The Role of Vertical Linkages in the Propagation of the Global Downturn of 2008*

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1 Introduction

Beginning in mid-2007, the world witnessed a sequence of increasingly disturbing outcomes in the housing and financial sectors in the United States and several European countries. Then, in September 2008, a critical point was reached with the entire U.S. financial system seemingly reaching the brink of collapse and Europe simultaneously experiencing multiple financial crises. Until that month, most countries and most non-financial sectors had been spared any significant spillover effects emanating from the distressed financial sectors in the U.S. and other countries. After that watershed month, the crisis became truly global in its geographic and sectoral reach. Of the 14 countries whose GDP exceeded 1 trillion dollars in 2007, countries which collectively account for three-fourths of world GDP, only India and China experienced growth in the last quarter of 2008 and the first quarter of 2009. The other 12 countries all suffered real GDP declines, ranging from 2.5 percent in Canada to 10.8 percent in Russia. The change in global GDP growth between the middle two quarters of 2008 and the ensuing two

*PRELIMINARY. The views expressed here are those of the authors and are not necessarily reflective of views of the Federal Reserve Bank of Philadelphia, the Federal Reserve System, or the International Monetary Fund.

quarters, in which global GDP fell at an annual rate of about seven percent, was both sudden and severe.[1] The distinctive features of the "Great Recession", then, are its suddenness, its severity, and its synchronization.

In this paper, we seek to understand better the propagation of the global downturn. Why was it so synchronized across so many countries? One natural source of propagation is international trade: Output in a country declines leading to a decline in demand, including demand for imports. The country's trading partners suffer a decline in their exports, which leads, all else equal, to a decline in their output. Indeed, the decline in real global exports between 2008Q1 and 2009Q1, 15.8 percent, exceeded the decline in global GDP by a factor of four. This channel, which we call the "standard" trade channel, is typically thought of in terms of final goods. Recently, however, empirical research has established that an increasingly large share of trade involves goods at different stages of the sequential production process.[2] For example, automobile engine parts are made in the United States, then exported to Mexico where the parts are assembled into engines; these engines are exported back to the United States where they are installed in cars, and some of the cars are exported to Canada. Before they reach their final destination, then, engine parts have crossed international borders at least twice and possibly three times. A key element in these production chains is imported intermediate goods, which we call vertical linkages.

The primary way in vertical linkages can propagate shocks is simply the wide geographic swath of the global supply chain. Baldwin and Evenett (2009) provide an example in which 10 countries supply components for the manufacture of hard disk drives in Thailand. Undoubtedly, these hard drives are exported to other countries, in which the drives are installed into computers, which are then exported to their final destinations. The impact, then, of a reduction in demand for computers is felt in a wider range of countries than it would be if the computer was made in a single country. In addition, vertical linkages can potentially amplify shocks. To the extent the

[1] Source: IMF, GDS world summary tables. Real GDP, MER-weighted.

In addition, between 1960Q1 and 2008Q3, there was only one quarter (1980Q2) in which real GDP growth in every G7 country was negative.

[2] See Hummels, Ishii, and Yi (2001), for example, as well as the OECD (http://oberon.sourceoecd.org/vl=1289015/cl=40/nw=1/rpsv/sti2007/h-9.htm)

The importance of intermediate goods has risen over time, as well; in 2008, for example, 60 percent of U.S. imports were intermediate goods. This number is almost 80 percent if capital goods are also included. (Source: U.N. Comtrade Database. Intermediate goods are defined as BEC codes 111, 121, 2, 31, 32, 42, and 53. Capital goods are defined as BEC codes 41 and 521.)

global supply chains are disrupted, so that production becomes de-verticalized with fewer countries involved in production, the trade response to a negative shock could be amplified relative to what would be implied by the standard trade channel. Also, to the extent that shocks occur asymmetrically on industries with greater vertical linkages, then the trade response to shocks can also be amplified.

Our goal is a quantitative assessment of the role of such linkages in the propagation and synchronization of the Great Recession. To conduct our assessment, we employ the global bilateral input-output framework developed by Johnson and Noguera (2009).[3] Consider a world with N countries and S sectors. The core part of their framework is an NS x NS table that provides the value of goods produced in sector s, country i that are used as intermediates to produce goods in sector t, country j. This framework enables tracing the effects of a change in final demand backwards through the production chain to the ultimate producers of intermediate goods. For example, if U.S. demand for automobiles declines, the Johnson and Noguera framework will deliver the reduction in production, exports, imports, and value-added for each country-sector that contributes to the production of automobiles that are exported to the United States. Adding up each sectoral contribution yields each country's change in production, trade, and GDP as a result of the change in U.S. automobile demand. The standard input-output tables, by contrast, are *national*; that is, the table focuses on one country and its trade flows vis-a-vis the rest of the world. Clearly, questions about synchronization and propagation across countries cannot be addressed with the standard framework.

We note, however, that our framework is an accounting framework; it is not a substitute for an economic model, such as the workhorse international real business cycle (IRBC) model that embodies what we call the standard trade channel: Output in a country declines, thus leading to a decline in demand, including a decline in demand for imports. Thus the country's trading partners suffer a decline in exports leading to, all else equal, a decline in their output. This channel has traditionally been thought of in terms of final goods and demand.[4] Moreover, as an accounting framework, it cannot deliver exogenous shock to demand distinct from endogenous responses of demand to

[3] Related frameworks have been developed by Wang, Wei, and Powers (2009), and by Daudin, Rifflart, and Schweisguth (2009).

[4] In a setting with complete financial markets, there is another propagation mechanism, which occurs when the reduced output is a result of a negative productivity shock. Then, resources are transferred to the country that has relatively high productivity. Note that this "resource shifting" channel is a negative transmission mechanism; a bad shock in one country leads, via capital flows, to a good outcome in the other country.

those shocks. Consequently, we ask, given the changes in final demand – regardless of whether the change was an exogenous shock or an endogenous response to other shocks – what are the implied changes in trade, gross output, and GDP. Nevertheless, we show that our framework yields useful qualitative and quantitative insights about the nature of trade spillovers during this crisis. On the qualitative side, we demonstrate that traditional aggregate and bilateral measures of openness need to be adjusted in the presence of vertical linkages. Countries whose exports may pass through other countries before ultimately reaching a destination country have a larger linkage to the destination country than what would be implied by the direct bilateral trade share, for example. In addition, standard IRBC models usually have two or three countries; this is a framework that cannot hope to capture the qualitative and quantitative extent of the propagation of this crisis to countries all over the world.

The empirical framework we implement has 54 countries (plus 1 composite rest of the world region) and up to three sectors. We use the framework to examine three sets of exercises. In the first set of exercises, we implement the actual change in real final demand between 2008Q1 and 2009Q1 in the United States and the European Union (EU) assuming that change is symmetric across all sectors. We assess the extent of propagation and synchronization to other countries' gross output, GDP, exports and imports from these demand changes relative to the corresponding data. We then compare this propagation to the actual data, as well as to an exercise in which we implement the actual change in real final demand in all countries. In the second set of exercises, we assume that the entire change in aggregate real final demand hits the industrial sector (construction, utilities, and manufacturing), only. The goal here is to assess the role of the sector-bias in the demand changes, especially in light of the evidence that manufacturing has suffered greatly during the downturn. Again, we examine the effects of changes in final demand occurring in the United States and EU only, as well as of changes occurring in the entire world. In our final set of exercises, we focus on durable goods industries only. We calculate the change in final demand occurring in these sectors for the United States and the EU and investigate the implications of that change for gross output, trade, and GDP of all the other countries in our framework.

Our main results are as follows. First, vertical linkages are quantitatively important in understanding the global trade collapse. They account for about 1/2 to 3/5 of the model's implications for trade. Moreover, vertical specialization, those vertical linkages that also involve exports of goods embodied with imported intermediate inputs, plays a quantitatively important role in the co-movement of exports with imports. Second, the asymmetric nature of the changes in demand plays a key role in explaining why the decline in global trade has been four times larger than the decline in GDP. A two-sector framework with goods separated from services implies that the trade/GDP "elasticity" is about 2.3, more than double the elasticity in a one-sector framework. Moreover, the two-sector framework can explain more than 1/2 of the total decline in trade. Finally, our three-sector framework generates even higher elasticities. Thus, even as our framework is not able to capture all of the theoretically possible vertical linkages, it still demonstrates the importance of such linkages in understanding the largest decline in global trade since World War 2.

The rest of the paper is organized as follows. Section 2 provides an overview of the related empirical research. It focuses on the variables and countries that will play a key role in our subsequent analysis. We then lay out our input-output framework, which is followed in section IV by our methodology for backing out shocks from this framework. Section 5 presents the results from this framework. The final section concludes.

2 Overview of Related Empirical Research

By now the main facts of the crisis are well known; hence, we focus on empirical research on the crisis that deals with synchronization and propagation across countries. We will discuss the related theoretical research in the ensuing section. Even before the onset of the crisis, a number of recent contributions focused attention on the role of intermediate goods trade in generating comovement in economic activity across borders. This literature focuses attention on the role that bilateral trade in intermediates plays in explaining the positive correlation between bilateral trade and output correlations at the sector level. Di Giovanni and Levchenko (2009) document that bilateral trade is more important in explaining comovement for home and foreign sectors that use each other as intermediates than for unrelated sector pairs. Using data for the U.S. on trade flows between U.S. multinationals and their affiliates abroad, Burstein, Kurz, and Tesar (2008) show that countries that intensively engage in production sharing with the United States display higher correlations between U.S. and foreign manufacturing output.

This work on intermediate goods and comovement has naturally led to attempts to understand and explain the recent trade collapse. Intermediate linkages have been widely cited as a possible explanation for both the strong transmission and high synchronization of the decline across countries. Aside from anecdotes, hard empirical work is scarce in this area. Levchenko, Lewis, and Tesar (2009) is one exception. Looking at disaggregated U.S. trade data, they find that U.S. imports fell more in sectors that are intensively used as intermediate inputs, controlling for other possible determinants of the decline.

While this evidence suggests intermediates played a role in explaining the severity of the downturn, others have suggested that intermediate goods are unlikely to play a large role in explaining the trade collapse because, in theory, trade and output are roughly proportional regardless of whether or not intermediate goods are traded. Adherents of this view include O'Rourke (2009), Bénassy-Quéré, Decreux, Fontagné, and Khoudor-Casteras (2009), and Altomonte and Ottaviano (2009). This basic argument appears to be contradicted by evidence in Freund (2009), Cheung and Guichard (2009), and Irwin (2002), all of which have documented that trade tends to fall more than proportionally with GDP, with an elasticity of trade to GDP on the order of three and a half.

These seemingly conflicting views can possibly be reconciled by noting that the composition of trade differs from that of GDP, with trade heavily dominated by industrial output while GDP is divided between industry and services. This suggests that to understand the collapse in trade, one needs to understand the collapse in output. Baldwin (2009) neatly summarizes this basic argument that demand declines centered on highly traded durable goods sectors can lead to a very large decline in trade relative to GDP. This is a theme that we pick up in our work, and that has been echoed by others in the VoxEU volume on the trade collapse.

While we emphasize the distinct role of intermediates in transmitting the global recession and the composition of demand shocks in explaining the collapse of trade, we do not discount other perspectives on the trade collapse. Changes in trade frictions may also have played a role, including heightened policy barriers, trade credit disruptions, or general breakdowns in trading relationships.[5] We view this work as useful, particularly in helping us understand bilateral reorientations of trade that our framework is does not capture.

[5] See useful work by Evenett (2009) on measuring barriers directly, or Eaton, Kortum, Neiman, and Romalis (2009) and Jacks, Meissner, and Novy (2009) on measuring them indirectly. Also, see Amiti and Weinstein (2009), Iacovone and Zavacka (2009) and Chor and Manova (2009), among others, on credit frictions.

3 Framework for Analysis

A typical input-output table provides information linking output, demand, and trade vis-à-vis the rest of the world. In the output (horizontal) dimension, it gives the allocation of output from each sector in the economy into use as intermediate inputs, use in domestic final demand, and use as exports. In the input (vertical) dimension, it provides the value of intermediates purchased by producers in a sector, broken down by product and split between domestic sourcing and imports.[6] As in Johnson and Noguera (2009), we link these national input-output tables together using bilateral trade data to form a global input-output table.[7] This global table indicates how output from each source country is allocated between intermediate and final use for each destination country to which that output is shipped. Further, for an individual sector in a given destination, it indicates both the sector and country origin of intermediates purchased. This global framework thus quantifies intermediate and final goods linkages across sectors and across countries.

We use this global input-output framework to study how exogenous changes in demand filter backwards through final and intermediate linkages to generate changes in trade and output. Quantifying the response of trade and output requires accurate measurement of both aggregate openness and bilateral trade linkages. We show below that the presence of cross-border intermediate linkages implies that conventional measures of aggregate openness and of bilateral linkages may be inaccurate measures of the true linkages between countries. We also demonstrate that intermediate goods linkages induce responses of trade to demand changes that are absent in conventional models that ignore intermediates. For example, we show that traded inputs can induce co-movement in exports and imports following changes in final demand in a single country.

