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Demand Spillovers and the Collapse of Trade in the Global Recession

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Abstract

This paper uses a global input-output framework to quantify US and EU demand spillovers and the elasticity of world trade to GDP during the global recession of 2008-2009. We find that 20-30 percent of the decline in the US and EU demand was borne by foreign countries, with NAFTA, Emerging Europe, and Asia hit hardest. Allowing demand to change in all countries simultaneously, our framework delivers an elasticity of world trade to GDP of nearly 3. Thus, demand alone can account for 70 percent of the trade collapse. Large changes in demand for durables play an important role in driving these results.

JEL Classification Numbers: F4; F1

Keywords: Demand spillovers; trade collapse; input-output model; trade elasticity

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I. INTRODUCTION

The Global Recession of 2008-2009 was sudden, severe, and synchronized. In the months preceding September 2008, the housing and financial sectors in the United States and several European countries experienced increasingly negative outcomes. During this period, there was very little spillover to other sectors and countries. However, beginning in September, the crisis in these few sectors and countries spread suddenly to encompass virtually all sectors and all countries. In the fourth quarter of 2008, real world GDP contracted by 6.5 percent (annualized), and it fell a further 7.9 percent in the ensuing quarter, among the most severe declines since the end of World War 2. Nor was the decline in output limited to the largest economies. GDP fell in countries directly exposed to the U.S. and Europe, as well as in countries with minimal direct exposure.[1]

Accompanying the severe decline in world GDP, world trade also collapsed. Real world trade fell by approximately 15% between 2008Q1 and 2009Q1, exceeding the fall in real world GDP by a factor of roughly four.[2] The synchronized decline in output across countries and the collapse of world trade are obviously closely related. Trade transmits country or sector-specific shocks abroad. For example, the "demand spillover" in standard open-economy macroeconomic models that cause output to comove across countries are channeled through trade. More fundamentally, changes in output and demand automatically imply changes in imports and exports in any trade model that implies the gravity equation. Taking the collapse of output or demand as given, a collapse of trade naturally follows.

Traditionally, these theoretical links between trade and output have been thought of in terms of final goods. A large and increasing share of trade, however, involves goods at different stages of the sequential production process. Consequently, attention has shifted to studying explicitly the roles of production sharing and of trade in intermediate goods.[3] This shift in perspective is important because trade in intermediate goods has many implications for understanding the transmission of shocks across borders and the empirical relationship between demand, trade, and production.

In this paper, we focus on three key implications.[4] First, the presence of traded intermediate goods implies that measures of aggregate openness and bilateral exposure to foreign demand

[1]Among the 57 countries covered by the IMF's GDS database, 53 suffered declines in output in these 2 quarters. Only China, India, Indonesia and Pakistan had higher real GDP in 2009Q1 than in 2008Q3. Source: IMF-GDS.

[2]Source: IMF-GDS.

[3]See Hummels, Ishii, and Yi (2001), Miroudot and Ragoussis (2009), or Amador and Cabral (2009) for evidence on rising vertical specialization.

[4]We do not address many other implications of intermediate goods trade. For example, we do not address how de-fragmentation of international production chains in response to shocks or increased trading frictions could lower trade. Thus, the mechanism highlighted by Yi (2003) is not covered in this paper. In addition, we do not study how

changes must be modified. For example, exposure to changes in foreign demand depends on the share of GDP that is absorbed into final demand abroad, not on the share of exports in GDP. Moreover, bilateral exports do not determine exposure to specific foreign destinations, because changes in demand for exports from a particular source (e.g., China) may be passed upstream through the production chain to input suppliers (e.g., Korea). Second, when sectors differ in the extent of their integration into cross-border production chains, the sectoral composition of demand changes will matter for the overall response of trade and the transmission of those changes. Third, traded intermediate inputs tend to cause exports and imports to move together for a particular country, because imported inputs are used to produce exports.

To capture these influences, we need to measure intermediates trade and trace out international production chains. To that end, we combine national input-output tables with bilateral trade data to construct a synthetic global bilateral input-output table, (hereafter, global input-output table) as in Johnson and Noguera (2009).[5] There are two components of this framework. First, the global input-output matrix is an $(NS \times NS)$ table, with S sectors and N countries, that records the approximate value of goods produced in sector s country i that are used as intermediates to produce goods in sector t, country j. Second, the final demand vector for each destination is an $(NS \times 1)$ vector indicating the value of final goods purchased from sector s in source i. Together, these two objects indicate 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 input-output framework links demand to production via trade flows.[6] Therefore, we can use it to trace demand changes through the production structure. Specifically, we manipulate the global input-output framework to develop expressions for a country's production, exports, and imports as weighted averages of sector and country-specific demand changes. The weight on individual elements of the vector of demand changes depends on both intermediate and final goods linkages across sectors and countries. Because each variable – production, exports, or imports – has a unique set of weights, each responds differently to a given vector of demand changes. These weights can be thought of as partial elasticities; they translate proportional changes in demand in a particular sector and destination into proportional changes in production and trade (holding demand in all other countries and sectors constant). One contribution of the paper is to compute these elasticities using our detailed global input-output framework.

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low elasticities of substitution across stages in a production chain might amplify shock transmission, a point that has been emphasized by Burstein, Kurz, and Tesar (2008).

[5] Related frameworks have been developed by Trefler and Zhu (2005) to study the factor content of trade and Daudin, Rifflart, and Schweisguth (2009) to study regionalization of trade patterns.

[6] Because we use national accounts definitions in classifying intermediates and final goods in constructing this table, the data can be matched to standard macroeconomic data.

With these partial elasticities in hand, we conduct two quantitative exercises that shed light on several key issues in the transmission of the crisis and in the trade collapse. First, we study how changes in final demand in the U.S. and Europe generated changes in trade and production at home and abroad.[7] Second, we measure the elasticity of world trade to world production implied by our framework given the realized changes in demand in all countries. In both exercises, we focus on the important role that sectoral composition of demand changes plays in explaining the strength of the trade transmission mechanism and the magnitude of the trade response to changes in final demand.

We find that changes in final demand in the U.S. and the EU15 during the crisis were strongly transmitted abroad via international trade. For the U.S., we estimate that 27% of the fall in U.S. demand and 18% of the fall in total EU15 demand was borne by foreign countries in terms of lower GDP. (Note that in our exercises, we hold constant foreign final demand.) The strength of the spillovers reflects the important role played by durable goods. The change in demand for durables was roughly 4-6 times larger than for non-durables and services. In addition, durable goods are intensively traded, as both final goods and intermediate goods, compared to non-durables and services.

At the regional and bilateral levels, spillovers were naturally strongest for countries with strong trade linkages with the U.S. and the EU15. Further, because the U.S. and EU15 together constitute 60% of world GDP in our data, countries with the strongest linkages suffered large output declines. NAFTA (Mexico and Canada) GDP falls by 70% as much as U.S. GDP following the decline in U.S. demand, while GDP in Emerging Europe falls by 35% of the fall in EU15 GDP following the decline in EU15 demand. Spillovers were also strong for countries specialized in production of durables, such as Japan, China, and Emerging Asia.

As the transmission channel for these spillovers, international trade suffered large declines as well. These declines reflect both final and intermediate goods linkages. For example, both exports and imports for NAFTA countries fell substantially following the change in U.S. demand (even though non-U.S. demand is held constant). Imports declined owing to the use of imported intermediates in production of exports. Imported intermediates also declined substantially in China and Emerging Asia following the fall in U.S. and E.U. demand.

Turning to the overall decline of world trade, we find that the elasticity of world trade to world GDP is 2.8 in our framework. We obtain this elasticity by feeding estimated demand changes

[7] We compute the response of trade and production to realized US and European demand changes, not identified idiosyncratic shocks. Realized changes combine the effect of exogenous shocks and the endogenous propagation of those shocks, which we do not model explicitly.

for durables, nondurables, and services for all countries through the input-output framework simultaneously. This elasticity lies between two natural benchmarks. One benchmark value is one, which would arise if all demand changes were the same size across sectors and countries. The fact that the elasticity is substantially above one indicates that the changes in (final) demand were not symmetric across sectors and countries. The second benchmark is the observed elasticity (about 4) in the crisis episode. We are able to "explain" 70% (2.8/4) of the trade collapse via changes in (final) demand alone, despite the fact that our framework embeds strong proportionality assumptions at the country and sector level. Importantly, we document that the estimated elasticity of trade to GDP is high because we allow asymmetries in demand changes across sectors. Combined with our previous results, we conclude that models that fail to appropriately disaggregate demand changes will not generate quantitatively realistic trade elasticities.

The next section of the paper reviews the related empirical research. Section III lays out our framework and discusses the data. The following section develops expressions for elasticities of output and trade to sectoral changes in demand. Section V then applies our framework to the Global Recession. The final section concludes.

II. RELATED EMPIRICAL RESEARCH

Our work contributes to an active contemporary literature on trade and propagation of the Global Recession, which itself builds on a number of recent developments at the intersection of international trade and international macroeconomics.

First, in focusing on the role of intermediate goods trade, we add to a recent literature quantifying the role of intermediate goods in the transmission of shocks across borders. Di Giovanni and Levchenko (2010) and Burstein, Kurz, and Tesar (2008) argue that bilateral trade in intermediates helps explain the positive association between bilateral trade and the correlation of output at the sector level. We highlight the importance of intermediate goods linkages for tracking shocks through the production structure to the sectors and countries that ultimately produce the final goods that are absorbed in a particular destination. In this sense, we argue that the multilateral structure of production sharing and cross-sector intermediate goods linkages matters above and beyond bilateral sector-to-sector linkages.

