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 a global input-output model with a gravity trade structure 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 in fact larger than would be expected, though the scale of this deviation does not stand out as historically exceptional. 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] The recent episode marked the largest 4-quarter percentage decline in this ratio for each of the largest three economies, and in Germany was second only to the rapid downward movement in 1990. 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

[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.

flows in the recent episode. In this scenario, in addition to the initial shock that led to a decline in 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 unusual decline, however, does not stand out as historically exceptional. For instance, 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.

We use the model to 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 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 gravity model of trade. Our analytical results will generally hold for any trade model within the broad class that produces a gravity structure.

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 all the key dynamics of the episode (and 2009 data would not be available for some time still). 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 take manufacturing as our tradable sectors, so the results are not impacted by the dramatic fall in commodity prices over this period. 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 a trade frictions term.

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 et al. (2009), for example, uses U.S. trade data to show that the decline is unusual relative to previous recessions. They find that a dummy variable for durable goods sectors is a statistically significant indicator of a larger drop in trade and other evidence suggesting the importance of the relative decline in demand for tradables in this recession.

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 on 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

[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).

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] 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 (2008). 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, which takes the opposite approach, as complementary to these U.S.-based empirical studies in fully understanding the global trade collapse. 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 model, which builds upon Eaton and Kortum (2002), Lucas and Alvarez (2008), and Dekle et al. (2008). We start by describing the input-output structure. Next, we merge this with trade share equations from the class of gravity models.

Our setup is most closely related to recent work by Caliendo and Parro (2009), which studies the impact of NAFTA in a multi-sector model. Their model contains significantly more sectors and input-output linkages, but unlike our work, does not seek to "account" for changes in trade

[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 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).

patterns with various shocks. Bems et al. (2010) 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 our work allows endogenously for changes in bilateral trade patterns, an important feature to match the recent experience, whereas their predictions assume fixed trade shares within each sector over the crisis.

3.1 Demand and Input-Output Structure

Consider a world of $i = 1, \ldots, N$ countries with constant return to scale production and perfectly competitive markets. There are three sectors: non-manufacturing, durable manufacturing, and non-durable manufacturing. We refer to these categories with the letters S, D, and N. The variable S was chosen because "services" are a large share of non-manufacturing, though this category also includes commodities such as petroleum. We define the set $\Omega = \{S, D, N\}$ to stand for all types of goods in the economy, and abuse notation slight by defining Ω_{-j} to mean the set of elements of Ω not including j. For example, the manufacturing sector is denoted $\Omega_{-S} = \{D, N\}$.

We choose these three categories because the assumptions in our trade model apply most naturally to manufactured goods. As such, we only seek to match trade patterns for the manufacturing sectors. As an added benefit, this largely insulates the interpretation of our results from large declines in some commodity prices during the recent global recession. We further allow for both durables and non-durables within manufacturing because these two groups have been characterized by shocks of different sizes, as noted in Levchenko et al. (2009), and to allow for the possibility that durables are traded more than non-durables.

Let Y_i^j denote country i's gross production of type $j \in \Omega$. Country i's gross absorption of type j is X_i^j and D_i^j its deficit of this type, where $Y_i^j = X_i^j - D_i^j$. Similar to Basu (1995), each type of good is used both as inputs into production and also to satisfy final demand. This round-about production structure, where the output elasticities are fixed, can be modeled as a Cobb-Douglas function where manufacturing outputs are themselves used as inputs. Value-added is a share β_i^j of gross production in sector j of country i, while γ_i^{jk} denotes the share of sector k in the production of intermediates for sector j, with $\sum_k \gamma_i^{jk} = 1$ for each $j \in \Omega$. [Explain here that we keep gammas fixed, but allow beta's to move year to year. The counterfactual exercise fixes both. Give evidence on stability of these parameters in I/O tables.] Our counterfactual experiments will hold the parameters γ_i^{jk} and β_i^j fixed over time.

We denote by α_i^j the share of sector j in country i's total final demand (across all sectors), so the total demand for sector j in country i is:

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

To interpret (1), 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, which is equal to GDP Y_i plus the overall trade deficit D_i. If, for example, there were a disproportionately strong negative demand shock for final spending on automobiles, trucks, and tractors in country i, it would manifest as a decline in α_i^D. Some autos, trucks, and tractors, however, are used as inputs to make additional durable and non-durable manufactures. The demand for durable manufactures as intermediate inputs for those sectors is accounted for with the second term of (1). 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.

We stack equations (1) for each value of j and write the linear system: $\mathbf{X}_i = \mathbf{Y}_i + \mathbf{D}_i = \boldsymbol{\alpha}_i X_i + \Gamma \mathbf{Y}_i$, where the boldface variables denote 3-by-1 vectors with each row containing the variable with a superscript of S, N, or D. We can thus easily express production in each sector as:

$$\mathbf{Y}_i = (I - \Gamma)^{-1} (\boldsymbol{\alpha}_i X_i - \mathbf{D}_i). \tag{2}$$

X_i is a scalar representing total final absorption, and the 3-by-3 matrix Γ is simply a function of the input-output coefficients. Production in each sector can be expressed as a function of these objects as well as that sector's trade deficits and share of final demand.

The first three equilibrium conditions in the model require clearing of global goods markets. Any country's production in each sector must be absorbed by other countries, including itself. Define π_{ni}^{j} as the share of country n's expenditures on goods in sector j purchased from country i. Thus, we require:

$$Y_i^j = \sum_{n=1}^{N} \pi_{ni}^{j} X_n^j, \tag{3}$$

for all $j \in \Omega$. Substituting the solutions of (2) into (3), we can express the N goods market clearing conditions for each sector in terms only of the above (easily-observable) variables and the trade shares π_{ni}^{j}. This set of equilibrium conditions embody the input-output structure in our framework.

3.2 Determining Trade Shares

Next, we put structure on the trade shares π_{ni}. Most of the benchmark models in modern trade theory generate a gravity relationship, and gravity models of trade have had tremendous empirical success.[6] These models generate equations for trade shares of the form:

$$\pi_{ni}^{j} = \frac{A_i^j \left(c_i^j d_{ni}^j\right)^{-\theta^j}}{\sum_{k=1}^{N} A_k^j \left(c_k^j d_{nk}^j\right)^{-\theta^j}}. \tag{4}$$

For instance, Appendix A shows that this structure emerges 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). This deep similarity in the predicted trade patterns from such seemingly disparate models is striking and is the subject of Arkolakis et al. (2009).

Below, we introduce the details of production from Eaton and Kortum (2002), which will give structural meaning to the terms A_i^j, θ^j, etc., but we emphasize that little would change if we instead preferred a different gravity model and interpreted the variables accordingly. For example, in the setup below, shocks to A_i^j will be interpreted as shocks to manufacturing and non-manufacturing

[6] See, for instance, XXX.

productivity. If one prefers the Armington setup, however, one could simply re-interpret shocks to A_i^j as preference shocks for that country's goods. Relatedly, θ^j will be presented as a parameter from the Frechet distribution. If the reader prefers Redding and Venables' (2004) implementation of Krugman (1980), for example, she may instead choose to think of this as a function of the elasticity of demand.

3.3 Production

Durable and non-durable manufactures each consist of a unit continuum of differentiated goods indexed by z. We denote country i's efficiency making good z in sector j as $a_i^j(z)$. The cost of producing good z in sector j in country i is thus $c_i^j/a_i^j(z)$, where c_i^j is the cost of an input bundle for sector j in country i. Given the production structure introduced above:

$$c_i^j = \kappa_i^j w_i^{\beta_i^j} \prod_{k\in\Omega} \left(p_i^k\right)^{\gamma_i^{jk}(1-\beta_i^j)}, \tag{5}$$

where p_i^k is the price index for sector k in country i, to be determined below, and the constant κ_i^j is defined as:

$$\kappa_i^j = \left(\beta_i^j\right)^{-\beta_i^j} \prod_{k\in\Omega} \left[\gamma_i^{jk}(1-\beta_i^j)\right]^{-\left[\gamma_i^{jk}(1-\beta_i^j)\right]}. \tag{6}$$

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

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

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

$p_{ni}^j(z)$ is:

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

Buyers in destination n buy each manufacturing good z^j in sectors $j = D, N$ from the cheapest source. We assume that the individual manufacturing goods, whether used as intermediates or in final demand, combine with constant elasticity $\sigma^j > 0$. As detailed in Eaton and Kortum (2002), we then compute the price index by integrating over the prices of individual goods to get:

$$p_n^j = \varphi^j \left[\sum_{i=1}^{N} T_i^j \left(c_i^j d_{ni}^j\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{7}$$

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

Trade shares thus take the form (4), where $A_i^j = \left(\kappa_i^j\right)^{-\theta^j} T_i^j$:

$$\pi_{ni}^j = \frac{T_i^j \left[\kappa_i^j w_i^{\beta_i^j} \prod_{k \in \Omega} \left(p_i^k\right)^{\gamma_i^{jk}(1-\beta_i^j)} d_{ni}^j\right]^{-\theta^j}}{\sum_{k=1}^{N} T_k^j \left[\kappa_k^j w_k^{\beta_k^j} \prod_{l \in \Omega} \left(p_k^l\right)^{\gamma_k^{jl}(1-\beta_k^j)} d_{nk}^j\right]^{-\theta^j}}. \tag{8}$$

Substituting expressions (5) into expressions (7) yields expressions for the price indices of the two types of manufactured goods. World equilibrium is a set of wages and price levels w_i and p_i^j for each sector j and country i that solve equations (3), (8), and (7) given parameters, including labor endowments L_i and deficits, D_i and D_i^j.

[NOTE: THE BELOW RESULTS ARE FROM THE TWO-SECTOR STRUCTURE USED IN PREVIOUS DRAFTS. M DENOTES MANUFACTURING, WHILE THE OTHER SECTOR IS NON-MANUFACTURING. WE WILL SHORTLY POST RESULTS FROM THIS ANALYSIS USING THE THREE-SECTOR STRUCTURE DESCRIBED ABOVE.]

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. This follows both because the decline sharpened in the middle of 2008, but also because one needs to convert all flows into a common currency and doing so is significantly noisier at annual or quarterly frequency than at monthly frequency. Trade flow data are easily found at a monthly frequency – we use monthly bilateral trade flows from the Global Trade Atlas Database. We aggregate appropriate 2-digit HS categories to generate the total trade flows of manufactures.

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.[7]

4.1 Temporal Disaggregation

Appendix B details our procedure for disaggregating and extrapolating the annual production data in country i using the estimated relationship with several high frequency variables.[8] To build intuition for the procedure, one might start by thinking of a linear regression between the annual gross production of manufacturers and 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 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.

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

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

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

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 manufacturing sales. The U.S. monthly data are collected as part of the M3 manufacturing survey.[9] Appendix Figure B1 demonstrates the very high quality of fit for the U.S. case. Our procedure takes the 2007 level as the most recent annual production input. Further, these totals (from the OECD) do not exactly equal the annual totals one would get from adding up the monthly data from the M3 survey. It is reassuring that, despite the fact that our inputted annual series is several years old and does not perfectly match the series we wish to approximate, our procedure is still capable of capturing even high-frequency movements quite well.

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) and, for China, 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.

[9] 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.

4.2 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) Rev. 3 codes used in the production data. We started 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.

Next, we concorded the ISIC Rev. 3 industries to the categories: non-manufacturing, non-durable intermediates, non-durable consumption goods, durable intermediates, durable consumption goods, and capital goods. We did this in order to temporally disaggregate and extrapolate the annual production values in these categories into monthly values using the IP and PPI indices that are specific to each of the categories. Our definition of manufacturing comprises ISIC chapters 15 through 36 excluding 23 (petroleum). We further divide goods into the above categories using the U.S. import end use classification. 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 of each ISIC classification belongs into each of the categories.

4.3 Input-Output Coefficients

[TBD: Will describe beta and gamma values, taken from OECD input-output tables.]

4.4 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 in our model are driven entirely by four shocks to the system. First, there is the country-specific share of final demand that is for manufactured goods, α_i. The hypothesis that the decline in trade is precisely what one would expect implies that α-shocks are the only important determinants of recent trade flow changes. Second, non-manufacturing and manufacturing deficits, D_i^N and D_i^M, can of course change trade patters. Third, changes in the productivity parameter A_i (or in the Armington model, the preference parameter) will change flows. Finally, bilateral trade frictions $d_{ni}^{-\theta}$ 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 d-shocks are of first-order importance.

