of 2008 and ending in the first quarter of 2009. We highlight this window because that will be the period we use for our counterfactual analyses. The recent recession has led to a steep decline in final demand for manufactures in all these countries, with a particularly steep decline in durables (the blue line).

5.2 Deficits

Similarly, deficits changed dramatically over this period. Figure 5 shows manufacturing trade deficits for these same countries. The U.S. deficit's sharp reduction is balanced by reduced surpluses from countries like Japan, Germany, and China. This figure makes clear that the sharpest adjustment of deficits came in durables manufacturing, while non-durables deficits remained relatively stable.

5.3 Measuring Trade Frictions with the Head-Ries Index

Trade frictions are not as easily measured as the macro aggregates above. Hence, in this section, we derive the Head-Ries index, an inverse measure of trade frictions implied by our trade share equation (12), or any gravity model. The index will be an easily measurable object that reflects changes in trade frictions and is invariant to the scale of tradable good demand or the relative size and productivity of trading partners. Head and Ries (2001) uses this expression – equation (8) in the paper – to measure the border effect on trade between the U.S. and Canada for several manufacturing industries. Jacks, Meissner, and Novy (2009) studies a very similar object for a span

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

of over 100 years to analyze long-term changes in trade frictions.

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

$$\frac{X_{ni}^j}{X_{nn}^j} = \frac{\pi_{ni}^j}{\pi_{nn}^j} = \frac{T_i^j \left[c_i^j d_{ni}^j\right]^{-\theta^j}}{T_n^j \left[c_n^j\right]^{-\theta^j}}, \tag{13}$$

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

Multiplying (13) by the parallel expression for what i buys from n in sector j and taking the square root, we generate:

$$\Theta_{ni}^j = \left(\frac{X_{ni}^j}{X_{nn}^j}\frac{X_{in}^j}{X_{ii}^j}\right)^{1/2} = \left[d_{ni}^j d_{in}^j\right]^{-\theta^j/2}. \tag{14}$$

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

This index will change only in response to movements in the cost of trade. Other measures which might have been used to capture these movements include "openness" indices, similar to the left-hand side of (13), or the summation of bilateral trade flows relative to the summation of any

[15] Grouping together country-level terms as $S_i^j = T_i^j \left(c_i^j\right)^{-\theta^j}$ and taking logs of both sides of (13), we could run a regression at date t on country fixed effects. We might do this hoping to sweep out the components S_i^j so that we would be left with $\left(d_{ni}^j\right)^{-\theta^j}$, which is the object we would like to input into our analysis. Such a procedure would be misleading, however, due to a fundamental identification problem. For any set of parameters $\left\{S_i^j, d_{ni}^j\right\}$ we can fit the same data with another set of parameters $\left\{\widetilde{S}_i^j, \widetilde{d}_{ni}^j\right\}$ where:

$$\widetilde{S}_i^j = \phi_i^j S_i^j,$$

and

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

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

pair of countries' final demands. These other measures, however, have the disadvantage of being unable to isolate trade frictions.

Our dataset contains over 706 bilateral Head-Ries pairs and includes 30,467 pair-quarter observations of the Head-Ries index. We use all available pairs for which we have the data with the only exceptions being Belgium and the Netherlands. They are omitted because their manufacturing exports often exceed their manufacturing production (due to re-exports), and our framework is not capable of handling this situation. Table 2 lists the countries included and the number of countries and pair-months available for each year.[16]

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

$$d^j_{ni}(t) = e^{\eta^j(t)+\delta^j_n(t)+\mu^j_i(t)+\gamma^j_{ni}+\epsilon^j_{ni}(t)}. \tag{15}$$

We think of the exporter effect δ^j as reflecting, for example, the difficulties potentially imposed on exporting firms in obtaining trade credit and the importer effect μ captures, for example, an import tariff. Equations (14) and (15) imply:

$$\ln \Theta^j_{ni}(t) = \frac{\theta^j}{2} \ln \left(d^j_{ni}(t) d^j_{in}(t) \right) = \theta^j \eta^j(t) + \theta^j \gamma^j_{ni} + \frac{\theta^j}{2} \left(\delta + \mu\right)^j_n (t) + \frac{\theta^j}{2} \left(\delta + \mu\right)^j_i (t) + \frac{\theta^j}{2} \left(\epsilon_{ni} + \epsilon_{in}\right)(t),$$

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

$$\ln \Theta^j_{ni}(t) = \beta^j_n(t) + \beta^j_i(t) + \gamma^j_{ni} + \varepsilon^j_{ni}(t). \tag{16}$$

[16] Each analysis has also been run on a constant panel to ensure results aren't driven by entry or exit of countries from the data.

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

Figures 6 and 7 plot the four-quarter moving average of the country-time effects β_i^j from a weighted estimation of (16) for selected countries. We use a moving average due to the strong seasonal effects in the data. The coefficients are normalized to zero in the first quarter of 2000 and in some cases extend through the second quarter of 2009. The country-time effects act proportionately on the Head-Ries indices for all bilateral pairs involving any given country. For instance, if the series for country i increases from 0 to 0.1, it implies that the index would increase 10 percent for all pairs in which i is an exporter or an importer.

Looking at Figure 6, we see examples of countries where the recession did not bring with it marked declines in trade frictions. Only a small share, if any, of the large declines in trade flows for Germany, the U.S., France, and Italy should, according to this measure, be attributed to declining trade frictions. Figure 7, by contrast, includes only countries for which there is a steeper increase in trade frictions (a decline in the index) during the recession. These countries include Japan, China, Austria, and Canada, among others not shown. One important conclusion, thus, is that while there is evidence of a potentially important contribution from trade frictions to the trade collapse, this contribution appears to be quite heterogenous across countries.

Though the implied trade frictions for durable and non-durables rarely move in opposite directions, these patterns can certainly be different, even for a given bilateral trading pair. First, this may reflect differences in the within-country trade costs for the two types of goods. Given we normalize $d_{ii}^j = 1$ for all countries and sectors, changes in international trade costs must interpretted as relative to domestic trade costs. Different modes of transport for durable and non-durable goods, for example, could generate different changes in within-country trade costs across the sectors. Further, the elasticities, θ^j, may be different across sectors, and since the Head-Ries index includes this term, similar proportional changes in trade costs can generate different magnitude fluctuations

of the Head_Ries index across sectors. Finally, each of the possible stories driving changes in trade frictions, such as difficulties in acquiring trade financing, could plausibly differ across sectors. For example, if one sector is performing worse than another – due to differences in the demand shocks α^j, say – there might be differential increases in the higher cost of trade credit.

5.4 Measuring Trade Frictions During the Great Depression

To check the ability of the Head-Ries index to pick up changes in trade frictions, as well as to give a benchmark for the scale of any such changes, we calculate (14) using data from the Great Depression, which also coincided with a major collapse in trade. The lack of availability of data on bilateral manufacturing trade restricts our analysis to flows between the United States and 8 trading partners: Austria, Canada, Finland, Germany, Japan, Spain, Sweden, and the United Kingdom. We obtained data on bilateral and multilateral manufacturing trade as well as exchange rates for 1926-1937 from the annual *Foreign Commerce Yearbooks*, published by the U.S. Department of Commerce.[17] The gross value of manufacturing, required for the denominator of (14), were obtained from a variety of country-specific sources.[18] The U.S. ratio of 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

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

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

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 most complete, typically also the most recent, series value.

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

6 Calibration

Having set up the model, discussed the four categories of shocks that can change trade flows, and given historical context on the path of these shocks, we now calibrate the model to perfectly match the period from the first quarter of 2008 to the first quarter of 2009. The calibration exercise only includes a balanced panel of countries for which we have data on imports from and exports to all other included countries. This balancing means that data used here are only a subset of the data used in the previous sections. We are left with XX countries, combining the remaining ones into the "Rest of World," which represents about XX percent of global GDP in 2009 (when using exchange rates to translate each country's GDP into a common currency). First, we re-formulate the model in a notation that makes it easier to think about this four-quarter change. Next we describe how we parameterize the model.

6.1 Change Formulation

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

$$\hat{A}_i^j = \hat{T}_i^j \left(\widehat{\widetilde{a}}_i^j\right)^{\theta^j}.$$

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

$$\left(Y_i^j\right)' = \sum_{n=1}^{I} \left(\pi_{ni}^j\right)' \left(X_n^j\right)', \tag{17}$$

while sectoral demand (3) becomes:

$$\mathbf{X}_i' = \boldsymbol{\alpha}_i' \left(\hat{w}_i Y_i + D_i'\right) + \boldsymbol{\Gamma}_i^T \mathbf{Y}_i' \tag{18}$$

The intermediate goods price indices (9) become

$$\widehat{q}_i^j = \prod_{l \in \Omega_M} \left(\widehat{p}_i^l\right)^{\widetilde{\gamma}_i^{jl}}, \tag{19}$$

while the price equations (10) become:

$$\widehat{p}_n^j = \left(\sum_{i=1}^{I} \pi_{ni}^j \widehat{A}_i^j \widehat{w}_i^{-\theta^j \widetilde{\beta}_i^j} \left(\widehat{q}_i^j\right)^{-\theta^j (1-\widetilde{\beta}_i^j)} \left(\widehat{d}_{ni}^j\right)^{-\theta^j}\right)^{-1/\theta^j}. \tag{20}$$

The trade share equations (12) become:

$$\left(\pi_{ni}^j\right)' = \frac{\pi_{ni}^j \widehat{A}_i^j \widehat{w}_i^{-\theta^j \widetilde{\beta}_i^j} \left(\widehat{q}_i^j\right)^{-\theta^j (1-\widetilde{\beta}_i^j)} \left(\widehat{d}_{ni}^j\right)^{-\theta^j}}{\sum_{k=1}^{I} \pi_{nk}^j \widehat{A}_k^j \widehat{w}_k^{-\theta^j \widetilde{\beta}_k^j} \left(\widehat{q}_k^j\right)^{-\theta^j (1-\widetilde{\beta}_i^j)} \left(\widehat{d}_{nk}^j\right)^{-\theta^j}}. \tag{21}$$

The equations (17), (18), (19), (20), and (21) contain all of the equilibrium conditions in this system. We will solve this set of equations for the following counterfactual values: (i) $I-1$ changes in wages $\hat{w}_i$, (ii) $I-1$ sectoral deficits $\left(D_i^D\right)'$ and $\left(D_i^N\right)' = D_i' - \left(D_i^D\right)' - \left(D_i^S\right)'$, (iii) I changes in durable manufacturing prices $\hat{p}_i^D$, and (iv) I changes in non-durable manufacturing prices $\hat{p}_i^N$. Beginning-of-period trade shares and GDP are used to calibrate the model. The forcing variables are counterfactual values of the vector of spending shares $\boldsymbol{\alpha}_i'$, changes in trade frictions $\left(\hat{d}_{ni}^D\right)^{-\theta^D}$ and $\left(\hat{d}_{ni}^N\right)^{-\theta^N}$, changes in productivity $\hat{A}_i^D$ and $\hat{A}_i^N$, and end-of-period deficits $D_i^{S'}$ and D_i'.

6.2 Parameter Values and Shocks

We consider two values of θ. The low value of $\theta = 1$ is more consistent with work in open-economy macro while the high value of $\theta = 8$ is consistent with Eaton and Kortum (2002). It is easy to measure the change in demand for manufactures, $\hat{\alpha}_i$ or deficits $\widehat{D}_i$.[19] As described above, however, it is more difficult to separately measure the changes in trade costs or productivity shocks.

To approach this problem, we divide both sides of equation (21) by π^j_{ni} to get an expression for $\hat{\pi}^j_{ni}$. Dividing by the corresponding expression for $\hat{\pi}^j_{ii}$ and then substituting in (20) gives:

$$\left(\widehat{d}^j_{ni}\right)^{-\theta^j} = \frac{\hat{\pi}^j_{ni}}{\hat{\pi}^j_{ii}} \left(\frac{\hat{p}^j_i}{\hat{p}^j_n}\right)^{\theta^j}. \tag{22}$$

We can also use (21) (for $n = i$) and (20) to get

$$\hat{\pi}^j_{ii} = \widehat{A}^j_i \widehat{w}_i^{-\theta^j \widetilde{\beta}^j_i} \left(\widehat{q}^j_i\right)^{-\theta^j(1-\widetilde{\beta}^j_i)} \left(\widehat{p}^j_i\right)^{\theta^j}.$$

Substituting in (19) yields:

$$\hat{\pi}^j_{ii} = \widehat{A}^j_i \widehat{w}_i^{-\theta^j \widetilde{\beta}^j_i} \left(\widehat{p}^j_i\right)^{\theta^j\left[1-\widetilde{\gamma}^{jj}_i(1-\widetilde{\beta}^j_i)\right]} \left(\widehat{p}^l_i\right)^{-\theta^j \widetilde{\gamma}^{jl}_i(1-\widetilde{\beta}^j_i)}, \tag{23}$$

where $l \neq j$ is the other manufacturing sector. Combining equation (23) for sectors $j, l \in \Omega_M$ and rearranging yields:

$$\left(\widehat{p}^j_i\right)^{\theta^j} = \frac{1}{\Phi^j_i} \left(\hat{\pi}^j_{ii} \widehat{w}_i^{\theta^j \widetilde{\beta}^j_i}\right)^{\frac{1-\widetilde{\gamma}^{ll}_i(1-\widetilde{\beta}^l_i)}{\delta_i}} \left(\hat{\pi}^l_{ii} \widehat{w}_i^{\theta^l \widetilde{\beta}^l_i}\right)^{\frac{\theta^j \widetilde{\gamma}^{jl}_i(1-\widetilde{\beta}^j_i)}{\theta^l \delta_i}},$$

where

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

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

and

$$\Phi_i^j = \left(\widehat{A}_i^j\right)^{\frac{1-\widetilde{\gamma}_i^{ll}(1-\widetilde{\beta}_i^l)}{\delta_i}} \left(\widehat{A}_i^l\right)^{\frac{\theta^j \widetilde{\gamma}_i^{jl}(1-\widetilde{\beta}_i^j)}{\theta^l \delta_i}}, \tag{24}$$

with $l \neq j$. These expressions for price changes can be plugged into (22) to get:

$$\left(\widehat{d}_{ni}^j\right)^{-\theta^j} = \left(\varpi_{ni}^j\right)^{-1} \frac{\Phi_n^j}{\Phi_i^j}, \tag{25}$$

where

$$\varpi_{ni}^j = \frac{\hat{\pi}_{ii}^j}{\hat{\pi}_{ni}^j} \frac{\left(\hat{\pi}_{nn}^j \widehat{w}_n^{\theta^j} \widetilde{\beta}_n^j\right)^{\frac{1-\widetilde{\gamma}_n^{ll}(1-\widetilde{\beta}_n^l)}{\delta_n}}}{\left(\hat{\pi}_{ii}^j \widehat{w}_i^{\theta^j} \widetilde{\beta}_i^j\right)^{\frac{1-\widetilde{\gamma}_i^{ll}(1-\widetilde{\beta}_i^l)}{\delta_i}}} \frac{\left(\hat{\pi}_{nn}^l \widehat{w}_n^{\theta^l} \widetilde{\beta}_n^l\right)^{\frac{\theta^j \widetilde{\gamma}_n^{jl}(1-\widetilde{\beta}_n^j)}{\theta^l \delta_n}}}{\left(\hat{\pi}_{ii}^l \widehat{w}_i^{\theta^l} \widetilde{\beta}_i^l\right)^{\frac{\theta^j \widetilde{\gamma}_i^{jl}(1-\widetilde{\beta}_i^j)}{\theta^l \delta_i}}}. \tag{26}$$