Second, we contribute to a growing consensus that changes in demand were a central determinant of the collapse in trade. Specifically, we provide evidence that the large decline in trade could be rationalized by a large fall in the demand for durables. This theme surfaces in Alessandria, Kaboski, and Midrigan (2010); Eaton, Kortum, Neiman, and Romalis (2010; Engel and Wang

(2009); Levchenko, Lewis, and Tesar (2009); Wang (2010), and many contributions to the VoxEU e-book on the trade collapse edited by Richard Baldwin.[8] While we emphasize the role of demand changes in driving trade, we do not necessarily downplay the role of increased trade frictions, such as heightened policy barriers and/or trade credit disruptions, in explaining the trade collapse.[9] These frictions may well be quite important in accounting for residual declines in trade and bilateral re-orientations of trade that our framework does not capture.

Among these many recent contributions, our work is most closely related to Eaton, Kortum, Neiman, and Romalis (2010), so we pause to discuss the differences in greater detail.[10] The differences can be divided into two categories: structural and analytical. The first structural difference is that we directly measure bilateral intermediate goods linkages. Eaton et al. (2010) instead assume that bilateral trade is equally intermediate goods intensive across all trade partners within each aggregate sector. The second structural difference is that Eaton et al. (2010) allow quantity choices to depend on prices by specifying a partial equilibrium gravity model for trade flows. We shut down the dependence of quantity choices on relative prices via Leontief technology and preferences, with benefits and costs discussed when we introduce these assumptions below. The first analytical difference is that Eaton et al. (2010) perform an accounting exercise in which they decompose the fall in trade into components due to changes in demand and trade frictions. We instead predict values of trade based on feeding demand changes through our framework. The second analytical difference is that we address a number of distinct questions not touched on by Eaton et al. (2010) regarding the elasticity of trade to demand changes, the transmission of demand changes abroad, and the elasticity of world trade to world GDP.’

Lastly, our work also contributes to the recent literature attempting to explain the distribution of the impact of the crisis across countries. Blanchard, Faruqee, and Das (2010), Imbs (2009), and Lane and Milesi-Ferretti (2010) all point to trade as a key transmission vector of the crisis. Using a variety of specifications and control variables, these papers all present evidence that overall trade openness is a robust predictor of the severity of recession in particular countries. We add to this work by quantifying how changes in US and European demand are transmitted outward to particular destinations via trade linkages.

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[8] Borchert and Mattoo (2009) note that declines in services trade have been comparatively small.

[9] See Evenett (2009) on measured trade barriers, or Eaton, Kortum, Neiman, and Romalis (2009) and Jacks, Meissner, and Novy (2009) on gravity-based estimates of trade barriers. See Amiti and Weinstein (2009), Iacovone and Zavacka (2009), and Chor and Manova (2009) on credit frictions.

[10] The main point of similarity is that we, like Eaton et al. (2010), feed data-based demand changes through a model. Our procedure for computing demand changes differs, however, from their work.

III. Demand, Output, and Trade

A. The Framework

To link changes in real demand to output and trade, we need to take a stand on some structural features of the underlying economy. (We use 'demand' to denote 'final demand'.) 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. Output in each country is produced by combining local factor inputs with domestic and imported intermediate goods. Let the quantity of output in sector s of country i be denoted by $q_i(s)$. Let the quantity of intermediates from sector s in country i used in production of output in sector t in country j be $q^m_{ij}(s,t)$ and the quantity of final goods from sector s in country i absorbed in destination j be $q^d_{ij}(s)$. Then market clearing is given by: $q_i(s) = \sum_j \sum_t q^m_{ij}(s,t) + \sum_j q^d_{ij}(s)$.

We can then rewrite this market clearing condition in terms of percentage changes across two points in time:

$$\widehat{q}_i(s) = \sum_j \sum_t \left[\frac{q^m_{ij}(s,t)}{q_i(s)}\right] \widehat{q}^m_{ij}(s,t) + \sum_j \left[\frac{q^d_{ij}(s)}{q_i(s)}\right] \widehat{q}^d_{ij}(s), \tag{1}$$

where $\widehat{x} \equiv (\frac{x_t - x_{t-1}}{x_{t-1}})$ denotes the percentage change in variable x. There are two hurdles in using this framework for our analysis.

First, we need measures of quantity shares $\frac{q^m_{ij}(s,t)}{q_i(s)}$ and $\frac{q^d_{ij}(s)}{q_i(s)}$ for all i, j, s, t. If we observe shipment values computed at a common set of prices, then we can equate quantity shares to value shares. That is, if $p_i(s)$ is a common price used to compute the value of all shipments, then $\frac{q^m_{ij}(s,t)}{q_i(s)} = \frac{p_i(s)q^m_{ij}(s,t)}{p_i(s)q_i(s)}$ and $\frac{q^d_{ij}(s)}{q_i(s)} = \frac{p_i(s)q^d_{ij}(s)}{p_i(s)q_i(s)}$. We therefore insert value shares computed in this manner from our benchmark data in place of the quantity shares to get:

$$\widehat{q}_i(s) = \sum_j \sum_t \left[\frac{m_{ij}(s,t)}{y_i(s)}\right] \widehat{q}^m_{ij}(s,t) + \sum_j \left[\frac{d_{ij}(s)}{y_i(s)}\right] \widehat{q}^d_{ij}(s), \tag{2}$$

with $y_i(s) \equiv p_i(s)q_i(s)$, $m_{ij}(s,t) \equiv p_i(s)q^m_{ij}(s,t)$, and $d_{ij}(s) \equiv p_i(s)q^d_{ij}(s)$.

Second, we do not directly observe either $\widehat{q}^m_{ij}(s,t)$ or $\widehat{q}^d_{ij}(s)$. Therefore, we proceed to make additional assumptions to tie these to observables. First, we assume that the production function is Leontief 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: $\widehat{q}^m_{ij}(s,t) = \widehat{q}_j(t)$. Second, we assume that preferences are also Leontief 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 in real demand for output from sector s in country j: $\widehat{q}^c_{ij}(s) = \widehat{q}^d_j(s)$. Because we take the reduction in final demand from data, we do not need to take a stand on other aspects of preferences.

These assumptions imply that both final and intermediate input demand changes are sector, not source specific.[11] In fixing these quantity shares, we tie our own hands with attendant costs and benefits. The main benefit is that we can use available aggregate data to study the propagation of the crisis and trade collapse. A secondary benefit is that by shutting down the response of quantity shares to relative prices, we implicitly narrow the scope of our analysis to ask whether we can explain the collapse of trade solely based on the composition of demand changes across sectors and countries. The main cost is obviously loss of realism, as bilateral input sourcing and final goods shipments surely responded to relative price adjustments and changes in border frictions during the crisis. These adjustments are one reason why output and trade changes in our framework will not match the data exactly. The failure to capture these responses may not be a large loss, however. Levchenko, Lewis, and Tesar (2009) report that bilateral export and import shares did not change substantially for the United States during the crisis. Moreover, Behrens, Corcos and Mion (2010) argue that the share of intermediates sourced from abroad changed little in Belgian firm level data.

With these assumptions, we can then re-write equation (2) as:

$$\widehat{q}_i(s) = \sum_j \sum_t \left[\frac{m_{ij}(s,t)}{y_i(s)}\right] \widehat{q}_j(t) + \sum_j \left[\frac{d_{ij}(s)}{y_i(s)}\right] \widehat{q}^d_j(s) \tag{3}$$

Stacking and manipulating these expressions for many countries, we show in Appendix A that:

$$\begin{pmatrix} \widehat{q}_1 \\ \widehat{q}_2 \\ \vdots \\ \widehat{q}_N \end{pmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} \\ S_{21} & S_{22} & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ S_{N1} & \cdots & \cdots & S_{NN} \end{bmatrix} \begin{pmatrix} \widehat{q}^d_1 \\ \widehat{q}^d_2 \\ \vdots \\ \widehat{q}^d_N \end{pmatrix}, \tag{4}$$

where S_{ij} are matrices with elements $S_{ij}(s,t)$ recording the share of output from sector s in country i used directly or indirectly to produce final goods of sector t that are absorbed in country j.

[11] For example, if aggregate final 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. Similarly, if output falls by 1%, input purchases fall by 1% for all sector and country sources. To relax these assumption we would need data on consumption and input use changes broken down by origin of the goods, which is not generally available.

These share matrices depend on the structure of both final and intermediate goods linkages within and across countries. We discuss this interpretation at length in Appendix A.

We calculate real changes in aggregate output, exports, and imports using Laspeyres quantity indices.[12] Aggregate real output growth is given by: $\widehat{Q}_i = \sum_s (y_i(s)/y_i)\widehat{q}_i(s)$, where $y_i = \sum_s y_i(s)$. Aggregate real export and import growth are then given by:

$$\widehat{EX}_i = \sum_{j\neq i}\sum_s \left[\sum_t \left[\frac{m_{ij}(s,t)}{ex_i}\right]\widehat{q}_j(t) + \left[\frac{d_{ij}(s)}{ex_i}\right]\widehat{q}_j^d(s)\right] \tag{5}$$

$$\widehat{IM}_i = \sum_{j\neq i}\sum_s \left[\sum_t \left[\frac{m_{ji}(s,t)}{im_i}\right]\widehat{q}_i(t) + \left[\frac{d_{ji}(s)}{im_i}\right]\widehat{q}_i^d(s)\right], \tag{6}$$

where ex_i and im_i are the value of total exports and imports in the base period.

B. Example: Three Countries, One Good Per Country

We proceed directly to an example to fix ideas. Suppose that there are three countries, and that each country produces a single aggregate good. Then we can write real output in each country as a function of aggregate demand changes as follows:

$$\begin{pmatrix}\widehat{q}_1\\ \widehat{q}_2\\ \widehat{q}_3\end{pmatrix} = \begin{bmatrix} s_{11} & s_{12} & s_{13}\\ s_{21} & s_{22} & s_{23}\\ s_{31} & s_{32} & s_{33}\end{bmatrix}\begin{pmatrix}\widehat{q}_1^d\\ \widehat{q}_2^d\\ \widehat{q}_3^d\end{pmatrix}, \tag{7}$$

where s_{ij} is the share of gross output from country i that is used directly or indirectly in producing final goods absorbed in country j.