We also use our framework to address questions regarding the relationship between trade and economic activity. Much attention has focused on the elasticity of trade with respect to output changes, whether aggregate gross output or GDP, with a number of authors suggesting trade should respond proportionally to output changes. We docu-

[6]The vertical dimension also includes payments to domestic factors of production, though we do not explicitly make use of this information.

[7]Daudin, Rifflart and Schweisguth (2009) also work with a global input-output system, constructed in the same way. Wang, Powers, and Wei (2009) and Fukao and Yuan (2009), among others, work with regional input-output tables for East Asia.

ment the restrictive conditions under which trade and output respond proportionally to demand changes in our framework, and suggest that heterogeneity in demand changes across countries and/or sectors severs the proportional link between trade and output at the aggregate level. Our framework does not, however, include channels in which intermediate goods trade per se causes trade to change by a multiple of the change in output. Additional mechanisms related to intermediate goods (e.g., low elasticities for intermediates trade or de-fragmentation of production chains) would be needed to directly amplify fluctuations in trade relative to movements in final demand and/or output.

We emphasize again that our global input-output framework is primarily an *accounting framework*, not a fully specified DSGE economic model. The exercise we perform in feeding observed changes in real final demand through the framework provides a valid method for quantifying the transmission of disturbances under somewhat restrictive assumptions on technology and preferences (discussed below). While demand is given by data, realized trade and income respond endogenously according to how demand filters backwards through the input-output system to hit countries and sectors that produce goods embodied in final demand. The virtue of our analysis relative to the workhorse international real business cycle (IRBC) models is that we admit a rich set of inter-sectoral and cross-country linkages. In contrast, the IRBC literature typically ignores the type of intermediate linkages considered in this paper and focuses on models with only two or three countries. We discuss the relation between our work and the standard IRBC framework in greater detail below.

3.1 A Global Input-Output Table

This section draws on Johnson and Noguera (2009) to introduce notation for a static global input-output table. Assume there are N countries and S goods-producing sectors in each country. Each country produces a differentiated good within each sector that is either used as an intermediate input in production or used to satisfy final demand.[8] Output in each country is produced by combining local factor inputs with domestic and imported intermediate goods. Let $A_{ij}(s,t)$ be the cost share of intermediate goods from sector s in country i used in production in sector t in country j. If the total

[8] Conceptually, we find it easiest to assume that goods are differentiated by source country, following Armington (1969).

intermediates cost share of sector t in country j is $A_j(t) = \sum_i \sum_s A_{ij}(s,t)$, then the domestic factor share is $1 - A_j(t)$. Further, let the value of (gross) production in sector t in country j be denoted as $y_j(t)$. The value of intermediates from sector s in country i used by sector t in country j in production is $m_{ij}(s,t) = A_{ij}(s,t)y_j(t)$.

We now collect the total value of production in each sector in the $S \times 1$ vector y_i and allocate this output to final use and intermediate use. Let the expenditure of households and firms in country j on final goods from country i be collected in the $S \times 1$ vector d_{ij}. Then the S market clearing conditions (expressed in terms of revenue) for output from each country are:[9]

$$y_i = d_{ii} + m_{ii} + \sum_j [d_{ij} + m_{ij}]. \tag{1}$$

To re-express these relations in terms of share parameters, we define A_{ij} as an $S \times S$ input-output matrix with elements $A_{ij}(s,t)$. Then intermediate inputs shipped from i to j are given by $A_{ij}y_j$. Gross exports from i to j ($i \neq j$) are then $x_{ij} = d_{ij} + A_{ij}y_j$. Then (1) equivalently says that output is divided between domestic final use, domestic intermediate use, and gross exports.

With this notation in hand, we can stack the SN goods market clearing conditions to yield the $SN \times SN$ global input-output system. To do this, define:

$$A = \begin{bmatrix} A_{11} & A_{12} & \dots & A_{1N} \\ A_{21} & A_{22} & \cdots & A_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ A_{N1} & A_{N2} & \dots & A_{NN} \end{bmatrix}, \quad y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{pmatrix}, \quad c_i = \begin{pmatrix} d_{1i} \\ d_{2i} \\ \vdots \\ d_{Ni} \end{pmatrix}.$$

We refer to the matrix A as the global input-output matrix. Then for the world as a whole:

$$y = Ay + \sum_i d_i. \tag{2}$$

Johnson and Noguera (2009) further show that we rearrange this expression to yield a decomposition of output and value added produced in each source country according

[9] Market clearing holds in terms of quantities. If we multiply through the market clearing conditions using a common set of prices to evaluate quantities produced, consumed, and used as intermediates, then market clearing also holds in terms of revenue. In practice, we use the price that the producer receives.

to the destination in which it has a final use, hereafter "absorbed" or "consumed". Specifically, $(I-A)^{-1}d_i$ yields the vector of output used directly or indirectly to produce final goods absorbed in country i. Then we can think of output in each country as divided according to: $y_i = \sum_j y_{ij}$, where y_{ij} is the value of output produced in country i needed to produce final goods absorbed in country j.

3.2 Introducing Real Demand Disturbances

By linking production, trade, and final demand, this input-output framework provides the basic structure for analyzing transmission of demand changes across borders. We focus on real demand changes, because we presume this was the key type of shock characterizing the global downturn, especially after August 2008. To link changes in real demand to real output and trade, we need to take a stand on some structural features of the underlying economy.[10]

To illustrate the issues, we now split the elements of the input-output table above into prices and quantities. We write $y_i(s) = p_i(s)q_i(s)$, $m_{ij}(s,t) = p_i(s)q_{ij}^m(s,t)$, and $d_{ij}(s) = p_i(s)q_{ij}^d(s)$. At each point in time, market clearing holds in terms of quantities, $q_i(s) = \sum_j \sum_t [q_{ij}^m(s,t) + \sum_j q_{ij}^d(s)]$, and taking differences between two points in time yields: $\Delta q_i(s) = \sum_j \sum_t [\Delta q_{ij}^m(s,t) + \sum_j \Delta q_{ij}^d(s)]$. If we evaluate changes in quantities at base year prices and re-express changes in proportional terms, we can write:

$$\frac{\Delta q_i(s)}{q_i(s)} = \sum_j \sum_t \left[\frac{p_i(s)q_{ij}^m(s,t)}{p_i(s)q_i(s)}\right]\left(\frac{\Delta q_{ij}^m(s,t)}{q_{ij}^m(s,t)}\right) + \sum_j \left[\frac{p_i(s)q_{ij}^d(s)}{p_i(s)q_i(s)}\right]\left(\frac{\Delta q_{ij}^d(s)}{q_{ij}^d(s)}\right) \tag{3a}$$

$$\text{or rewriting } \widehat{q}_i(s) = \sum_j \sum_t \left[\frac{m_{ij}(s,t)}{y_i(s)}\right]\widehat{q}_{ij}^m(s,t) + \sum_j \left[\frac{d_{ij}(s)}{y_i(s)}\right]\widehat{q}_{ij}^d(s), \tag{3b}$$

where the hat notation indicates proportional changes (i.e., $\widehat{x} = \frac{\Delta x}{x}$) and we have substituted for the terms in brackets using definitions above.

Note here that we do not directly observe either $\widehat{q}_{ij}^m(s,t)$ or $\widehat{q}_{ij}^d(s)$. Therefore, we proceed to make assumptions to tie changes in real input use and final demand to

[10] While we study real shocks and real outcomes in this paper, one can also study nominal shocks using an input-output framework. With nominal shocks, then one can replace the Leontieff assumptions below with Cobb-Douglas preferences and technologies. Whereas we require the quantity of intermediates used to be proportional to the quantity of output, Cobb-Douglas implies that the value of intermediates used is proportional to the value of gross output.

observables.[11] First, we assume that the production function is Leontieff so that the change in the quantity of inputs shipped from sector s in country i to sector t in country j is proportional to the change in output in sector t: $\widehat{q}_{ij}^{m}(s,t) = \widehat{q}_j(t)$. This links bilateral intermediate goods shipments that we do not directly observe to production changes in the destination country, which we observe. Second, we assume that preferences are also Leontieff so that the change in the quantity of final goods shipped from sector s in country i to country j is proportional to the change real demand for output from sector s in country j: $\widehat{q}_{ij}^{c}(s) = \widehat{q}_j^{d}(s)$. We assume here that demand changes are sector, not source specific. So if overall demand falls by 1%, then domestic demand and import demand both fall by 1%, and import demand falls by the same percentage across all source countries. We impose this assumption because we do not have data on consumption changes broken down by origin of the goods. Further, because we take the reduction in consumption demand as given by data, we do not need to take a stand on other aspects of preferences, such as the intertemporal elasticity of substitution.

With these assumptions, we can then re-write the previous equation:

$$\widehat{q}_i(s) = \sum_j \sum_t \left[\frac{m_{ij}(s,t)}{y_i(s)}\right] \widehat{q}_j(t) + \sum_j \left[\frac{d_{ij}(s)}{y_i(s)}\right] \widehat{q}_j^{d}(s) \tag{4}$$

Stacking and manipulating these expressions for many countries, we can show that:

$$\begin{bmatrix} diag(y_1) & 0 & \cdots & 0 \\ 0 & diag(y_2) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \ldots & diag(y_N) \end{bmatrix} \begin{pmatrix} \widehat{q}_1 \\ \widehat{q}_2 \\ \vdots \\ \widehat{q}_N \end{pmatrix}$$
$$= [I-A]^{-1} \begin{bmatrix} diag(d_{11}) & diag(d_{12}) & \cdots & diag(d_{1N}) \\ diag(d_{21}) & diag(d_{22}) & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ diag(d_{N1}) & \cdots & \cdots & diag(d_{NN}) \end{bmatrix} \begin{pmatrix} \widehat{q}_1^{d} \\ \widehat{q}_2^{d} \\ \vdots \\ \widehat{q}_N^{d} \end{pmatrix}, \tag{5}$$

where the A matrix is the global input-output matrix defined above in the base period,

[11] The assumptions we make do not correspond exactly to any standard model in the literature. We believe they could be consistent with a modified version of Yi (2003) in which production and consumption are Leontieff and there is no endogenous adjustment of vertical specialization patterns. Developing this model explicitly is a topic for future research.

$\widehat{q}_i$ is a vector of proportional changes in output within each sector in country i, and $\widehat{q}_i^d$ is a vector of sector-level demand changes in country i. We can rewrite this as:

$$\begin{pmatrix} \widehat{q}_1 \\ \widehat{q}_2 \\ \vdots \\ \widehat{q}_N \end{pmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} \\ S_{21} & S_{22} & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ S_{N1} & \cdots & \cdots & S_{NN} \end{bmatrix} \begin{pmatrix} \widehat{q}_1^d \\ \widehat{q}_2^d \\ \vdots \\ \widehat{q}_N^d \end{pmatrix}, \tag{6}$$

where S_{ij} are matrices recording the share of output, by sector, produced in source country i that is used to produce consumption in country j. Rather than dwell on interpreting and manipulating this general form, we proceed directly to an example to fix ideas.

3.3 Example: Three Countries, One Good Per Country

Suppose that there are three countries, and that each country produces a single aggregate good. To reiterate, we presume that we observe changes in final demand q_i^d and wish to trace the consequences of these demand changes for output and trade. We can represent this economy as above:

$$\begin{bmatrix} y_1 & 0 & 0 \\ 0 & y_2 & 0 \\ 0 & 0 & y_3 \end{bmatrix} \begin{pmatrix} \widehat{q}_1 \\ \widehat{q}_2 \\ \widehat{q}_3 \end{pmatrix} = [I - A]^{-1} \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \begin{pmatrix} \widehat{q}_1^d \\ \widehat{q}_2^d \\ \widehat{q}_3^d \end{pmatrix}, \tag{7}$$

where $\{y_i, \{d_{ij}\}, \widehat{q}_i, \widehat{q}_i^d\}$ are all now scalers and A is a $(3x3)$ aggregated global input-output matrix. Then we can re-write this expression as:

$$\begin{bmatrix} y_1 & 0 & 0 \\ 0 & y_2 & 0 \\ 0 & 0 & y_3 \end{bmatrix} \begin{pmatrix} \widehat{q}_1 \\ \widehat{q}_2 \\ \widehat{q}_3 \end{pmatrix} = [I - A]^{-1} \begin{pmatrix} d_{11} \\ d_{21} \\ d_{31} \end{pmatrix} \widehat{q}_1^d + [I - A]^{-1} \begin{pmatrix} d_{12} \\ d_{22} \\ d_{32} \end{pmatrix} \widehat{q}_2^d + [I - A]^{-1} \begin{pmatrix} d_{13} \\ d_{23} \\ d_{33} \end{pmatrix} \widehat{q}_3^d.$$

As discussed above, $(I - A)^{-1} d_i$ yields the vector of output produced in each country that is used to produce final goods absorbed in country i, so that we can further refine this system:

$$\begin{bmatrix} y_1 & 0 & 0 \\ 0 & y_2 & 0 \\ 0 & 0 & y_3 \end{bmatrix} \begin{pmatrix} \widehat{q}_1 \\ \widehat{q}_2 \\ \widehat{q}_3 \end{pmatrix} = \begin{pmatrix} y_{11} \\ y_{21} \\ y_{31} \end{pmatrix} \widehat{q}_1^d + \begin{pmatrix} y_{11} \\ y_{21} \\ y_{31} \end{pmatrix} \widehat{q}_2^d + \begin{pmatrix} y_{13} \\ y_{23} \\ y_{33} \end{pmatrix} \widehat{q}_3^d,$$

where y_{ij} is the value of output from country i absorbed in final demand in country j. And finally, we are in a position to write proportional changes in real output as a weighted average of real final demand changes:

$$\begin{pmatrix} \widehat{q}_1 \\ \widehat{q}_2 \\ \widehat{q}_3 \end{pmatrix} = \begin{bmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{bmatrix} \begin{pmatrix} \widehat{q}_1^d \\ \widehat{q}_2^d \\ \widehat{q}_3^d \end{pmatrix}, \tag{8}$$

where $s_{ij} = y_{ij}/y_i$, which we defined above as the shares of gross output from country i that is used directly or indirectly in producing final goods absorbed in country j.