Combining equations (24) for j and l, we get:

$$\widehat{A}_i^j = \left(\Phi_i^j\right)^{1-\widetilde{\gamma}_i^{jj}(1-\widetilde{\beta}_i^j)} \left(\Phi_i^l\right)^{-\frac{\theta^j}{\theta^l}\widetilde{\gamma}_i^{jl}(1-\widetilde{\beta}_i^j)}. \tag{27}$$

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

Starting with the first method, since the Head-Ries index is $\Theta_{ni}^j = \left[d_{ni}^j d_{in}^j\right]^{-\theta^j/2}$, imposing $d_{ni}^j = d_{in}^j$ implies, in changes, $\widehat{\Theta}_{ni}^j = \left(\widehat{d}_{ni}^j\right)^{-\theta^j} = \left(\widehat{d}_{in}^j\right)^{-\theta^j}$. Substituting this result into (25), and allowing for an error term around symmetry, we get:

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

where μ_{ni}^j is a zero-mean shock. Taking logs gives our estimating equation:

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

The left-hand side can be calculated from our data, while for the right-hand side we estimate the coefficients on a set of N dummy variables, one for each country. For each (n, i) observation, there are two non-zero dummy values. The first, corresponding to country n, takes a value of $(+1)$, while the second, corresponding to country i, takes a value of (-1). We estimate Φ_i^j by exponentiating the coefficients (for each sector j) on the dummy variables for country i, with "Rest of World" dropped (since a common scalar won't change anything). Finally, to recover changes in sectoral productivity, we substitute these estimates into (27).

[NOTE: FROM HERE ONWARD, RESULTS DO NOT YET REFLECT 3-SECTOR STRUCTURE.]

Table 3 gives the estimates for the change in productivity (which are measured relative to the value 1 for the "Rest of World") and the other three shocks [TBD: Add deficits] over the four-quarters ending in the first quarter of 2009 for all countries in our dataset. These estimates depend on the value of θ. To interpret what they mean for productivity, we back out the implied changes in $\widehat{a_i} = \widehat{b_i}$ (for this interpretation we assume a common change in productivity across the manufacturing and non-manufacturing sector).

An alternative to this procedure is to write $\widehat{A}_i$ as function of sectoral prices. With appropriate data (such as changes in the PPI), we can back out the implied shocks to productivity. We have not yet pursued this strategy.

We can now use the productivity shock estimates to back out the trade friction estimates according to (**??**). Given the regression methodology we use to obtain the $\hat{A}_i$, the geometric means of a country i's importing trade frictions are identical to the geometric means of its exporting frictions, $\prod_n \hat{d}_{ni} = \prod_n \hat{d}_{in}$, so this is the form in which the trade friction shocks are reported in the table. The resulting geometric means of the $\hat{d}_{ni}^{-\theta}$ by country are essentially the same as changes in the country-time effects from our Head-Ries regressions.

Figures 8 to 11 plot the information in Table 3. For example, Figure 8 plots the shocks to tradables demand $\widehat{\alpha}_i$ against the change in trade (imports plus exports) relative to GDP. The other figures do the same for the other shocks. Finally, Figure 12 is a histogram of the implied bilateral

trade frictions $\hat{d}_{ni}^{-\theta}$ for all country pairs in the calibration exercise, excluding the largest and smallest 5 percentile values (generally small country-pair outliers). The histogram shows that while most countries experienced an increase in trade costs (left of zero in the picture due to the negative exponent), there are certainly pairs in which trade costs decreased. This is plausible, given, for instance, steep declines in oil prices over this period.[20]

7 Counterfactuals

We now discuss our counterfactual exercises. Given values for the changes in the forcing variables we solve (17), (20), and (21), using an algorithm adapted from Dekle, Eaton, and Kortum (2008). Throughout, we take world GDP, measured in US Dollars, as given. In fact, world GDP can be thought of as the numeraire in our analysis. We will have nothing to say about the drop in world GDP over the past year. Formally, we could express every nominal variable in the model as a fraction of world GDP.[21] In the results that follow we treat all end-of-period deficits as exogenous, so that wage changes are endogenous. In future drafts we will consider a case of exogenous wage changes and endogenous end-of-period manufacturing deficits.

7.1 Root Mean Squared Error Results

We start with counterfactuals that consider the country-level trade flows implied by a given configuration of the four shocks. For example, if we solve the model with the shock vector $(\widehat{\alpha}_i, \widehat{D}_i^M, \widehat{D}_i^N, \widehat{d}_{ni}, \widehat{A}_i) = data$, where "data" means that the shock values are as given in the previous tables and plots, the model would generate trade patterns precisely equal to those seen in the first quarter of 2009. If, on the other hand, we solve the model with the shock vector $(\widehat{\alpha}_i, \widehat{D}_i^M, \widehat{D}_i^N, \widehat{d}_{ni}, \widehat{A}_i) = 1$, implying constant values for the shocks, the model would generate trade patterns precisely equal to those seen in the first quarter of 2008, as if the recession never occurred.

[20] Further, it is again worth noting that our measure of trade frictions must be interpreted as *relative* to domestic trade costs.

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

If one compares the predicted country-level trade flows in this latter case to that seen in the data, one can calculate a trade weighted root mean squared error (RMSE) of 0.20. One way in which we can quantify the relative import of each shock is to see how much its introduction reduces this RMSE.

Figure 13 demonstrates this when we only consider the non-manufacturing deficit shocks, or when $\widehat{D}_i^N = data$ and $(\widehat{\alpha}_i, \widehat{D}_i^M, \widehat{d}_{ni}, \widehat{A}_i) = 1$. Comparing the counterfactual trade flows to those experienced in the recession, one finds a very poor fit. In fact, the trade-weighted RMSE=0.20, suggesting that the changes in non-manufacturing deficits have literally no power for explaining the trade collapse. Figures 13 to 17 do this exercise for all individual shocks and show that only the demand and trade friction shocks have any real explanatory power. Separately, they each eliminate about 1/3 of the variation, and taken together, shown in Figure 18, they do a good job of explaining the patterns in trade, reducing the RMSE from 0.20 to 0.08. For clarity on the exercise, we show in Figure 19 the prediction when all shocks are added, $(\widehat{\alpha}_i, \widehat{D}_i^M, \widehat{D}_i^N, \widehat{d}_{ni}, \widehat{A}_i) = data$, which by construction, has complete explanatory power. These plots demonstrate that deficits and productivity/preference shocks have no explanatory power for the decline in trade. This is unsurprising – in all the work and speculation about the drivers of the trade decline, the changes in non-manufacturing deficits or productivity shocks have not been seriously mentioned as likely culprits.

7.2 Global Counterfactuals

Next, in Table 4, we consider these results at the global level. The country values mirror the values that appeared in the previous plots, but the boldface line labeled "World" gives the implied total change in imports and exports. We see that trade dropped 22 percent relative to world economic activity in the recession. Compared to this 22 percent, a 12 percent decline is generated from a counterfactual recession in which manufacturing demand dropped as it did but with no other shocks.[22] A counterfactual recession in which the only change is the shock to trade frictions

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

produces a 10 percent decline in global trade. In this sense, we conclude [tentatively, until we add durables/non-durables] that the demand decline is the most salient single factor, responsible for nearly 60 percent of the drop, though changes in trade frictions were also first-order contributors.

7.3 Other Counterfactuals

Given the heterogeneity in the shocks impacting countries in the recent recession, we also consider counterfactuals run at the country- or region-level. As an example, image one only wishes to consider the demand or trade friction shocks hitting Japan. Table 5 shows these results for Japan itself and for a limited set of other countries in the system. We note the impact of geography and the input-output structure. Aside from Japan itself, the incidence of these shocks rests with countries that trade closely with Japan, such as China, Korea, and the U.S.. Countries that do not, like Germany, Mexico, and the U.K., are largely unaffected.

[WE WILL GREATLY EXPAND THIS SECTION.]

[INSERT DFS ILLUSTRATION HERE.]

8 Conclusion

[TBD]

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Tables

Durable Manufacturing

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

Non-Durable Manufacturing

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

Non-Manufacturing

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

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

Notes:

	Country	Year	# Countries Included	# Head Ries Observations
(1)	Argentina	1995	4	180
(1)	Austria	1996	7	432
(2)	Belgium	1997	25	4,212
(3)	Brazil	1998	27	4,872
(4)	Bulgaria	1999	35	7,297
(5)	Canada	2000	38	8,775
(6)	Chile	2001	38	8,635
(7)	China	2002	38	8,484
(8)	Colombia	2003	38	8,473
(9)	Czech Republic	2004	38	8,484
(10)	Denmark	2005	38	8,416
(11)	Finland	2006	38	8,248
(12)	France	2007	38	8,168
(13)	Germany	2008	38	8,448
(14)	Greece	2009	38	4,252
(15)	Hungary			
(16)	India			
(17)	Indonesia			
(18)	Ireland			
(19)	Italy			
(20)	Japan			
(21)	Malaysia			
(22)	Mexico			
(23)	Netherlands			
(24)	Norway			
(25)	Philippines			
(26)	Poland			
(27)	Portugal			
(28)	Romania			
(29)	Singapore			
(30)	Slovakia			
(31)	South Africa			
(32)	South Korea			
(33)	Spain			
(34)	Sweden			
(35)	Thailand			
(36)	Turkey			
(37)	United Kingdom			
(38)	United States			

Table 2: Country and Year Coverage of Data

Notes: [NOTE: THIS IS FROM 2-SECTOR CASE; 3-SECTOR CASE WILL HAVE FEWER COUNTRIES.]

	$\theta = 8$					$\theta = 1$				
	$\widehat{A_i}$	$\widehat{a_i} = \widehat{b_i}$	$\widehat{\alpha_i}$	$\left(\prod_j \widehat{d_{ij}}\right)^{1/J}$	$\left(\prod_j \widehat{d_{ij}^{-\theta}}\right)^{1/J}$	$\widehat{A_i}$	$\widehat{a_i} = \widehat{b_i}$	$\widehat{\alpha_i}$	$\left(\prod_j \widehat{d_{ij}}\right)^{1/J}$	$\left(\prod_j \widehat{d_{ij}^{-\theta}}\right)^{1/J}$
Argentina	1.38	1.03	0.82	1.03	0.79	0.92	0.93	0.82	1.26	0.79
Austria	0.77	0.98	1.01	1.04	0.75	1.10	1.07	1.01	1.33	0.75
Brazil	0.36	0.91	0.98	1.00	1.04	0.73	0.79	0.98	0.97	1.04
Bulgaria	1.08	1.01	0.93	1.04	0.73	1.14	1.10	0.93	1.38	0.73
Canada	0.37	0.91	0.95	0.99	1.04	0.75	0.80	0.95	0.96	1.04
Chile	0.28	0.89	1.15	1.00	1.01	0.71	0.78	1.15	0.99	1.01
China	2.23	1.08	1.01	1.02	0.89	1.11	1.08	1.01	1.13	0.89
Colombia	0.43	0.92	0.98	1.03	0.82	0.64	0.70	0.98	1.23	0.82
Czech Republic	0.48	0.93	0.81	1.00	0.96	0.82	0.86	0.81	1.04	0.96
Denmark	0.63	0.96	0.93	1.00	0.97	0.90	0.92	0.93	1.03	0.97
Finland	0.54	0.94	0.72	1.02	0.88	0.82	0.86	0.72	1.13	0.88
France	0.63	0.96	0.86	1.01	0.94	0.83	0.87	0.86	1.07	0.94
Germany	0.51	0.94	0.88	1.01	0.93	0.79	0.83	0.88	1.07	0.93
Greece	0.72	0.97	0.92	1.00	0.98	0.84	0.87	0.92	1.02	0.98
Hungary	0.36	0.91	0.88	1.02	0.85	0.85	0.88	0.88	1.18	0.85
Ireland	0.47	0.93	0.98	1.02	0.85	0.97	0.98	0.98	1.18	0.85
Italy	0.60	0.95	0.79	1.01	0.91	0.83	0.87	0.79	1.10	0.91
Japan	1.65	1.05	0.85	1.02	0.85	0.92	0.94	0.85	1.18	0.85
Mexico	0.24	0.87	0.98	1.00	1.00	0.68	0.74	0.98	1.00	1.00
Norway	0.35	0.90	0.88	1.00	1.03	0.76	0.81	0.88	0.97	1.03
Poland	0.29	0.89	0.86	0.99	1.08	0.71	0.77	0.86	0.93	1.08
Portugal	0.68	0.96	0.95	1.03	0.77	0.94	0.95	0.95	1.31	0.77
Slovakia	0.78	0.98	0.60	0.99	1.10	0.84	0.88	0.60	0.91	1.10
South Korea	0.20	0.86	0.87	1.00	1.00	0.70	0.76	0.87	1.00	1.00
Spain	0.63	0.96	0.78	1.02	0.88	0.84	0.87	0.78	1.14	0.88
Sweden	0.28	0.88	0.88	1.02	0.87	0.75	0.81	0.88	1.15	0.87
Thailand	0.73	0.97	0.86	1.02	0.88	0.93	0.94	0.86	1.14	0.88
Turkey	0.22	0.86	0.80	1.00	1.00	0.72	0.77	0.80	1.00	1.00
United Kingdom	0.20	0.85	0.91	1.00	0.98	0.68	0.74	0.91	1.02	0.98
United States	1.35	1.03	0.86	1.01	0.95	0.97	0.98	0.86	1.05	0.95
Rest of World	1.00	1.00	0.88	1.03	0.78	1.00	1.00	0.88	1.28	0.78

Table 3: Key Parameters

Notes: [FROM 2-SECTOR CASE.]