Looking at source country i, output can be written as:

$$\widehat{q}_i = s_{ii}\widehat{q}_i^d + \sum_{j\neq i} s_{ij}\widehat{q}_j^d \qquad \text{(8)a}$$

$$= s_{ii}\widehat{q}_i^d + (1-s_{ii})\widehat{\overline{q}}_{-i}, \quad \text{where } \widehat{\overline{q}}_{-i} = \sum_{j\neq i}\frac{s_{ij}}{1-s_{ii}}\widehat{q}_j^d \qquad \text{(8)b}$$

These shares attached to demand changes can be interpreted as elasticities describing how output responds to demand changes in each destination. Importantly, these shares are not export shares,

[12] Because we have input-output data only for the base period, we are constrained to initial period prices and share data.

but rather a function of final and intermediate goods linkages. 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 $(1-s_{ii})$.[13]

Second, at the bilateral level, output allocation shares $\{s_{ij}\}_{j\neq i}$ measure the strength 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 compute how demand changes feed through to changes in real trade:

$$\widehat{IM}_i = \sum_{j\neq i}\left[\frac{m_{ji}}{im_i}\right]\widehat{q}_i + \left[\frac{d_{ji}}{im_i}\right]\widehat{q}_i^d = \widehat{q}_i\left(\frac{m_{Ii}}{im_i}\right) + \widehat{q}_i^d\left(\frac{d_{Ii}}{im_i}\right) \tag{9}$$

$$\widehat{EX}_i = \sum_{j\neq i}\left[\frac{m_{ij}}{ex_i}\right]\widehat{q}_j + \left[\frac{d_{ij}}{ex_i}\right]\widehat{q}_j^d, \tag{10}$$

where 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.

[13]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.

We can further refine these expressions to express changes in trade as a 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:

$$\widehat{IM}_1 = \left[\left(\frac{m_{I1}}{im_1}\right)s_{11} + \left(\frac{d_{I1}}{im_1}\right)\right]\widehat{q}_1^d + \left[\left(\frac{m_{I1}}{im_1}\right)s_{12}\right]\widehat{q}_2^d + \left[\left(\frac{m_{I1}}{im_1}\right)s_{13}\right]\widehat{q}_3^d. \tag{11}$$

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

These expressions yield an explicit scheme for linking demand disturbances to trade outcomes, where we again think of these weights as elasticities of trade to demand changes. These elasticities depend on the input-output structure in a complex, though intuitive, way. For example, imports in country 1 depend on demand changes in country 2 because imports contain 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 changes abroad, but also on domestic demand changes 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. 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.

A last point to note from this aggregate example is that final and intermediate goods shipments do not respond in the same way to demand changes. To see this, note that real import changes in equation (9) are comprised of changes in imported intermediate goods and imported final goods.

Intermediates goods imports are proportional to domestic production, whereas imported final goods are proportional to domestic demand. In our framework, production itself is a weighted average of demand in all countries, therefore production falls by less than one for one with changes in domestic demand. This means that imported intermediates have a lower elasticity to domestic demand changes than final goods imports. When demand changes both at home and abroad, whether intermediate imports fall more or less than final goods imports depends on how demand changes interact with intermediate goods linkages. In the special case where demand changes are equal in all countries, then intermediate and final goods imports will fall by the same amount. More generally, intermediate goods trade could fall by more or less than final goods trade depending on the configuration of demand changes.

C. Proportionality of Trade and Production

In analyzing the recent trade downturn, the proposition has been advanced that, as a matter of theory, trade should respond proportionally to overall economic activity (production or demand), regardless of whether or not there are vertical production linkages.[14] On the other hand, the data indicate that the elasticity of trade to GDP for the world as a whole is on the order of 3.5 in recent data, and rising over time.[15] We believe these two observations can be straightforwardly reconciled by acknowledging that the composition of demand changes has an important influence on the elasticity of trade to aggregate production. 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.

To illustrate the basic issues, we turn to the three-country, one-sector example presented earlier. In this case, the conditions under which trade and global production are proportional are easy to describe with reference to equation (7) linking output growth to demand changes and the trade equations (11) and (12). Note that if changes in demand are equal in proportional terms across countries ($\widehat{q}_i^d = \widehat{q}^d \; \forall \; i$), then changes in output 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 the demand changes. Thus, with identically-sized demand changes across countries trade falls proportionally with income. This special case

[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 Khoudour-Casteras (2009) and Altomonte and Ottaviano (2009).

[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.

with complete symmetry in demand changes across countries is the only situation in which exact proportionality holds.

With many countries and sectors, the conditions needed to generate a unit elasticity of trade to total production are considerably more restrictive. Namely, changes in 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 changes in demands interact with this configuration. Though the precise elasticity depends on the particulars of the scenario, we quantify below the actual empirical elasticity of trade to output changes implied by our input-output framework given the configuration of changes in demand during the 2008-2009 recession.

D. Data

To operationalize the framework laid out in previous sections, we need to measure bilateral final and intermediate goods flows. As discussed in the introduction, we do so by combining national input-output tables with bilateral trade data as in Johnson and Noguera (2009). Our primary data source is the GTAP 7 Data Base assembled by the Global Trade Analysis Project at Purdue University.[16] The GTAP data includes bilateral trade statistics and input-output tables for 94 countries plus 19 composite regions covering 57 sectors in 2004.[17] In the raw data, demand, output, and trade are recorded in dollars at market exchange rates.

In the data, we have information on 6 objects $\{y_i, d_{Di}, d_{Ii}, M_{ii}, M_{Ii}, \{ex_{ij}\}_{\forall j \neq i}\}$ for each country i:

1. y_i is a 57×1 vector of the total gross production.
2. d_{Di} is a 57×1 vector of the domestic final demand.
3. d_{Ii} is a 57×1 vector of final import demand.

[16] This data is compiled based on several sources, including World Bank and IMF macroeconomic and Balance of Payments statistics, United Nations Comtrade and OECD Services trade databases, and input-output tables from national statistical sources. To reconcile data from these different sources, GTAP researchers adjust individual countries input-output tables to be consistent with international data sources.

[17] Composite regions are composed of countries for which GTAP does not have individual input-output tables. GTAP assigns these regions "representative" input-output tables, constructed as linear combinations of input-output tables of similar countries.

4. M_{ii} is a 57×57 domestic input-output matrix with elements $M_{ii}(s,t)$ indicating total purchases by sector t of domestic intermediates from sector s.

5. M_{Ii} is a 57×57 aggregate import input-output matrix $M_{Ii}(s,t)$ indicating total purchases by sector t of foreign intermediates from sector s.

6. $\{ex_{ij}\}$ is a collection of 57×1 vectors of exports from i to j.

The definition of final demand here follows the national accounts definition of "final goods," including private consumption, government purchases, and investment. We value each country's output at a single set of prices, independent of where that output is shipped or how it is used. This ensures that the value of production revenue equals expenditure. Put differently, while quantity choices may reflect prices differences across destinations or uses that arise due to transport costs, tariffs, and markups, we value the resulting quantity flows at a single set of prices. Following input-output conventions, we use "basic prices" in our empirical work, defined as price received by a producer (minus tax payable or plus subsidy receivable by the producer).[18]

To measure bilateral intermediate and final goods flows, we use the bilateral trade data to split the imported intermediates matrix M_{Ii} and the imported final goods vector d_{Ii} into bilateral input-output matrices M_{ji} and bilateral final demand vectors d_{ji}. We assume that imports from each source country are split between final and intermediate in proportion to the overall split of imports between final and intermediate use in the destination. Further, conditional on being allocated to intermediate use, we assume that imported intermediates from each source are split across purchasing sectors in proportional to overall imported intermediate use in the destination. Formally, for goods from sector s used by sector t, we define bilateral input-output matrices and consumption import vectors:

$$M_{ji}(s,t) = M_{Ii}(s,t)\left(\frac{ex_{ji}(s)}{\sum_j ex_{ji}(s)}\right) \quad \text{and} \quad d_{ji}(s) = d_{Ii}(s)\left(\frac{ex_{ji}(s)}{\sum_j ex_{ji}(s)}\right). \tag{13}$$

This assumption implies that all variation in bilateral intermediate and final goods flows arises due to variation in the composition of imports across partners. For example, we would find that US imports from Canada are intermediate goods intensive because most imports from Canada are goods that are on average used as intermediates (e.g., auto parts).

[18]As a consequence, the level of value added is distorted relative to the national accounts. Whereas the national accounts measure value added as the value of output at basic prices minus the value of intermediate inputs at the purchaser's price, we calculate value added as the value of output at basic price minus the value of intermediate inputs at basic prices.

After splitting the data at the disaggregate level, we aggregate the data to form three composite sectors – durable industrial production, nondurable industrial production, and other "services" production.[19] In addition to this input-output data, we use national accounts data from the IMF's Global Data Source, the OECD, and national sources. We highlight specific data below where appropriate. We have real output and demand data for 55 countries. We aggregate the 15 pre-accession EU members to form a single EU15 composite and form a composite rest-of-the-world region out of countries for which output and demand data is not available.

Table 1 summarizes global output, demand and trade flows as they appear in the parametrized global input-output framework. Because our data are based on the 2004 benchmark data, we implicitly assume that all the shares in our data are stable between 2004 and the onset of the crisis. We report data on shares of world aggregates for the four largest economies (U.S., EU15, Japan and China) and five additional regions that cover the rest of the world. In this table and those that follow (excluding Table 5), EU15 trade includes only trade between EU members and the rest of the world, netting out intra-EU trade flows. One point of interest in the table is that roughly two-thirds of trade flows are destined for intermediate use. This is obviously a strong rationale for dedicating attention to intermediate goods trade in propagating demand changes. Note also that the share of intermediates in trade varies across regions. For example, intermediate goods imports account for over 80% of imports in China, but only slightly more than half of imports in the U.S. On the export side, in contrast, only 54% of Chinese exports are destined for intermediate use, comparable to the U.S. or EU15.