An important point is the output allocation shares computed using the global input-output table provide loadings for each of the disturbances in determining output of each source country. Output in each country can be written as:

$$\widehat{q}_i = s_{ii}\widehat{q}_i^d + \sum_{j \neq i} s_{ij}\widehat{q}_j^d \tag{9a}$$

$$= s_{ii}\widehat{q}_i^d + (1 - s_{ii})\widehat{\overline{q}}_{-i}, \quad where\ \widehat{\overline{q}}_{-i} = \sum_{j \neq i} \frac{s_{ij}}{1 - s_{ii}}\widehat{q}_j^d \tag{9b}$$

These shock loadings are not export shares, but rather a function of the pattern of intermediate goods trade. There are two ways in which this distinction matters.

First, aggregate openness measured in a manner consistent with traded intermediates does not equal either exports to GDP or exports to gross output, the two most commonly used measures of openness. This distinction matters because openness governs the strength of demand spillovers. Specifically, a 1% fall in composite foreign demand $\widehat{\overline{q}}_{-i}$ reduces domestic output by $(1 - s_{ii})$.[12]

Second, at the bilateral level, output allocation shares $\{s_{ij}\}_{j \neq i}$ measure the strength

[12] Further, note that if there is a one percent disturbance to country 1's demand alone ($q_1^c = 1$ & $q_{j \neq 1}^c = 0$), then country 1's output declines by only fraction s_{11}, with the remainder of the fall in demand hitting the other two countries.

of bilateral transmission links, and these implicit links differ from bilateral export shares due to intermediate input channels. This is perhaps best understood via example. Consider the strength of the bilateral linkage between the U.S. and Korea. If U.S. import demand falls, a particular country like Korea may be hit hard because a large share of Korea's exports goes to the United States. However, Korea's export share to the United States actually underestimates the strength of this linkage. Because Korea exports large amounts of intermediate goods to China, which then processes these goods into final goods and re-exports them to the United States, the true bilateral linkage between Korea and the United States is larger than the simple Korean export share to the United States. These indirect linkages are automatically accounted for in our global input-output framework.

Once we have a solution for output changes as a function of demand changes, we can illustrate concisely how demand changes feed through to changes in real trade. We begin by writing imports and exports for country i in the base period in terms of the prices and quantities of final and intermediate goods crossing borders:

$$p_i^m im_i = \sum_{j \neq i} p_j q_{ji}^m + p_j q_{ji}^d \tag{10}$$

$$p_i^x ex_i = \sum_{j \neq i} p_i q_{ij}^m + p_{ij} q_{ij,}^d \tag{11}$$

where $\{im_i, ex_i\}$ are aggregate export and import quantity indices and $\{p_i^m, p_i^x\}$ are aggregate export and import price indices. Then if we evaluate quantities for two different periods at base year prices, we can write real changes in exports and imports as:

$$\widehat{im}_i = \sum_{j \neq i} \left[\frac{p_j q_{ji}^m}{p_i^m im_i} \right] \widehat{q}_{ji}^m + \left[\frac{p_j q_{ji}^d}{p_i^m im_i} \right] \widehat{q}_{ji}^d \tag{12}$$

$$\widehat{ex}_i = \sum_{j \neq i} \left[\frac{p_j q_{ij}^m}{p_i^x ex_i} \right] \widehat{q}_{ij}^m + \left[\frac{p_j q_{ij}^d}{p_i^x ex_i} \right] \widehat{q}_{ij}^d . \tag{13}$$

Then, the last step is to substitute out for intermediate and final goods quantity changes using the Leontieff assumptions introduced above:

$$\widehat{im}_i = \sum_{j\neq i} \left[\frac{m_{ji}}{p_i^m im_i}\right] \widehat{q}_i + \left[\frac{d_{ji}}{p_i^m im_i}\right] \widehat{q}_i^d = \widehat{q}_i \left(\frac{m_{Ii}}{p_i^m im_i}\right) + \widehat{q}_i^d \left(\frac{d_{Ii}}{p_i^m im_i}\right) \tag{14}$$

$$\widehat{ex}_i = \sum_{j\neq i} \left[\frac{m_{ij}}{p_i^x ex_i}\right] \widehat{q}_j + \left[\frac{d_{ij}}{p_i^x ex_i}\right] \widehat{q}_j^d, \tag{15}$$

where we re-introduce notation above for nominal shipments of final (d_{ji}) and intermediate goods (m_{ji}). Further, we have defined $m_{Ii} \equiv \sum_{j\neq i} m_{ji}$, $d_{Ii} \equiv \sum_{j\neq i} d_{ji}$ to be total intermediate and final imports, respectively. The first expression states that real imports are a weighted average of the real output and real final demand growth in the home country, where the weights correspond to the aggregate shares of intermediate and final goods imports in the total value of imports in the base year. The second expression states that real exports are a weighted average of real output and final demand growth in all foreign countries, where the weights correspond to the bilateral shares of intermediate and final goods shipments to the destinations.

We can further refine these expressions to express changes in trade as function of demand changes alone by noting that we have previously solved for real output changes as a function of demand. For notational clarity, we focus here on country 1 and substitute for output changes to express changes in trade as a reduced form function of the demand changes:

$$\begin{aligned}\widehat{im}_1 = &\left[\left(\frac{m_{I1}}{p_1^m im_1}\right) s_{11} + \left(\frac{d_{I1}}{p_1^m im_1}\right)\right] \widehat{q}_1^d \\ &+ \left[\left(\frac{m_{I1}}{p_1^m im_1}\right) s_{12}\right] \widehat{q}_2^d + \left[\left(\frac{m_{I1}}{p_1^m im_1}\right) s_{13}\right] \widehat{q}_3^d.\end{aligned} \tag{16}$$

$$\begin{aligned}\widehat{ex}_1 = &\left[\left(\frac{m_{12}}{p_1^x ex_1}\right) s_{21} + \left(\frac{m_{13}}{p_1^x ex_1}\right) s_{31}\right] \widehat{q}_1^d \\ &+ \left[\left(\frac{m_{12}}{p_1^x ex_1}\right) s_{22} + \left(\frac{m_{13}}{p_1^x ex_1}\right) s_{23} + \left(\frac{d_{12}}{p_1^x ex_1}\right)\right] \widehat{q}_2^d \\ &+ \left[\left(\frac{m_{12}}{p_1^x ex_1}\right) s_{23} + \left(\frac{m_{13}}{p_1^x ex_1}\right) s_{33} + \left(\frac{d_{13}}{p_1^x ex_1}\right)\right] \widehat{q}_3^d.\end{aligned} \tag{17}$$

These expressions yield an explicit scheme for linking demand disturbances to trade outcomes, where the weighting scheme depends on the input-output structure in a complex, though intuitive, way. For example, imports in country 1 depend on demand changes in country 2 to the extent that some imports are intermediate goods that are processed into final goods that are ultimately consumed in country 2. Further, exports in country 1 depend not only on demand disturbances abroad, but also on domestic disturbances because an increase in domestic demand increases consumption of foreign produced goods that contain exported domestic intermediates.

These intermediate goods linkages imply that exports and imports for a given country tend to move together in response to idiosyncratic changes in demand. That is, following a fall in demand in country 1, both imports and exports fall. In contrast, in the absence of intermediate linkages, only imports would decline following the idiosyncratic domestic downturn. Whether imports are more or less responsive than exports to domestic demand is an empirical matter. In our data, imports typically put a larger weight on the domestic disturbance than exports. Therefore a disturbance to country 1 alone ($q_1^d > 0$, $q_2^d = q_3^d = 0$) leads imports to rise more than exports and causes the trade balance to deteriorate.[13] Note also that if all the q's are the same, then all countries have identical export declines and exports and imports are synchronized, regardless of differences in the weights. More generally, differences in weights across countries interact with the configuration of global demand changes to drive differences in the response of trade across countries.

3.4 Proportionality of Trade and Production

In analyzing the recent trade downturn, several authors have advanced the proposition that, as a matter of theory, trade should respond proportionally with overall economic activity (production or demand), and emphasized that this result should hold regardless of whether or not there are vertical production linkages.[14] On the other hand, others have pointed out that the elasticity of trade to GDP for the world as a whole is on the

[13] This result has a similar flavor to simple empirical models of net exports, Keynesian in spirit, which link changes in domestic demand to changes in import demand.

[14] A blog post by O'Rourke (2009) with a simple numerical example is typically cited as the genesis of this idea, though it was percolating various places at the time. This point has been picked up and advanced by others, including Bénassy-Quéré, Decreux, Fontagné, and Khoudor-Casteras (2009) and Altomonte and Ottaviano (2009).

order of 3.5 in recent data, and rising over time.[15] We believe these two observations can be straighforwardly reconciled by acknowledging that the composition of demand changes has an important influence on the elasticity of trade to aggregate production. Indeed, there is a growing consensus that the sectoral composition of demand changes is essential for understanding why trade has collapsed.[16] To understand the role that shock composition plays, we pause here to formalize some intuition about the manner in which trade and production jointly respond to demand changes.

The conditions under which trade and global production are proportional are easy to describe with reference to equation (8) linking output growth to demand changes and the trade equations (16) and (17). Note that if demand changes are equal in proportional terms across countries ($\widehat{q}_i^d = \widehat{q}^d \forall i$), then output changes are also equal across countries (with $\widehat{q}_i = \widehat{q}^d \forall i$) because they are weighted averages of the demand changes, with weights that sum to one. It follows that world real output growth also naturally equals the world change in final demand. Finally, proportional changes in exports and imports for every country are also equal to $\widehat{q}^d$, since for each country they are a weighted average of demand changes with weights that sum to one. Thus, with identically sized demand changes across countries, then trade falls proportionally with income.

It should be immediately evident that this exact trade-production proportionality result hold exactly only in a special case. Specifically, the proportional decline in demand must be identical across countries. With many countries and sectors, the restrictions needed to generate a unit elasticity of trade to total production are even more restrictive. Namely, demand changes must be symmetric across both sectors and countries. Asymmetric demand changes in this framework will cause the elasticity of trade to income to deviate from one. In this event, general results are not attainable. Whether trade responds more or less than proportional to production depends on both the initial economic configuration (e.g., production levels, allocation of demand, intermediate goods intensity, etc.) and how the pattern of demand changes interact with these conditions.

Though the precise elasticity depends on the particulars of the scenario, we quantify

[15] See Freund (2009), Cheung and Guichard (2009), and Irwin (2002). Since GDP is a roughly constant multiple of gross production in the data, then the elasiticy of trade with respect to production changes will be similar.

[16] For example, see Baldwin (2009) and the other contributions in the VoxEU ebook on "The Great Trade Collapse."

the elasticity of trade with total world demand and production in our empirical work below. To motivate that work, we present a simple numerical example that provides some concrete intuition. The example echoes and amplifies an example using the Barbie doll, presented by Kevin O'Rourke.

Suppose there are two countries, United States and China. There are two sectors, Barbies and corn, and Barbies are produced in a vertically specialized production process. Specifically, suppose the U.S. exports \$50 of parts to China, where Chinese workers add value by assembling parts, and ship \$100 of finished Barbies back to the United States. Further, suppose the United States ships \$50 of corn to China for consumption and consumes \$50 of corn itself.[17] Total world exports are \$200 and the ratio of value added embedded in exports to gross exports is equal to 1/2 for each country. Further, total consumption in the United States is \$150 and total consumption in China is \$50, these equal value added generated in each country due to balanced trade.

Within this framework, consider two scenarios:

1. Suppose first that there is a 1% global shock that hits both countries and sectors symmetrically. That is, worldwide consumption falls by \$2, with consumption of Barbies in the United States falling by \$1, consumption of corn in the United States falling by \$.5, and consumption of corn in China falling by \$.5 as well. Then, U.S. exports of Barbie parts fall by \$.5 and U.S. exports of corn fall by \$.5 as well, for a total decline in U.S. exports of \$1. Chinese exports of Barbies fall by \$1. Adding these up, total trade falls by \$2 or 1%. Finally, world production also falls by 1%. Thus, with this symmetric shock, both world demand, production, and trade all fall proportionally.