	No Recession	Recession				Counterfactual 1				Counterfactual 2				Counterfactual 3			
Shocks:	No Shocks Introduced	All Shocks Introduced				Demand Shocks				Trade Friction Shocks				Demand and Trade Friction Shocks			
	All Vars	$\widehat{((Ex+Im)/Y)}_r$	$\widehat{(Ex/Y)}_r$	$\widehat{(Im/Y)}_r$	$\widehat{Y}_r$	$\widehat{((Ex+Im)/Y)}_r$	$\widehat{(Ex/Y)}_r$	$\widehat{(Im/Y)}_r$	$\widehat{Y}_r$	$\widehat{((Ex+Im)/Y)}_r$	$\widehat{(Ex/Y)}_r$	$\widehat{(Im/Y)}_r$	$\widehat{Y}_r$	$\widehat{((Ex+Im)/Y)}_r$	$\widehat{(Ex/Y)}_r$	$\widehat{(Im/Y)}_r$	$\widehat{Y}_r$
World	**1**	**0.78**	**0.78**	**0.78**	**1.00**	**0.88**	**0.88**	**0.88**	**1.00**	**0.90**	**0.90**	**0.90**	**1.00**	**0.80**	**0.80**	**0.80**	**1.00**
Argentina	1	0.71	0.77	0.69	1.10	0.86	0.82	0.88	1.06	0.83	0.80	0.85	1.12	0.72	0.65	0.75	1.19
Austria	1	0.81	0.77	0.86	0.93	1.03	1.03	1.02	0.91	0.92	0.94	0.90	0.81	0.94	0.97	0.91	0.74
Brazil	1	1.05	0.89	1.18	0.85	0.97	0.96	0.97	0.96	1.03	1.03	1.02	1.02	1.00	1.00	1.00	0.98
Bulgaria	1	0.73	0.69	0.76	1.00	0.99	0.98	1.00	0.94	0.86	0.81	0.90	0.86	0.85	0.78	0.89	0.82
Canada	1	0.94	0.87	1.00	0.86	0.95	0.95	0.96	0.97	0.94	0.94	0.95	1.01	0.90	0.89	0.91	0.97
Chile	1	0.92	0.74	1.15	0.79	1.10	1.11	1.10	0.89	0.85	0.88	0.82	0.96	0.94	0.97	0.90	0.85
China	1	0.74	0.73	0.76	1.20	1.02	1.03	0.99	0.92	0.87	0.90	0.82	0.99	0.89	0.94	0.82	0.91
Colombia	1	1.12	1.08	1.14	0.93	0.98	0.95	1.00	0.97	1.03	1.16	0.97	1.21	1.01	1.11	0.97	1.17
Czech Republic	1	0.81	0.80	0.82	0.88	0.87	0.88	0.86	1.00	0.95	0.96	0.95	0.96	0.83	0.85	0.81	0.96
Denmark	1	0.90	0.90	0.89	0.93	0.92	0.91	0.92	0.98	0.97	0.97	0.97	0.99	0.89	0.89	0.90	0.97
Finland	1	0.72	0.71	0.75	0.91	0.80	0.82	0.77	1.05	0.96	0.98	0.93	0.90	0.77	0.81	0.72	0.93
France	1	0.82	0.79	0.85	0.94	0.86	0.86	0.87	1.01	0.95	0.95	0.95	1.00	0.82	0.82	0.83	1.02
Germany	1	0.86	0.82	0.91	0.91	0.92	0.94	0.90	0.96	0.95	0.96	0.94	1.00	0.88	0.91	0.84	0.97
Greece	1	0.86	0.77	0.89	0.98	0.91	0.84	0.93	1.03	0.96	0.93	0.97	1.02	0.88	0.78	0.90	1.05
Hungary	1	0.86	0.85	0.86	0.82	0.93	0.94	0.92	0.96	0.96	0.97	0.95	0.89	0.90	0.91	0.88	0.85
Ireland	1	1.00	1.11	0.83	0.86	0.97	0.99	0.94	0.94	0.97	0.99	0.94	0.95	0.94	0.98	0.88	0.89
Italy	1	0.79	0.79	0.79	0.93	0.83	0.84	0.82	1.03	0.93	0.94	0.92	1.00	0.78	0.79	0.75	1.03
Japan	1	0.62	0.56	0.74	1.16	0.92	0.95	0.86	0.97	0.84	0.89	0.74	0.97	0.78	0.86	0.63	0.92
Mexico	1	1.07	1.05	1.08	0.80	1.01	1.01	1.01	0.93	0.98	0.98	0.98	1.10	0.99	0.99	0.99	1.02
Norway	1	0.94	0.98	0.92	0.84	0.88	0.84	0.90	1.03	0.98	1.00	0.97	1.05	0.87	0.84	0.88	1.08
Poland	1	0.90	0.91	0.88	0.81	0.88	0.87	0.88	1.00	0.96	0.96	0.96	1.05	0.84	0.84	0.85	1.05
Portugal	1	0.78	0.76	0.80	0.94	0.92	0.90	0.93	0.98	0.87	0.83	0.89	0.97	0.80	0.75	0.83	0.95
Slovakia	1	0.77	0.75	0.80	0.99	0.71	0.72	0.69	1.13	1.02	1.02	1.02	0.99	0.72	0.73	0.71	1.13
South Korea	1	1.11	1.15	1.06	0.73	0.92	0.94	0.89	0.97	1.05	1.04	1.07	1.01	0.97	0.98	0.96	0.99
Spain	1	0.76	0.79	0.74	0.94	0.79	0.76	0.81	1.09	0.94	0.92	0.94	1.01	0.74	0.70	0.76	1.10
Sweden	1	0.85	0.85	0.86	0.79	0.91	0.92	0.89	0.98	0.94	0.95	0.92	0.94	0.85	0.87	0.82	0.92
Thailand	1	0.79	0.85	0.72	0.96	0.90	0.90	0.89	0.99	0.90	0.91	0.89	0.96	0.81	0.82	0.79	0.95
Turkey	1	0.95	1.04	0.88	0.78	0.86	0.84	0.87	1.03	0.99	0.99	0.99	1.03	0.85	0.84	0.86	1.06
United Kingdor	1	0.96	0.96	0.97	0.77	0.91	0.89	0.92	0.99	0.97	0.97	0.98	1.01	0.89	0.87	0.90	1.00
United States	1	0.80	0.80	0.80	1.09	0.88	0.87	0.90	1.02	0.95	0.95	0.95	1.02	0.84	0.82	0.86	1.04
Rest of World	1	0.80	0.88	0.75	1.01	0.87	0.84	0.89	1.03	0.89	0.85	0.91	0.98	0.77	0.71	0.81	1.01

Table 4: Global Counterfactual Results

Notes: [FROM 2-SECTOR CASE.]

	No Recession	Counterfactual 2				Counterfactual 3			
Shocks:	No Shocks Introduced	Japan Demand Shock				Japan Trade Friction			
	All Vars	$\widehat{((Ex+Im)/Y)_r}$	$\widehat{(Ex/Y)_r}$	$\widehat{(Im/Y)_r}$	$\widehat{Y_r}$	$\widehat{((Ex+Im)/Y)_r}$	$\widehat{(Ex/Y)_r}$	$\widehat{(Im/Y)_r}$	$\widehat{Y_r}$
World	**1**	**0.99**	**0.99**	**0.99**	**1.00**	**0.99**	**0.99**	**0.99**	**1.00**
China	1	1.00	1.00	0.99	0.99	0.98	0.99	0.98	1.00
Germany	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
Japan	1	0.92	0.93	0.89	1.04	0.84	0.90	0.73	0.93
Mexico	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
South Korea	1	1.00	1.00	0.99	1.00	1.03	1.03	1.04	0.99
United Kingdom	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
United States	1	1.00	1.00	1.00	1.00	0.99	0.98	0.99	1.01

Table 5: Japan Counterfactual Results

Notes: [FROM 2-SECTOR CASE.]

Figures

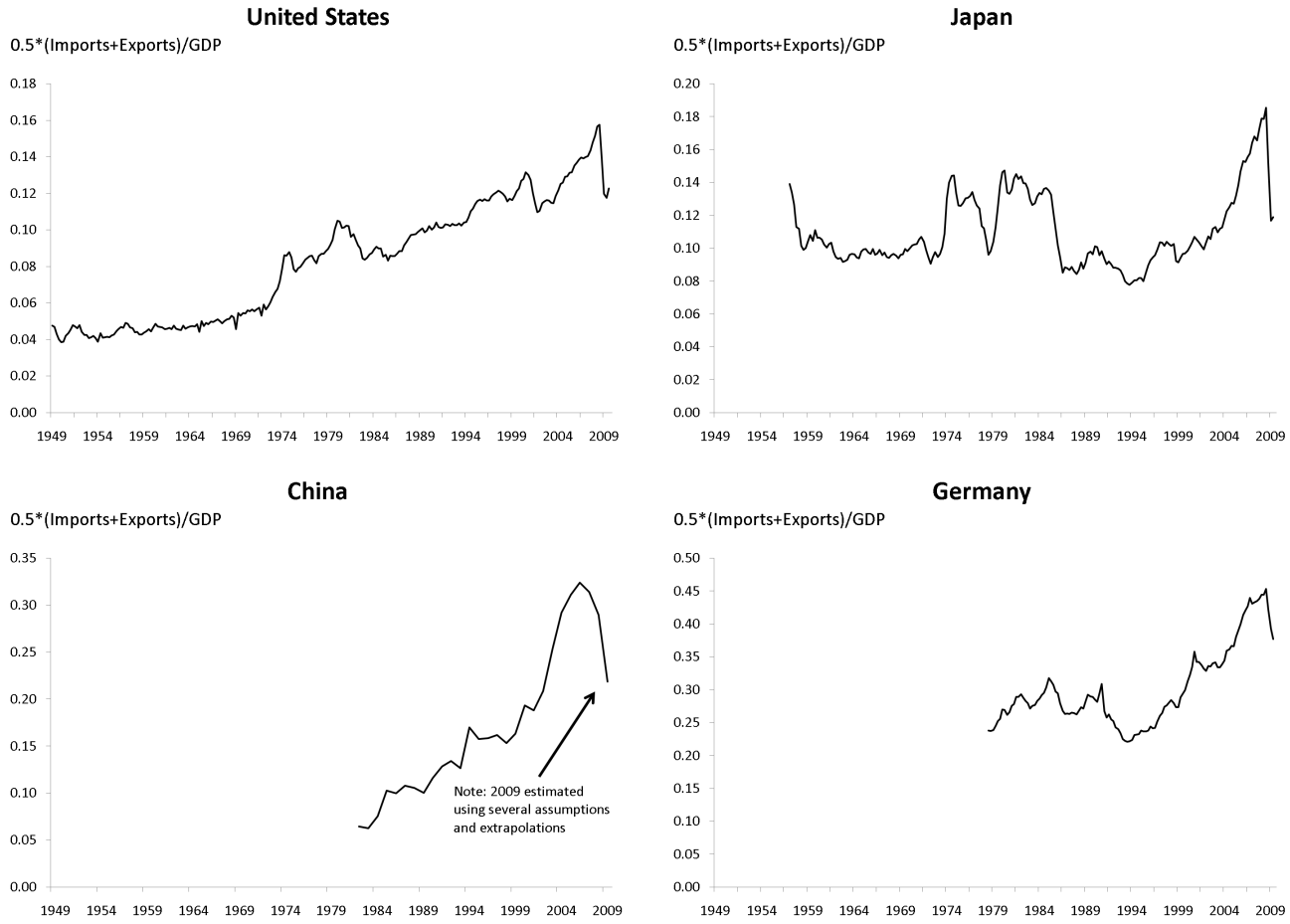

Figure 1: Trade as a Share of Output in the Four Largest Economies

Notes:

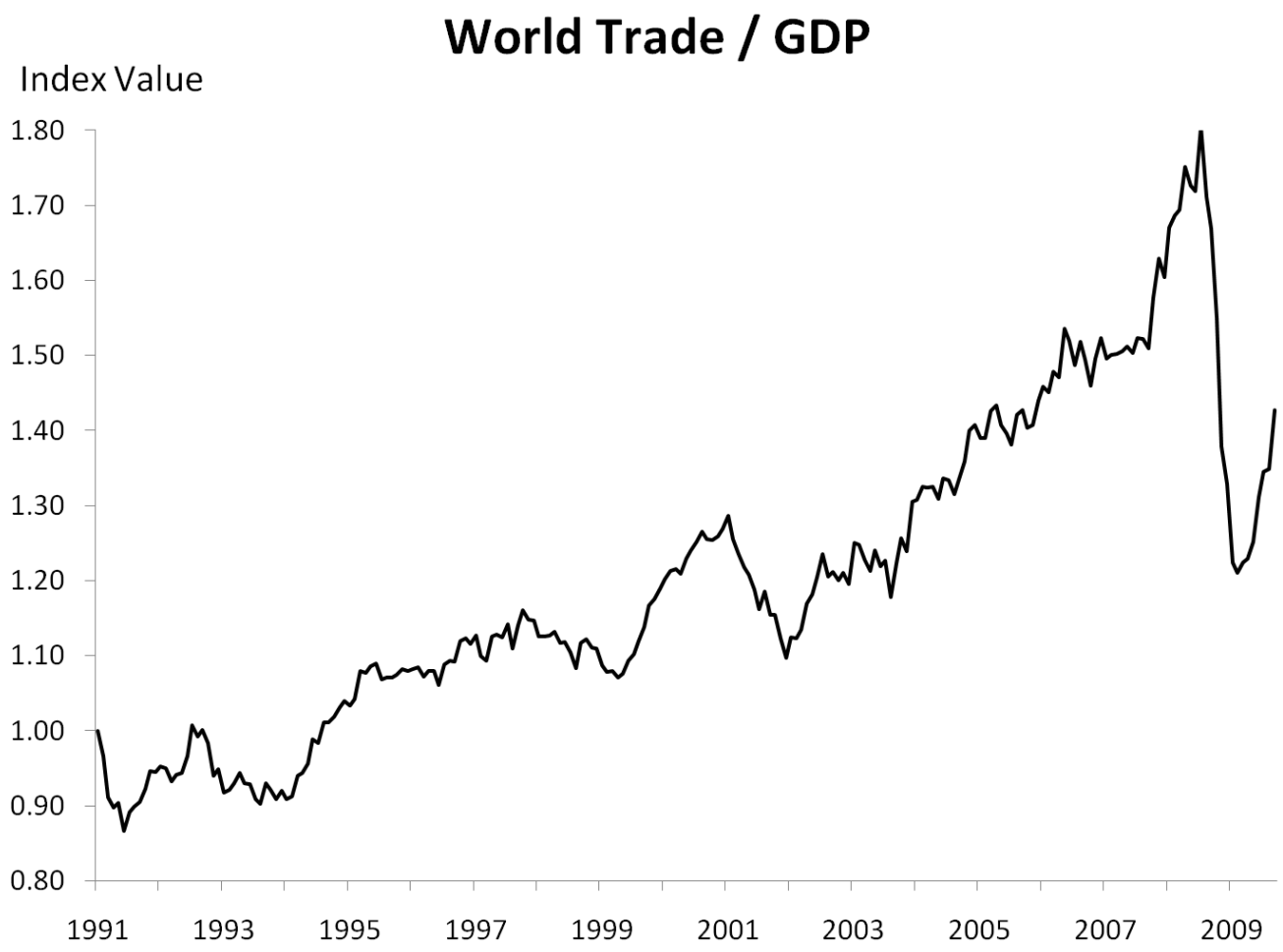

Figure 2: Global Trade Relative to GDP

Notes:

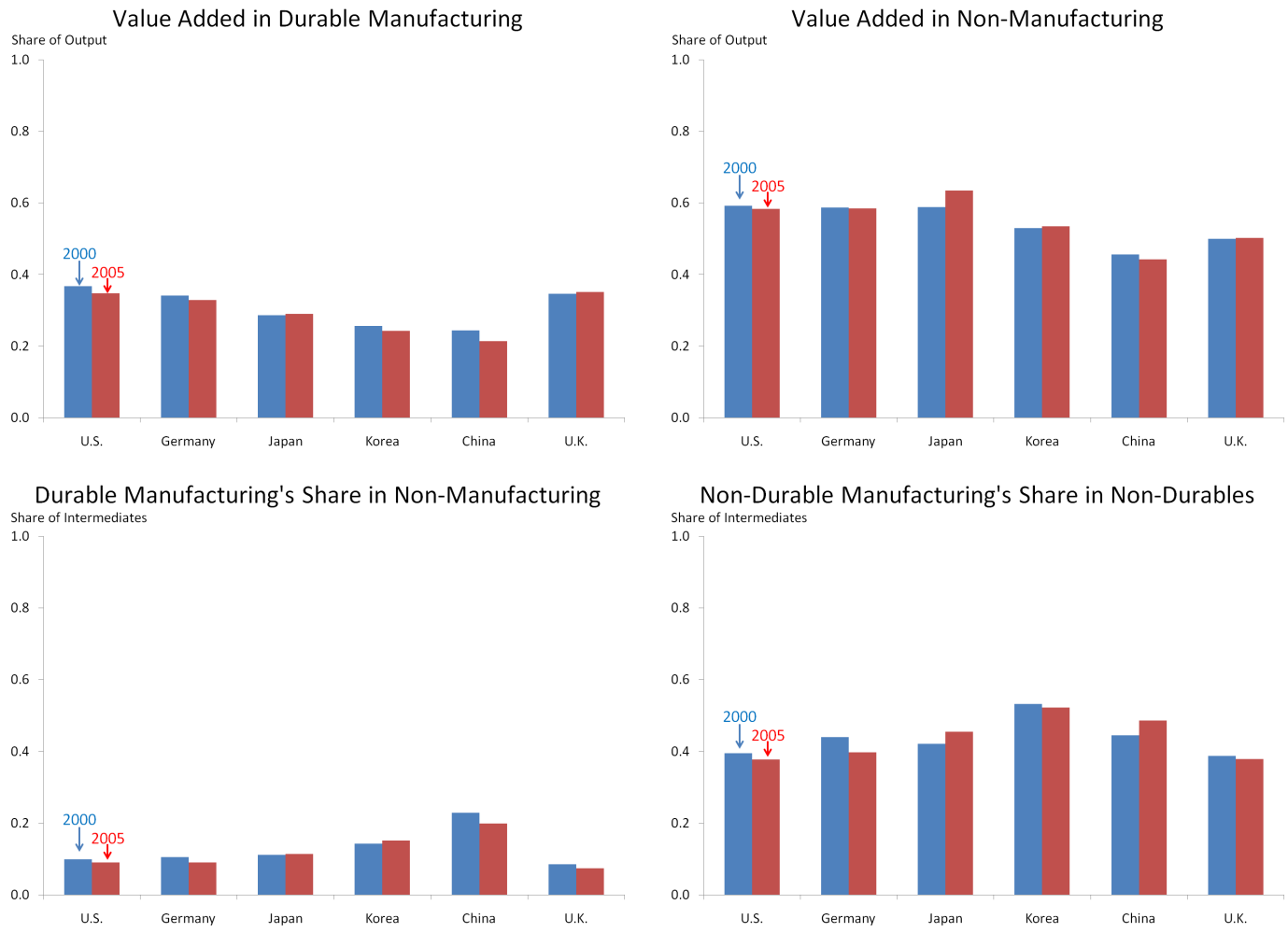

Figure 3: Sample Input-Output Coefficients (β_i^D, β_i^N, γ_i^{ND}, and γ_i^{NN})

Notes:

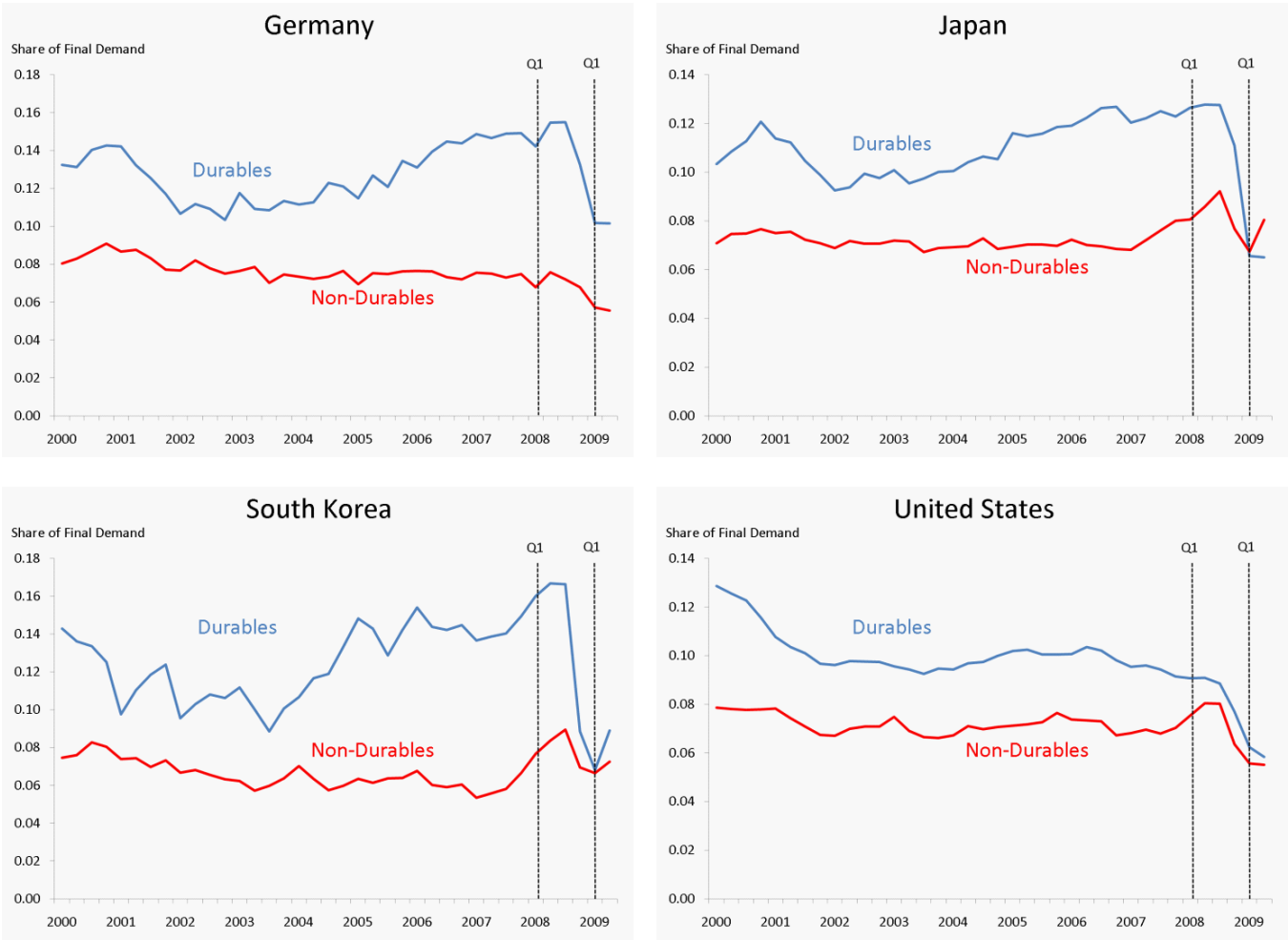

Figure 4: Shares of Manufacturing in Final Demand

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

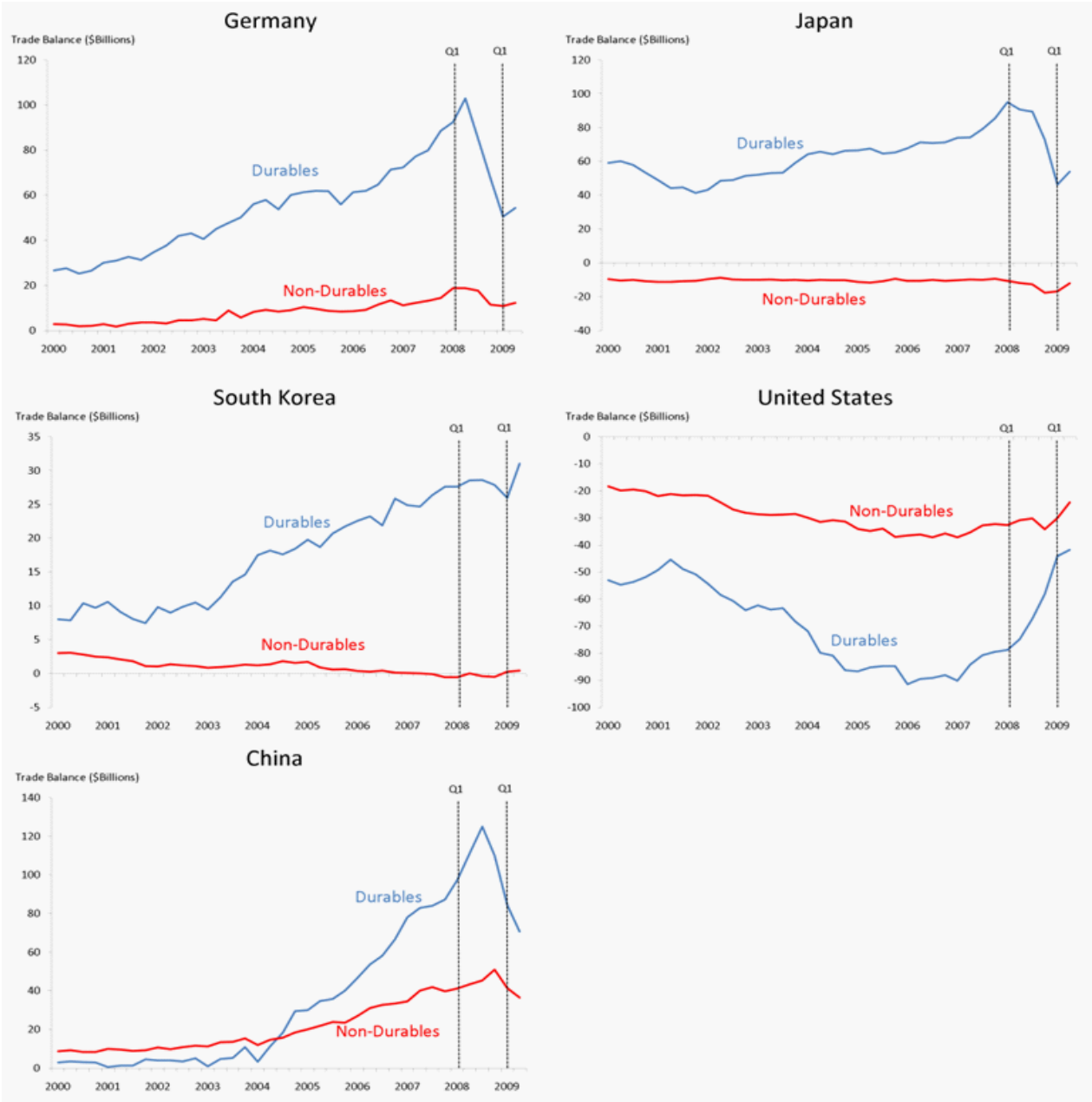

Figure 5: Manufacturing Trade Deficits

Notes:

Figure 6: Countries without Large Negative Shock to Trade Frictions

Notes: Generated using interpolation procedure with endogenous elasticites.