IV. Elasticity of Output and Trade to Sectoral Demand Changes

This section uses the parametrized global input-output framework to study the elasticities of trade and output to changes in final demand. The partial elasticities calculated below summarize the response of trade and output to a change in demand in a particular destination country and sector, holding demand in other countries and sectors constant. The resulting responses of trade and output form the building blocks for our analysis of the trade collapse and transmission below. Specifically, responses to combinations of demand changes can be computed by aggregating the reported elasticities, where aggregation weights would be based on the size of the shock hitting each sector. In the main text, we present results for demand changes originating in the U.S., and include results for the EU15, Japan, and China in Appendix B for comparison purposes. In the

[19] Durables are defined as sectors 38-42 in GTAP7 data and broadly include machinery and equipment. Non-durables are defined as sectors 15-37 and 43-45 and include all other industrial production and utilities. All other sectors, i.e., 1-14 and 46-57, are included in services.

tables, we report responses for the four largest economies (U.S., EU15, Japan and China) separately and collect responses for other countries into five regions to streamline the presentation.

Table 2 presents results for demand changes in the U.S. Column 1 summarizes the setup of the exercise, recording the response of total final demand to the demand change in each panel. When demand in each sector in the falls by 1%, total demand falls by that sector's share in total final demand (0.10% for durables, 0.11% for non-durables, and 0.79% for services).[20] We then report elasticities for gross output, GDP, exports and imports in Columns 2-9, decomposing the overall trade elasticities into separate elasticities for final and intermediate goods trade.

To interpret the response of output to demand changes in a particular sector, we recall that $\widehat{Q}_i = \sum_s (y_i(s)/y_i)\widehat{q}_i(s)$ and $\widehat{q}_i(s) = \sum_j \sum_t S_{ij}(s,t)\widehat{q}^d_j(t)$, where the $S_{ij}(s,t)$ are share weights indicating the share of output produced by sector s in source i used (directly or indirectly) to produce final goods of sector t absorbed in country j. Then if all demand changes other than those in sector r in the US are zero, then $\widehat{Q}_i = \sum_s (y_i(s)/y_i)S_{ij}(s,r)\widehat{q}^d_{US}(r)$. This says that the decline in output in country i equals the total share of output from i that is used to produce final goods in sector r absorbed in the U.S. Changes in aggregate GDP are close to, but not equal to, changes in aggregate output. Since value added to output ratios vary across sectors, the composition of output changes can drive a wedge between aggregate GDP and aggregate output, even though output is proportional to GDP within each individual sector. For example, looking at Columns 2 and 3 in Panel A of Table 2, we see that the demand change in services increases gross output by 0.72%, whereas the increase in GDP is equal to 0.78%.

To summarize the strength of demand spillovers, we compute a metric of the "total demand spillover" associated with each change: $1 - (\widehat{GDP}_{US}/\widehat{D}_{US})$ where $\widehat{D}_{US}$ is the total change in US final demand. Since the total change in world GDP equals the total change in final demand, this metric captures the share of the change in final demand that is borne by foreign countries. Unsurprisingly, demand changes for services have primarily domestic repercussions; spillovers are measured at 0.01. The strength of spillovers rises significantly for changes in nondurables and durables demand, with spillover ratios of 0.27 for nondurables and 0.4 for durables. That is, demand changes for durables are strongly transmitted abroad, with nondurables not far behind. On a bilateral basis, U.S. demand changes influence output and GDP in NAFTA most strongly, in all three sectors. Following a change in durables or nondurables demand, GDP changes by nearly as much in NAFTA (in proportional terms) as in the U.S. Within the durables sector, transmission of U.S. demand changes to Asia is also relatively strong, a point we return to below.

[20] To re-normalize shocks so as to generate equal changes in total demand, one can divide the shock by the share of the sector in total demand. Dashes in the table indicate entries that are zero by construction of the exercise.

The response of trade to demand changes is a function of final and intermediate goods linkages. To see these channels in action, we report elasticities for final and intermediate goods trade separately, along with the overall elasticity for trade in response to a shock. To interpret the response of imports, we find it helpful to re-write equation (6) describing the change in imports as:

$$\widehat{IM}_i = \left[\frac{im_i^m}{im_i}\right]\widehat{IM}_i^m + \left[\frac{im_i^d}{im_i}\right]\widehat{IM}_i^d \tag{14}$$

$$\text{with } \widehat{IM}_i^m = \sum_t \left[\frac{m_{Ii}(t)}{im_i^m}\right]\widehat{q}_i(t), \text{ and } \widehat{IM}_i^d = \sum_t \left[\frac{d_{Ii}(t)}{im_i^d}\right]\widehat{q}_i^d(t), \tag{15}$$

where im_i^m and im_i^d are total intermediate and final goods imports for country i, $m_{Ii}(t) = \sum_s M_{Ii}(s,t)$ is total intermediates imported by sector t. The overall import elasticity is a convex combination of the separate final and intermediate goods elasticities, where the weights reflect the shares of final and intermediate goods in exports or imports. Thus, column 7 in Table 2 is a weighted average of columns 8 and 9 of the table.

Looking at US imports following US-based demand changes, US imports rise by 0.35% following a 1% rise in services sector demand, 0.25% for nondurables demand, and 0.33% for durables demand. The similarity of these headline numbers masks large differences in mechanics of the adjustment, however. First, note that the absolute size of the change in total final demand is very different for demand changes in each sector. Normalizing the change in imports relative to the total change in domestic demand, imports rise by 0.44 times the change in total demand following the 1% change in services demand, and by 2.23 and 3.27 times the change in total demand for demand changes falling on the nondurables and durables sectors respectively. Second, note that the distribution of the import adjustment between final and intermediate goods is quite different across different sectors. The elasticity of intermediate goods trade is higher than that for final goods for demand changes hitting services, but the opposite is true for both nondurables and durables. This requires further explanation.

For final goods, the intuition is simple. The elasticity of final goods imports to a sector-specific change in demand depends on the share of that sector in total imports: $\frac{d_{Ii}(t)}{im_i^d}$. For example, for the durables and nondurables sectors, the change in final goods imports is large because each sector has a large weight in total final goods imports. By contrast, services constitute a small share of final goods imports; hence, changes in demand in the service sector have a small effect on final goods imports. Total final goods imports decline by 5.4 times the change in total demand following a 1% change in durables demand, and only by 0.1 times the change in total demand following a 1% change in services demand.

The elasticity of intermediate goods imports to a sector-specific change in demand depends on two forces, the response of sectoral output to sector-specific demand changes and the distribution of intermediate import shares across sectors. To develop intuition, note that the percentage change in U.S. output in sector t for a change in demand in sector r is: $\widehat{q}_{US}(t) = S_{US,US}(t,r)\widehat{q}_i^d(r)$. Then,

$$\widehat{IM}_{US}^m = \sum_t \left[\frac{m_{IUS}(t)}{im_{US}^m}\right] S_{US,US}(t,r)\widehat{q}_i^d(r). \tag{16}$$

Thus, the elasticity of intermediate imports differs from that of final imports because of two factors. First, sectoral weights for intermediate imports, $\frac{m_{IUS}(t)}{im_{US}^m}$, do not equal the sectoral weights for final imports. For example, in the U.S., final goods imports are concentrated in durables, but, intermediate goods imports put more weight on services and nondurables.[21] Second, changes in sectoral output are not equal to changes in domestic demand, as output at the sector level is a weighted average of demands at home and abroad. Sectoral output changes less than one-for-one with domestic demand ($S_{US,US}(t,r) < 1$), and empirically output is more sensitive to changes in domestic demand for services than other sectors. These two forces combine to generate a higher elasticity for intermediate goods imports relative to final goods in response to changes in services demand, and the opposite result for changes in durables demand.[22]

Looking at imports for other countries (i.e., not the U.S.), we highlight that the change in imports for all these countries is entirely due to intermediate goods linkages. Output changes abroad following the U.S. demand change, which raises or lowers imports of intermediate goods that are used produce output that is ultimately absorbed in the U.S. These linkages are strongest for durable goods and among countries that engage in production sharing with the U.S. (i.e., NAFTA, China, and Emerging Asia).

Just as with imports, we can think of the aggregate export elasticity in column 4 of Table 2 as the weighted sum of the elasticity of final and intermediate goods trade to demand changes:

$$\widehat{EX}_i = \left[\frac{ex_i^m}{ex_i}\right]\widehat{EX}_i^m + \left[\frac{ex_i^d}{ex_i}\right]\widehat{EX}_i^d \tag{17}$$

$$\text{with } \widehat{EX}_i^m = \sum_{j\neq i}\sum_t \left[\frac{m_{ij}(t)}{ex_i^m}\right]\widehat{q}_j(t), \text{ and } \widehat{EX}_i^d = \sum_{j\neq i}\sum_t \left[\frac{d_{ij}(t)}{ex_i^d}\right]\widehat{q}_j^d(t), \tag{18}$$

[21] In particular, the distribution of weights for final imports across services, nondurables and durables is: 0.11, 0.34 and 0.55, while for intermediate imports the weights are correspondingly 0.21, 0.50 and 0.30.