2. Now consider a shock that hits U.S. consumption of Barbies only that generates a 1% decline in global final demand, as in the previous example. This leads U.S. Barbie consumption to fall by \$2. Then, world trade falls by \$3 (\$2 in Barbies shipped from China to the United States plus \$1 in parts not shipped from the United States to China), or 1.5%. World production in this case falls by \$3 as well, a decline of 1.2%. So, trade falls more than proportionally than world production. Further, we emphasize that composition is the crucial issue here. Specifically, increasing vertical specialization does not raise the elasticity of trade with respect to production in the example. To see this, re-calculate changes

[17] Note that by construction, trade is balanced in this example, though this is not essential.

in production and trade in scenario 2 under the assumption that the Barbie is produced in four stages rather than two (a more vertically specialized production process).

As these examples show, it is fairly easy to concoct examples in which trade is not proportional to either final demand or total production. To quantify the actual empirical elasticity of trade to output changes implied by our input-output framework given the configuration of shocks during 2008-2009 recession, we turn to numerical computations below.

3.5 Comparison to IRBC Framework

To understand the distinct role of intermediates in our framework, it is helpful to clarify language. Most of the IRBC literature refers to trade in differentiated "intermediate goods" that are combined via Armington aggregation into a composite "final good" used for consumption and investment. For example, see Backus, Kehoe, and Kydland (1994), Kose and Yi (2006), and Burstein, Kurz, and Tesar (2008). Despite the nomenclature, trade in these models could be thought of as trade in final, rather than intermediate, goods because these goods are not subject to any additional value-added and there is no double counting problem in trade flows in the model (i.e., the ratio of value added embodied in exports to gross exports is one).[18]

There are several areas in which our framework differs from a more standard IRBC-type framework. First, the direct role that intermediate linkages play in transmitting disturbances in our framework operates in addition to the usual "resource shifting" and "demand spillover" channels that operate in IRBC models. For example, at the country level, a fall in U.S. imports from China can affect Korea in the standard IRBC framework only if Chinese income and demand for final goods from Korea falls. In our framework, a fall in U.S. imports from China is passed through the production chain to Korean intermediate goods suppliers directly. A similar phenomenon occurs at the sector level. For example, the only way in which reduced U.S. demand for cars can

[18] Ambler, Cardia, and Zimmerman (2002) and Arkolakis and Ramanarayan (2009) are the only IRBC models to our knowledge that incorporate trade in intermediate goods. Their structures are not suited to our purposes as they involve a small number of sectors and countries. Burstein, Kurz, and Tesar (2008) study a case of their model in which there is double counting in trade flows, but this has no consequences for the basic behavior of their model relative to the benchmark in which all goods cross borders once.

affect Canada's purchases or production of steel and rubber is through intermediate linkages. The usual story in which the lower demand for cars leads to fewer Canadian exports, which reduces Canadian income, which reduces Canadian demand for steel and rubber, is not operative in our framework. Our framework does, however, generate comovement across countries and sectors arising from decline in demand in a single country, holding all other final demands constant.

This discussion leads to the second way in which our framework is different than the IRBC framework. In feeding individual demand changes into the model, we take these realized demands as essentially exogenous. In reality, they are a combination of truly exogenous shocks and the endogenous response of demand to changes in production and income. We are not interested in recovering the underlying structural shocks that drive these final demand movements. Rather, we are focused on tracing the consequences of the realized, cumulative demand changes on production and trade.

A third way in which our framework differs from standard models is the way we measure openness and bilateral exposure. Though we alluded above to the fact that our measures differ from standard measures, let us explain further. The standard approach to calibrating IRBC models essentially ignores the double counting problem in trade statistics generated by input trade. When one ignores trade in intermediate goods, one cannot calibrate all values in the model to be consistent with the national accounts statistical framework. Within the IRBC literature, the typical approach to calibration is to assume that production equals value added and that all exports are final goods absorbed abroad. This implies that domestic final demand is defined as a residual equal to value added minus exports: $\widetilde{d}_{ii} = va_i - p_i^x ex_i$. This residual domestic demand $\widetilde{d}_{ii}$ is distorted downward relative to the corresponding national accounts definition of demand. This makes the economy appear "too open" and makes output more sensitive to foreign shocks than it should be given the true model includes trade in both intermediate and final goods.

We view inclusion of realistic intermediate goods linkages into a multi-country, multi-sector IRBC framework to be a productive approach to studying propagation in future work.[19] As such a framework is not yet available, we proceed in our analysis using a central piece of this ideal framework – a descriptive set of multi-sector,

[19] Johnson (in progress) is working to develop a framework of this sort and we hope to apply it to study the collapse of trade in future work. This extended framework would link fundamental shocks to final outcomes via the endogenous adjustment of output, demand, and trade in all countries.

multi-country input-output linkages.

4 Results

This section applies our framework to the global crisis of 2008-09. Taking as given changes in global, U.S., or EU demand, we solve for the effects on every country's gross output, GDP, exports and imports. We also use the model to quantify the role of imported intermediate goods linkages in the collapse of global trade and in the propagation of demand shocks across countries. To assess the role of sectoral asymmetries in the change in demand, we conduct exercises involving one-sector, two-sector, and three-sector versions of the framework.

Our primary data set for the changes in demand is the IMF Global Data Source (GDS) data set, which covers 54 countries, as well as the world as a while. The GDS data set has quarterly data, but it cannot replicate in countries and sectors our global I-O model, which has 107 countries/regions and 57 sectors. Hence, we aggregate all the countries that are not covered by the data set into a "rest of the world" region. The data for this region is computed as the difference between the countries covered by the data set and the world as a whole. We also aggregate the 57 sectors in each country to the level of sectoral detail covered by our three main exercises. The crisis is defined as taking place between 2008Q1 and 2009Q1. This is the time period over which the annual real growth rate of aggregate demand for the majority of countries exhibited the largest decline.

We start by investigating the global crisis episode through the lens of a one-sector framework. We first implement the actual changes in total real domestic demand for every country, and then we do a separate analysis for the change in U.S. real domestic demand alone, and an analysis for the change in EU real domestic demand alone. Second, we consider a two-sector version of the model by categorizing the sectors into industry and non-industry (essentially, goods and services). We then compute and implement the actual changes in industry and non-industry demand. Finally, we further divide industry into durables and non-durables, and for this three-sector framework we study the effects of the actual changes in U.S. real demand in each of these sectors.

4.1 One-Sector Analysis

We take our framework consisting of 54 countries and a rest-of-the-world region, and first implement the actual change in total real domestic demand that each experienced. The changes in demand are presented in **figure 1**. We solve for the implied changes in gross output, GDP and trade flows in all countries. We begin by investigating the extent to which one-sector model outcomes for economy activity and trade flows can replicate the changes observed in the data during the global crisis episode.

Figure **2** compares outcomes for GDP, exports and imports in the model and data, and additional summarizing statistics are reported in Figure **3**. The model captures a significant share of output changes in data. The model's implied fall in global GDP amounts to 97 percent of the fall in the data, and the cross-country correlation in growth rates between the model and data is 0.76. While it may not seem surprising that, conditional on matching the fall in global domestic demand, the model closely matches the fall in global GDP, note that because of our open economy framework changes in domestic output need not match changes in domestic demand. Owing to our assumption that changes in demand impinge equally on domestic goods and on imports, a fraction of the change in demand spills over to the rest of the world.[20] As depicted in Panel A of figure **4,** one consequence of such demand spillovers is that the model's economies exhibit a smaller range of variation for changes in GDP than domestic demand. Equation (9a) shows that this is the case because changes in GDP are a weighted average of demand changes at home and in the rest of the world. Panel B of Figure **4** shows that the relationship between a domestic demand and GDP finds some support in data.

Turning to trade flows, the model can account for about one-fourth of the trade collapse observed in data. In particular, as mentioned in the introduction, a key feature of the crisis is that global trade fell by four times as much as global GDP. However, in our one-sector framework, the fall is roughly proportional to GDP. This proportionality aspect of the one-sector model will be examined in more detail below. Interestingly, the model fails to capture any of the cross-country variation in export growth rates, while it does capture a significant amount of the variation in imports. The correlations between the model-implied change and the actual change in exports, and in imports, are -0.23 and 0.68, respectively. Further, the standard deviation of the model's export

[20]For further discussion of this assumption see the previous section.

response is 1.0, considerably smaller than in the data (7.8) or when compared to the standard deviation of the model's import response (6.9). The underpinnings of this result are conveyed by equations (14)-(15), which show the role of changes in demand in determining outcomes for exports and imports. As depicted in Panel A of figure **4**, for most countries the change in GDP deviates only slightly from the change in domestic demand. Then equation (14) implies that changes in imports in the model are close to proportional to changes in domestic demand, while export flows are determined by a weighted average of demand shocks in partner countries, leading to more limited cross-country variation in the response of exports. The one-sector framework's failure in this dimension could at least partly stem from its inability to capture specialization in exports at the level of individual countries, which follows from the assumption that changes in demand affect imports from all sources proportionally. Although data limitations do not allow us to relax this assumption, increasing the number of sectors in the model might help to address the problem.[21]

We now turn to the propagation of the changes in demand in the model and highlight the role played by vertical linkages. To identify the role of vertical linkages in the transmission of shocks from final demand to changes in economic activity and trade flows, we exploit the exogenous nature of final demand in our framework. The standard transmission of a change in demand to foreign countries works through direct export exposure and requires an endogenous response from final demand in foreign markets. Since final demand in our input-output framework is exogenous, all the spillovers, beyond the direct effect on exports of final goods, are generated exclusively through vertical linkages. (As a reminder, given the absence of endogenous links between final demands and the cumulative rather than structural nature of the changes in final demand, the results here constitute an accounting exercise that traces the effects of changes in demand in one or more countries on production and trade across the world.)

We begin by implementing the actual change in final demand that the United States, and separately, the EU15, experienced during the crisis.[22] Panels A in figures **5** and

[21] We note the model cannot explain qualitatively the changes in imports in China and India during the crisis. Both countries exhibited growth in GDP and domestic demand, while exports and imports contracted. In the model imports are driven by domestic demand shocks; hence, the model predicts imports in China and India increase proportionally to the expanding domestic economic activity.

[22] When considering a shock to EU15, relevant countries are aggregated into one region. Otherwise, for the purpose of trade flows one is not keeping final demand constant in foreign markets. In this case, the framework used is a 41-country global I-O model, which excludes the intra-EU15 trade flows, but is otherwise consistent with the 55-country model.

6 trace out the response of GDP, gross output, exports and imports in eight countries/regions, as well as the world as a whole. For each exercise, all other final demands are held constant. Columns 1-3 of the figure re-state the setup of the exercise; by construction, the model captures 100 percent of the change in demand in the United States or the EU15 and none of the change in the other regions. Columns 4-11 present model outcomes for gross output, GDP, exports and imports. Both export and import flows are further decomposed according to final or intermediate use. To help interpret the relative magnitudes of the implied changes, figure **7** reports regional shares in global domestic demand, economic activity, and trade flows as implied by the GTAP 7 dataset. The figure shows, for example, that 2/3 of world trade flows are for intermediate consumption, and the United States and EU15 together account for 59 percent of total world demand.

Panel A in figure **5** shows that U.S. (final) domestic demand during the crisis fell by 4.41%. We focus first on the responses of trade, given in columns 6-11. U.S. exports and imports fall by 0.3% and 4.2%, respectively. The fall in imports is close to the magnitude of the fall in domestic demand. This follows because demand for final goods imports falls in proportion to the fall in domestic demand, while demand for intermediate goods imports falls in proportion to the fall in gross output, which, as column 4 shows, is close to the fall in domestic demand.[23] The export response to the change in demand owes entirely to vertical linkages. The small magnitude of the export response reflects the fact that the United States is not, in the aggregate, tightly integrated into cross-border production networks.

Vertical linkages play a large role in the relative impact of the U.S. demand change across regions. Consider, for example Canada and Mexico, which are combined into NAFTA in the figure. Exports fall by 3.3%; about three-fifths of this decline involves exports of intermediate goods. In addition, NAFTA imports fall by 0.6%, all of which is intermediate goods. Also, consider China and Japan. Exports from both regions fall by about the same amount. The export responses are similar despite the fact that the U.S. is a bigger market for China than it is for Japan.[24] The response is similar because a good deal of Japanese value-added is exported to the United States through

[23]To see this result in Panel A of figure **5** one needs to translate decomposed growth rates into percent change for each component of trade flows.

[24]China exports approximately 60% more goods to the United States than Japan in our data. In 2004, the base year in our data, China exported about $211 billion of goods to the United States, while Japan exported $133 billion.

China and other countries. This can be seen via the result that the percentage drop in China's imports of intermediates is three times larger than Japan's. Overall, panel A in figure **5** shows that vertical linkages account for more than three-fifths of the change in overall trade.