These four shocks can be divided into two types. The first two – tradable demand and deficits – 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 Tradable Demand and Deficits

We start with the first two shocks, which can be readily observed or computed from the data. The first, the demand for tradables, or manufactures, can be calculated using (**??**) as:

$$\alpha_i = \frac{[1-(1-\gamma)(1-\beta_i)]\, Y_i^M + D_i^M}{X_i},$$

where data for all the right hand side terms have been described above. Figure 3 plots the paths of α_i for seven large countries since 2000. The dashed vertical lines on the right of the plot correspond to the period starting in the first quarter of 2008 and ending in the first quarter of 2009. We highlight this window because that will be the period we use for our counterfactual analyses. The recent recession has led to a steep decline in manufacturing's share for all these countries except Mexico, where it remained flat. The red line representing the U.S., for example, drops about 14 percent from the first vertical dashed line to the second.

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

5.2 Measuring Trade Frictions with the Head-Ries Index

Trade frictions are not as easily be 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 (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 et al. (2009) studies a very similar object for a span of over 100 years to analyze long-term changes in trade frictions.

Denote country n's spending on manufactures from country i by X_{ni}, measured in U.S. Dollars. All variables are indexed by time, though we generally omit this from our notation. We have:

$$\frac{X_{ni}}{X_{nn}} = \frac{\pi_{ni}}{\pi_{nn}} = \frac{T_i \left[c_i d_{ni}\right]^{-\theta}}{T_n \left[c_n\right]^{-\theta}}, \tag{9}$$

where we normalize $d_{nn} = 1$. Domestic absorption of manufacturing production, X_{nn}, is equal to gross manufacturing production less exports: $X_{nn} = Y_n^M - \sum_i X_{in}$. Grouping together country-level terms as $S_i = T_i c_i^{-\theta}$ and taking logs of both sides of (9), we could run a regression at date t on country fixed effects. We might do this hoping to sweep out the components S_i so that we would be left with $d_{ni}^{-\theta}$, which is the object we want to study.

Such a procedure would be misleading, however, due to a fundamental identification problem. For any set of parameters $\{S_i, d_{ni}\}$ we can fit the same data with another set of parameters $\{S_i', d_{ni}'\}$ where:

$$S_i' = \phi_i S_i,$$

and

$$d_{ni}' = \left[\frac{\phi_i}{\phi_n}\right]^{1/\theta} d_{ni}.$$

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

Multiplying (9) by the parallel expression for what i buys from n and taking the square root, we generate:

$$\Theta_{ni} = \left(\frac{X_{ni}}{X_{nn}}\frac{X_{in}}{X_{ii}}\right)^{1/2} = \left[d_{ni}d_{in}\right]^{-\theta/2}. \tag{10}$$

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 (9), or the summation of bilateral trade flows relative to the summation of any pair of countries' final demands. These other measures, however, have the disadvantage of being unable to isolate trade frictions.

In all, 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 unique structure. Table 1 lists the countries included and the number of countries and pair-months available for each year.[10]

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), exporter (δ), and importer (μ) components that change over time, as well as a bilateral term (γ_{ni}) that is fixed, and finally a shock (ϵ_{ni}):

$$d_{ni}(t) = e^{\eta(t)+\delta_n(t)+\mu_i(t)+\gamma_{ni}+\epsilon_{ni}(t)}. \tag{11}$$

We think of the exporter effect δ 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 (10) and (11) imply:

$$\ln \Theta_{ni}(t) = \frac{\theta}{2} \ln \left(d_{ni}(t) d_{in}(t)\right) = \theta\eta(t) + \theta\gamma_{ni} + \frac{\theta}{2}\left(\delta+\mu\right)_n(t) + \frac{\theta}{2}\left(\delta+\mu\right)_i(t) + \frac{\theta}{2}\left(\epsilon_{ni}+\epsilon_{in}\right)(t),$$

which shows that, even though there might be distinct importer and exporter frictions, we can only learn about their combination ($\beta_n = \left(\delta_n + \mu_n\right)/2$) 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, j, t:

$$\ln \Theta_{ni}(t) = \beta_n(t) + \beta_i(t) + \gamma_{ni} + \varepsilon_{ni}(t). \tag{12}$$

Note that there are only N country dummy variables each period, any given observation will be influenced by two of them, and each one represents the sum of the trade frictions experienced by that country's exporters and importers.

Figures 5 and 6 plot the four-quarter moving average of the country-time effects β_i from a

[10] 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.

weighted estimation of (12) for selected countries. We use a moving average due to the strong seasonal effects in the data. The coefficients are normalized to zero in the first quarter of 2000 and in some cases extend through the second quarter of 2009. The country-time effects act proportionately on the Head-Ries indices for all bilateral pairs involving any given country. For instance, if the series for country i increases from 0 to 0.1, it implies that the index would increase 10 percent for all pairs in which i is an exporter or an importer.

Looking at Figure 5, we see examples of countries where the recession did not bring with it marked declines in trade frictions. Only a small share, if any, of the large declines in trade flows for Germany, the U.S., India, and Mexico should, according to this measure, be attributed to declining trade frictions. Figure 6, by contrast, includes only countries for which there is a steep increase in trade frictions (a decline in the index) during the recession. These countries include Japan, China, Austria, and Portugal, 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.

5.3 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 (10) 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.[11] The gross value of manufacturing, required for the denominator of (10), were obtained from a variety of country-specific sources.[12] The U.S. ratio of gross output to value added

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

[12] 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 thousands 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,

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

The bilateral trade and the manufacturing totals often reflect changing availability of data for disaggregated categories. For example, one year's total growth may reflect both 20% growth in Paper Products as well as the initial measurement (relative to previous missing values) of Transportation Equipment. Since inspection suggests that such missing values do not simply reflect zero values, we calculate year-to-year growth rates using only the common set of recorded goods. For manufacturing production, we not only need the growth rate, but the level also matters because we subtract the level of exports to measure absorption. We apply the growth rate backwards from the most 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 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 30 countries, combining the remaining ones into the "Rest of World," which represents about 23 percent of global GDP (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.

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.

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 $Y_i' = \hat{w}_i Y_i$. We assume that κ_i changes only due to changes in non-manufacturing productivity $\hat{a}_i$, so that $\hat{\kappa}_i = \hat{a}_i^{-\gamma(1-\beta_i)}$. Since non-manufacturing productivity and manufacturing productivity always enter the model together, we define:

$$\hat{A}_i = \hat{T}_i \hat{a}_i^{\theta\gamma(1-\beta_i)} = \left[\hat{b}_i \hat{a}_i^{\gamma(1-\beta_i)}\right]^{\theta},$$

where $\hat{b}_i = \hat{T}_i^{1/\theta}$ denotes the change in manufacturing productivity.

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

$$\frac{\alpha_i'\left(\hat{w}_i Y_i + D_i^{N'} + D_i^{M'}\right) - D_i^{M'}}{1-(1-\gamma)(1-\beta_i)} = \sum_{n=1}^{N} \pi_{ni}' \frac{\alpha_n'\left(\hat{w}_n Y_n + D_n^{N'} + D_n^{M'}\right) - (1-\gamma)(1-\beta_n) D_n^{M'}}{1-(1-\gamma)(1-\beta_n)}. \quad (13)$$

The trade share equations (8) become:

$$\pi_{ni}' = \frac{\pi_{ni}\hat{A}_i \hat{w}_i^{-\theta[1-(1-\gamma)(1-\beta_i)]}\hat{p}_i^{-\theta(1-\gamma)(1-\beta_i)}\hat{d}_{ni}^{-\theta}}{\sum_{k=1}^{N}\pi_{nk}\hat{A}_k \hat{w}_k^{-\theta[1-(1-\gamma)(1-\beta_k)]}\hat{p}_k^{-\theta(1-\gamma)(1-\beta_k)}\hat{d}_{nk}^{-\theta}}, \quad (14)$$

and the price equations (7) become:

$$\hat{p}_n = \left(\sum_{k=1}^{N}\pi_{nk}\hat{A}_k \hat{w}_k^{-\theta[1-(1-\gamma)(1-\beta_k)]}\hat{p}_k^{-\theta(1-\gamma)(1-\beta_k)}\hat{d}_{nk}^{-\theta}\right)^{-1/\theta}. \quad (15)$$

We will solve this set of equations either for changes in wages $\hat{w}_i$ and prices $\hat{p}_i$ or for second period manufacturing deficits $D_i^{M'}$ and changes in prices $\hat{p}_i$. In either case changes in bilateral trade shares, manufacturing production, and manufacturing absorption are endogenous. Beginning-of-period trade shares and GDP are used to calibrate the model. The forcing variables are changes in demand for manufactures $\hat{\alpha}_i = \alpha_i'/\alpha_i$, changes in trade frictions $\hat{d}_{ni}^{-\theta}$, changes in productivity $\hat{A}_i$, end-of-period non-manufacturing deficits $D_i^{N'}$, and either end-period manufacturing deficits $D_i^{M'}$ or changes in wages $\hat{w}_i$.

6.2 Parameter Values and Shocks

Turning first to the parameters we treat as constant throughout the exercise, we calculate the share of nonmanufactures in manufacturing intermediates $\gamma = 0.43$ from input-output tables as described in Dekle et al. (2008). We calculate country-specific values of the β_i as the ratio of value added to gross production in manufacturing from the UNIDO data. 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 $\widehat{D}_i$.[13] 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 (14) by π_{ni} to get an expression for $\hat{\pi}_{ni}$. Dividing by the corresponding expression for $\hat{\pi}_{ii}$ and then substituting in (15) gives:

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

We can also use (14) (for $n = i$) and (15) to get

$$\hat{\pi}_{ii} = \widehat{A}_i \hat{w}_i^{-\theta[1-(1-\gamma)(1-\beta_i)]} \hat{p}_i^{\theta[1-(1-\gamma)(1-\beta_i)]}. \tag{16}$$

Combining these two equations and rearranging yields:

$$\widehat{d}_{ni}^{-\theta} = \frac{\hat{\pi}_{ni}}{\hat{\pi}_{ii}} \left(\frac{\hat{w}_i}{\hat{w}_n} \right)^{\theta} \frac{\left(\hat{\pi}_{ii}/\widehat{A}_i \right)^{1/[1-(1-\gamma)(1-\beta_i)]}}{\left(\hat{\pi}_{nn}/\widehat{A}_n \right)^{1/[1-(1-\gamma)(1-\beta_n)]}} \tag{17}$$

To go any further, we need a measure of the productivity change, and calculate this in two way.

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

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, we can rearrange (17) to get:

$$\widehat{d}_{ni}^{-\theta}\frac{\hat{\pi}_{ii}}{\hat{\pi}_{ni}}\frac{(\hat{\pi}_{nn})^{1/[1-(1-\gamma)(1-\beta_n)]}}{(\hat{\pi}_{ii})^{1/[1-(1-\gamma)(1-\beta_i)]}}\left(\frac{\hat{w}_n}{\hat{w}_i}\right)^{\theta}=\left(\frac{\widehat{A}_n}{\widehat{A}_i}\right)^{1/[1-(1-\gamma)(1-\beta_n)]},$$

which can itself be written as:

$$\widehat{d}_{ni}^{-\theta}\varpi_{ni}=\frac{\Phi_n}{\Phi_i}. \tag{18}$$

Since the Head-Ries index is $\Theta_{ni}=[d_{ni}d_{in}]^{-\theta/2}$, imposing $d_{ni}=d_{in}$ implies, in changes, $\widehat{\Theta}_{ni}=\widehat{d}_{ni}^{-\theta}=\widehat{d}_{in}^{-\theta}$. Substituting this result into (18), and allowing for an error term around symmetry, we get:

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

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

$$\ln(\widehat{\Theta}_{ni}\varpi_{ni})=\ln(\Phi_n)-\ln(\Phi_i)+\mu_{ni}. \tag{19}$$

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 then recover the changes in technology using:

$$\widehat{A}_i=\exp\left\{[1-(1-\gamma)(1-\beta_i)]\widehat{\ln(\Phi_i)}\right\}$$

where the "hat" in the term on the right hand side is the regression coefficient on a dummy variable for country i, with "Rest of World" dropped (since a common scalar won't change anything).