[22] Because U.S. services output is very sensitive to domestic demand changes in the service sector ($S_{US,US}(services, services) \approx 1$), and the service sector has a larger weight in intermediate imports ($\frac{m_{IUS}(services)}{im_{US}^m} > \frac{d_{Ii}(services)}{im_i^d}$), the elasticity of intermediate imports is higher than the elasticity of final imports in response to services demand changes. In contrast, output for durables is less sensitive to changes in domestic demand and intermediate imports by the durables sector constitute a smaller share of total intermediate imports, so the ranking is reversed for durables.

where ex_i^m and ex_i^d are total intermediate and final goods exports for country i, and $m_{ij}(t) = \sum_s m_{ij}(s,t)$ is total intermediate imports by sector t in country j.

We highlight three points among the export results. First, U.S. exports fall in response to the U.S. demand shock due to intermediate goods linkages. This response is strongest for durable goods, consistent with integrated production chains in this sector. Second, the breakdown in changes in exports for other countries between final and intermediate goods varies across sectors in line with our discussion of U.S. imports. The elasticity of intermediate goods exports is high relative to the final goods elasticity for the US demand change in services, and lower for demand changes in the other two sectors. Third, looking at the export decline across countries, exports decline by sizable amounts for NAFTA in response to demand changes in all three sectors. Transmission of demand changes to Asia (especially China and Japan) is much stronger for durables than in other categories.

Before turning to quantitative results for the Global Recession, we draw out one further implication of these responses for world trade as a whole. The elasticity of world trade to world output varies depending on the sector in which demand changes. For example, for the U.S., a 1% decline in services demand implies an elasticity of world trade to world output of less than one-half (0.35 without rounding), whereas a 1% decline in durables demand raises that elasticity to nearly 3 (2.87 without rounding). This foreshadows the important role that composition of demand changes will play in explaining the collapse of trade during the Global Recession.

V. Application to the Global Recession of 2008-2009

This section applies the input-output framework to analyze the collapse of trade and transmission of the Global Recession in 2008-2009. Specifically, we estimate country and sector-specific changes in demand over the period 2008Q1 to 2009Q1. We then feed these demand changes through the input-output framework to compute the overall elasticity of trade and output to empirically realistic combinations of demand changes. We focus on two sets of demand changes. First, we examine the effects of the realized changes in final demand in the U.S. and EU15 only. Second, we examine the effects of the realized changes in final demand in all countries simultaneously. This second exercise yields an estimate of the “global elasticity of trade to output“ that we then compare to the observed elasticity from this recession.

To estimate changes in demand separately for durables, nondurables and services, we follow a three-step procedure. First, we take realized changes in aggregate demand from national accounts data. Second, we decompose the changes in aggregate demand changes into changes in goods (durables plus nondurables)demand and changes in services demand. We do this by combining data on GDP and Industrial Production with production shares in our input-output framework, making the assumption that changes in domestic demand for services equal changes in domestic supply of services. Third, we decompose changes in goods demand into changes in durables demand and changes in non-durables demand using estimates of durable goods demand changes taken primarily from expenditure data on machinery and equipment.[23] All calculations are based on real domestic currency denominated quarterly data, and we define the crisis as taking pace between 2008Q1 and 2009Q1.[24] Details regarding both data and the procedure are included in Appendix C.

A. Transmission of U.S. and EU15 Demand Changes

Figure 1 reports the estimates of sector-specific demand changes for the US and EU15. The total declines in final demand for the U.S. and EU15 were 4.4% and 4.9%, respectively, between 2008 and 2009. Importantly, the decline in demand was distributed very unevenly across sectors. Demand for durables fell by 32% in the U.S. and 23% in EU15, while demand for nondurables and services fell by less than 4%.

Table 3 reports the changes in production and trade that result from changes in demand in the United States, feeding estimated changes in demand for services, nondurable, and durables through the framework simultaneously. The overall changes should be thought of as a weighted aggregation of the three panels in Table 2, with the realized sectoral demand changes in Figure 1 used as weights for each panel.[25] Given the dominance of demand changes for durables in aggregate data, it is not surprising that results in Table 3 resemble most closely Panel C in Table 2.

Though the overall decline in U.S. demand is only 4.4%, the sectoral asymmetry of the decline implies that the changes are transmitted strongly abroad. In columns 4-9, we see that U.S. exports and imports fall by 1.7% and 11.4%, respectively. Note here that exports fall, even though final demand in all other countries/regions is kept constant entirely due to the U.S. involvement

[23]We obtain durables demand data from a mix of OECD and national sources. For the U.S. and EU15 we use data from the BEA and Eurostat. Because this durables expenditure data is missing for many emerging markets and smaller OECD countries, we make additional assumptions where necessary. If durables production data is available, we use this data for guidance. Alternatively, where no data is available (e.g., for China) we assume that demand declines symmetrically across durables and non-durables. See the Appendix C for details.

[24]This is the period with the largest decrease in global demand. Further, in looking at Q1 to Q1 changes, we can ignore seasonal adjustments.

[25]For example, aggregate demand change in the U.S. is derived as $(-31.6)*0.10+(-2.2)*0.11+(-1.3)*0.79=-4.4$, while the response of gross exports in the U.S. is derived as $(-31.6)*0.05+(-2.2)*0.02+(-1.3)*0.03=-1.7$. In the same way, using only results in Table 2, one can derive any other response of interest.

in cross-border production networks. The demand elasticity of exports in the U.S. is measured to be 0.4, a sizable figure. The large decline in durables demand combined with integrated cross-border production networks for durable goods causes exports to fall significantly, while total demand falls only modestly because durables make up only a small share of total demand.

Turning to imports, the fall in US imports is several times larger than the fall in demand. This is another implication of the asymmetric change in demand across sectors, with demand falling most for durables. Breaking down this import decline, both final and intermediate goods imports exhibit elasticities to total demand that exceed 1. However, the effect on imports of intermediates is much less pronounced. Recall that the intermediate goods elasticity depends on the interaction of imported intermediate input intensity of production and production changes at the sector level, whereas the final goods elasticity depends on the interaction of demand changes with final goods import shares at the sector level.

The cross-country transmission of the demand changes reflects both intermediate and final goods linkages. Among U.S. trade partners, Canada and Mexico (NAFTA) are hit hard by the decline in demand, with gross exports falling by 10.5% and about 1/4 of this decline involves exports of intermediate goods. As a direct consequence of production sharing, NAFTA imports fall by 3.9% in response to the fall in U.S. demand. There is thus substantial comovement in exports and imports due to production sharing, with imports falling about 4/10 as much as exports holding NAFTA demand constant. Other regions suffering large contractions in trade are all in Asia: Japan, China and Emerging Asia. The strength of this transmission to Asia is a product of the fact that they produce durables.

One further point to note about cross-border transmission patterns is that they cannot be explained with the standard openness measures, such as trade/GDP. Consider China and Japan, for example. Both intermediate and final exports from Japan fall by more than exports from China. This is the case despite the fact that the U.S. is a bigger direct export market for China than it is for Japan.[26] The export response for Japan is larger because a good deal of Japanese value-added is exported to the United States through China and other countries. This can be seen via the result that the percentage drop in China's (and Emerging Asia's) imports of intermediates is 60-80% larger than Japan's. Our input-output framework takes this indirect transmission channel into account.

Looking directly at output and GDP, U.S. gross output and GDP fall by 3.9% and 3.2%, respectively, which is less than the fall in U.S. final demand. The total demand spillover (defined above)

[26]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.

is 0.37, which implies large total cross-border spillovers. For example, GDP in NAFTA falls by 2.3%, which is nearly 3/4 of the size of the fall in U.S. GDP. In Emerging Asia and China GDP contracts by 1.1% and in Japan by 0.9%, all of these are sizable contraction in absolute terms.

Results for estimated demand changes in EU15 are presented in Table 4**.** Because the EU is of similar size to the U.S., it has comparable demand elasticities for trade and output at sectoral level (see the Appendix B), and has a similar pattern of demand changes, results for trade and output following the EU-only demand change are comparable to the U.S. Notably, Emerging Europe takes the place of NAFTA as the region with the most intensive trade linkages and is hence hit hardest by the fall in EU demand. Overall, the global impact of demand changes in the two regions is quite similar, owing to the fact that the two economies represent comparable shares of the world demand, output and trade.

B. Elasticity of Trade to Output

To quantify the model-based elasticity of trade to output (GDP or production) during the crisis, we feed demand changes for all countries through the framework simultaneously. To generate results that are comparable to standard approaches to calculating this elasticity in data, we now disaggregate EU15 into 15 separate countries, each with its own vector of demand changes.[27] Figure 2 collects estimated demand changes for the largest 10 countries that we use in studying the elasticity of world trade to global demand changes.[28] As noted previously for the U.S. and EU15, demand changes are highly asymmetric across sectors, with durables demand falling substantially more than demand for either nondurables or services.

Table 5, Panel A reports the changes in trade and production by country/region when demand changes simultaneously in all countries and sectors.[29] We generate a synchronized global recession, which is unsurprising since observed demand changes are synchronized across countries in the data. The relevant question is whether the framework delivers a quantitatively realistic decline in world trade.

The elasticity of world trade to world GDP is 2.8 in our framework. This elasticity lies between two polar benchmarks. At one end, even though our framework embeds proportionality assump-

[27] With the disaggregation of the EU15 composite, we now count intra-EU trade in our world trade aggregates and in the table report changes in trade for the EU including both extra-EU and intra-EU trade.

[28] Note that we do not disaggregate durables and nondurables demand for China due to lack of data. This assumption almost surely biases our global elasticity estimates downward.

[29] Further details about the fit of the I-O model results with data at the level of 55 countries are provided in Appendix D.

tions in production and demand, we find trade falls more than one-for-one with income for realistic changes in demand. At the other end, the elasticity in our framework is lower than that observed during the crisis. Whereas our framework delivers an elasticity of 2.8, the elasticity during the crisis in data is about 4. While we are unable to “account“ for the full collapse of world trade, our framework delivers approximately 70% of the decline relying solely on changes in final demand. To unpack this elasticity, we focus attention on three points.