As discussed in the previous section, the vertical specialization concept developed in Hummels, Ishii, and Yi (2001) and generalized in Johnson and Noguera (2009) and other recent papers is a subset of vertical linkages: it is those imported intermediates that are embodied in exports. Panel A of figure **5** illustrates the role of vertical specialization cleanly in two places. First, the fall in U.S. exports is entirely a result of vertical specialization. These exports are used as inputs in the production of other countries' goods that are eventually exported back to the United States. Second, the import responses of all countries other than the United States are also entirely a result of vertical specialization. For example, China's imports of intermediates fall to the extent that its exports of goods that eventually wind up in the United States fall.[25] More broadly, as the discussion of China in the previous paragraph highlighted, owing to vertical specialization, the response of final goods exports may be greater or smaller than the true "value-added" linkage. Finally, we note that the presence of vertical specialization implies that exports and imports co-move positively in every country. Otherwise, the co-movement would be zero.

We now turn to the responses in output and GDP. The model implies that U.S. gross output and GDP fall by 4.1%, less than the fall in U.S. final demand. Note, that the implied fall in global domestic demand and GDP are the same, 1.4%, which is natural given the fact that the world economy is, on net, closed. Any difference between the U.S. fall in final demand and the U.S. fall in GDP owes to trade spillovers to the rest of the world. The trade spillovers are determined, as discussed in the previous section, by both vertical linkages and the share of trade to the U.S. in GDP. These spillovers across the 9 regions are summarized separately in figure **8**. Rather than reporting the percent fall in GDP induced by the change in U.S. demand, the figure reports the allocation of the total change in world GDP across regions. Column 1 shows that a $1 fall in final demand in the United States lowers U.S. GDP by $0.88. The remaining $0.12 are allocated to the rest of the world, with the EU15 and NAFTA accounting for the

[25] In addition, vertical specialization plays a role in the decline in U.S. imports of intermediates. To the extent that some of these intermediates are imported, only to be processed and exported to other countries, and then eventually exported back to the United States, then these intermediates are part of a vertical specialization process.

largest shares.

The results for the EU are presented in panel A of figure **6.** They are broadly similar to the U.S. results, with Eastern Europe taking the place of NAFTA as the region with the most intensive trade linkages.[26]

Now we return to the exercise in which we implement the changes in demand for all countries. We aggregate the results for gross output, GDP, exports and imports into nine regions, as we did for the U.S. and EU exercises, and present the findings in Panel A in figure **9**. Now the change in global demand matches its data counterpart, and consequently, so does global GDP. We examine results for the global economy, as well as how some of the earlier findings for the United States and the EU are altered once all changes in demand are included.

Panel A of figure **9** shows that vertical linkages continue to account for the bulk of the change in trade flows. This the case at the level of individual regions/countries as well as globally, with 60% of changes generated by trade in intermediates. We can compute the elasticity of global trade with respect to global GDP, as well.[27] The panel shows that it is about one, which is only one-fourth of its actual value. In addition, the fall in global gross output, 3.7%, is close to the fall in global GDP, 3.8%. Thus, the key global variables fall approximately proportionally to the fall in demand. We will see that this will not hold once we implement sectorally-asymmetric changes in demand.

Finally, we turn to a comparison of the effects on the NAFTA countries in response to the global change in demand relative to the U.S. change in demand. Comparing Panel A of figures **9** and figures **5,** we see that about 80% of the overall model-implied fall in NAFTA exports is induced by the change in U.S. demand. However, less than 20% of the model-implied fall in NAFTA imports and GDP is induced by the change in U.S. demand. Thus the one-sector model does not deliver large spillovers to GDP

[26]Figure **7** shows that, with the exception of exports, the EU15 and United States represent very similar shares of the world economy, making the global effects of the two demand shocks easier to compare.

[27]As discussed in the previous section, it is difficult to attain any general theoretical results about the size of this elasticity. This is the case even in a one-sector model, because proportional changes at the level of individual countries/regions are not preserved at a more aggregate level. Results in **Panel A of Figure 9** provide an instructive illustration about the degree of proportionality between model responses for economic activity and trade. In particular, at the country-level changes in GDP are proportional to changes in gross output (see e.g. USA, China and Japan). For aggregated regions this result does not hold, since countries have different weights in the aggregated gross output and GDP. Quantitatively, in majority of regions changes in gross output and GDP closely track changes in domestic demand.

arising from a change to U.S. demand. The panel shows similar results for China, and for Eastern Europe with respect to the change in EU15 demand.

4.2 Two-sector analysis: goods and services

This section extends our analysis to a two-sector framework. We are motivated by the observation that the demand for tradables, for durables, in particular, tends to fall by more than non-tradables during recessions, and the crisis was no exception. Allowing for such an asymmetry in changes in demand can significantly alter the model results, because sectors producing tradables are more intensely engaged in trade and international production networks than the rest of the economy.

We define tradables as goods and non-tradables as services. Owing to data limitations, especially at the quarterly frequency, we make use of industrial production (IP) data as our proxy for the goods sectors. We take two approaches to estimating the changes in demand in the two sectors. The first approach used data on changes in IP and GDP (both from IMF GDS data set) as well as sectoral weights for IP in GDP, as implied by the global I-O model, to back out changes in the GDP of services for each country.[28] Then, because services are assumed non-tradable, we have the change in the demand for services. Finally, data on (i) changes in real total domestic demand (from IMF GDS data set), (ii) imputed changes in demand for services and (iii) IP weights in domestic demand, as implied by the global I-O model, are sufficient to compute changes in the demand for goods. The second approach assigns all the changes in aggregate demand during the global crisis to changes in demand for goods, and, hence, assumes zero change in the demand for services. In this case, changes in real total domestic demand (from IMF GDS data set) and IP weights in domestic demand are sufficient to compute the change in demand for goods.

The resulting sectoral demand growth rates for both approaches are summarized in figure **10**. Although the assumption of zero growth in the service sector may be difficult to motivate, it has the advantage of being more transparent and it appears to provide a good approximation for what happened during the recent crisis – changes in demand for services across the sample countries are not systematically different from zero. Furthermore, both approaches offer very similar results. In the rest of this section

[28] In the aggregation of the underlying GTAP 7 I-O tables goods producing sectors are defined as sectors 15-45, so as to correspond to sectors included in the IP index.

we present results only of the case when changes in demand for services equal changes in supply.[29] Results from the other approach are reported in the Appendix.

Panel B of figure **3** and figure **11** compare the model solution for exports, imports and GDP with the data. The two-sector model captures 56 percent of the change in global trade flows, more than double the 26 percent explained by the one-sector model. The mean-square error of the model relative to the data falls from 11.9 to 4.3 for imports and from 16 to 8.5 for exports. The exports correlation is now no longer negative, as well, at 0.03. However, the change in exports still falls considerably short of capturing the cross-sectional variation in the data, and the volatility of export growth remains only a fraction of what is observed in data.

Panel B in figures **5** and **6** present the model solution for the case of the changes in demand in the U.S. only and the EU15 only, respectively. In the U.S. case, demand for goods falls by 16% and demand for services falls by 1% (see figure 10). For the EU15, the corresponding numbers are -8% and -1%. Clearly, the changes in demand are asymmetric across sectors. But, note that the change in *total* demand is, by construction, the same as on the one-sector case studied above. Comparing the results in panel B to those in panel A, it is immediately clear that the effects on exports and imports are about two to three times larger. For example, NAFTA exports fall by 8.2%, in contrast to the 3.3% fall in the one-sector case. Also, NAFTA imports are four times higher in this case. This magnified effect stems, by and large, from the fact that industrial goods tend to be more widely traded than services and non-industrial goods. With the export declines about two to three times larger, it is no surprise that the GDP declines in the different regions are also about two to three times larger than in the symmetric one-sector case. For example, GDP falls by 1.0% in China and by 2.1% in the NAFTA countries. Finally, the larger import effects are associated with vertical specialization. Because exports of final and intermediate goods to the United States have fallen by a larger amount, imports of intermediate goods needed to make those export goods fall by a correspondingly larger amount. The overall impact on global exports and imports is 2.5 times larger than in the one-sector case.[30] The results for the EU shock are again

[29] This case is somewhat less favorable to our main conclusions.

[30] Interestingly, in relative terms the increase is larger for trade in final goods. While trade in intermediates doubles, for final goods the increase is approximately threefold. As a result, the relative role of vertical linkages and trade in intermediates in the two-sector model fall to accounting for 1/2 of the collapse in trade flows, from explaining 2/3 of the collapse in the one-sector case. To understand this, think of the following extreme case. Suppose the services sectors had zero vertical linkages. Then, the one-sector results are driven entirely by the goods sectors. Moreover, because the change in services

broadly similar, although the relevant magnitudes are smaller. This is partly because of the smaller size of the aggregate negative demand shock in the EU15 economy and partly because the demand shock in EU15 is less asymmetric across the two sectors.

The results in column 2 of figure **8** show that the two-sector model exhibits larger cross-country spillovers in economic activity. For example, in panel A, a \$1 fall in final demand in the United States now lowers GDP by \$0.74, with the remaining \$0.26 allocated abroad. This is more than twice as large as in the one-sector case. Among the foreign regions the spillover to Japan increases by most, from 1.2% in the one-sector case to 3.2% in the two-sector case. (Recall that the spillovers presented in this figure are by construction purely due to reallocation of the same decrease in global GDP, i.e., in the one-sector and two-sector models fall in the U.S. final demand by 4.4% generates a 1.4% fall in world GDP regardless of the sectoral composition of demand shocks.)

Panel B of figure **9** shows that the two-sector model generates similarly magnified results when the asymmetric shocks in all countries are considered simultaneously. Comparing Panel B to Panel A, we can see that the two-sector model generates a significantly larger elasticity of trade to economic activity. For the global economy, the model-implied changes in trade flows exceed changes in GDP by a factor of 2.3. This is more than twice the elasticity of the one-sector case. Intuitively, this result stems from the fact that the fall in demand is concentrated in the sector that is more intensely engaged in trade with the rest of the world. Consequently, the larger sectoral demand shock has a bigger weight in determining gross trade flows than in determining aggregate economic activity. These results suggest that within-country asymmetries in changes in demand are more important than cross-country asymmetries. [31] Note also that aggregate numbers in the two-sector model are subject to an additional layer of aggregation. In particular, the various proportionality results discussed in the previous section (e.g., changes in GDP are proportional to changes in gross output) now hold at the level of the two sub-sectors of each individual economy. Strict proportionality is

demand in the two-sector scenario is small, the two-sector scenario would essentially be a scaled up version of the one-sector scenario. Then, the incremental change in intermediates trade would match the incremental change in final goods trade. However, to the extent services does have vertical linkages, the incremental change in intermediates trade will be less than the incremental change in final goods trade.

[31] In the two-sector model, only 5% of the generated disproportional increase in trade flows, relative to changes in GDP, is due to asymmetries in demand shocks across countries. The remaining 95% is due to within-country asymmetries across sectors. This is computed from the following relation: (4.01/3.76-1)/(8.71/3.76-1))=0.05.

absent from any of the results reported in Panels B, because all computations for both individual countries and regions require aggregation.

Although both final and intermediate trade contribute to the increasingly disproportional response of trade to output, final trade contributes more to this result. Decomposing the trade flows, we find that the final trade elasticity is 3.3, while the intermediate trade elasticity is 1.7. (See footnote 29.) Overall, the results from the two-sector model provide evidence that the international transmission mechanism can be quite strong when shocks are concentrated in the tradable sectors.

4.3 Three sector analysis: durables, nondurables and services

BEA data for the United States shows that the decrease in domestic demand was not uniform across different types of goods. Demand for durable goods decreased by 18 percent, while demand for nondurables decreased by only 1 percent.[32] Consequently, the large overall decline in the demand for goods in the U.S. was driven almost entirely by the demand for durable goods. This empirical observation and our results from the two-sector model suggest that it might be more appropriate to treat durable goods as a separate sector. Unfortunately, owing to data limitations, such an exercise cannot be implemented for the entire global economy. Therefore, the investigation of this section is limited to estimation of the change in U.S. demand in the durable sector and evaluation of the effect of this change on global economic activity.

Mapping the detailed BEA expenditure data into the sectors of the U.S. input-output table presents several challenges. Most importantly, the BEA expenditure data is measured at consumer prices, while the input-output table measures expenditure at producer prices. Consequently, the former includes wholesale, retail, and other services. As a result, expenditures on goods in the BEA data account for a significantly larger share of GDP (30 percent) than the size of the goods sector in the input-output tables (20 percent of GDP). Because of these compatibility problems and to preserve continuity with our previous results from the one-sector and two-sector models, we use the BEA data only to correct the allocation of the decline in demand within the goods sector between durables and nondurables. In particular, instead of demand for both types of goods contracting uniformly by 16%, we now implement a 32.5% decline in durables

[32] The same BEA data also shows that demand for services decreased by 1.6%, which should be compared to our estimate of a 1.3% decrease.

demand and a 1% decline in nondurables demand.[33]

The results from the three-sector model offer two findings beyond our previous results. First, as expected, separation of the durable sector from the rest of the economy further increases global spillovers and the collapse in trade flows in response to the same aggregate demand shock. In Panel C of figure **6** global trade flows fall by 3.1%, larger than the 2.5% decline in the two-sector model, with contributions from trade in both final and intermediate goods. This added fall in trade flows in the three-sector model further increases the elasticity of trade to changes in economic activity (2.2 vs. 1.8 in the two-sector model.) By the same token, in Figure **8** U.S. GDP now absorbs $0.70 from every $1 fall in domestic demand, a further decrease from $0.74 in the two-sector model. As in the case of the two-sector model, the crucial ingredient for this result is the positive correlation between the size of the change in sectoral demand and the intensity with which the sector is engaged in trade and international production networks.