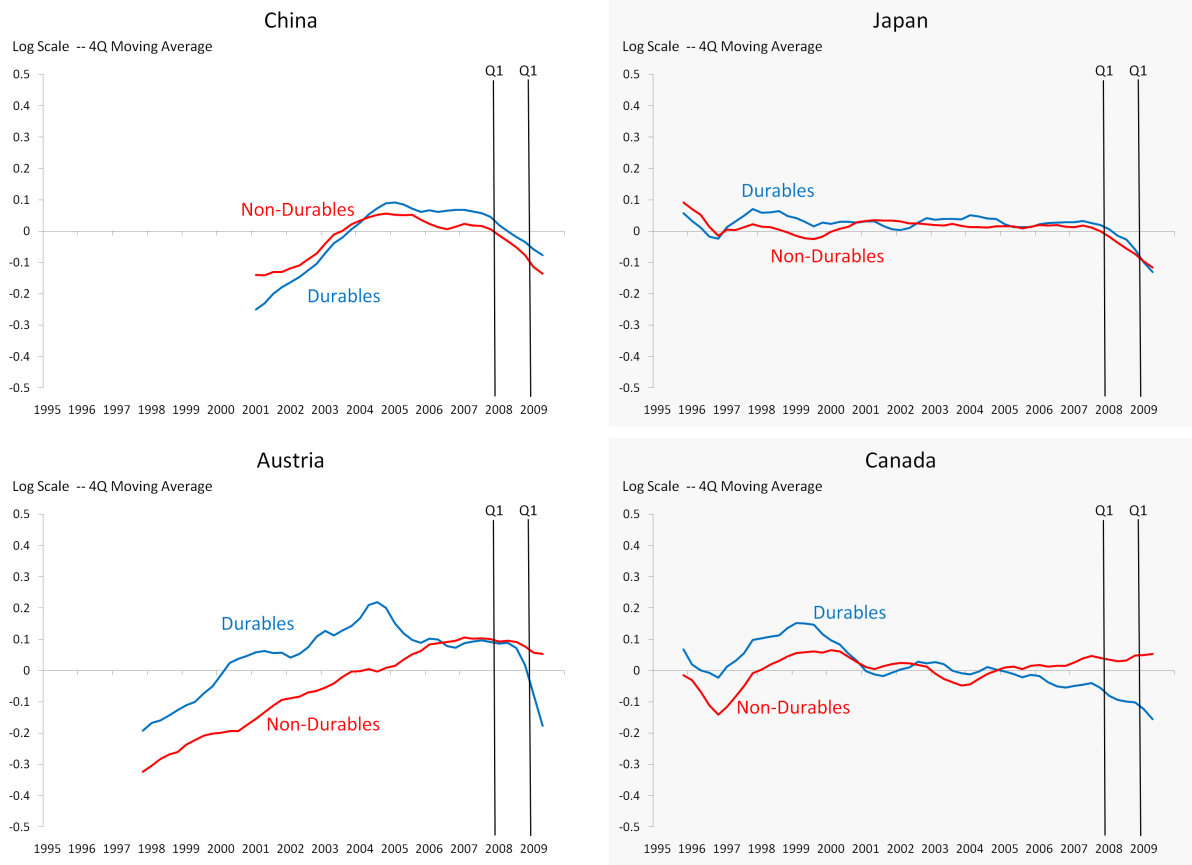

Figure 7: Countries with Large Negative Shock to Trade Frictions

Notes: Generated using interpolation procedure with endogenous elasticites.

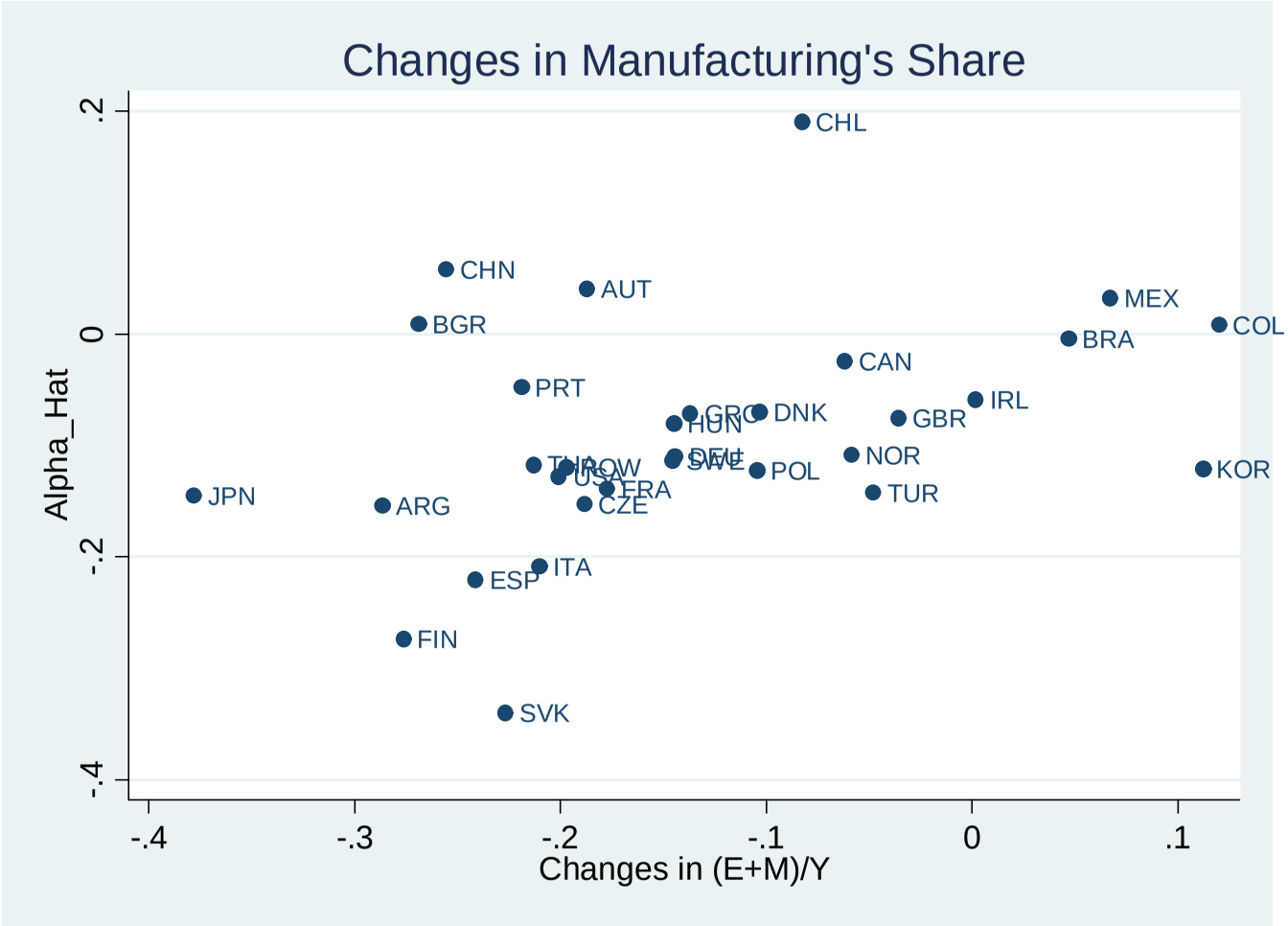

Figure 8: Shocks to Manufacturing's Share and Trade from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

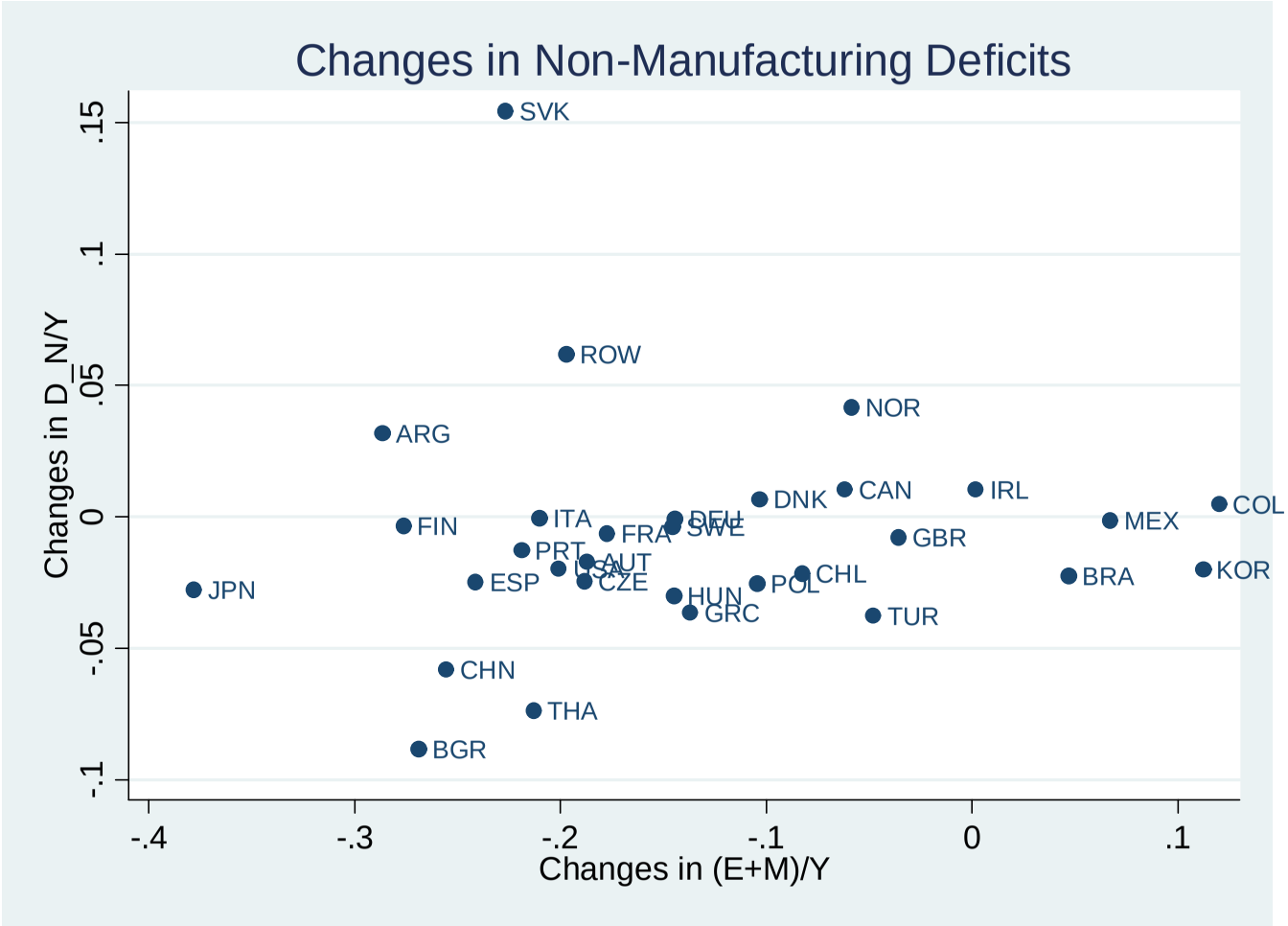

Figure 9: Shocks to Non-Manufacturing Deficits and Trade from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

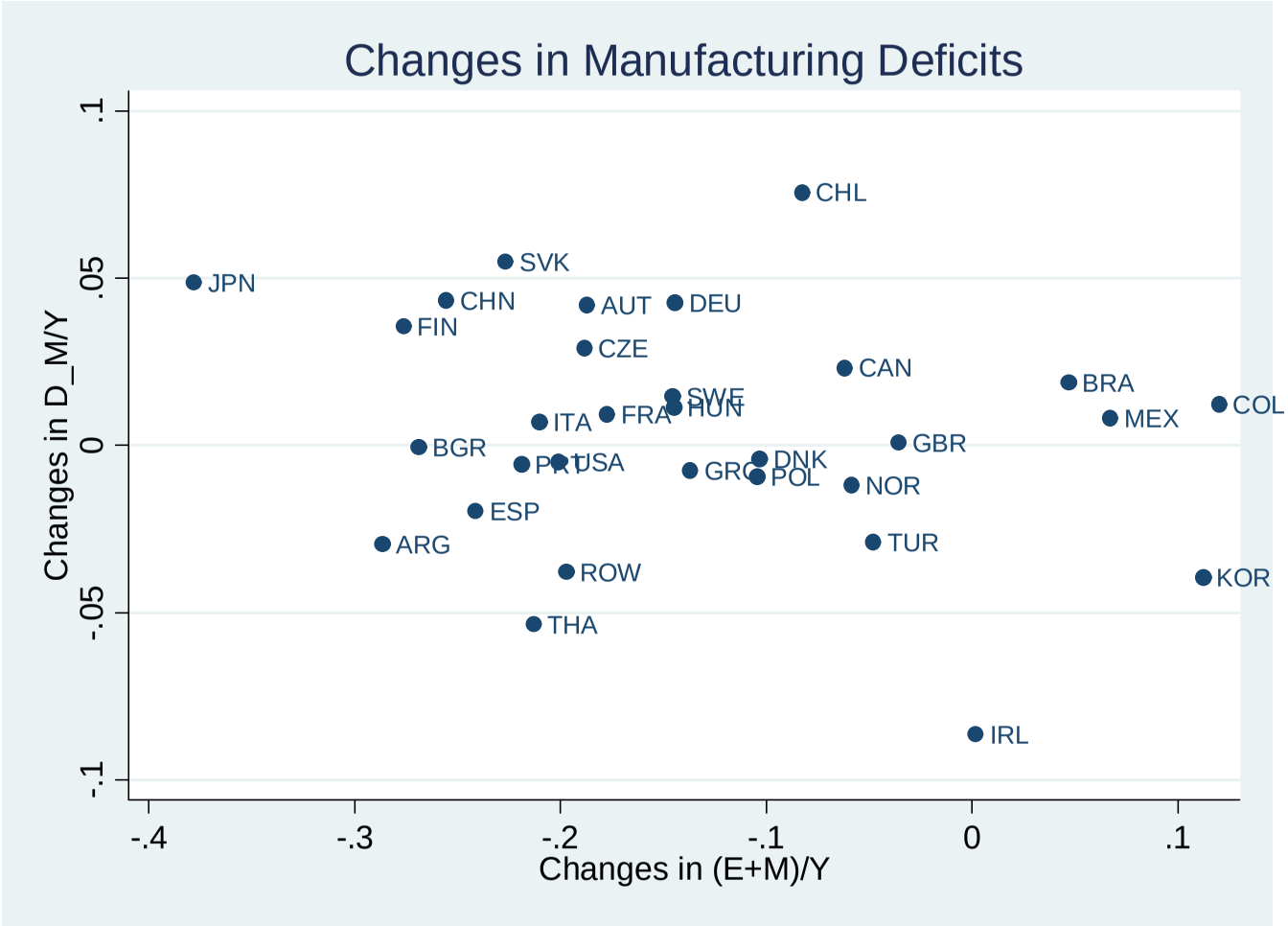

Figure 10: Shocks to Manufacturing Deficits and Trade from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