First, the elasticity in our framework is high because we (realistically) allow asymmetries in the collapse of demand across sectors. To illustrate this, we compute the response of output and trade within our framework under alternative, counter-factual, more symmetric changes in demand.[30] Panel B of Table 5 reports results where we assume demand changes are identical in durable and nondurable sectors (a two-sector economy). Panel C of Table 5 reports results where we assume demand changes are identical in all three sectors (a one-sector economy). Note that the elasticity of world trade to production falls as we move from asymmetric to symmetric demand changes, Panels A to C. In the extreme case of a one-sector economy, trade and output are both approximately proportional to the change in world demand. Moving to a two-sector framework, the elasticity rises to 2.3, which is substantially higher and more realistic based on historical data. There is substantial additional gain from moving to the three-sector framework in terms of matching data relative to the two-sector framework.

Second, this aggregate elasticity is a composite of underlying heterogeneous sub-elasticities – for intermediate versus final goods, for particular countries. For example, the headline elasticity is higher than the elasticity of world trade in response to demand changes in just the United States, which was 2.2 in Table 2.[31] The elasticity for simultaneous demand changes in all countries is higher partly because most other countries are more open than the U.S.

Third, we find a quantitatively large difference in trade elasticities for final and intermediate goods – 4.3 for final goods and 2.0 for intermediates. This finding is interesting when set against the common perception that intermediates in aggregate trade flows should *increase* the income elasticity of trade, not decrease it. Our results do not necessarily rule out a role for intermediates in making world trade sensitive to income changes, but we point out that the opposite holds in our input-output framework.

[30] Changes in total demand are taken directly from the data and are the same across specifications. Thus, the only difference across panels is the extent to which we restrict demand changes to be symmetric across sectors.

[31] This elasiticity is even lower for EU15-only demand changes, estimated at 1.5 in Appendix B.

VI. Concluding Remarks

Using a global input-output framework, we have argued that demand spillovers played an important role in explaining both the collapse of trade and transmission of the global recession. Demand changes in the U.S. and EU15, the epicenter of the crisis, appear to have been strongly transmitted to foreign countries via trade channels. The large magnitude of these spillovers hinges on the fact that demand changes were concentrated on the durables sector, which is both highly traded as a final good and tightly integrated into global supply chains. Feeding demand changes in all countries through our framework simultaneously, we find that demand changes alone can account for a large portion of the fall in the ratio of world trade to GDP. In particular, our framework can easily generate an elasticity of three, about 70% of that observed during the recession. Based on the fact that the elasticity rises as we disaggregate our model, we believe the trade to GDP elasticity would rise if we had the data available to disaggregate the model even further. In sum, this evidence suggests that the durables-biased collapse in aggregate demand during the global crisis is a key piece of the explanation of both the strength of transmission of the crisis via trade and the collapse of world trade.

In developing these results, we have dedicated attention to specifying a rich set of cross-country intermediate and final goods linkages. One shortcoming of our approach, however, is that our framework omits the “standard“ trade transmission channel in which home income declines, leading to decreased import demand, and thereby causing a decline in foreign exports and income, and so on. Rather, we take realized demand changes from data and study the response of trade, remaining agnostic about the source of the demand changes themselves. As a result, we cannot use our framework to recover fundamental structural shocks or study how those shocks are transmitted across countries. In future work, we plan to build articulate both the supply and demand side of the model more fully so as to recover genuine shocks. This structural approach will open the door to a more precise quantification of the role of trade as a transmission channel, as well as allow us to quantify how much different countries/regions have contributed the fall in global trade and output.

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	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*

Table 1. Regional shares in world totals (%, GTAP7 data)

Country/ Region	Total domestic demand	Gross output	GDP	Gross exports	by type: final	by type: intermediate	Gross imports	by type: final	by type: intermediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PANEL A: 1 % demand increase for services									
EU15	--	0.01	0.01	0.11	0.04	0.16	0.01	--	0.02
USA	0.79	0.72	0.78	0.03	--	0.04	0.35	0.11	0.53
Em. Europe	--	0.01	0.01	0.04	0.01	0.05	0.01	--	0.01
NAFTA (ex. US)	--	0.07	0.06	0.23	0.05	0.37	0.06	--	0.09
China	--	0.03	0.02	0.08	0.01	0.14	0.03	--	0.03
Japan	--	0.01	0.01	0.07	0.01	0.12	0.01	--	0.02
Em. Asia	--	0.03	0.03	0.07	0.04	0.09	0.03	--	0.04
South America	--	0.03	0.03	0.12	0.03	0.16	0.02	--	0.04
World	0.24	0.21	0.24	0.09	0.03	0.12	0.09	0.03	0.12
PANEL B: 1 % demand increase for nondurables									
EU15	--	0.01	0.01	0.06	0.07	0.04	0.01	--	0.01
USA	0.11	0.10	0.08	0.02	--	0.03	0.25	0.35	0.17
Em. Europe	--	0.01	0.01	0.02	0.02	0.02	0.01	--	0.01
NAFTA (ex. US)	--	0.06	0.05	0.18	0.22	0.15	0.04	--	0.07
China	--	0.03	0.03	0.09	0.14	0.04	0.02	--	0.03
Japan	--	0.00	0.00	0.03	0.03	0.03	0.01	--	0.01
Em. Asia	--	0.02	0.02	0.04	0.07	0.03	0.02	--	0.02
South America	--	0.03	0.02	0.11	0.13	0.11	0.02	--	0.04
World	0.03	0.04	0.03	0.06	0.08	0.05	0.06	0.08	0.05
PANEL C: 1 % demand increase for durables									
EU15	--	0.01	0.01	0.08	0.12	0.06	0.01	--	0.02
USA	0.10	0.09	0.06	0.05	--	0.08	0.33	0.54	0.16
Em. Europe	--	0.01	0.01	0.02	0.02	0.03	0.01	--	0.01
NAFTA (ex. US)	--	0.09	0.07	0.31	0.55	0.14	0.12	--	0.19
China	--	0.04	0.03	0.12	0.15	0.09	0.05	--	0.06
Japan	--	0.03	0.02	0.16	0.26	0.10	0.02	--	0.04
Em. Asia	--	0.04	0.03	0.09	0.13	0.08	0.05	--	0.07
South America	--	0.01	0.01	0.06	0.06	0.06	0.01	--	0.02
World	0.03	0.04	0.03	0.09	0.13	0.07	0.09	0.13	0.07

Table 2. Regional and global responses of output and trade to a 1% increase in sectoral final demand in the U.S. (% change)

Country/ Region	Total domestic demand	Gross output	GDP	Gross exports	by type: final	by type: intermediate	Gross imports	by type: final	by type: intermediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
EU15	--	-0.4	-0.3	-2.8	-3.9	-2.0	-0.4	--	-0.6
USA	-4.4	-3.9	-3.2	-1.7	--	-2.7	-11.4	-18.1	-6.2
Em. Europe	--	-0.3	-0.2	-0.9	-0.7	-1.0	-0.3	--	-0.5
NAFTA (ex. US)	--	-3.0	-2.3	-10.5	-18.0	-5.2	-3.9	--	-6.2
China	--	-1.3	-1.1	-4.0	-5.1	-3.1	-1.6	--	-1.9
Japan	--	-0.9	-0.6	-5.3	-8.4	-3.2	-0.8	--	-1.2
Em. Asia	--	-1.4	-1.1	-3.2	-4.3	-2.6	-1.7	--	-2.2
South America	--	-0.5	-0.4	-2.2	-2.2	-2.2	-0.5	--	-0.8
World	-1.4	-1.6	-1.4	-3.1	-4.3	-2.3	-3.1	-4.3	-2.3

Table 3. Global spillovers from the U.S. demand changes for durables, nondurables and services in the I-O model , % change

Country/ Region	Total domestic demand	Gross output	GDP	Gross exports	by type: final	by type: intermediate	Gross imports	by type: final	by type: intermediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
EU15	-4.9	-4.4	-4.0	-0.8	--	-1.3	-7.6	-11.2	-5.5
USA	--	-0.2	-0.2	-2.4	-3.1	-2.0	-0.2	--	-0.4
Em. Europe	--	-1.7	-1.4	-5.4	-7.5	-4.1	-1.9	--	-3.0
NAFTA (ex. US)	--	-0.2	-0.2	-0.8	-0.6	-1.0	-0.2	--	-0.4
China	--	-0.8	-0.7	-2.6	-3.0	-2.3	-1.0	--	-1.2
Japan	--	-0.5	-0.3	-2.8	-3.6	-2.3	-0.4	--	-0.6
Em. Asia	--	-1.0	-0.8	-2.2	-2.7	-2.0	-1.2	--	-1.5
South America	--	-0.3	-0.3	-1.4	-1.4	-1.5	-0.3	--	-0.5
World	-1.4	-1.7	-1.4	-2.1	-2.4	-1.9	-2.1	-2.4	-1.9

Table 4. Global spillovers from the EU15 demand changes for durables, nondurables and services in the I-O model , % change