Second, the model's extension to three-sectors with changes in U.S. demand (as estimated for the crisis of 2008-09) does not affect all regions equally. While most regions show larger effects, the magnitudes vary, and some regions have smaller effects. For example, Japan's exports fall by 5.4%, considerably larger than the 3.1% decline in the two-sector case. This increase is considerably larger than in the case of China, breaking the proportional response of trade in the two countries that we reported in the one-sector and two-sector models. On the other hand, the decline in South America's exports in response to the decline in U.S. durables demand is now 2.1%, less than the 2.9% decline in the two sector model. Figure **8** documents a similar pattern of changes across the regions for the GDP spillovers. Japan's share among the foreign markets exhibits the largest increase, while shares for South America and the rest of the world decline in level terms. This pattern of non-monotonic responses across countries could be explained with the type of trade linkages that the U.S. maintains with NAFTA and Asia versus South America and the rest of the world. With the former regions, linkages are mostly through durable goods, while in the latter two regions trade in non-

[33] The appendix shows how we obtained these numbers. Intuitively, since in the BEA data the decline in demand for nondurables (1.2%) was the same as the decline in demand for services (1.6%), exclusion of retail services from demand for nondurables has no effect on the rate of decline. In contrast, demand for durables declined by 18.2 percent. In this case, exclusion of retail service expenditures (assumed to growth at the same rate as demand for other services) significantly increases the decline rate for the remaining expenditures on durables.

The durable goods sectors in the GTAP data base are defined as sectors 38-41, and include equipment and machinery and consumer durables.

durable goods is more important. Hence, the three-sector model teaches us that an overly aggregated sectoral structure can significantly under or over-estimate economic exposures between any two regions.

5 Conclusion

In order to understand better the collapse in global trade during the Great Recession, we employed a global bilateral input-output framework to account for the changes in output and trade resulting from changes in demand between 2008Q1 and 2009Q1. If the actual changes in demand in each of 55 countries/regions are fed into the two-sector version of our model, close to three-fifths of the global decline in trade during this period can be matched. Also, the global trade elasticity with respect to output is 2.3. These magnitudes are primarily driven by the asymmetric nature of the changes of demand. Global demand for goods, which tend to be more tradable, fell 13.8%, while the demand for services was essentially unchanged, during this period.

At the heart of our framework is vertical linkages and vertical specialization. Vertical linkages account for almost half of the trade response in the two-sector model. The responses by particular countries depends on the exact nature of the trading relationship; to the extent a country's output eventually winds up in a destination country, no matter how long the production chain, the spillovers between the source and destination countries will be larger. Moreover, vertical specialization helps explain why imports and exports co-move positively in response to the changes in demand.

In all input-output frameworks, changes in demand are the driving force. How then, does our methodology tie into the widely held view that financial disruptions underlie the global recession and trade collapse? We believe the financial crisis spilled over to other sectors of the economy via two main channels. First, financial intermediation was severely curtailed, thus reducing the efficiency at which inputs were combined into outputs. In other words, total factor productivity (TFP) fell. This had consequent effects on output in other sectors, which then generated reductions in demand. Second, the unprecedented nature of this crisis created in late 2008 and in early 2009, in particular, a heightened sense of uncertainty. Precautionary motives on the part of both consumers and firms conspired to drive down aggregate demand. Thus, the financial shocks led directly or indirectly to a collapse in aggregate demand, and these changes in demand form the starting point for our analysis.

Nevertheless, a clearly preferred framework would be one that combines an open economy business cycle model with the rich bilateral input-output linkages of our accounting framework. The primary benefit of such an approach is it digs deeper into the sources of shocks that drive the joint behavior of demand, output, and trade. Indeed, one of us, (Johnson), is currently pursuing this approach. Of course, an even deeper methodology is one that marries a financial sector, as well as a trade structure that allows for endogenous vertical specialization, to the framework. With the advent of the new financial models, as well as ever increasing computing power, perhaps the day at which these frameworks come to fruition is not so far off.

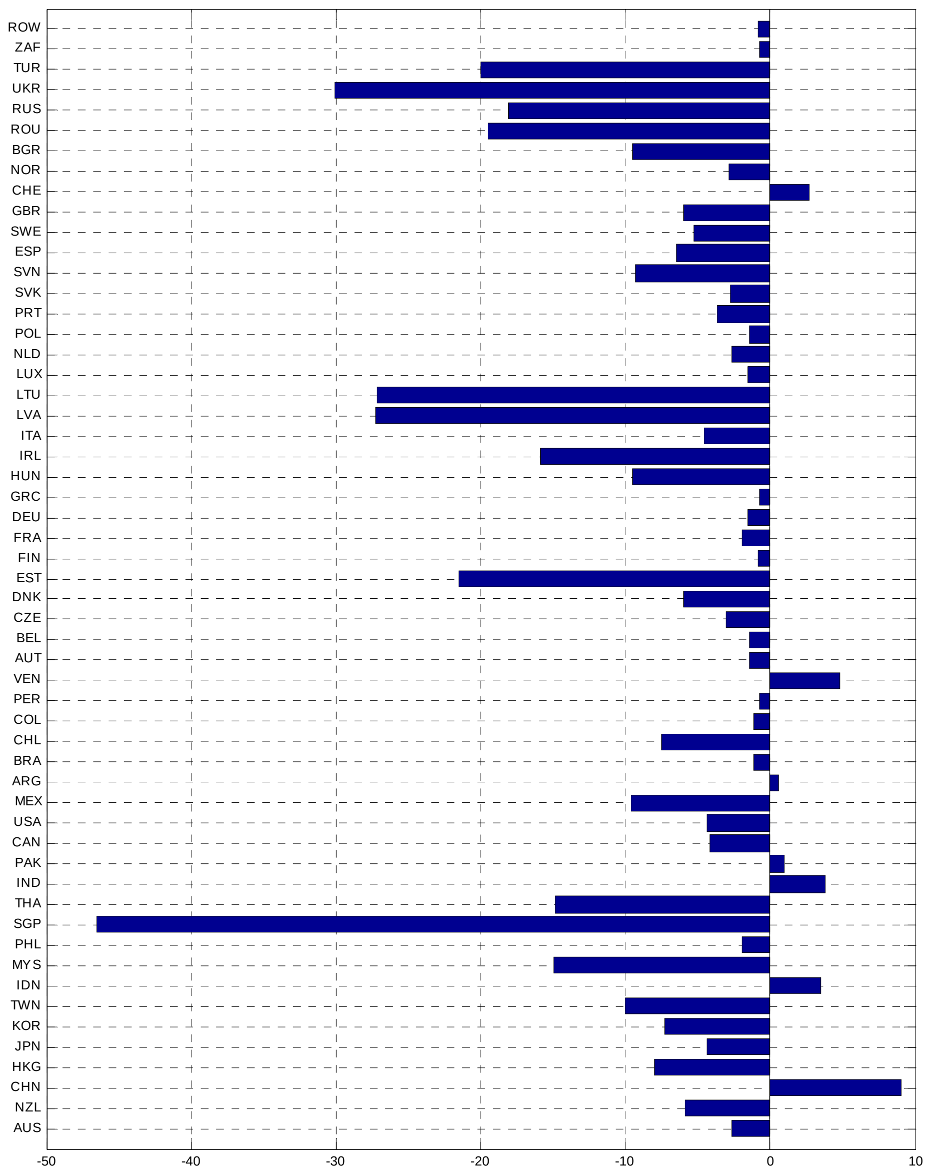

Figure 1: Change in real total domestic demand by country (%, 2009Q1/2008Q1). Source: IMF Global Data Source.

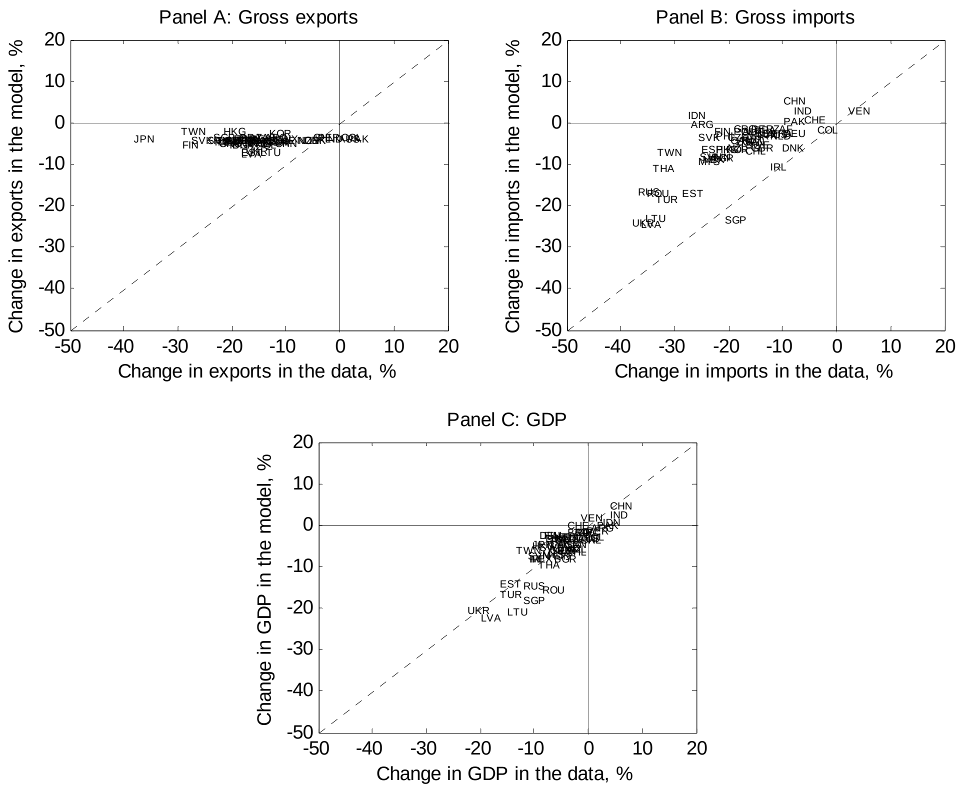

Figure 2: Comparison of the contraction in trade flows and GDP in the global 1-sector I-O model and data (%, 2009Q1/2008Q1). Source: IMF Global Data Source.

	Mean Square Error	Correlation (model,data)	% of change in data
1-SECTOR MODEL			
Exports	16	-0.24	26.4
Imports	11.9	0.68	26.4
GDP	0.8	0.76	96.7
2-SECTOR MODEL			
Exports	8.5	0.03	56.1
Imports	4.3	0.74	56.1
GDP	0.7	0.81	97.9

Figure 3: Selected statistics for the 1-sector and 2-sector I-O models' fit with data. Notes: Mean square error and correlation based on weighted growth rates. "Percent of change in data" refers to the sum of changes in the model, as percent of corresponging changes in data.

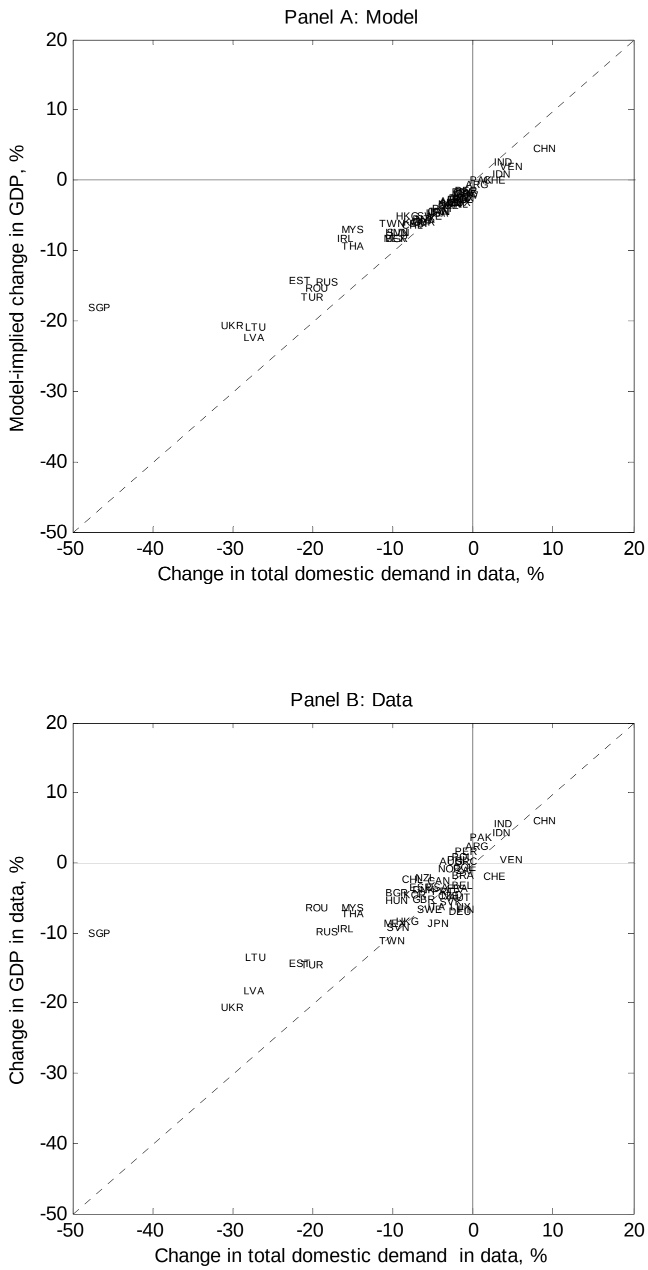

Figure 4: Comparison of changes real GDP and real total domestic demand in the model and data (%, 2009Q1/2008Q1). Source: IMF Global Data Source.