Table 2 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 rearrange (16) to write $\widehat{A}_i$ as:

$$\widehat{A}_i = \hat{\pi}_{ii}\hat{w}_i^{\theta[1-(1-\gamma)(1-\beta_i)]}\hat{p}_i^{-\theta[1-(1-\gamma)(1-\beta_i)]}.$$

With appropriate data on prices (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 (17). 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 7 to 10 plot the information in Table 2. For example, Figure 7 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 11 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.[14]

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

7 Counterfactuals

We now discuss our counterfactual exercises. Given values for the changes in the forcing variables we solve (13), (14), and (15), using an algorithm adapted from Dekle et al. (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.[15] 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. 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 12 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,

[15] 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 $\hat{Y}$.

suggesting that the changes in non-manufacturing deficits have literally no power for explaining the trade collapse. Figures 12 to 16 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 17, 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 18 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 3, 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.[16] A counterfactual recession in which the only change is the shock to trade frictions 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

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

consider the demand or trade friction shocks hitting Japan. Table 4 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

	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 1: Country and Year Coverage of Data

Notes:

	$\theta = 8$					$\theta = 1$				
	$\widehat{A_i}$	$\widehat{a}_i = \widehat{b}_i$	$\widehat{\alpha}_i$	$\left(\prod_j \widehat{d_{ij}}\right)^{1/J}$	$\left(\prod_j \widehat{d_{ij}^{-\theta}}\right)^{1/J}$	$\widehat{A_i}$	$\widehat{a}_i = \widehat{b}_i$	$\widehat{\alpha}_i$	$\left(\prod_j \widehat{d_{ij}}\right)^{1/J}$	$\left(\prod_j \widehat{d_{ij}^{-\theta}}\right)^{1/J}$
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 2: Key Parameters

Notes:

	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 3: Global Counterfactual Results

Notes:

	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 4: Japan Counterfactual Results

Notes:

Figures

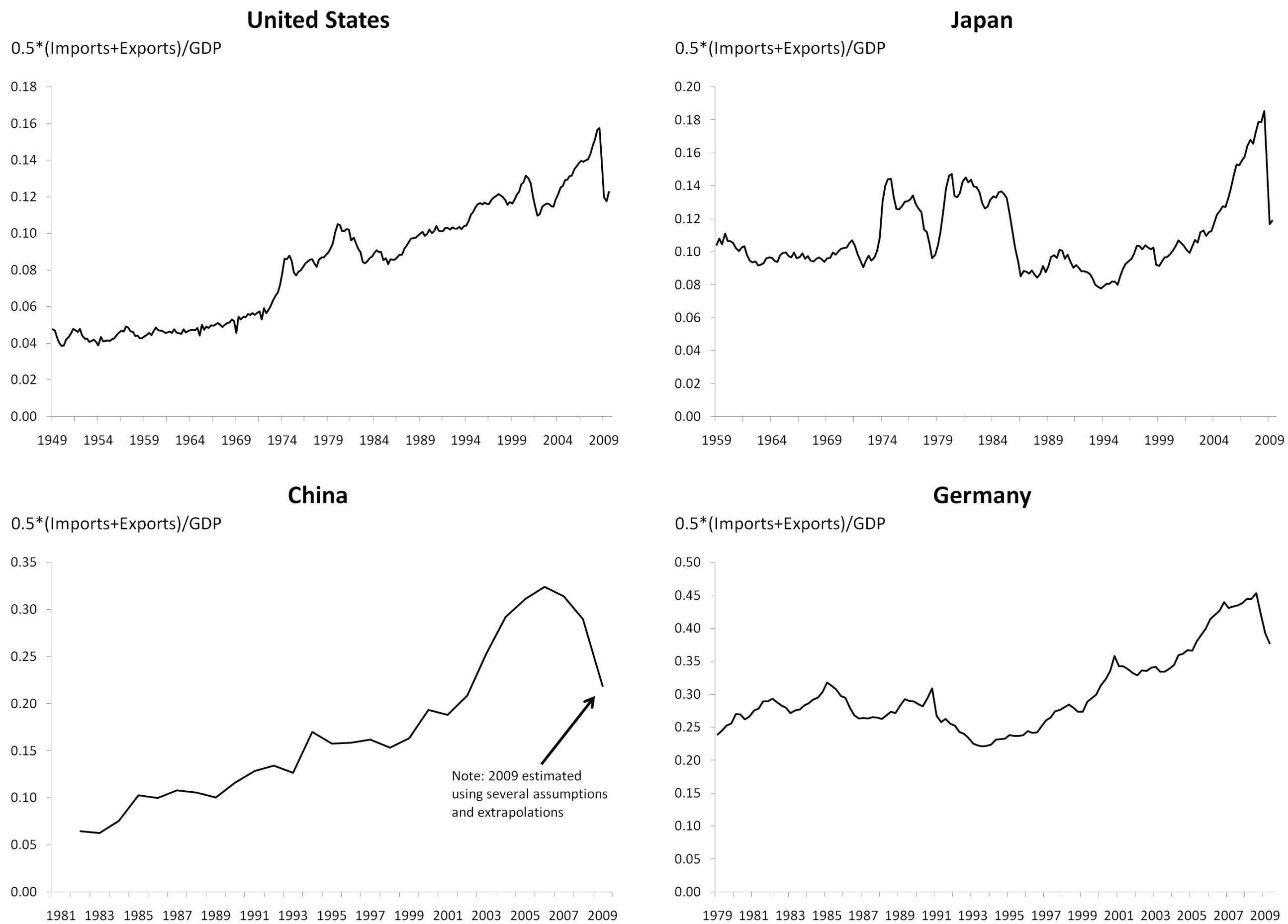

Figure 1: Trade as a Share of Output in the Four Largest Economies

Notes:

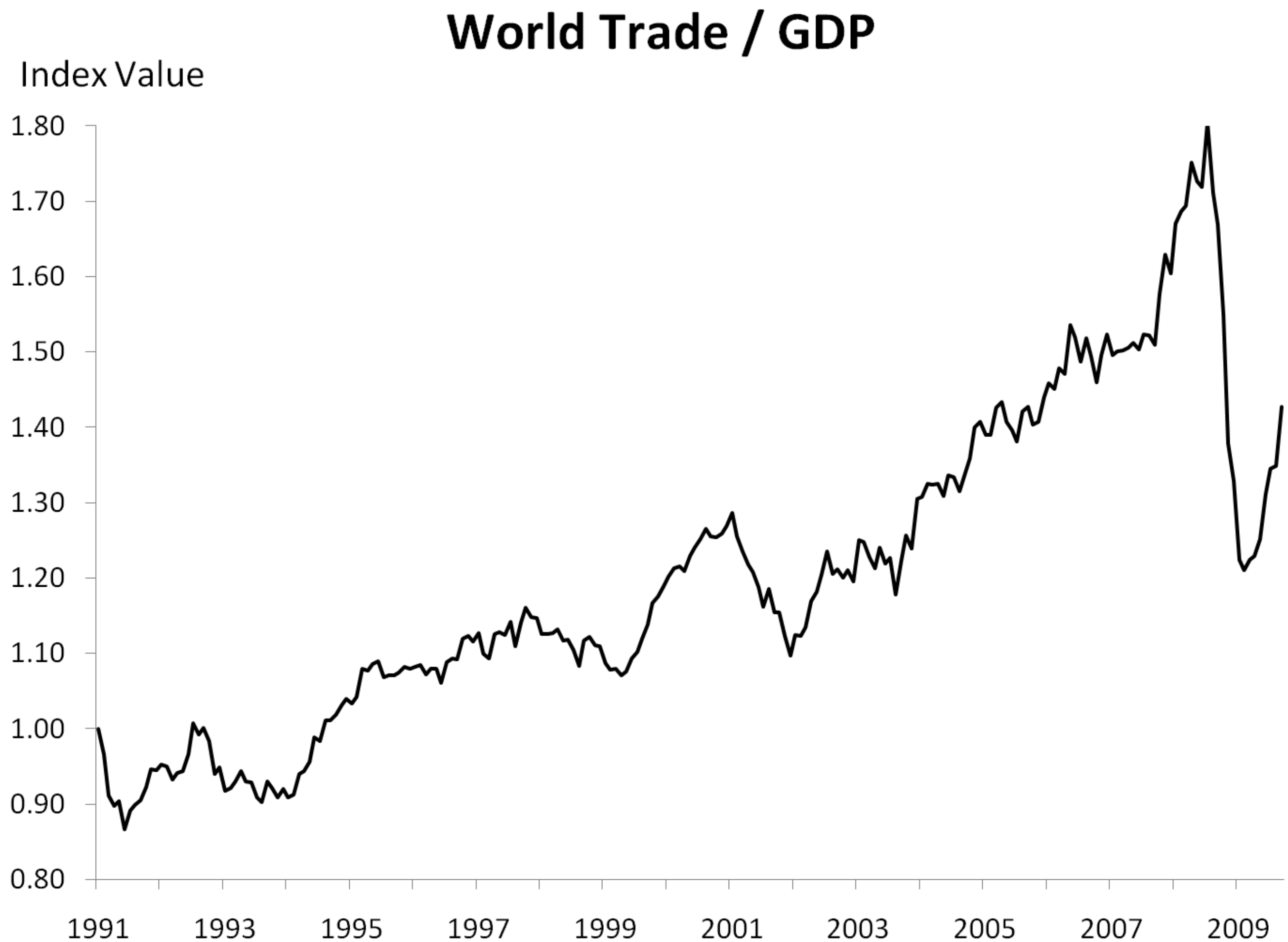

Figure 2: Global Trade Relative to GDP

Notes:

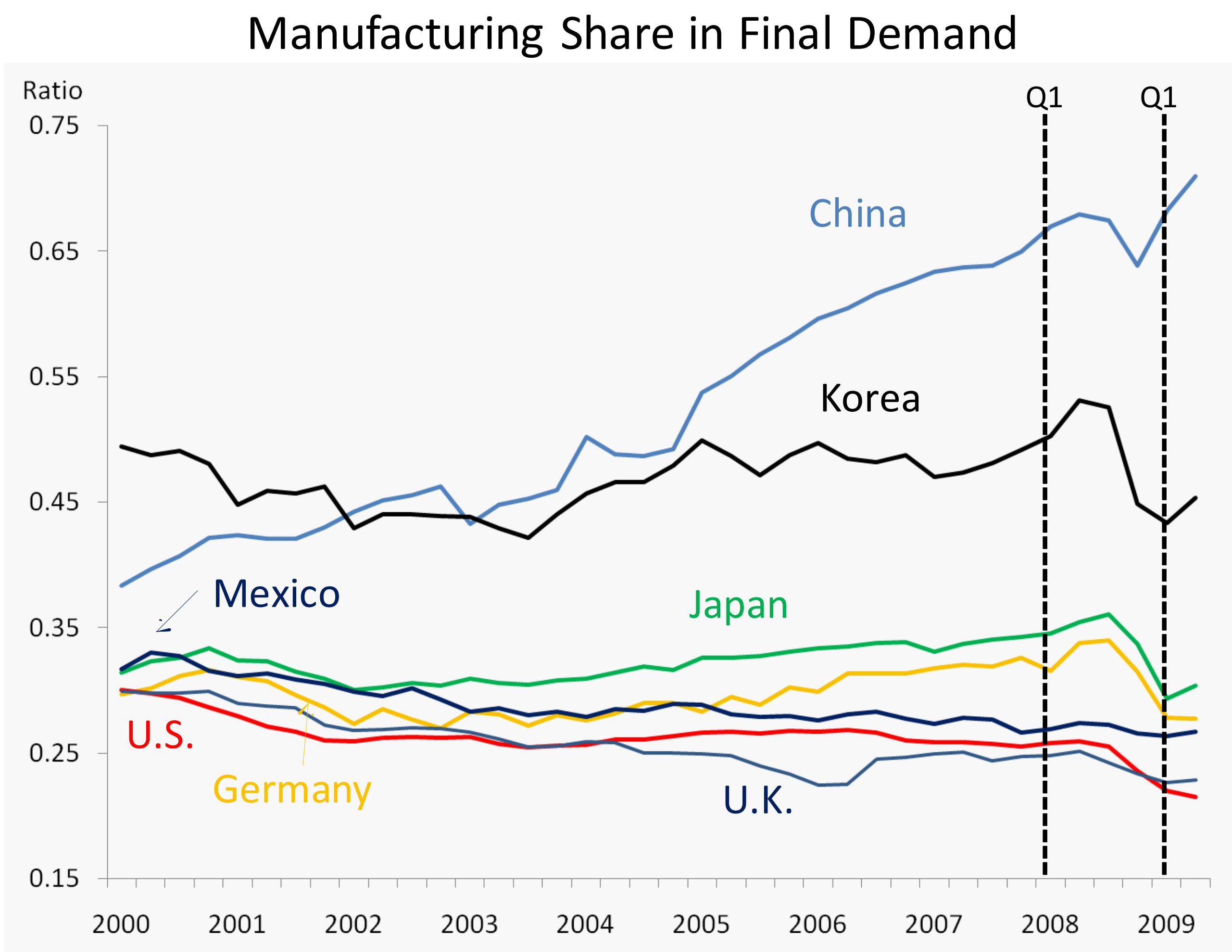

Figure 3: Shares of Manufacturing in Final Demand

Notes:

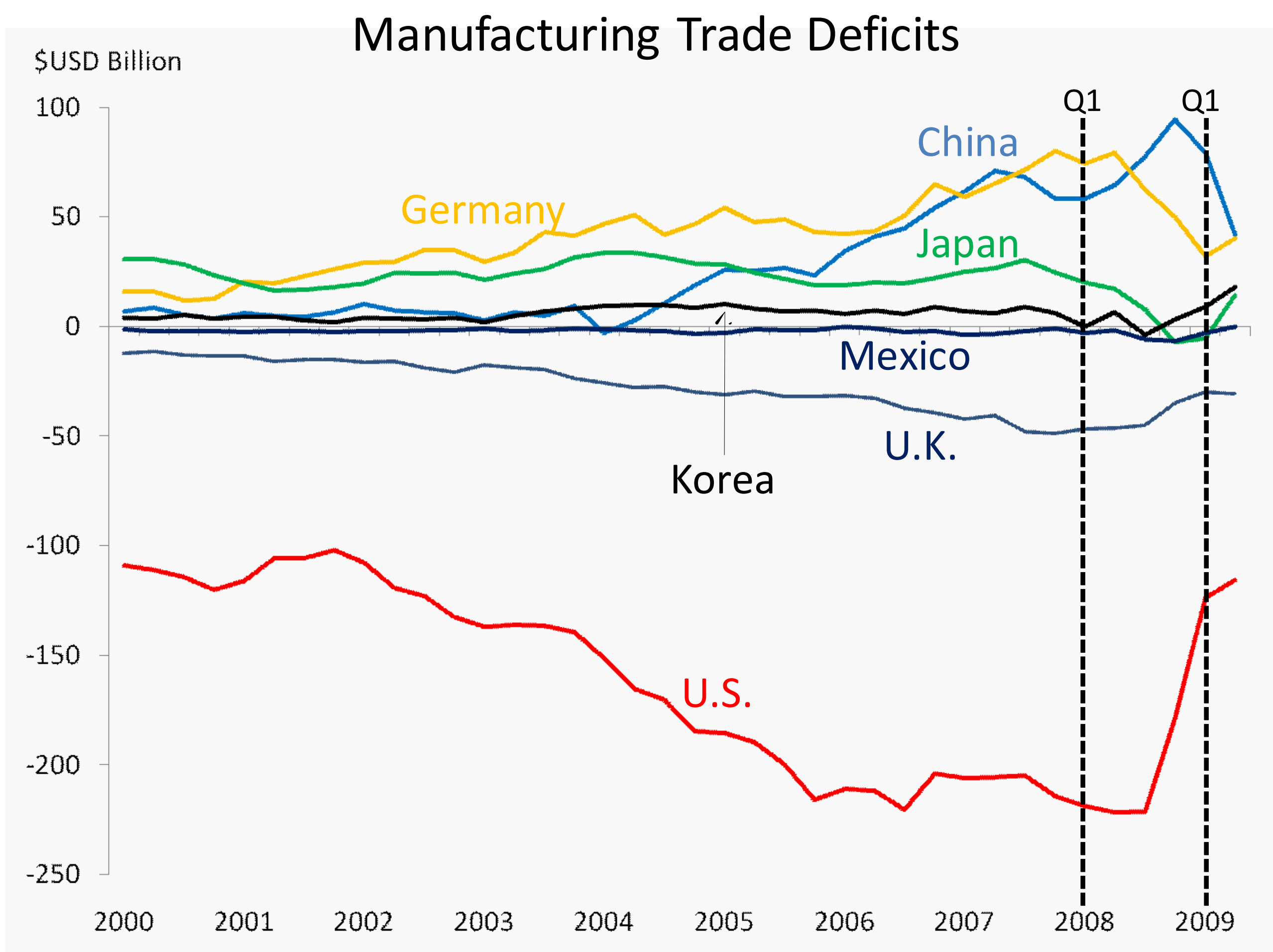

Figure 4: Manufacturing Trade Deficits

Notes:

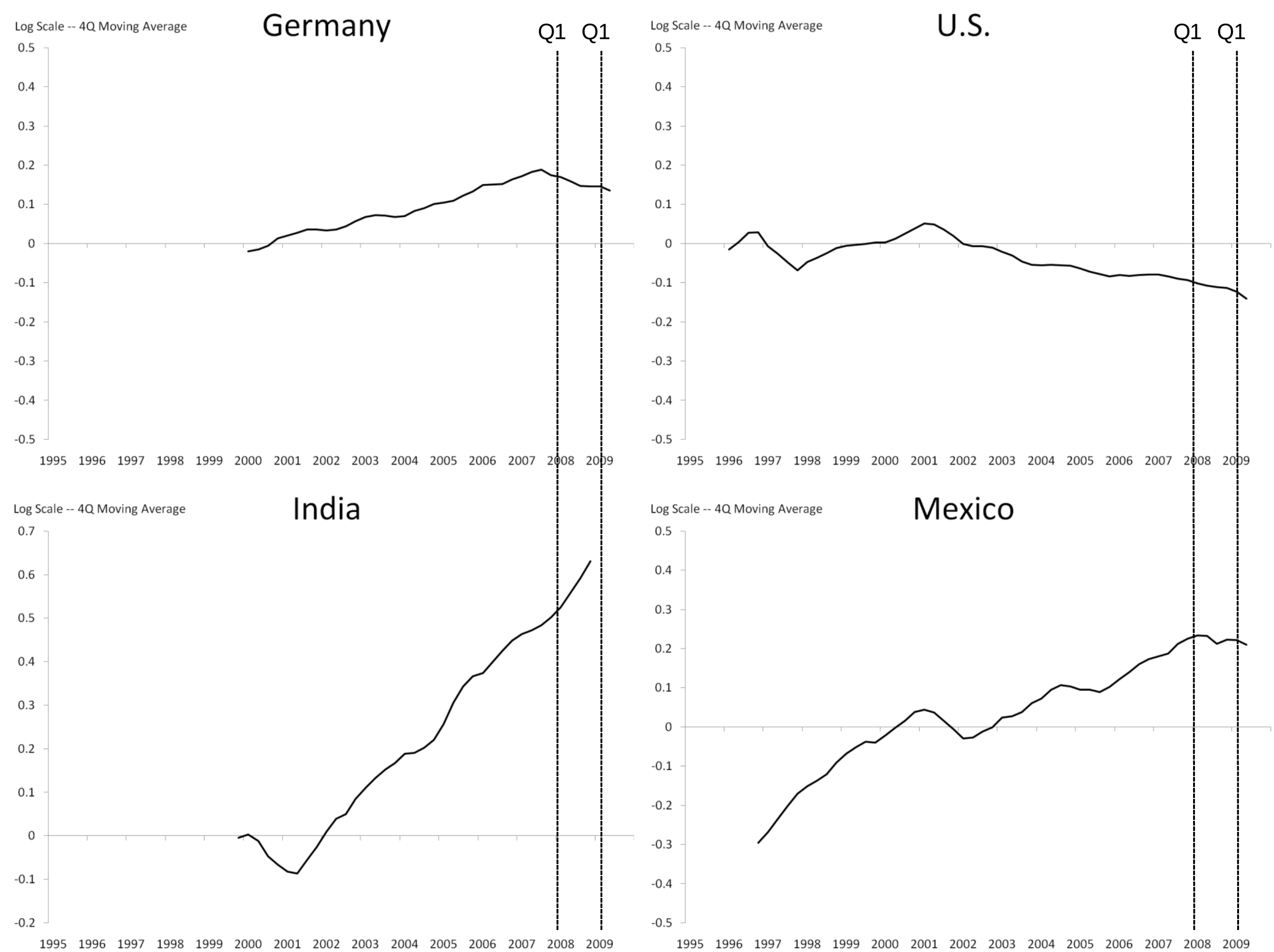

Figure 5: Countries without Large Negative Shock to Trade Frictions

Notes:

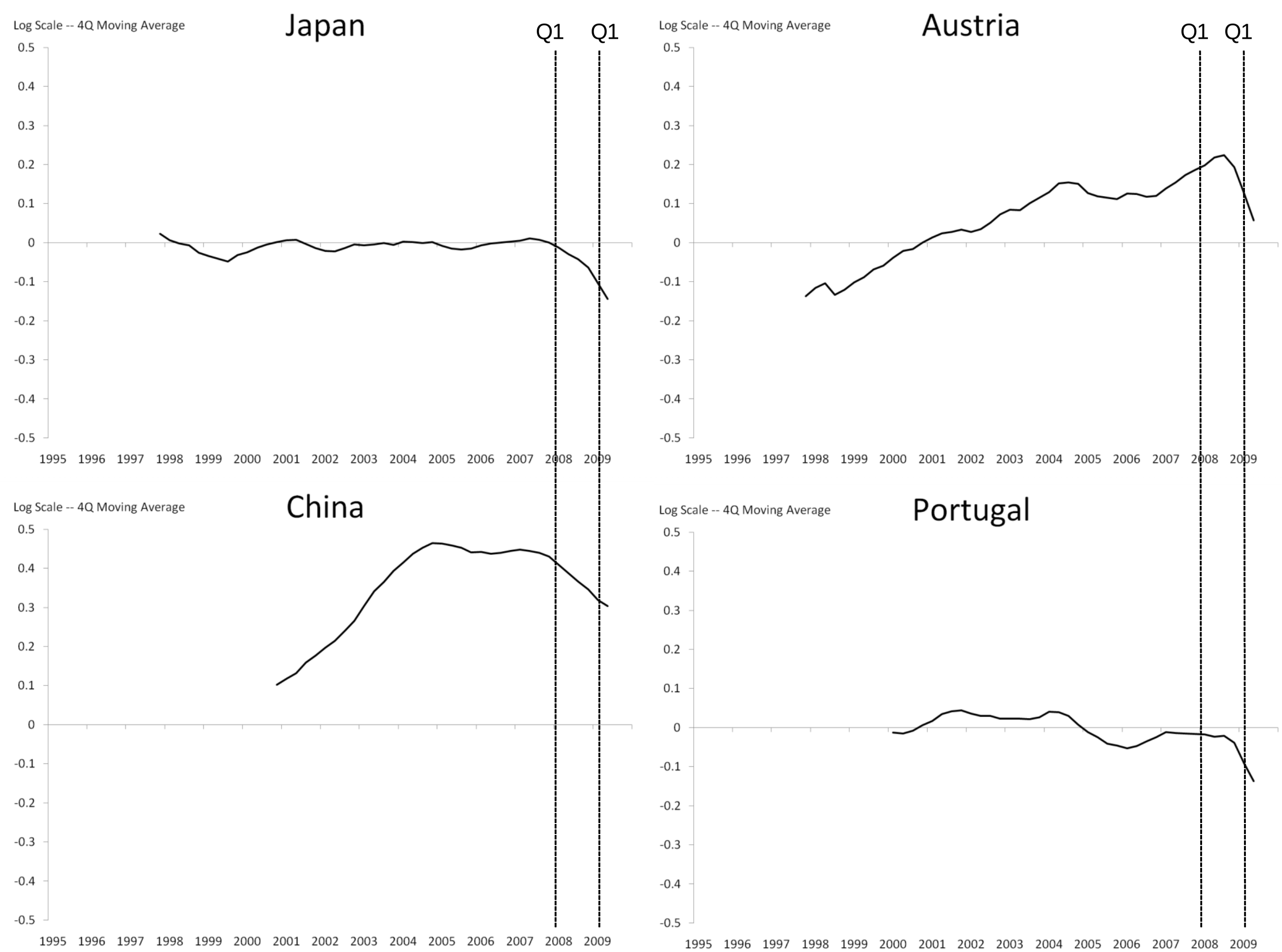

Figure 6: Countries with Large Negative Shock to Trade Frictions

Notes:

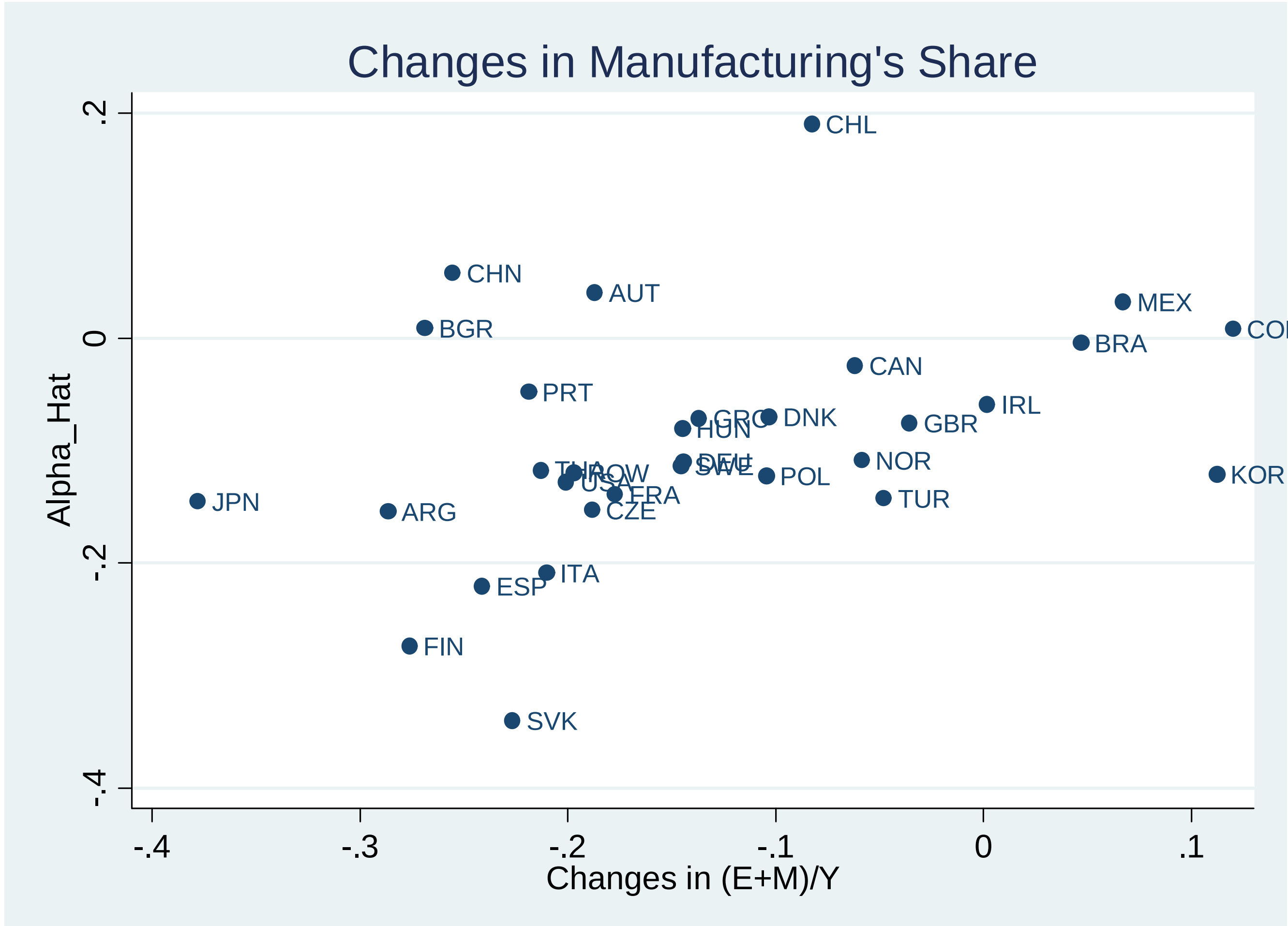

Figure 7: Shocks to Manufacturing's Share and Trade from 2008:Q1 to 2009:Q1

Notes:

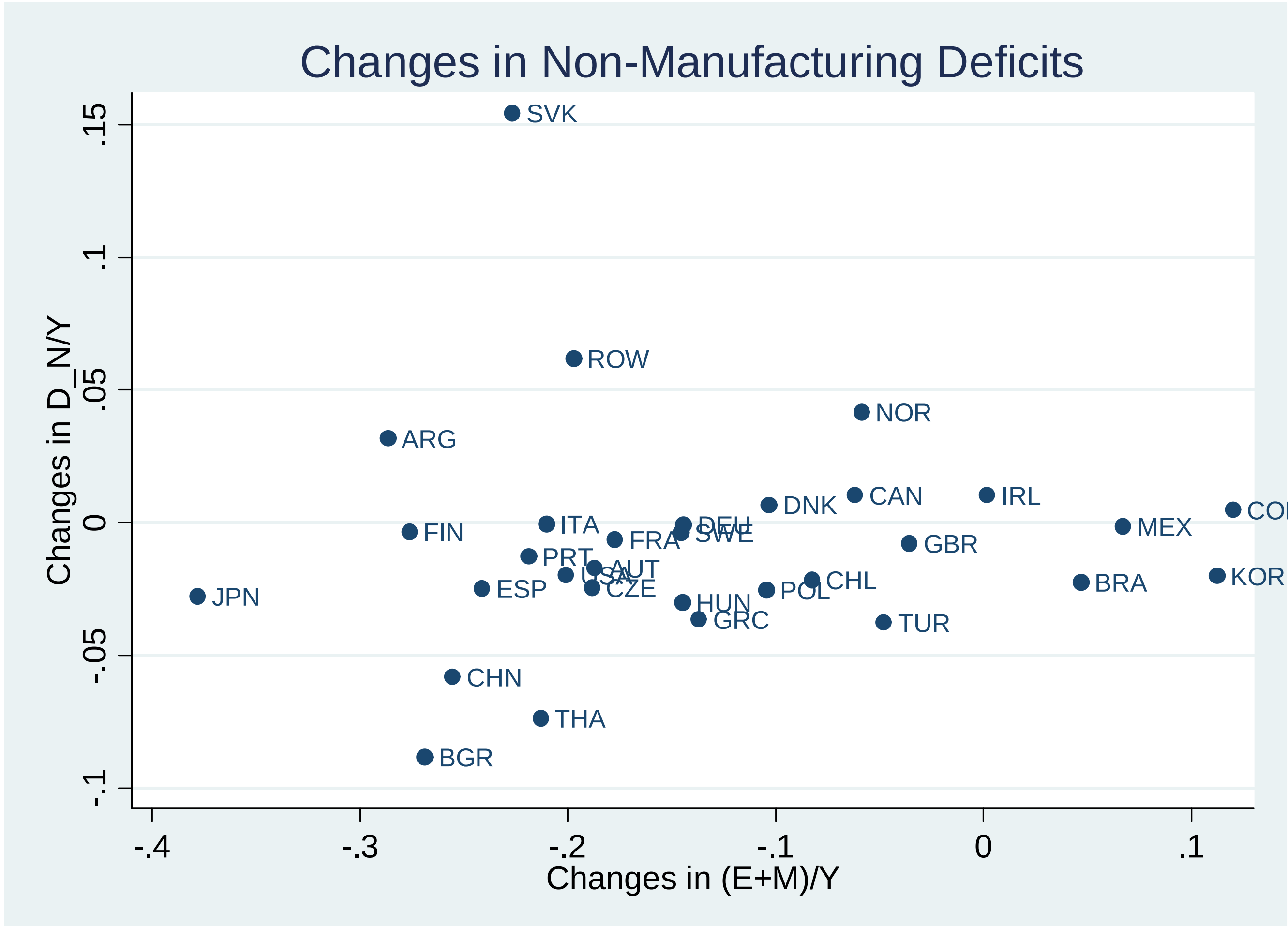

Figure 8: Shocks to Non-Manufacturing Deficits and Trade from 2008:Q1 to 2009:Q1

Notes:

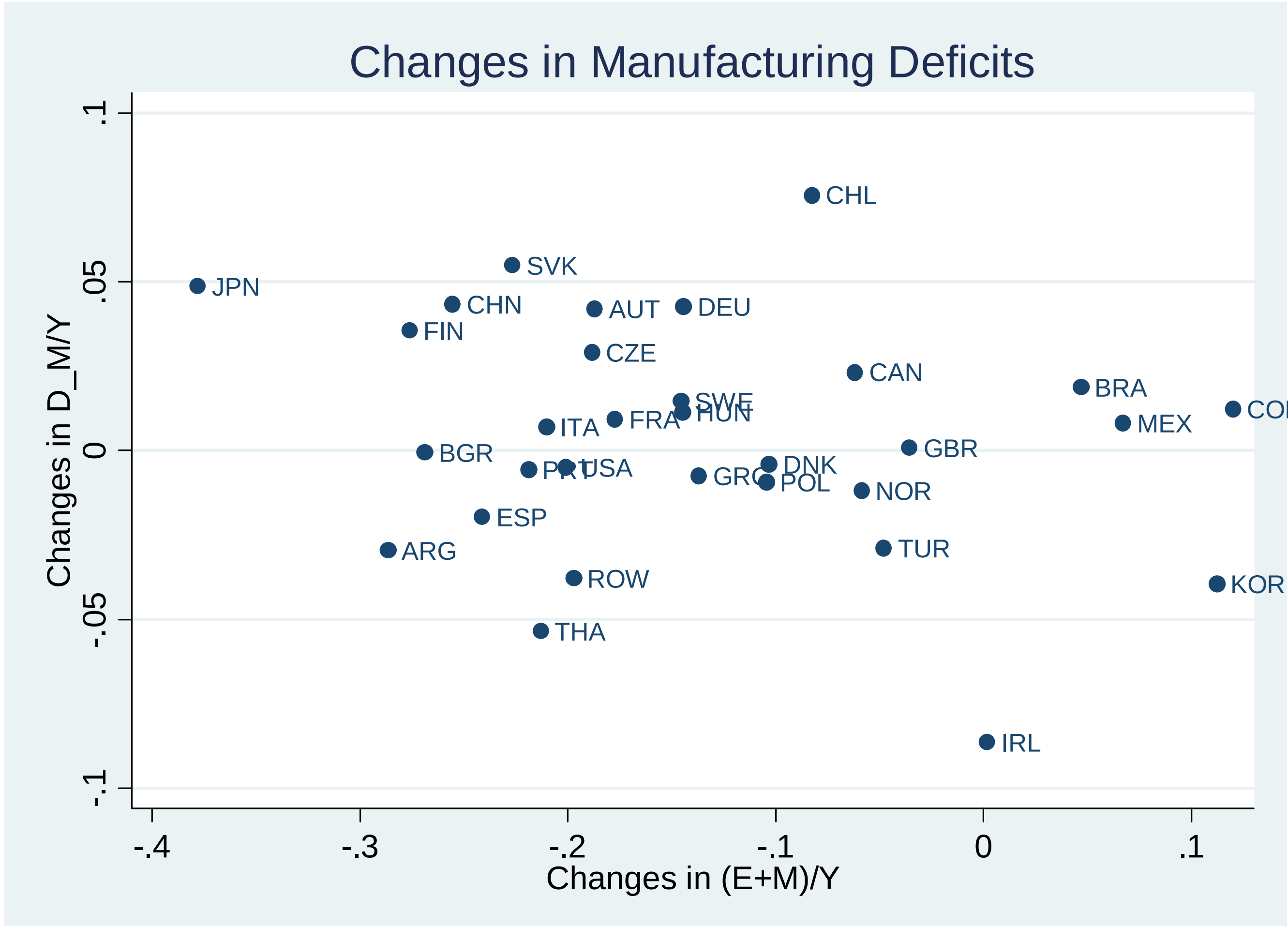

Figure 9: Shocks to Manufacturing Deficits and Trade from 2008:Q1 to 2009:Q1

Notes:

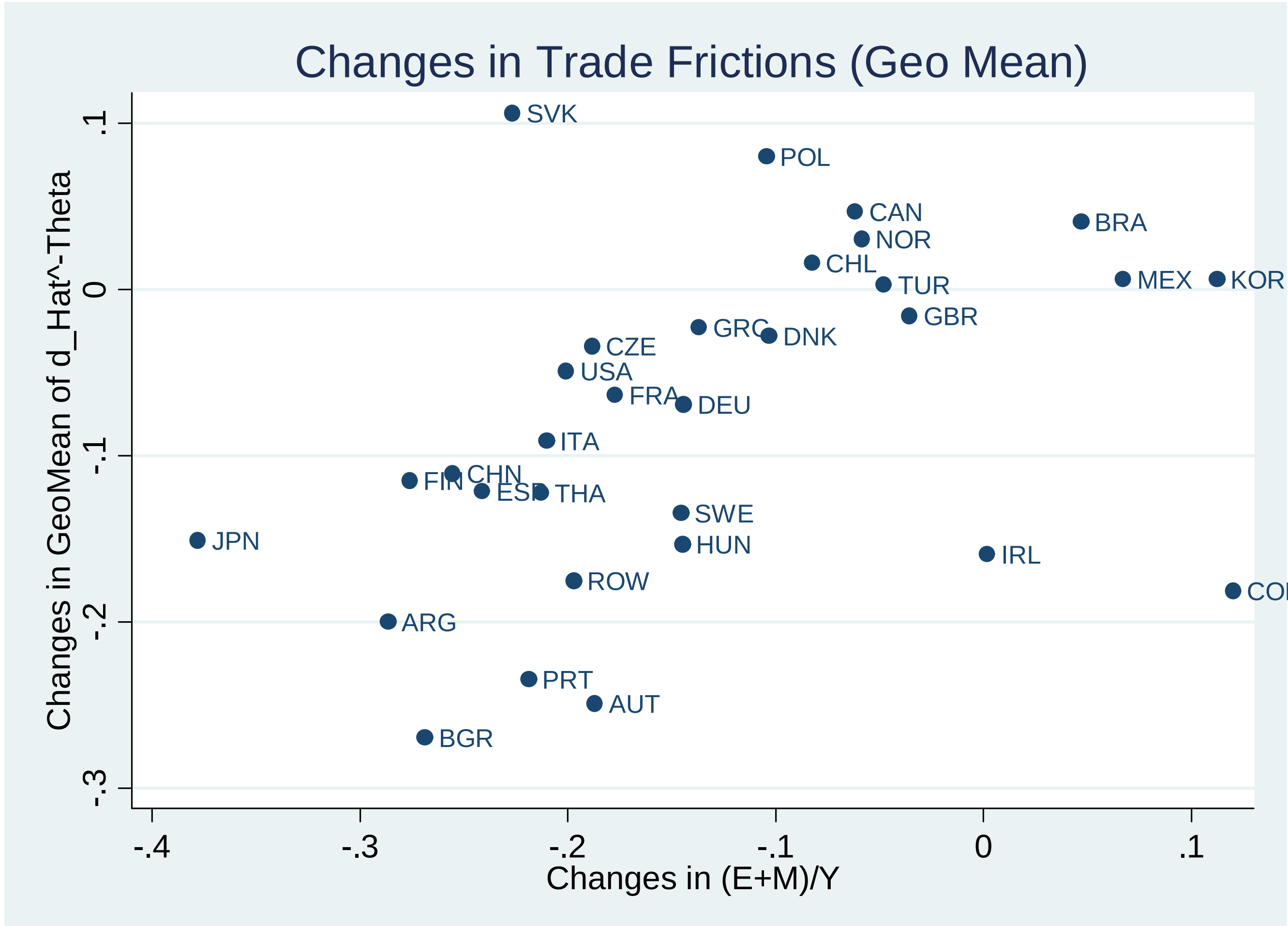

Figure 10: Shocks to Trade Frictions and Trade from 2008:Q1 to 2009:Q1

Notes:

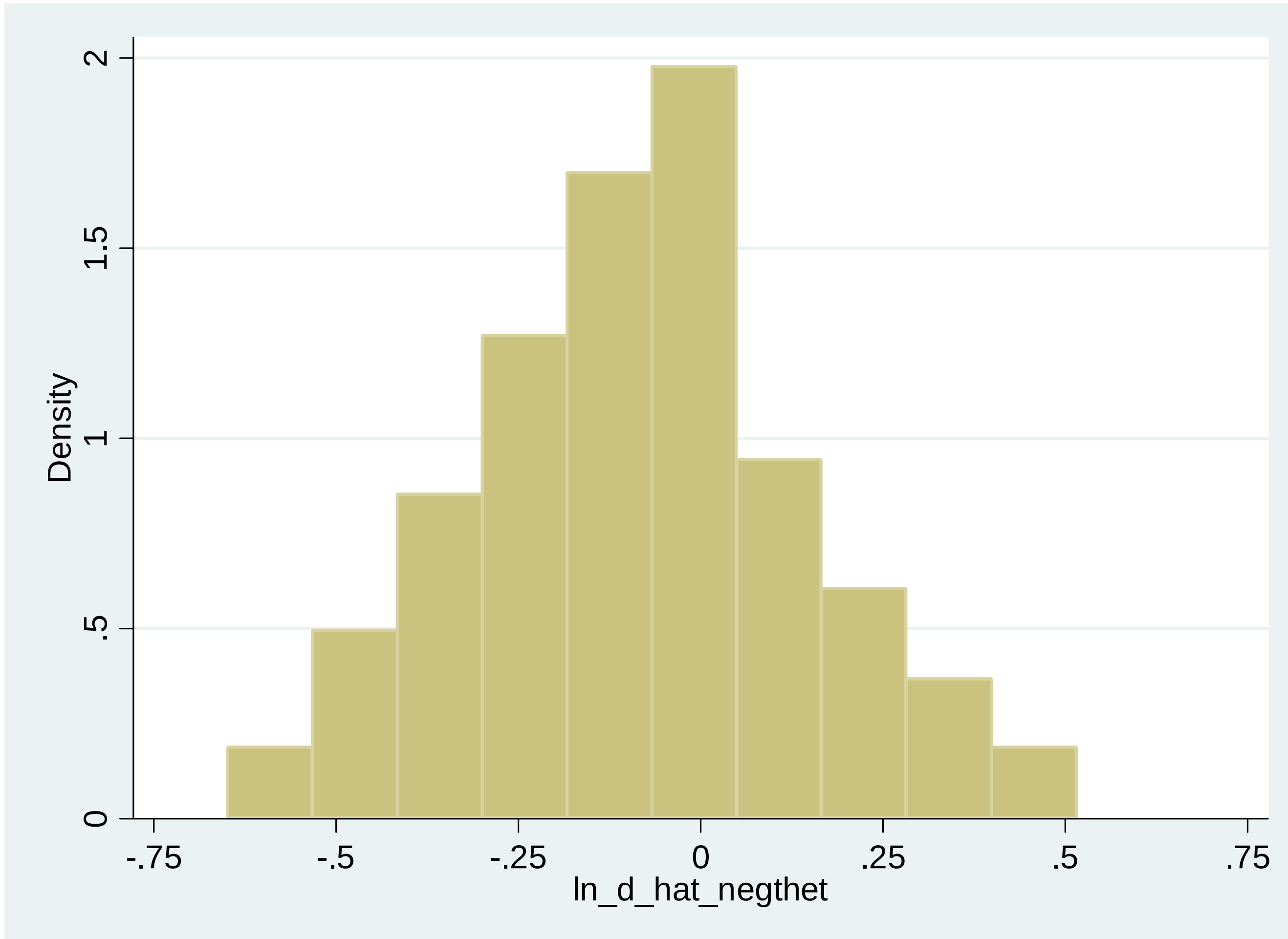

Figure 11: Shocks to Bilateral Trade Frictions Used in Counterfactuals

Notes:

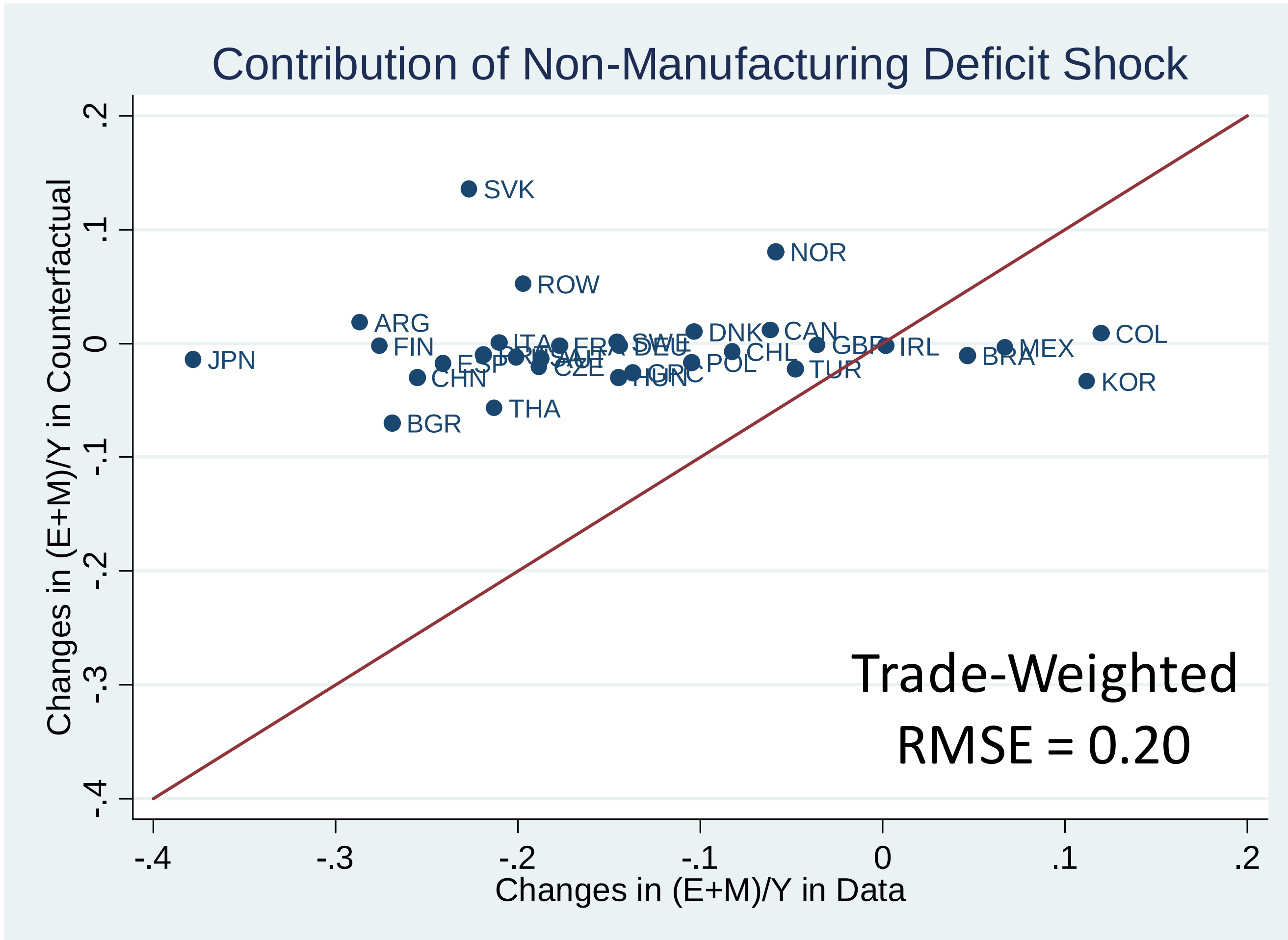

Figure 12: Explanatory Power of Shocks to Non-Manufacturing Deficits from 2008:Q1 to 2009:Q1

Notes:

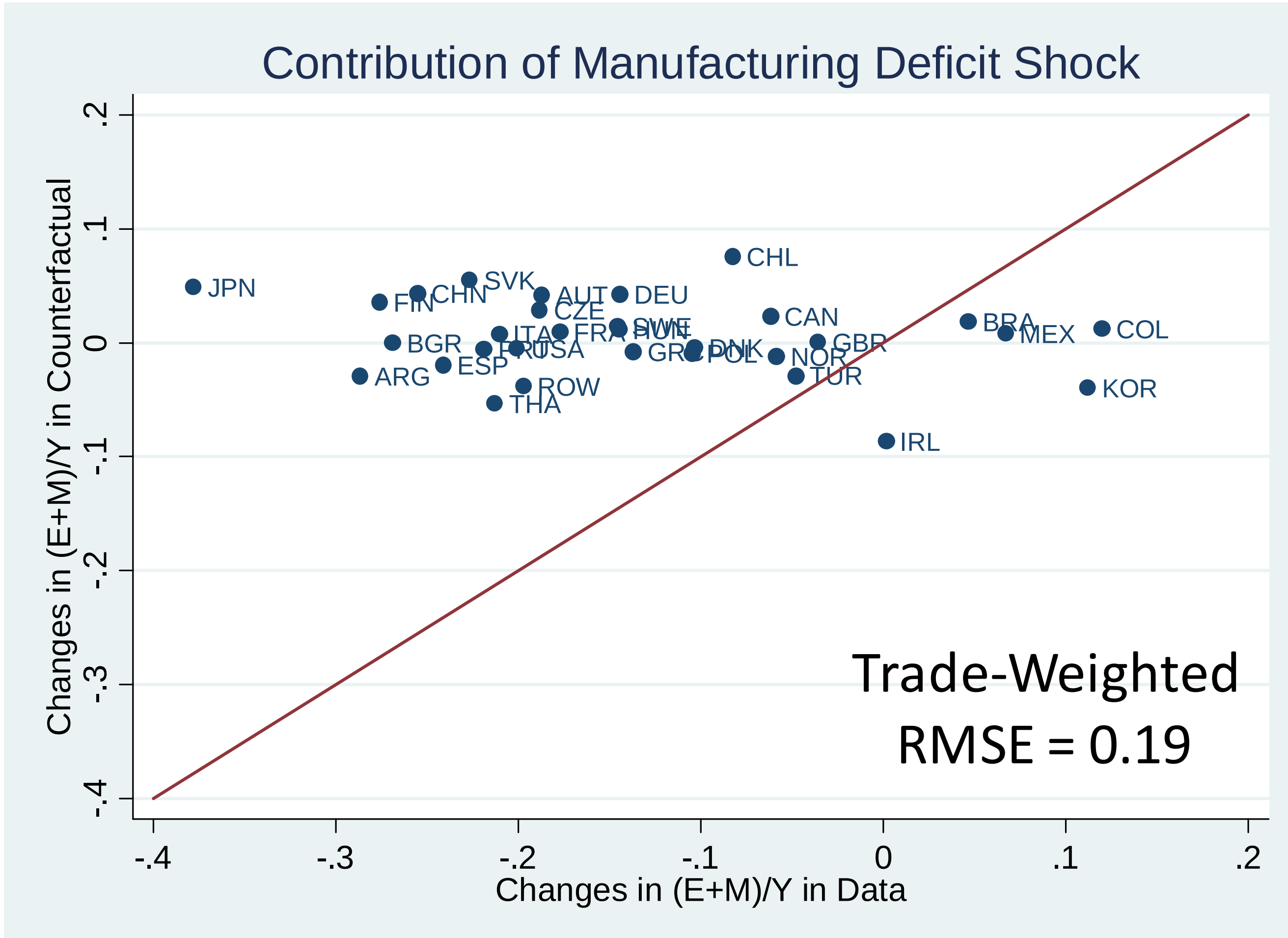

Figure 13: Explanatory Power of Shocks to Manufacturing Deficits from 2008:Q1 to 2009:Q1