Country/ Region	Total domestic demand	Gross output	GDP	Gross exports	by type: final	by type: intermediate	Gross imports	by type: final	by type: intermediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PANEL A: Demand changes for durables, nondurables and services									
EU15	-3.8	-5.2	-4.3	-10.2	-15.0	-7.1	-8.6	-10.8	-7.3
USA	-4.4	-4.9	-4.0	-11.9	-17.3	-8.5	-12.5	-18.2	-8.1
Em. Europe	-12.3	-8.8	-8.1	-10.8	-14.8	-8.1	-19.8	-34.1	-11.9
NAFTA (ex. US)	-6.4	-6.7	-5.6	-13.1	-20.4	-7.9	-15.1	-21.1	-11.6
China	12.2	3.5	3.5	-13.6	-17.8	-10.0	7.5	29.3	2.8
Japan	-4.9	-6.9	-5.5	-15.1	-24.2	-9.1	-11.7	-15.6	-9.5
Em. Asia	-9.0	-6.7	-4.6	-10.0	-15.9	-6.9	-18.3	-39.1	-11.5
South America	-1.2	-2.4	-1.2	-7.4	-11.9	-5.6	-10.4	-19.4	-5.3
World	-3.7	-4.7	-3.7	-10.5	-15.9	-7.3	-10.5	-15.9	-7.3
PANEL B: Demand changes for goods and services									
EU15	-3.8	-5.0	-4.2	-8.2	-11.2	-6.2	-7.0	-7.8	-6.5
USA	-4.4	-4.8	-4.0	-9.1	-12.7	-6.9	-10.6	-14.6	-7.5
Em. Europe	-12.3	-9.6	-8.9	-9.2	-12.1	-7.3	-16.5	-25.3	-11.8
NAFTA (ex. US)	-6.4	-6.6	-5.8	-10.3	-14.4	-7.5	-12.0	-16.4	-9.4
China	12.2	4.0	3.8	-12.0	-16.7	-8.0	8.4	29.3	4.0
Japan	-4.9	-5.9	-4.9	-9.4	-14.4	-6.1	-10.6	-14.2	-8.7
Em. Asia	-9.0	-6.2	-4.3	-7.2	-11.6	-4.9	-15.5	-33.1	-9.8
South America	-1.2	-3.2	-1.9	-8.5	-13.1	-6.7	-8.1	-12.0	-6.0
World	-3.7	-4.5	-3.7	-8.7	-12.4	-6.5	-8.7	-12.4	-6.5
PANEL C: Aggregate demand changes									
EU15	-3.8	-3.9	-3.9	-4.0	-4.3	-3.9	-3.9	-3.8	-3.9
USA	-4.4	-4.4	-4.4	-4.4	-4.9	-4.0	-4.4	-4.4	-4.4
Em. Europe	-12.3	-9.1	-10.2	-4.7	-4.8	-4.6	-9.8	-12.3	-8.4
NAFTA (ex. US)	-6.4	-5.7	-5.7	-4.2	-4.3	-4.1	-5.9	-6.6	-5.6
China	12.2	6.7	7.4	-4.5	-4.9	-4.2	6.7	12.2	5.5
Japan	-4.9	-4.6	-4.7	-3.0	-3.9	-2.5	-4.6	-4.9	-4.5
Em. Asia	-9.0	-5.5	-5.7	-2.4	-3.5	-1.8	-7.1	-11.9	-5.5
South America	-1.2	-1.8	-1.7	-3.4	-3.7	-3.2	-1.8	-1.4	-2.1
World	-3.7	-3.6	-3.7	-3.8	-4.3	-3.6	-3.8	-4.3	-3.6

Table 5. I-O model results with all demand changes included, % change

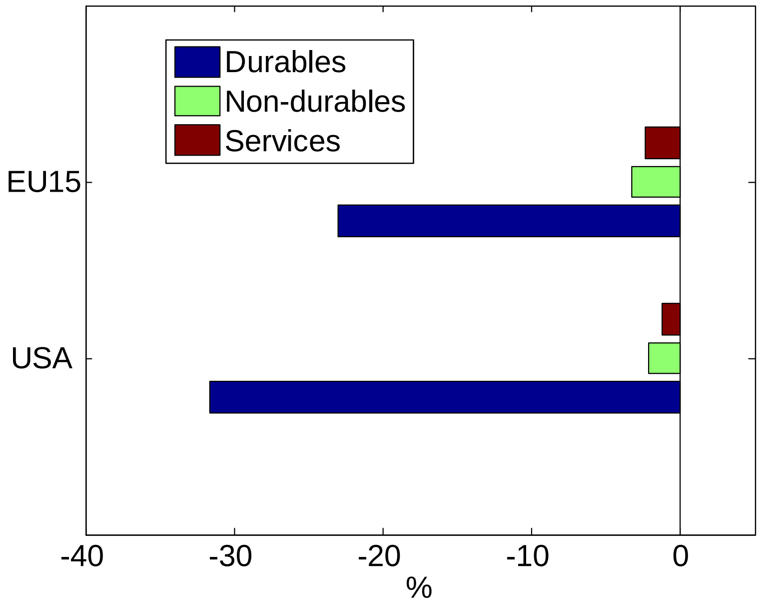

Figure 1. Estimated sectoral demand changes for the U.S. and EU15, 2009Q1/2008Q1.

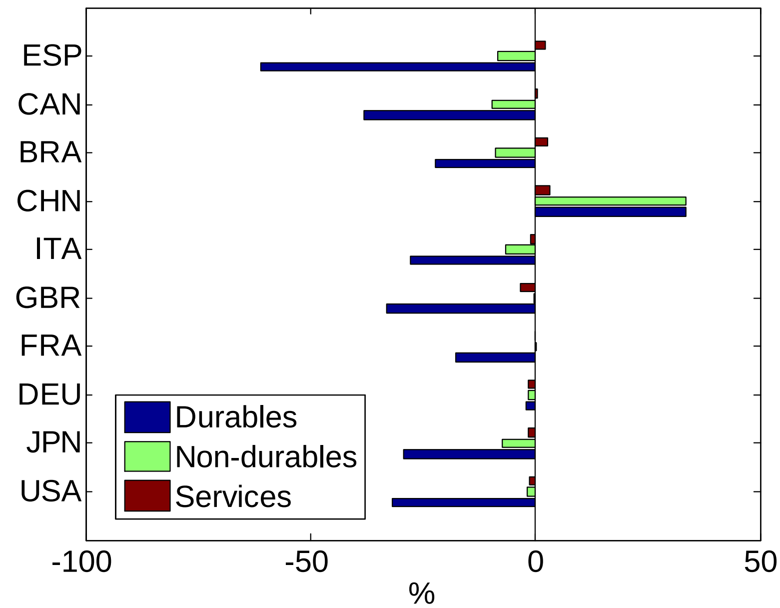

Figure 2. Estimated sectoral demand changes for the 10 largest economies, 2009Q1/2008Q1.

APPENDIX A. INTERPRETING THE SHARE WEIGHTING MATRIX

This appendix discusses the derivation and interpretation of the equation linking output to demand changes: equation (4) in the text. Stacking and manipulating equation (3), we can write:

$$[I-A]\,[diag(y)]\begin{pmatrix}\widehat{q}_1\\ \widehat{q}_2\\ \vdots\\ \widehat{q}_N\end{pmatrix}=\begin{bmatrix}diag(d_{11}) & diag(d_{12}) & \cdots & diag(d_{1N})\\ diag(d_{21}) & diag(d_{22}) & \cdots & \vdots\\ \vdots & \vdots & \ddots & \vdots\\ diag(d_{N1}) & \cdots & \cdots & diag(d_{NN})\end{bmatrix}\begin{pmatrix}\widehat{q}^d_1\\ \widehat{q}^d_2\\ \vdots\\ \widehat{q}^d_N\end{pmatrix}$$

where $[diag(y)]$ is an $(SN \times SN)$ matrix with elements $y_i(s)$ along the diagonal, $\widehat{q}_i$ is a vector of proportional changes in output within each sector in country i, and $\widehat{q}^d_i$ is a vector of sector-level demand changes in country i. The A matrix is the global input-output matrix with elements $A_{ij}(s,t)$ that record the cost share of intermediate goods from sector s in country i used in production in sector t in country j. It takes the form:

$$A=\begin{bmatrix}A_{11} & A_{12} & \dots & A_{1N}\\ A_{21} & A_{22} & \cdots & A_{2N}\\ \vdots & \vdots & \ddots & \vdots\\ A_{N1} & A_{N2} & \dots & A_{NN}\end{bmatrix}\quad\text{with}\quad A_{ij}(s,t)\equiv\frac{m_{ij}(s,t)}{y_j(t)}.$$

The share matrix is then defined as:

$$\begin{bmatrix}S_{11} & S_{12} & \cdots & S_{1N}\\ S_{21} & S_{22} & \cdots & \vdots\\ \vdots & \vdots & \ddots & \vdots\\ S_{N1} & \cdots & \cdots & S_{NN}\end{bmatrix}\equiv[diag(y)]^{-1}\,[I-A]^{-1}\begin{bmatrix}diag(d_{11}) & diag(d_{12}) & \cdots & diag(d_{1N})\\ diag(d_{21}) & diag(d_{22}) & \cdots & \vdots\\ \vdots & \vdots & \ddots & \vdots\\ diag(d_{N1}) & \cdots & \cdots & diag(d_{NN})\end{bmatrix}.$$

To interpret this matrix, we define:

$$d_j\equiv[I-A]^{-1}\begin{bmatrix}d_{1j}\\ d_{2j}\\ \vdots\\ d_{Nj}\end{bmatrix}.$$

This $(SN \times 1)$ vector d_j is the vector of output used either directly or indirectly to produce final goods absorbed in country j.

To interpret this expression, $[I-A]^{-1}$ is the Leontief inverse of the global input-output matrix. The Leontief inverse can expressed as a geometric series: $[I-A]^{-1}=\sum_{k=0}^{\inf}A^k$. Multiplying by the consumption vector, the zero-order term d_j is the direct output absorbed as consumption, the first-order term $[I+A]d_j$ is the direct output plus the intermediates used to produce that output, the second-order term $[I+A+A^2]d_j$ includes the additional intermediates used to produce the first round of intermediates (Ad_j), and the sequence continues as such. Therefore, $[I-A]^{-1}d_j$ is the vector of output used both directly and indirectly to produce final goods absorbed in country j. Then the output vector can be written as: $y = \sum_j [I-A]^{-1} d_j$. This defines a decomposition of output decomposition according to where that output is embedded in final demand.