Country/ Region	Total domestic demand: % change in data	% change in model	(2)/(1) %	Gross output, % change in model	GDP, % change in model	Exports (% change in the model): gross =	final +	inter-mediate	Imports (% change in the model): gross=	final+	inter-mediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
PANEL A: 1-SECTOR GLOBAL INPUT-OUTPUT MODEL											
EU15	-3.65	0.00	*0*	-0.14	-0.14	-1.06	-0.40	-0.66	-0.09	0.00	-0.09
USA	-4.41	-4.41	*100*	-4.05	-4.05	-0.28	0.00	-0.28	-4.20	-1.90	-2.30
Em. Europe	-12.88	0.00	*0*	-0.11	-0.11	-0.33	-0.10	-0.23	-0.07	0.00	-0.07
NAFTA (ex. US)	-6.00	0.00	*0*	-0.95	-0.95	-3.29	-1.51	-1.78	-0.60	0.00	-0.60
China	9.01	0.00	*0*	-0.38	-0.38	-1.23	-0.61	-0.63	-0.32	0.00	-0.32
Japan	-4.38	0.00	*0*	-0.14	-0.14	-1.12	-0.53	-0.59	-0.09	0.00	-0.09
Em. Asia	-9.45	0.00	*0*	-0.39	-0.39	-0.87	-0.36	-0.51	-0.32	0.00	-0.32
South America	-0.82	0.00	*0*	-0.27	-0.27	-1.27	-0.28	-1.00	-0.18	0.00	-0.18
World	-3.76	-1.37	*36*	-1.25	-1.37	-1.00	-0.38	-0.62	-1.00	-0.38	-0.62
PANEL B: 2-SECTOR GLOBAL INPUT-OUTPUT MODEL											
EU15	-3.65	0.00	*0*	-0.34	-0.28	-2.31	-1.25	-1.06	-0.28	0.00	-0.28
USA	-4.41	-4.41	*100*	-3.96	-3.37	-1.03	0.00	-1.03	-9.70	-6.28	-3.42
Em. Europe	-12.88	0.00	*0*	-0.26	-0.22	-0.76	-0.28	-0.48	-0.22	0.00	-0.22
NAFTA (ex. US)	-6.00	0.00	*0*	-2.51	-2.06	-8.18	-5.26	-2.93	-2.33	0.00	-2.33
China	9.01	0.00	*0*	-1.12	-0.96	-3.35	-2.17	-1.18	-1.10	0.00	-1.10
Japan	-4.38	0.00	*0*	-0.47	-0.37	-3.09	-1.89	-1.20	-0.51	0.00	-0.51
Em. Asia	-9.45	0.00	*0*	-1.04	-0.85	-2.21	-1.11	-1.10	-1.06	0.00	-1.06
South America	-0.82	0.00	*0*	-0.71	-0.60	-2.93	-0.88	-2.04	-0.63	0.00	-0.63
World	-3.76	-1.37	*36*	-1.51	-1.37	-2.50	-1.26	-1.24	-2.50	-1.26	-1.24
PANEL C: 3-SECTOR GLOBAL INPUT-OUTPUT MODEL											
EU15	-3.65	0.00	*0*	-0.42	-0.34	-2.81	-1.58	-1.24	-0.37	0.00	-0.37
USA	-4.41	-4.41	*100*	-3.87	-3.21	-1.71	0.00	-1.71	-11.39	-7.86	-3.53
Em. Europe	-12.88	0.00	*0*	-0.28	-0.23	-0.88	-0.29	-0.58	-0.30	0.00	-0.30
NAFTA (ex. US)	-6.00	0.00	*0*	-3.02	-2.33	-10.62	-7.61	-3.01	-4.00	0.00	-4.00
China	9.01	0.00	*0*	-1.31	-1.06	-4.03	-2.31	-1.72	-1.57	0.00	-1.57
Japan	-4.38	0.00	*0*	-0.87	-0.65	-5.40	-3.42	-1.98	-0.80	0.00	-0.80
Em. Asia	-9.45	0.00	*0*	-1.44	-1.15	-3.20	-1.49	-1.71	-1.69	0.00	-1.69
South America	-0.82	0.00	*0*	-0.52	-0.43	-2.11	-0.60	-1.52	-0.48	0.00	-0.48
World	-3.76	-1.37	*36*	-1.58	-1.37	-3.07	-1.57	-1.50	-3.07	-1.57	-1.50

Figure 5: Global spillovers from the US-only demand shock in the 1, 2 and 3-sector global I-O model.

	Total domestic demand:			Gross output,	GDP,	Exports (% change in the model):			Imports (% change in the model):		
Country/ Region	% change in data	% change in model	(2)/(1) %	% change in model	% change in model	gross =	final +	inter-mediate	gross=	final +	inter-mediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
PANEL A: 1-SECTOR GLOBAL INPUT-OUTPUT MODEL											
EU15	-3.65	-3.65	*100*	-3.21	-3.21	-0.22	0.00	-0.22	-3.38	-1.35	-2.03
USA	-4.41	0.00	*0*	-0.09	-0.09	-0.98	-0.37	-0.60	-0.05	0.00	-0.05
Em. Europe	-12.88	0.00	*0*	-0.67	-0.65	-2.06	-0.87	-1.18	-0.47	0.00	-0.47
NAFTA (ex. US)	-6.00	0.00	*0*	-0.09	-0.10	-0.33	-0.09	-0.24	-0.06	0.00	-0.06
China	9.01	0.00	*0*	-0.28	-0.28	-0.89	-0.39	-0.50	-0.23	0.00	-0.23
Japan	-4.38	0.00	*0*	-0.09	-0.09	-0.74	-0.29	-0.45	-0.06	0.00	-0.06
Em. Asia	-9.45	0.00	*0*	-0.33	-0.32	-0.73	-0.26	-0.48	-0.28	0.00	-0.28
South America	-0.82	0.00	*0*	-0.19	-0.19	-0.87	-0.27	-0.60	-0.13	0.00	-0.13
World	-3.76	-1.03	*27*	-1.08	-1.03	-0.84	-0.28	-0.56	-0.84	-0.28	-0.56
PANEL B: 2-SECTOR GLOBAL INPUT-OUTPUT MODEL											
EU15	-3.65	-3.65	*100*	-3.40	-2.96	-0.47	0.00	-0.47	-5.30	-2.59	-2.71
USA	-4.41	0.00	*0*	-0.14	-0.12	-1.45	-0.63	-0.82	-0.13	0.00	-0.13
Em. Europe	-12.88	0.00	*0*	-1.22	-1.08	-3.60	-1.90	-1.70	-1.08	0.00	-1.08
NAFTA (ex. US)	-6.00	0.00	*0*	-0.16	-0.14	-0.53	-0.14	-0.38	-0.14	0.00	-0.14
China	9.01	0.00	*0*	-0.54	-0.47	-1.63	-0.87	-0.76	-0.53	0.00	-0.53
Japan	-4.38	0.00	*0*	-0.20	-0.16	-1.35	-0.63	-0.72	-0.22	0.00	-0.22
Em. Asia	-9.45	0.00	*0*	-0.57	-0.48	-1.24	-0.50	-0.74	-0.59	0.00	-0.59
South America	-0.82	0.00	*0*	-0.33	-0.28	-1.37	-0.43	-0.94	-0.29	0.00	-0.29
World	-3.76	-1.03	*27*	-1.25	-1.03	-1.42	-0.54	-0.88	-1.42	-0.54	-0.88

Figure 6: Global spillovers from the EU15-only demand shock in the 1-sector and 2-sector global I-O models.

	Domestic demand	Gross Output	GDP	Exports			Imports		
				Total	*Final*	*Interme-diate*	Total	*Final*	*Interme-diate*
EU15	28	29	28	20	*8*	*12*	21	*8*	*13*
USA	31	27	30	14	*5*	*9*	20	*9*	*11*
Emerging Europe	3	3	2	5	*2*	*3*	6	*2*	*4*
NAFTA (excl. US)	4	3	4	6	*3*	*4*	6	*2*	*4*
China	4	6	4	8	*4*	*5*	7	*1*	*6*
Japan	12	11	12	8	*3*	*5*	7	*2*	*4*
Emerging Asia	4	6	5	15	*5*	*10*	13	*3*	*10*
South America	3	3	3	3	*1*	*2*	2	*1*	*1*
Other countries	12	12	13	20	*5*	*15*	18	*8*	*10*
World	100	100	100	100	*36*	*64*	100	*36*	*64*

Figure 7: Regions' shares in world totals (%, GTAP 7 dataset)

Rountry-region \ Model specification	1 sector	2 sectors	3 sectors
Panel A: Shock to domestic demand in the U.S.			
EU15	2.8	5.8	6.9
USA	88.2	73.5	70.0
Emerging Europe	0.2	0.4	0.4
NAFTA (excl. US)	2.4	5.3	6.0
China	1.2	3.0	3.3
Japan	1.2	3.2	5.6
Emerging Asia	1.4	3.0	4.1
South America	0.6	1.2	0.9
Rest of the world	2.0	4.6	2.8
World total	100	100	100
Panel B: Shock to domestic demand in the EU15			
EU15	87.1	80.3	n.a.
USA	2.5	3.4	n.a.
Emerging Europe	1.6	2.5	n.a.
NAFTA (excl. US)	0.3	0.5	n.a.
China	1.2	1.9	n.a.
Japan	1.1	1.8	n.a.
Emerging Asia	1.5	2.3	n.a.
South America	0.5	0.7	n.a.
Rest of the world	4.3	6.5	n.a.
World total	100	100	n.a.

Figure 8: Geographical allocation of changes in world GDP in response to the US and EU15 demand shocks, as implied by the 1, 2 and 3-sector global I-O models (% of tatal change in world GDP).

Country/ Region	Total domestic demand: % change in data	% change in model	(2)/(1) %	Gross output, % change in model	GDP, % change in model	Exports (% change in the model): gross =	final +	inter-mediate	Imports (% change in the model): gross=	final +	inter-mediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
PANEL A: 1-SECTOR GLOBAL INPUT-OUTPUT MODEL											
EU15	-3.65	-3.65	100	-3.77	-3.76	-4.01	-1.68	-2.33	-3.69	-1.39	-2.29
USA	-4.41	-4.41	100	-4.41	-4.41	-4.49	-1.89	-2.60	-4.41	-1.90	-2.51
Em. Europe	-12.88	-12.88	100	-9.54	-10.46	-4.67	-1.89	-2.77	-10.59	-4.55	-6.06
NAFTA (ex. US)	-6.00	-6.00	100	-5.46	-5.42	-4.19	-1.80	-2.40	-5.84	-2.29	-3.55
China	9.01	9.01	100	4.74	4.74	-4.74	-2.22	-2.52	5.49	1.57	3.92
Japan	-4.38	-4.38	100	-4.29	-4.29	-3.65	-1.69	-1.96	-4.32	-1.57	-2.76
Em. Asia	-9.45	-9.45	100	-5.93	-5.65	-3.04	-1.34	-1.70	-8.88	-3.17	-5.71
South America	-0.82	-0.82	100	-1.40	-1.34	-3.45	-1.07	-2.38	-1.47	-0.39	-1.08
World	-3.76	-3.76	100	-3.67	-3.76	-4.01	-1.62	-2.40	-4.01	-1.62	-2.40
PANEL B: 2-SECTOR GLOBAL INPUT-OUTPUT MODEL											
EU15	-3.65	-3.65	100	-4.81	-4.08	-7.96	-4.33	-3.63	-6.61	-2.82	-3.79
USA	-4.41	-4.41	100	-4.78	-4.03	-9.12	-4.94	-4.18	-10.49	-6.28	-4.21
Em. Europe	-12.88	-12.88	100	-9.76	-9.22	-8.83	-4.63	-4.20	-16.97	-9.29	-7.68
NAFTA (ex. US)	-6.00	-6.00	100	-6.39	-5.45	-10.31	-6.00	-4.32	-11.78	-6.10	-5.68
China	9.01	9.01	100	2.00	2.16	-11.71	-7.49	-4.22	4.90	3.43	1.47
Japan	-4.38	-4.38	100	-5.45	-4.45	-9.75	-5.97	-3.77	-10.32	-4.85	-5.47
Em. Asia	-9.45	-9.45	100	-6.66	-4.88	-7.84	-4.34	-3.50	-16.12	-8.44	-7.68
South America	-0.82	-0.82	100	-2.88	-1.57	-8.68	-3.67	-5.01	-7.73	-4.18	-3.55
World	-3.76	-3.76	100	-4.57	-3.76	-8.71	-4.57	-4.14	-8.71	-4.57	-4.14

Figure 9: Summary of results from 1-sector and 2-sector global I-O models for regional/country groupings and the world as a whole, with all demand shocks included.