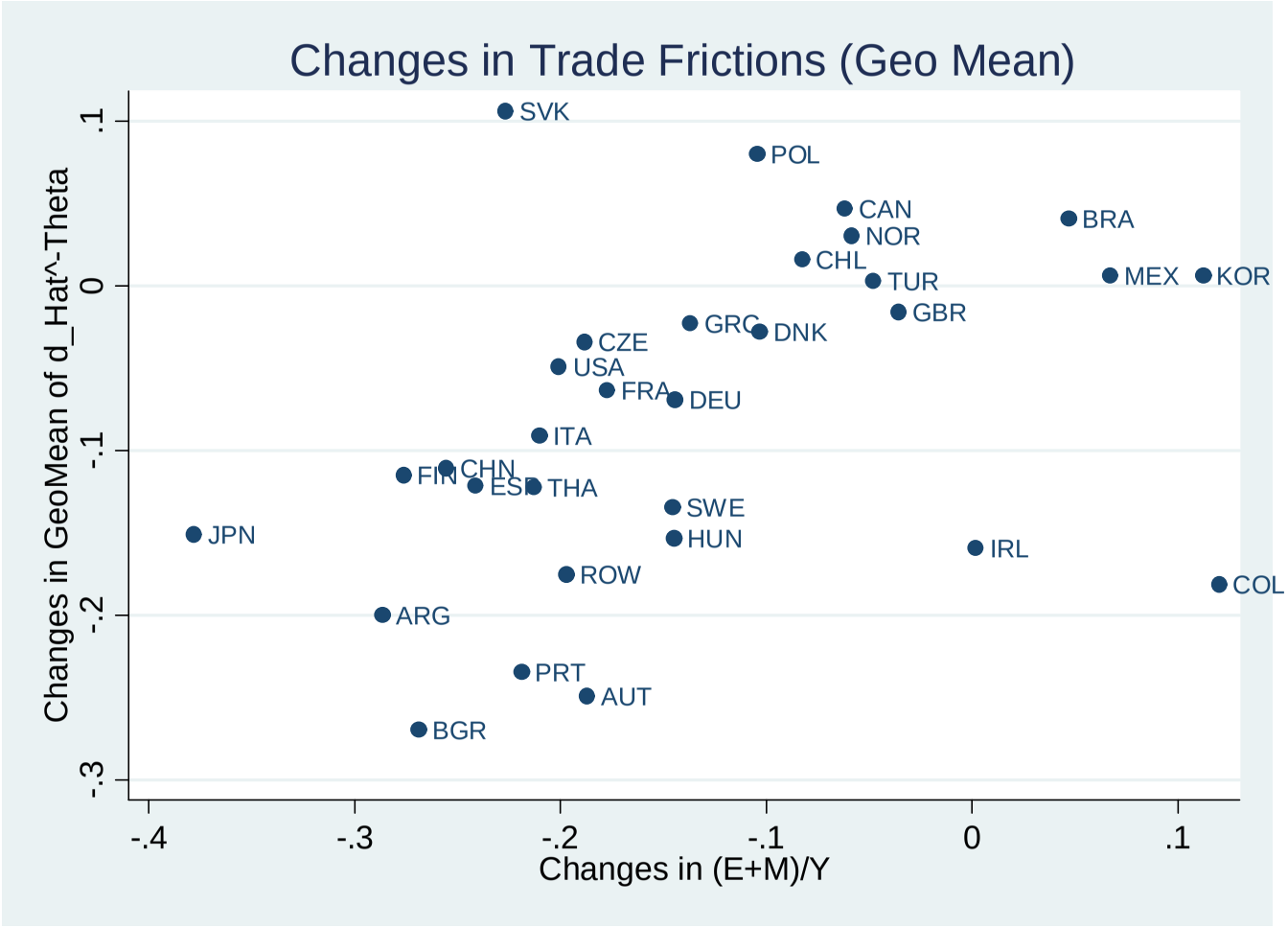

Figure 11: Shocks to Trade Frictions and Trade from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

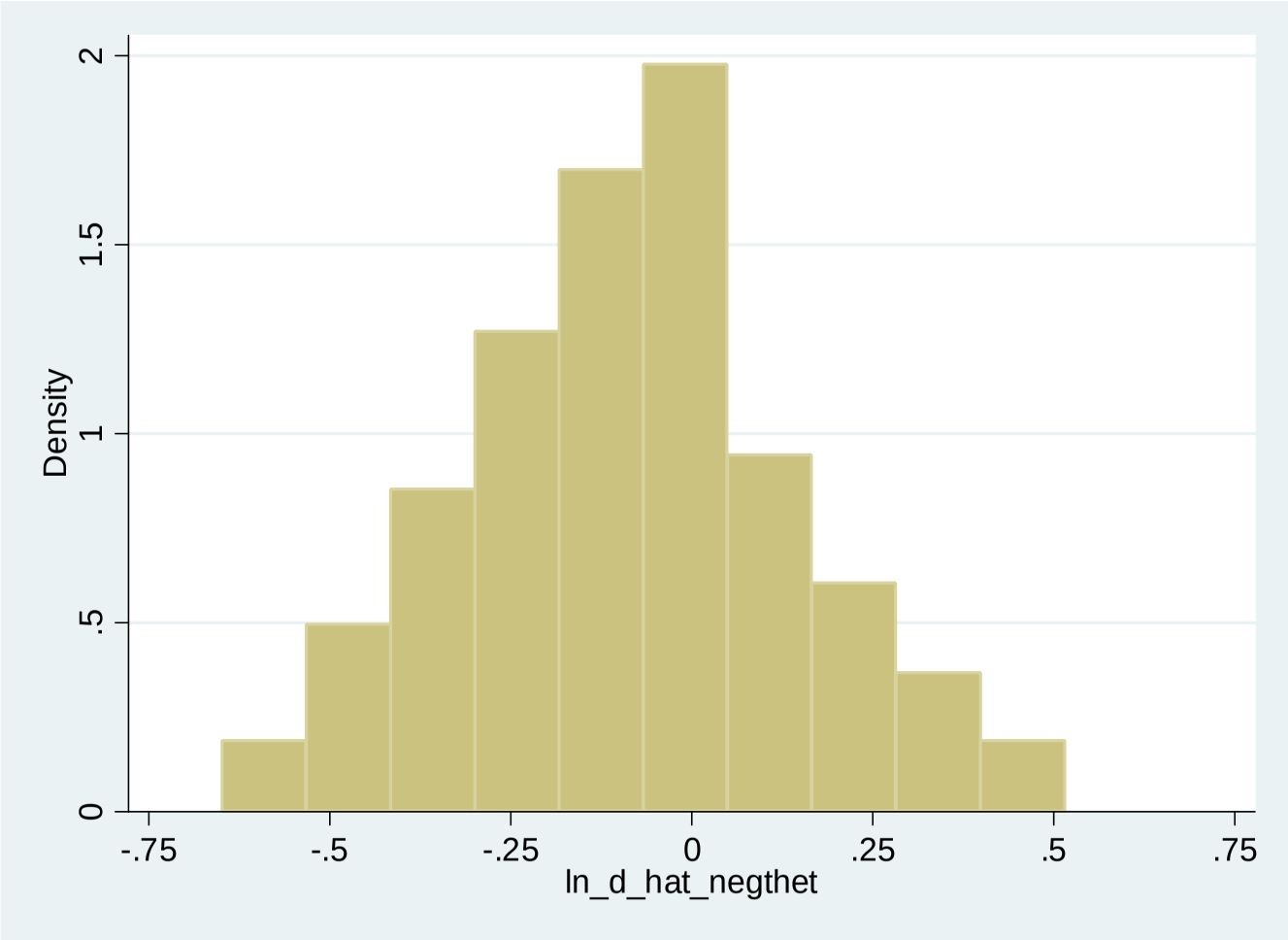

Figure 12: Shocks to Bilateral Trade Frictions Used in Counterfactuals

Notes: [FROM 2-SECTOR FRAMEWORK.]

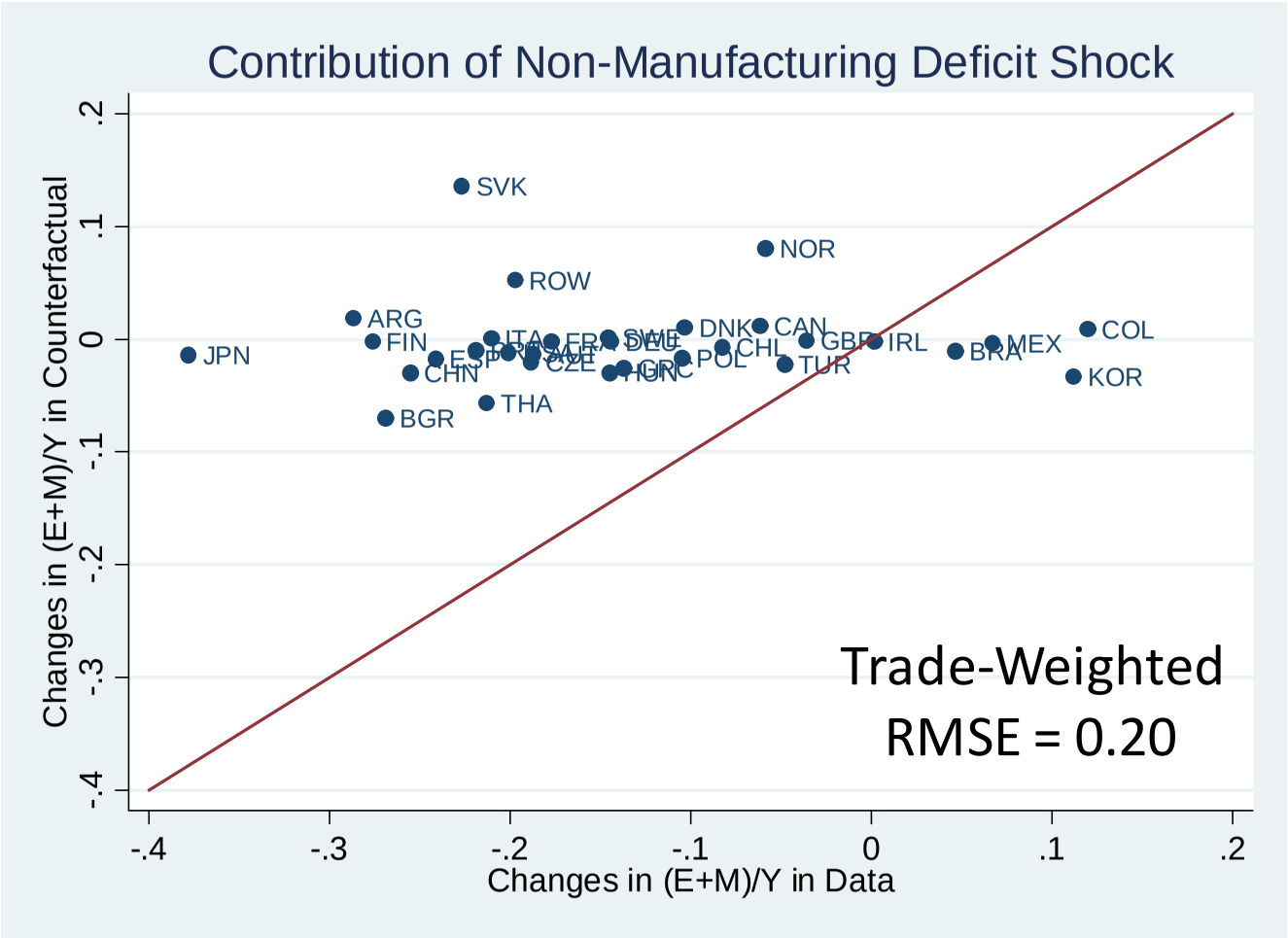

Figure 13: Explanatory Power of Shocks to Non-Manufacturing Deficits from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