Notes:

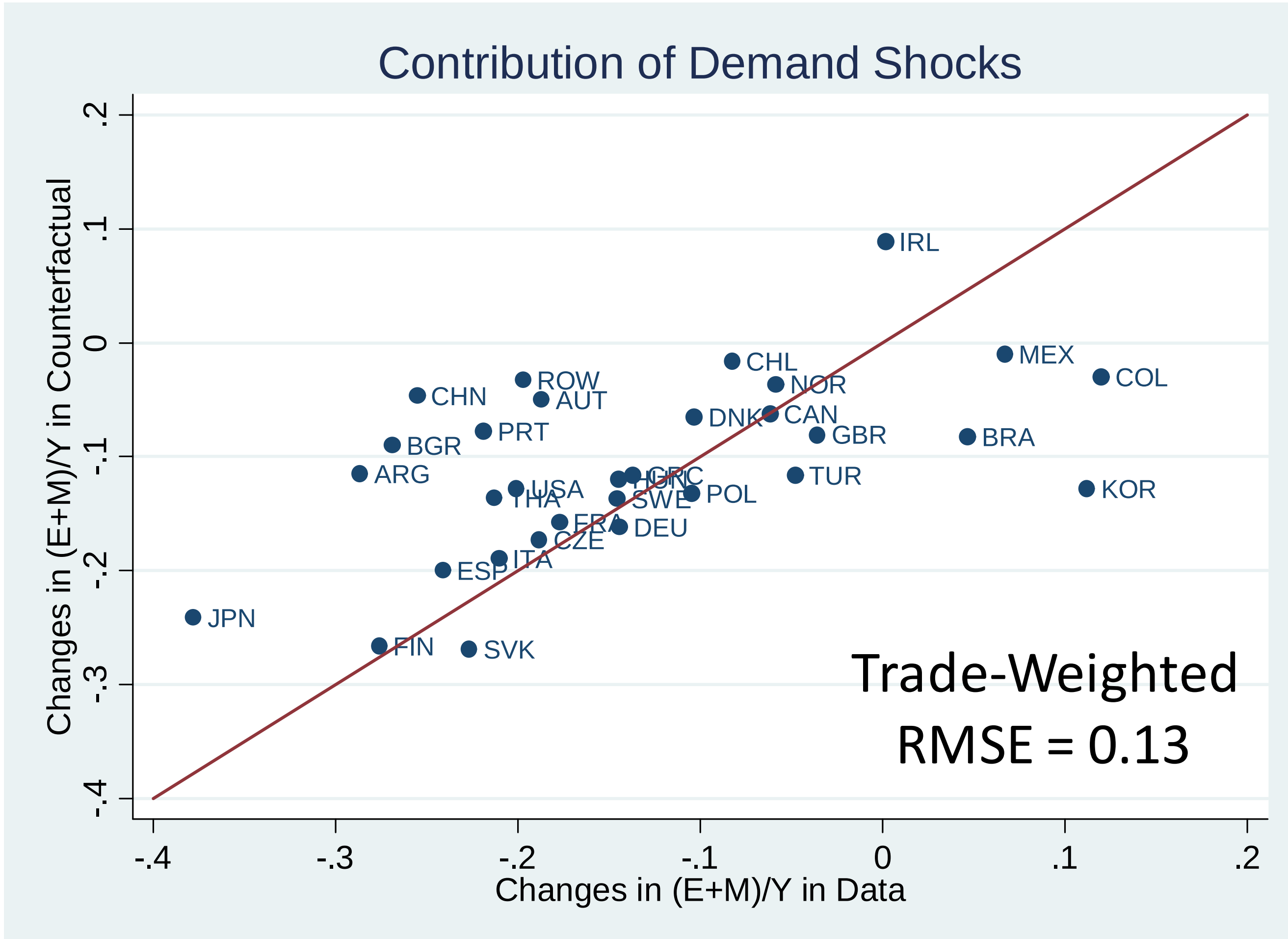

Figure 14: Explanatory Power of Shocks to Manufacturing's Share from 2008:Q1 to 2009:Q1

Notes:

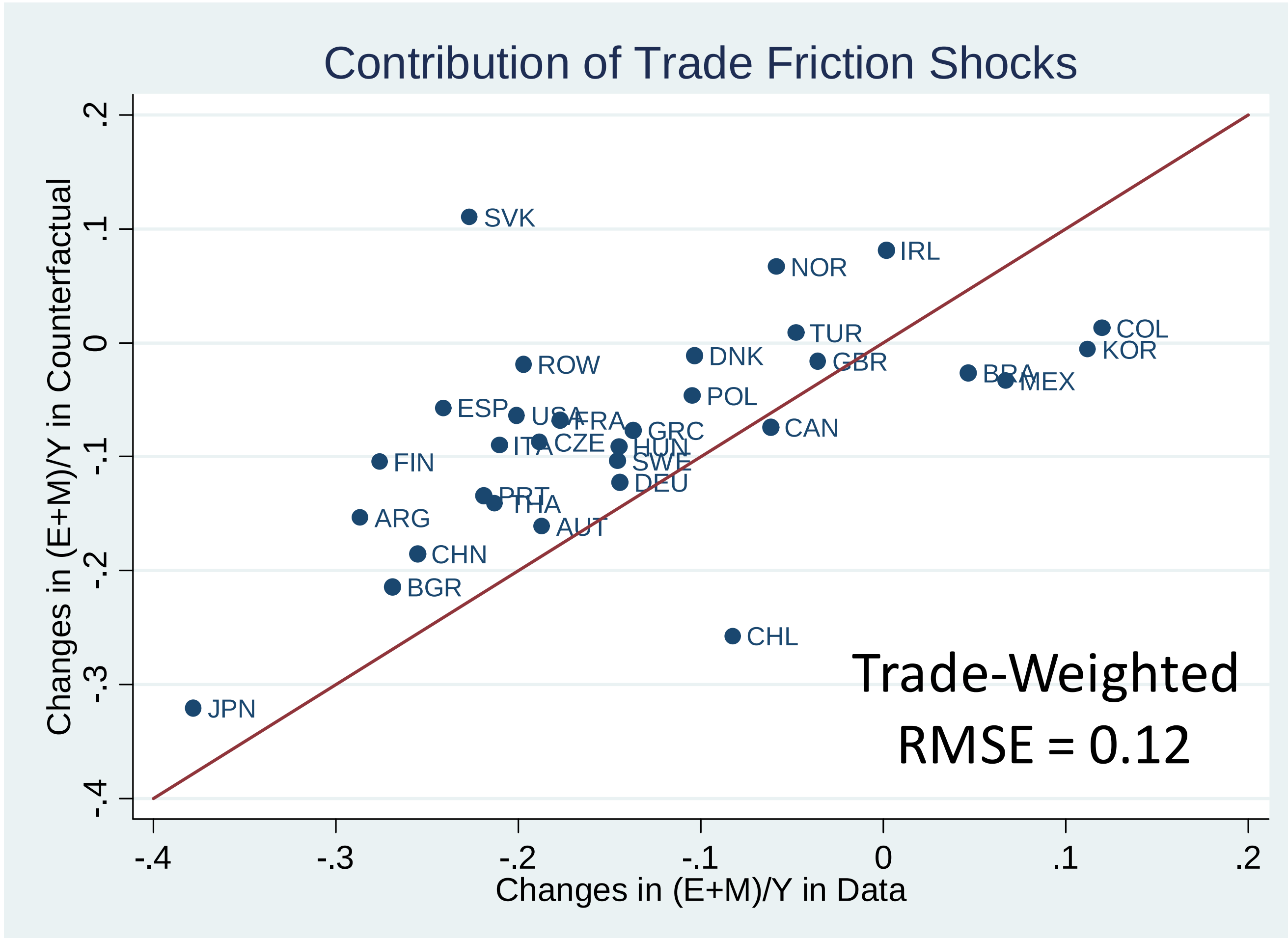

Figure 15: Explanatory Power of Shocks to Trade Frictions from 2008:Q1 to 2009:Q1

Notes:

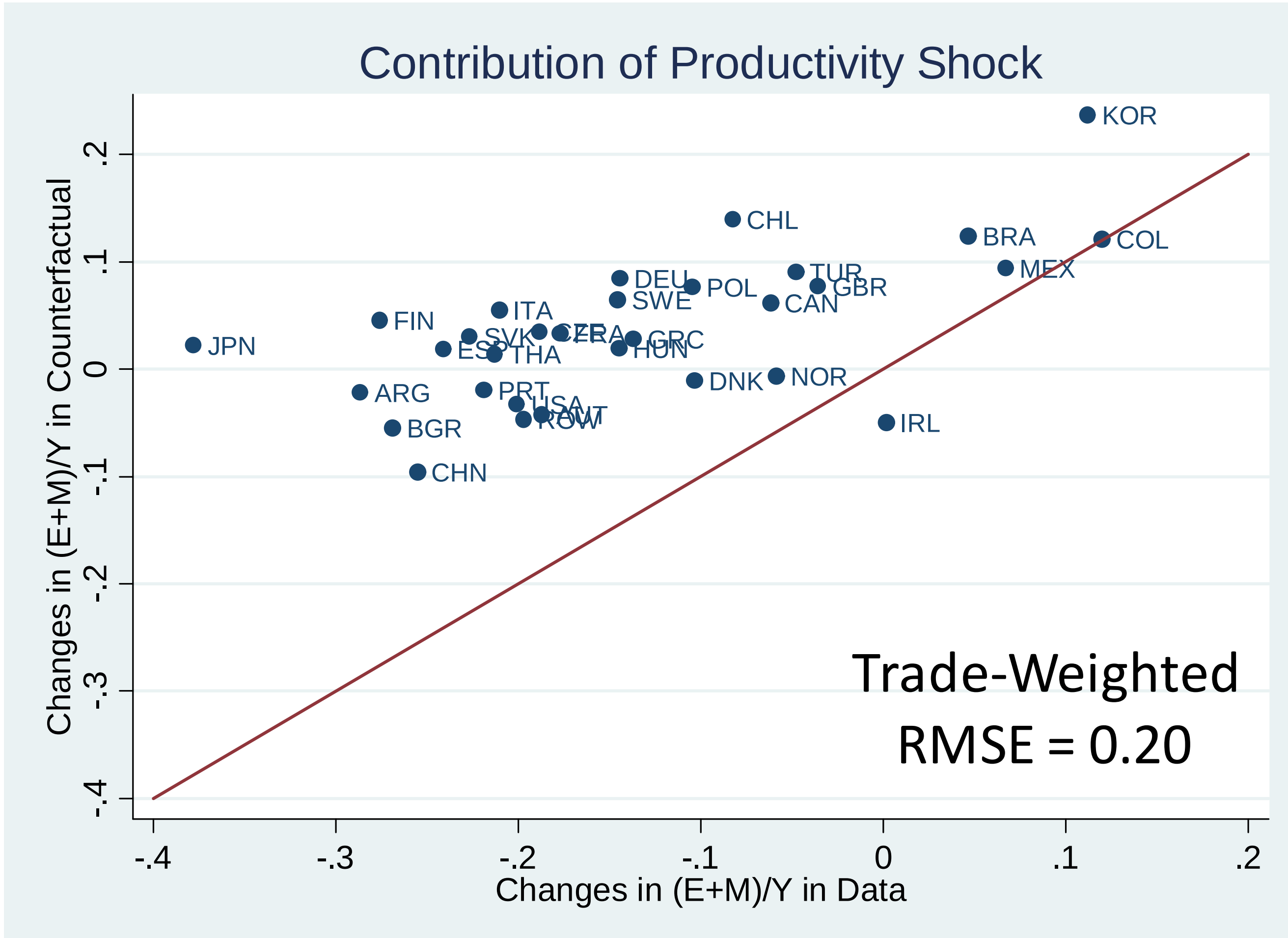

Figure 16: Explanatory Power of Shocks to Productivity from 2008:Q1 to 2009:Q1

Notes:

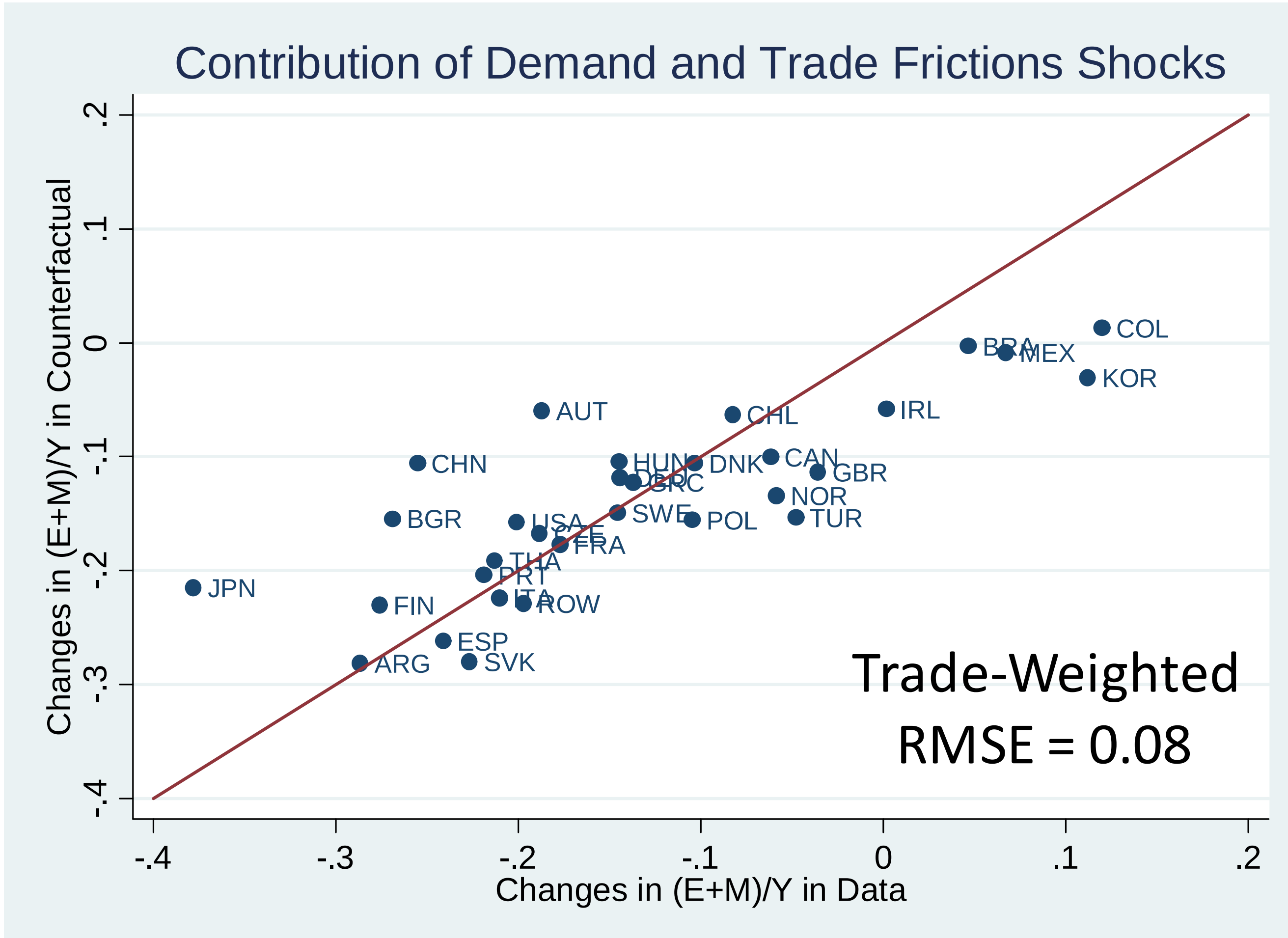

Figure 17: Explanatory Power of Shocks to Manufacturing Demand and Trade Frictions from 2008:Q1 to 2009:Q1

Notes:

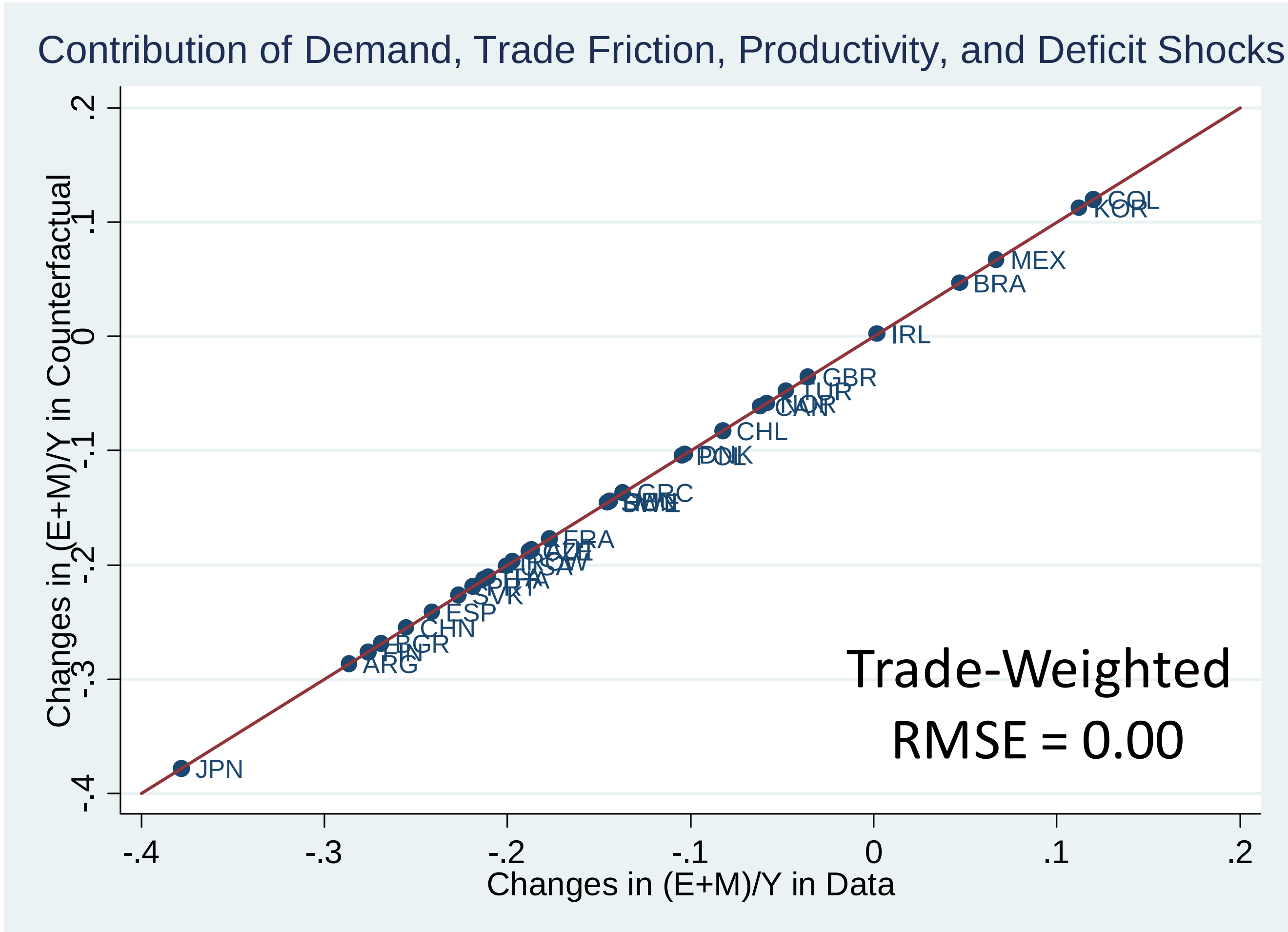

Figure 18: Explanatory Power of All Shocks from 2008:Q1 to 2009:Q1

Notes:

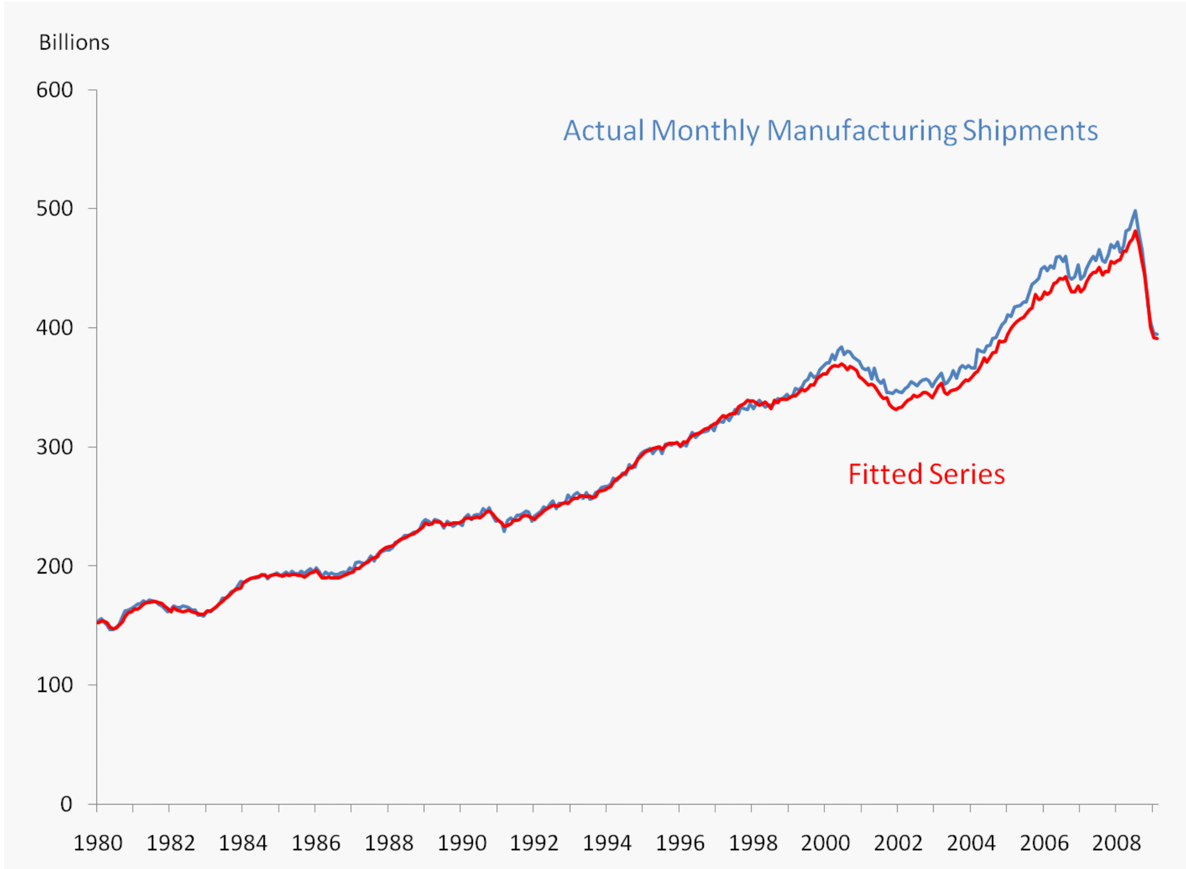

Figure B1: Checking Accuracy of Temporal Disaggregation Procedure for U.S.

Notes: “Actual Monthly Manufacturing Shipments” is AMTMVS series from M3 survey. It is recorded separately through 2001 using the SIC system and from 2001 using NAICS, so the above simply grows the SIC series by the NAICS growth rates. OECD annual production data were used to generate the fitted series. These totals differ slightly and only extend through 2007. Additionally, OECD series on IP and PPI were used in the temporal disaggregation procedure. See Appendix B for details.

Appendix A: Derivations of Expression (4)

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 (4). From there, the derivation of (10) 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 (4).

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 (4).

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 (4), 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 (4).

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:

$$\overline{Y}^M(\tau) = \sum_{t=12(\tau-1)+1}^{12\tau} Y^M(t), \tag{20}$$

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:

$$Y^M = Z\beta + \varepsilon \tag{21}$$

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 (21) 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:

$$\begin{aligned} \widehat{\beta} &= [Z'B(B'\Omega B)^{-1}B'Z]^{-1}Z'B\,(B'\Omega B)^{-1}\,\overline{Y}^M \\ \widehat{Y^M} &= Z\widehat{\beta} + \Omega B(B'\Omega B)^{-1}[\overline{Y}^M - B'Z\widehat{\beta}] \end{aligned} \tag{22}$$

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 (22) 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 (21) 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 (21) 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 (22), but with $\Omega = (D'D)^{-1}$:

$$\begin{aligned} \widehat{\beta} &= [Z'B(B'(D'D)^{-1}B)^{-1}B'Z]^{-1}Z'B\left(B'(D'D)^{-1}B\right)^{-1}\overline{Y}^M \\ \widehat{Y^M} &= Z\widehat{\beta} + (D'D)^{-1}B(B'(D'D)^{-1}B)^{-1}[\overline{Y}^M - B'Z\widehat{\beta}] \end{aligned} \tag{23}$$

The relationship (21) 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:

$$\ln Y^M = (\ln Z)\,\beta + \varepsilon. \tag{24}$$

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 (24) 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:

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