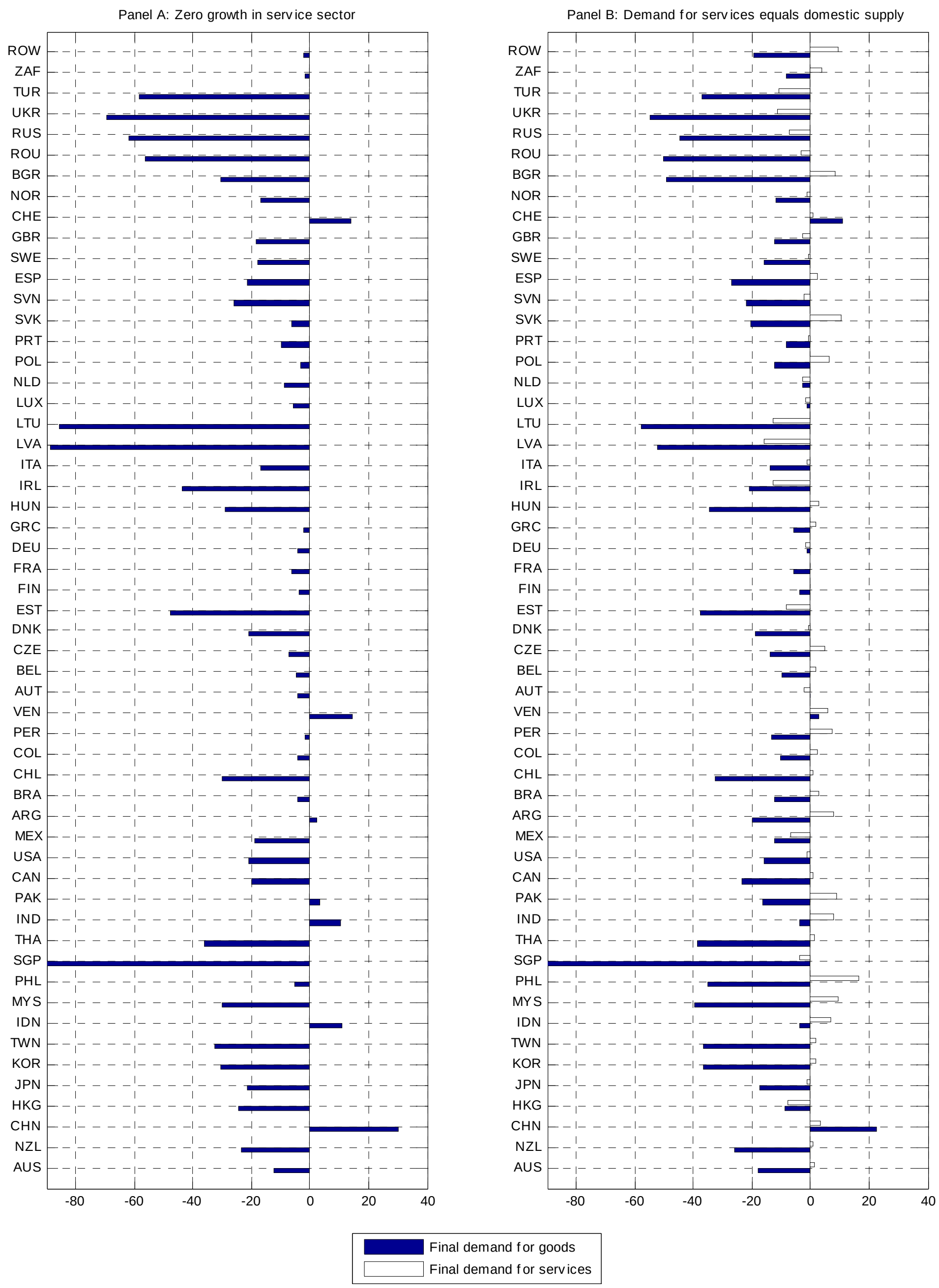

Figure 10: Real demand growth rates by coutnry and sector (%, 2009Q1/2008Q1). Source: IMF Global Data Source.

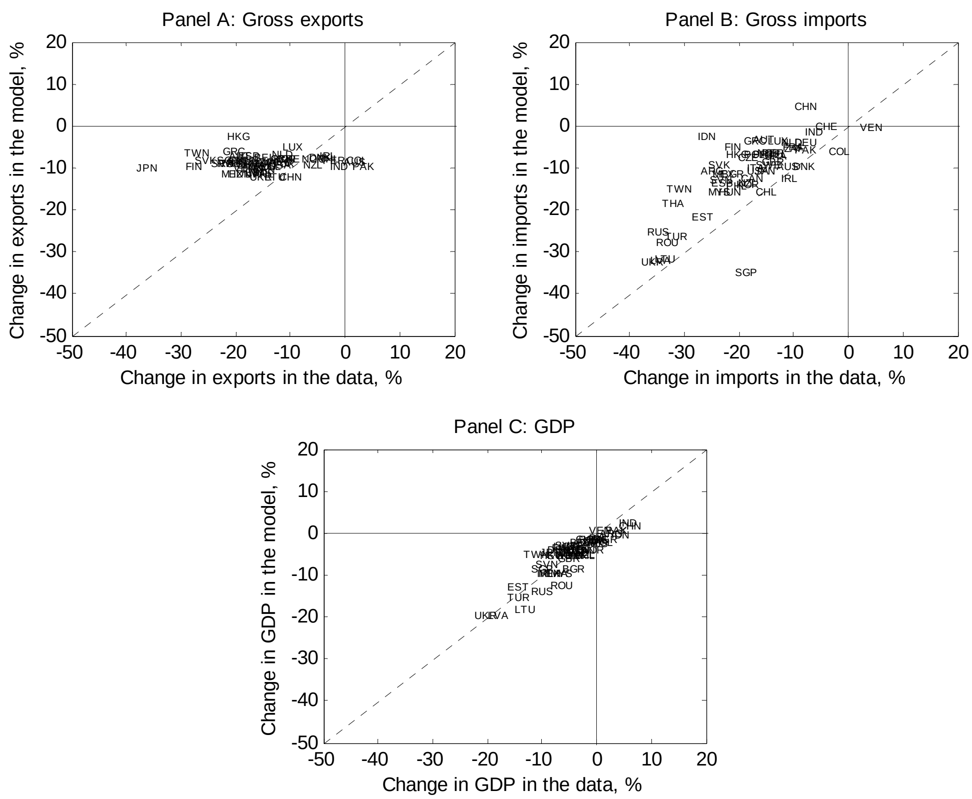

Figure 11: Comparison of the contraction in trade flows and GDP in the global 2-sector I-O model and data (%, 2009Q1/2008Q1). Source: IMF Global Data Source.

References

Altomonte, Carlo, and Gianmarco I.P. Ottaviano. 2009. "Resilient to the crisis? Global supply chains and trade flows." Chapter 11 of *The Great Trade Collapse: Causes, Consequences, and Prospects*, edited by Richard Baldwin, 95–100. VoxEU.org.

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

Amiti, Mary, and David Weinstein. 2009. "Exports and Financial Shocks." NBER Working Paper 15556.

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

Backus, David, Patrick Kehoe, and Finn Kydland. 1995. "Dynamics of the Trade Balance and the Terms of Trade: The J-Curve?" *The American Economic Review* 84 (1): 84–103.

Baldwin, Richard, ed. 2009. *The great trade collapse: Causes, Consequences and Prospects.* VoxEU.org.

Baldwin, Richard, and Simon Evenett, eds. 2009. *The collapse of global trade, murky protectionism, and the crisis.* VoxEU.org.

Benassy-Quere, Agnes, Yvan Decreux, Lionel Fontagne, and David Khoudour-Casteras. 2009. "Economic Crisis and Global Supply Chains." CEPII Document de Travail, No. 2009-15 (July).

Burstein, Ariel, Christopher Kurz, and Linda Tesar. 2008. "Trade, Production Sharing, and the International Transmission of Business Cycles." *Journal of Monetary Economics* 55:775–795.

Bussiere, Matthieu, Alexander Chudik, and Guila Sestieri. 2009. "Modelling Global Trade Flows: Results from a GVAR Model." European Central Bank, Working Paper Series 1087.

Cheung, Calista, and Stephanie Guichard. 2009. "Understanding the World Trade Collapse." OECD Economics Department Working Papers No. 729.

Chor, Davin, and Kalina Manova. 2009. "Off the Cliff and Back: Credit Conditions and Internatoinal Trade during the Global Financial Crisis." Unpublished Manuscript, Stanford University.

Daudin, Guillaume, Christine Rifflart, and Danielle Schweisguth. 2009. "Who Produces for Whom in the World Economy?" OFCE Document de travail, No. 2009-18.

DiGiovanni, Julian, and Andrei Levchenko. forthcoming. "Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement." *American Economic Journal: Macroeconomics*. Unpublished Manuscript, International Monetary Fund.

Eaton, Jonathan, Sam Kortum, Brent Neiman, and John Romalis. 2009. "Trade and the Great Recession." Unpublished Manuscript, University of Chicago.

Evenett, Simon. 2009. "Crisis-era protectionism one year after the Washington G20 meeting: A GTA update, some new analysis, and a few words of caution." In *The Great Trade Collapse: Causes, Consequences, and Prospects*, edited by Richard Baldwin. VoxEU.org.

Freund, Caroline. 2009. "The Trade Response to Global Downturns: Historical Evidence." World Bank Policy Reserach Working Paper 5015.

Fukao, Kyoji, and Tangjun Yuan. 2009. "Why Is Japan So Heavily Affected by the Global Economic Crisis? An Analysis Based on the Asian International Input-Output Tables." http://www.voxeu.org/index.php?q=node/3637.

Hummels, David, Jun Ishii, and Kei-Mu Yi. 2001. "The Nature and Growth of Vertical Specialization in World Trade." *Journal of International Economics* 54:75–96.

Iacovone, Leonardo, and Veronika Zavacka. 2009. "Banking crises and exports: lessons from the past." World Bank Policy Research Working Paper No. 5016.

Irwin, Douglas A. 2002. "Long-run trends in world trade and income." *World Trade Review* 1 (1): 89–100.

Jacks, David, Christopher Meissner, and Denis Novy. 2009. "The role of trade costs in the great trade collapse." In *The Great Trade Collapse: Causes, Consequences, and Prospects*, edited by Richard Baldwin. VoxEU.org.

Johnson, Robert C., and Guillermo Noguera. 2009. "Accounting for Intermediates: Production Sharing and Trade in Value Added." Unpublished Manuscript, Dartmouth College.

Kose, Ayhan M., and Kei-Mu Yi. 2006. "Can the standard internatoinal business cycle model explain the relation between trae and comovement?" *Journal of International Economics* 68 (2): 267–295.

Levchenko, Andrei, Logan Lewis, and Linda Tesar. 2009. "The Collapse of International Trade During the 2008-2009 Crisis." Unpublished Manuscript, University of Michigan.

Narayanan, Badri, and Terrie Walmsley, eds. 2008. *Global Trade, Assistance, and Production: The GTAP 7 Data Base*. Center for Global Trade Analysis, Purdue University.

ORourke, Kevin. 2009. "Collapsing Trade in a Barbie World." http://www.irisheconomy.ie/index.php/2009/06/18/collapsing-trade-in-a-barbie-world.

Tanaka, Kiyoyasu. 2009. "Trade Collapse and Vertical Foreign Direct Investment." http://voxeu.org/index.php?q=node/3537.

Tempest, Rone. 1996. "Barbie and the World Economy." *Los Angeles Times*, vol. Sept. 22.

Wang, Zhi, William Powers, and Shang-Jin Wei. 2009. "Value Chains in East Asian Production Networks: An International Input-Output Model Based Analysis." USITC Working Paper, No. 2009-10-C.

Yi, Kei-Mu. 2003. "Can Vertical Specialization Explain the Growth of World Trade?" *Journal of Political Economy* 111:52–102.

———. 2009. "The Collapse of Global Trade: The Role of Vertical Specialisation." In *The Collapse of Global Trade, Murky Protectionism, and the Crisis: Recommendations for the G20*, edited by Richard Baldwin and Simon Evenett, 45–48. VoxEU.org.