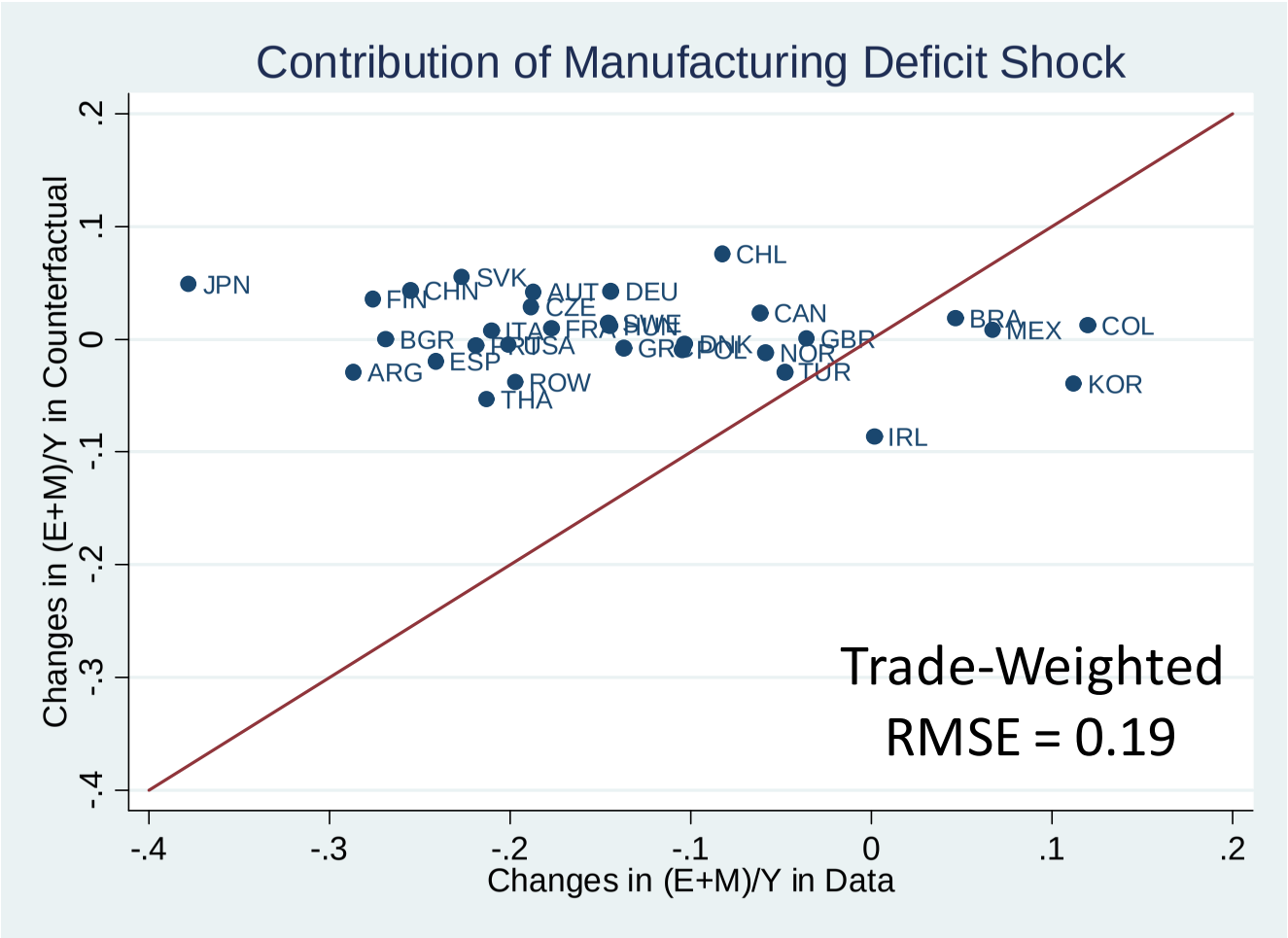

Figure 14: Explanatory Power of Shocks to Manufacturing Deficits from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

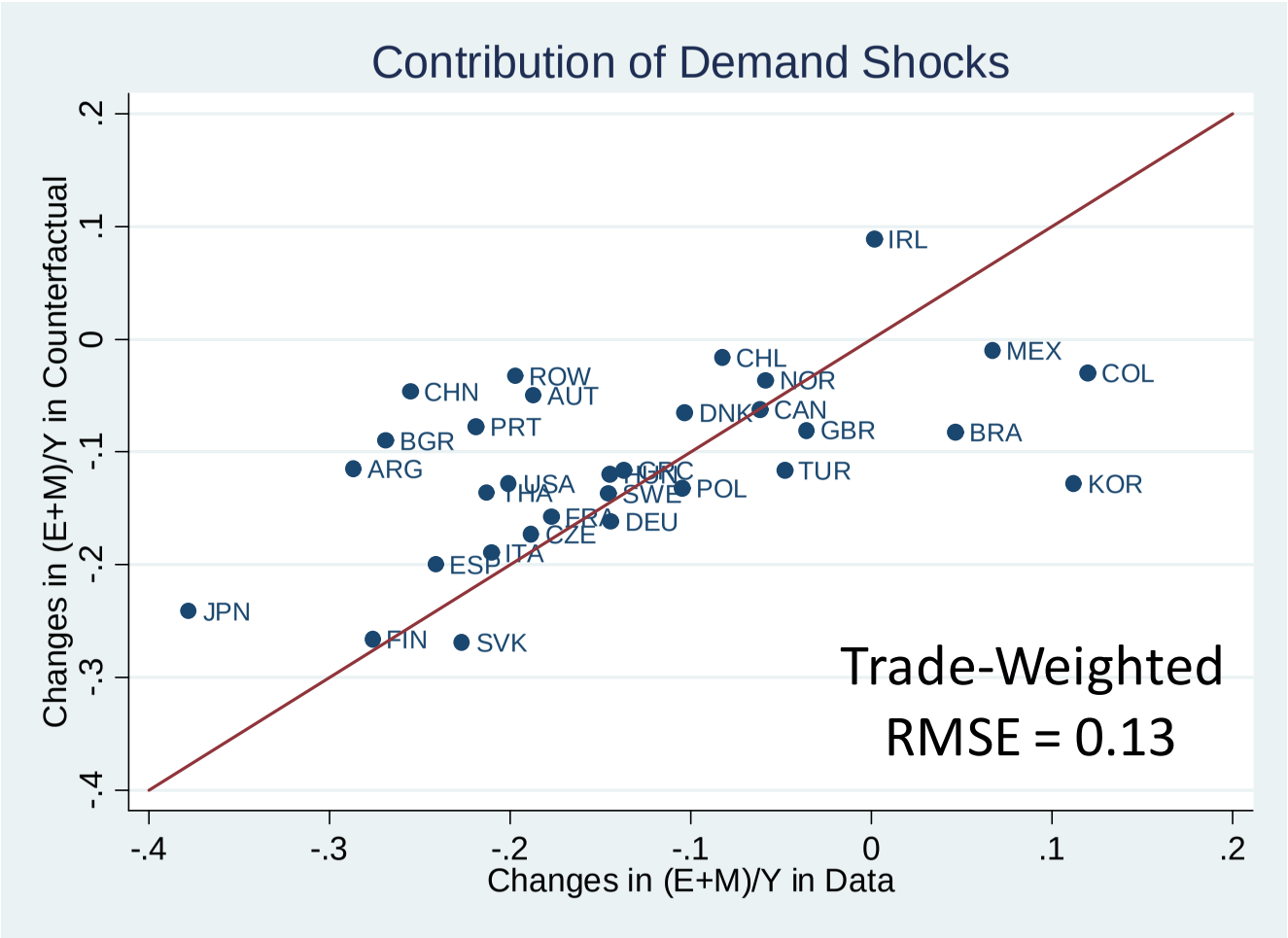

Figure 15: Explanatory Power of Shocks to Manufacturing's Share from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

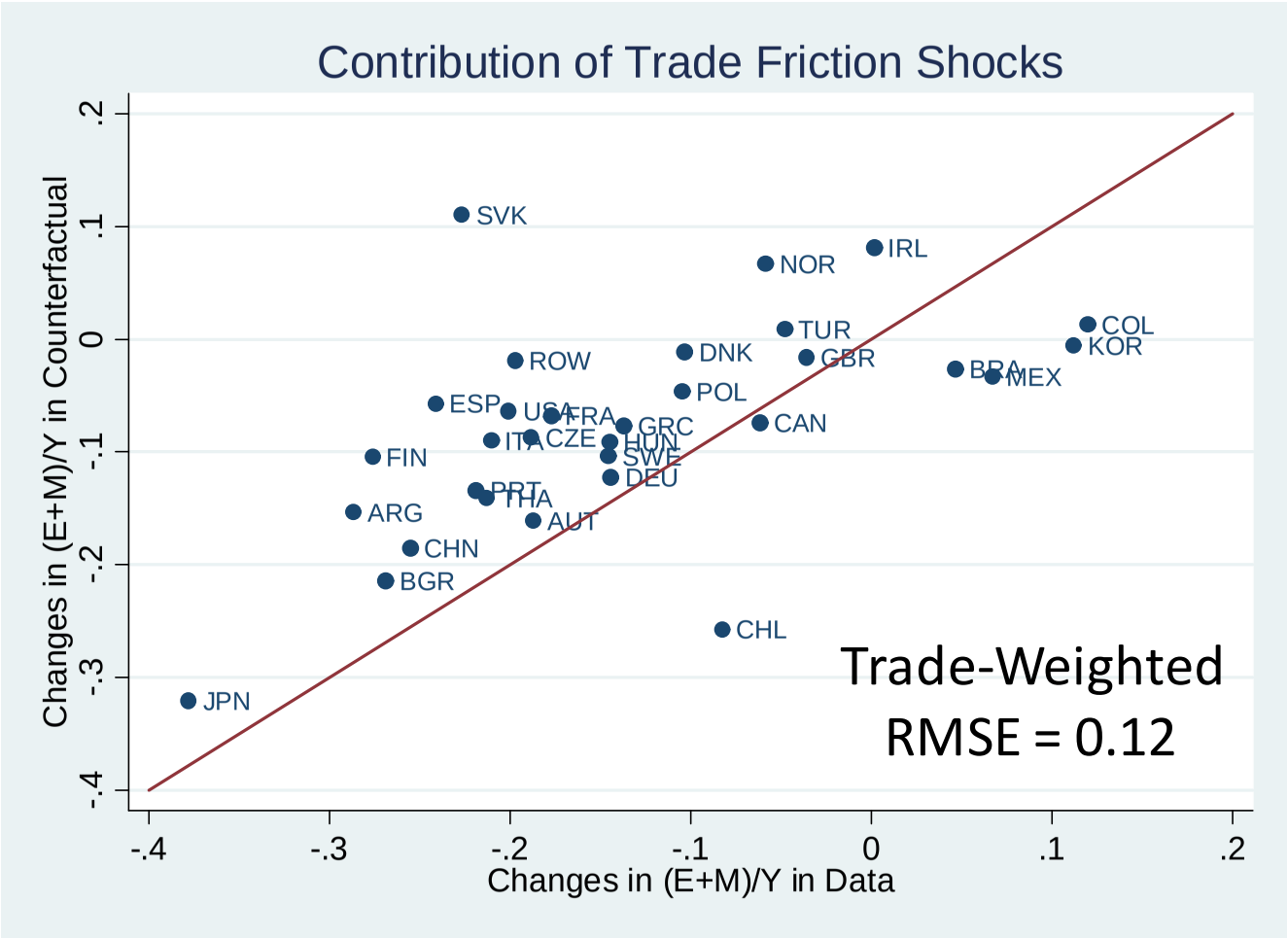

Figure 16: Explanatory Power of Shocks to Trade Frictions from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

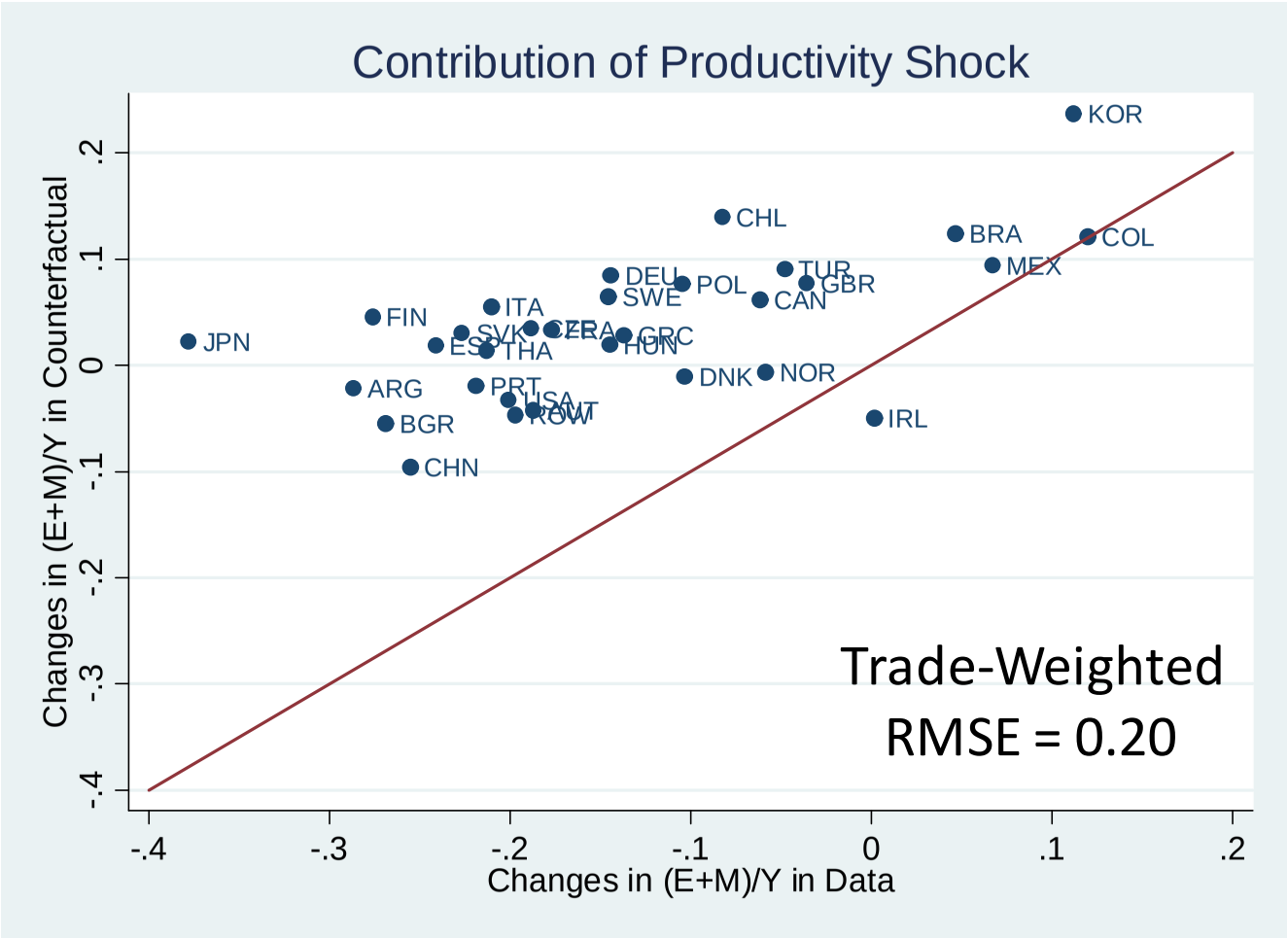

Figure 17: Explanatory Power of Shocks to Productivity from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

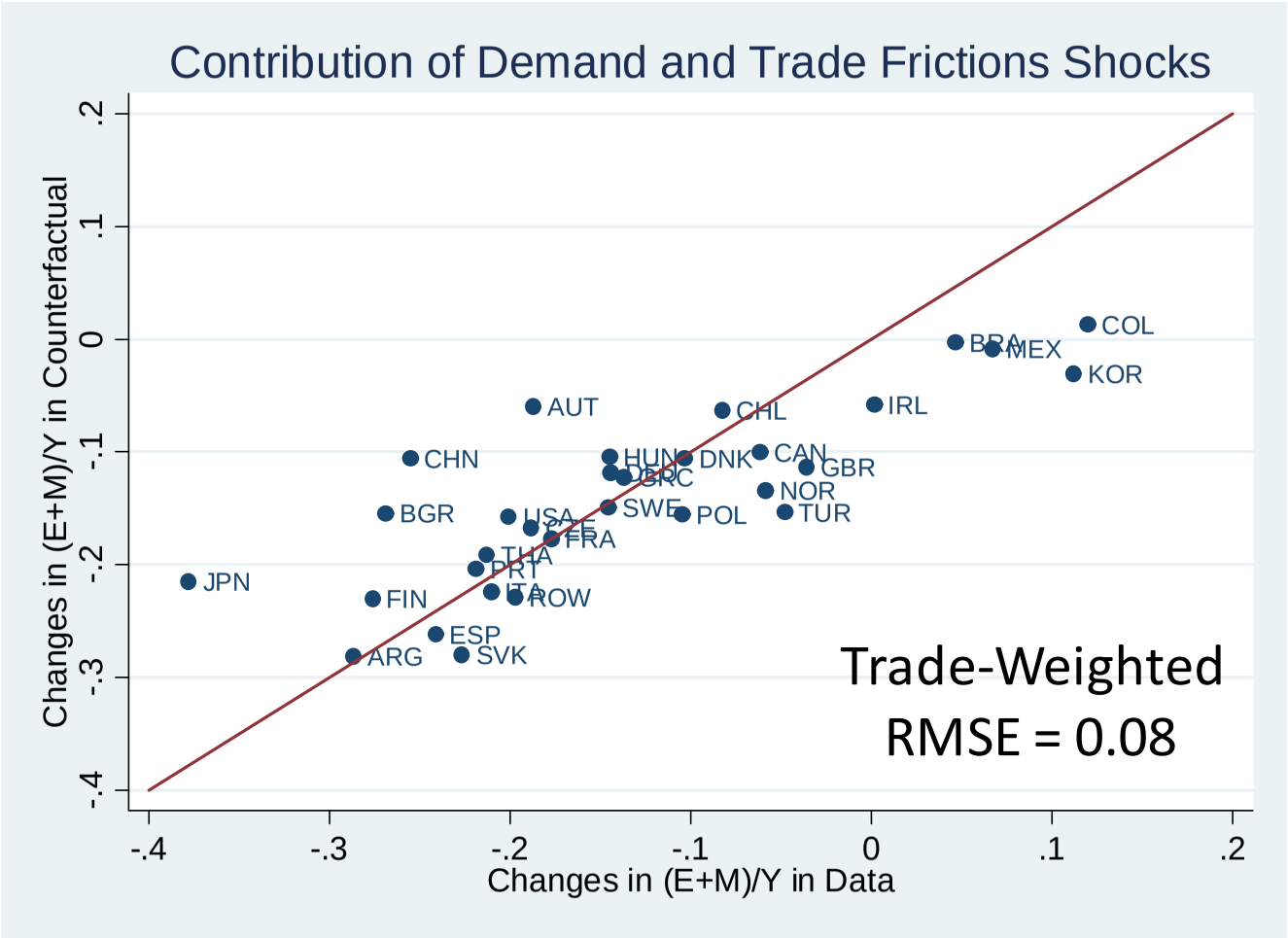

Figure 18: Explanatory Power of Shocks to Manufacturing Demand and Trade Frictions from 2008:Q1 to 2009:Q1
Notes: [FROM 2-SECTOR FRAMEWORK.]

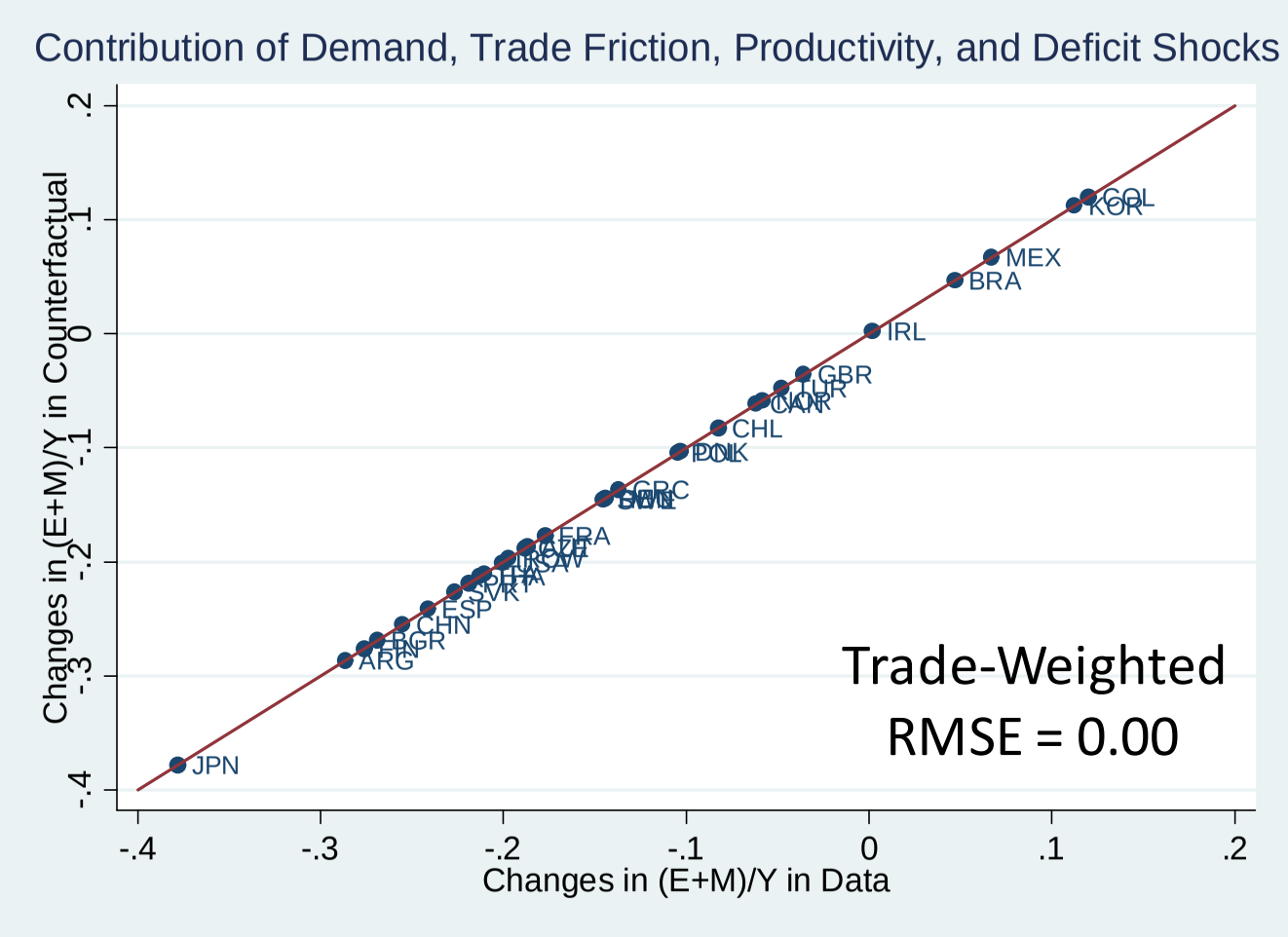

Figure 19: Explanatory Power of All Shocks from 2008:Q1 to 2009:Q1

Notes: [FROM 2-SECTOR FRAMEWORK.]

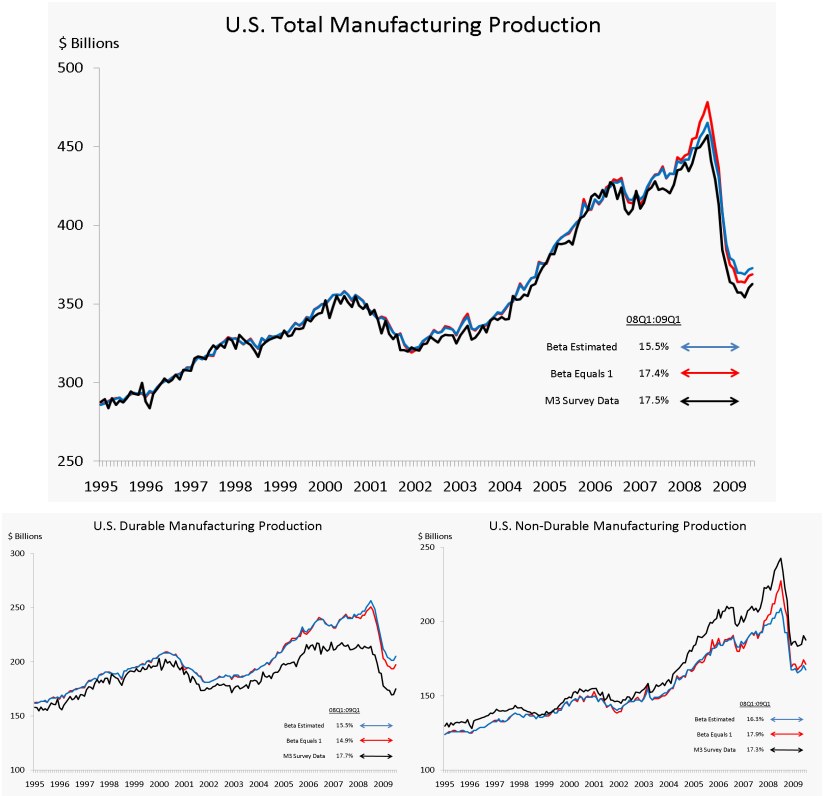

Figure B1: Checking Accuracy of Temporal Disaggregation Procedure for U.S.
Notes: Total Manufacturing scaled to match levels

Appendix A: Derivations of Expression (12)

In this appendix, we demonstrate that one can derive the Head-Ries index from many classes of trade models, such as a structure with Armington preferences, as in Anderson and van Wincoop (2003), monopolistic competition as in Redding and Venables (2004), the Ricardian structure in Eaton and Kortum (2002), or monopolistic competition with heterogeneous producers, as in Melitz (2003) and Chaney (2008). To do so, we need only show that each theory of international trade lead to a bilateral import share equation with the same form as equation (12). From there, the derivation of (14) follows exactly as in Section 2. This implies that for the first sections of the paper, we need not specify a particular trade structure, so long as it is in this larger set of models.

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

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

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

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

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

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

Relabeling $\theta = \sigma - 1$ and $T_i = \beta_i^{-\theta}$, we recover an expression equivalent to (12).

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

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

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

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

Again, this expression can be relabeled and made equivalent to (12).

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

country n is an expression identical to (12), their equation (8). Given that average expenditure per good in their model does not vary by source and invoking the low of large numbers, it follows that this probability is equivalent to the trade share.

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

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

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

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

which, again, is clearly in the same form as (12).

Appendix B: Temporal Disaggregation Procedure

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

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

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

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

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

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

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

where

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

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

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

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

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

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

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

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

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

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

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

model as:

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix C: Solving for the Equilibrium

In this appendix, we explain in more detail how we solve for the system's equilibrium. First we plug (19) into (20) and then, given a vector of wage changes $\widehat{\boldsymbol{w}}$, we solve (20) and (21) 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 service sector out of equation (3) to get

$$\begin{bmatrix} \left(X_i^D\right)' \\ \left(X_i^N\right)' \end{bmatrix} = \widetilde{\boldsymbol{\alpha}}_i' \left(Y_i' + D_i'\right) - \boldsymbol{\delta}_i \left(D_i^S\right)' + \widetilde{\boldsymbol{\Gamma}}_i^T \begin{bmatrix} \left(Y_i^D\right)' \\ \left(Y_i^N\right)' \end{bmatrix}, \tag{34}$$

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 $\widetilde{\boldsymbol{\Gamma}}_i$ 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 follow the approach of Caliendo and Parro (2009) and substitute (17) into the right hand side of (34). Given wage changes, we obtain a linear system in the $\left(X_i^j\right)'$'s by stacking (34) across all countries:

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

Here

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

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

with

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

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

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

and

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

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

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

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

Finally, summing up (17) over $j \in \Omega_M$ yields

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

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