The share matrix defined in equation (4) then computes the shares associated with this output decomposition and arranges them appropriately to premultiply the vector of demand changes.

APPENDIX B. ELASTICITY ESTIMATES FOR EU15, JAPAN, AND CHINA

This appendix presents demand elasticities of trade and output in response to sector-specific demand changes for the EU15, Japan, and China. These tables are the counterparts to Table 2 for the United States.

Results for the EU15 are qualitatively and quantitatively similar to results for the U.S., with Emerging Europe replacing NAFTA as the trading partner with the largest exposure. Results for Japan and China exhibit several notable differences. First, the size of cross-border impacts on trade and output are notably smaller for both countries. The reason is the considerably smaller weight for Japan and China in global economic activity and trade flows. Second, for China, demand spillovers are much stronger than for the U.S. or EU15. Spillovers range from 0.21 in services to 0.57 for durables. These large spillovers are reflected in China's trade elasticities, where trade is very response demand changes in China. For example, trade falls by 3.8 times the change in total demand following a decline in demand for durables. This illustrates the broad point that demand elasticities of output and trade are higher for more open economies in our framework.

Country/ Region	Total domestic demand	Gross output	GDP	Gross exports	by type: final	by type: intermediate	Gross imports	by type: final	by type: intermediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				PANEL A: 1 % demand increase for services					
EU15	0.68	0.56	0.64	0.02	--	0.04	0.36	0.26	0.41
USA	--	0.01	0.01	0.12	0.10	0.14	0.01	--	0.01
Em. Europe	--	0.06	0.05	0.18	0.08	0.24	0.04	--	0.07
NAFTA (ex. US)	--	0.01	0.01	0.04	0.03	0.06	0.01	--	0.01
China	--	0.02	0.02	0.08	0.03	0.12	0.02	--	0.03
Japan	--	0.01	0.01	0.07	0.02	0.09	0.01	--	0.01
Em. Asia	--	0.04	0.03	0.08	0.05	0.09	0.03	--	0.04
South America	--	0.02	0.02	0.11	0.10	0.11	0.02	--	0.03
World	0.19	0.18	0.19	0.09	0.06	0.11	0.09	0.06	0.11
				PANEL B: 1 % demand increase for nondurables					
EU15	0.20	0.20	0.16	0.02	--	0.04	0.29	0.33	0.26
USA	--	0.01	0.00	0.06	0.05	0.07	0.01	--	0.01
Em. Europe	--	0.07	0.06	0.18	0.23	0.15	0.05	--	0.07
NAFTA (ex. US)	--	0.01	0.01	0.03	0.01	0.04	0.01	--	0.01
China	--	0.03	0.02	0.08	0.09	0.07	0.02	--	0.03
Japan	--	0.00	0.00	0.03	0.02	0.04	0.01	--	0.01
Em. Asia	--	0.02	0.02	0.05	0.05	0.05	0.02	--	0.03
South America	--	0.02	0.02	0.10	0.12	0.09	0.02	--	0.03
World	0.06	0.07	0.06	0.07	0.07	0.08	0.07	0.07	0.08
				PANEL C: 1 % demand increase for durables					
EU15	0.12	0.11	0.08	0.03	--	0.05	0.25	0.41	0.16
USA	--	0.01	0.01	0.09	0.12	0.06	0.01	--	0.02
Em. Europe	--	0.06	0.05	0.19	0.28	0.13	0.07	--	0.11
NAFTA (ex. US)	--	0.01	0.01	0.03	0.02	0.03	0.01	--	0.01
China	--	0.03	0.02	0.09	0.11	0.08	0.04	--	0.04
Japan	--	0.02	0.01	0.11	0.15	0.08	0.02	--	0.03
Em. Asia	--	0.04	0.03	0.08	0.11	0.07	0.04	--	0.06
South America	--	0.01	0.01	0.04	0.03	0.04	0.01	--	0.01
World	0.03	0.04	0.03	0.07	0.09	0.06	0.07	0.09	0.06

Table 6. Regional and global responses of output and trade to a 1% increase in sectoral final demand in the EU15 (% change)

Country/ Region	Total domestic demand	Gross output	GDP	Gross exports	by type: final	by type: intermediate	Gross imports	by type: final	by type: intermediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PANEL A: 1 % demand increase for services									
EU15	--	0.003	0.003	0.027	0.016	0.034	0.002	--	0.004
USA	--	0.003	0.003	0.039	0.028	0.045	0.002	--	0.004
Em. Europe	--	0.003	0.003	0.009	0.006	0.011	0.002	--	0.003
NAFTA (ex. US)	--	0.004	0.003	0.012	0.004	0.018	0.002	--	0.004
China	--	0.011	0.010	0.033	0.008	0.055	0.009	--	0.011
Japan	0.798	0.659	0.736	0.006	--	0.010	0.381	0.243	0.457
Em. Asia	--	0.019	0.018	0.040	0.026	0.047	0.014	--	0.018
South America	--	0.005	0.005	0.023	0.008	0.029	0.005	--	0.007
World	0.092	0.081	0.092	0.030	0.016	0.038	0.030	0.016	0.038
PANEL B: 1 % demand increase for nondurables									
EU15	--	0.002	0.002	0.013	0.015	0.011	0.001	--	0.002
USA	--	0.002	0.001	0.016	0.016	0.015	0.001	--	0.002
Em. Europe	--	0.001	0.001	0.004	0.002	0.005	0.001	--	0.001
NAFTA (ex. US)	--	0.002	0.002	0.007	0.006	0.009	0.002	--	0.002
China	--	0.016	0.014	0.046	0.074	0.023	0.013	--	0.016
Japan	0.103	0.092	0.075	0.004	--	0.006	0.232	0.317	0.184
Em. Asia	--	0.010	0.009	0.020	0.021	0.020	0.008	--	0.011
South America	--	0.005	0.004	0.019	0.020	0.018	0.004	--	0.007
World	0.012	0.014	0.012	0.019	0.021	0.018	0.019	0.021	0.018
PANEL C: 1 % demand increase for durables									
EU15	--	0.003	0.002	0.017	0.022	0.014	0.002	--	0.004
USA	--	0.003	0.002	0.027	0.039	0.020	0.003	--	0.005
Em. Europe	--	0.001	0.001	0.005	0.003	0.006	0.002	--	0.002
NAFTA (ex. US)	--	0.002	0.002	0.007	0.004	0.008	0.002	--	0.003
China	--	0.016	0.013	0.048	0.065	0.034	0.019	--	0.023
Japan	0.099	0.097	0.071	0.013	--	0.022	0.244	0.439	0.136
Em. Asia	--	0.020	0.016	0.045	0.065	0.034	0.024	--	0.032
South America	--	0.002	0.001	0.007	0.001	0.009	0.002	--	0.002
World	0.011	0.015	0.011	0.022	0.029	0.019	0.022	0.029	0.019

Table 7. Regional and global responses of output and trade to a 1% increase in sectoral final demand in Japan (% change)

Country/ Region	Total domestic demand	Gross output	GDP	Gross exports	by type: final	by type: intermediate	Gross imports	by type: final	by type: intermediate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PANEL A: 1 % demand increase for services									
EU15	--	0.004	0.003	0.026	0.007	0.038	0.003	--	0.004
USA	--	0.002	0.002	0.023	0.006	0.033	0.002	--	0.003
Em. Europe	--	0.003	0.003	0.008	0.002	0.012	0.002	--	0.003
NAFTA (ex. US)	--	0.003	0.003	0.010	0.002	0.016	0.002	--	0.003
China	0.702	0.482	0.554	0.008	--	0.015	0.329	0.139	0.369
Japan	--	0.008	0.006	0.050	0.002	0.083	0.008	--	0.012
Em. Asia	--	0.034	0.028	0.071	0.010	0.103	0.032	--	0.042
South America	--	0.006	0.006	0.027	0.002	0.038	0.005	--	0.008
World	0.028	0.034	0.028	0.031	0.005	0.046	0.031	0.005	0.046
PANEL B: 1 % demand increase for nondurables									
EU15	--	0.001	0.001	0.006	0.002	0.009	0.001	--	0.001
USA	--	0.001	0.001	0.006	0.001	0.009	0.001	--	0.001
Em. Europe	--	0.001	0.001	0.002	0.000	0.003	0.001	--	0.001
NAFTA (ex. US)	--	0.001	0.001	0.003	0.001	0.005	0.001	--	0.001
China	0.140	0.110	0.098	0.002	--	0.004	0.101	0.069	0.108
Japan	--	0.002	0.002	0.014	0.003	0.021	0.002	--	0.004
Em. Asia	--	0.010	0.009	0.021	0.008	0.028	0.009	--	0.012
South America	--	0.003	0.002	0.012	0.006	0.015	0.002	--	0.004
World	0.006	0.008	0.006	0.010	0.002	0.014	0.010	0.002	0.014
PANEL C: 1 % demand increase for durables									
EU15	--	0.003	0.002	0.020	0.029	0.015	0.003	--	0.004
USA	--	0.002	0.001	0.017	0.016	0.017	0.002	--	0.003
Em. Europe	--	0.002	0.001	0.005	0.002	0.006	0.002	--	0.002
NAFTA (ex. US)	--	0.002	0.001	0.005	0.003	0.007	0.002	--	0.003
China	0.158	0.085	0.068	0.008	--	0.015	0.246	0.792	0.131
Japan	--	0.010	0.008	0.064	0.082	0.052	0.010	--	0.015
Em. Asia	--	0.028	0.022	0.061	0.076	0.053	0.032	--	0.043
South America	--	0.002	0.002	0.008	0.002	0.011	0.002	--	0.003
World	0.006	0.010	0.006	0.024	0.028	0.022	0.024	0.028	0.022

Table 8. Regional and global responses of output and trade to a 1% increase in sectoral final demand in China (% change)

APPENDIX C. ESTIMATING CHANGES IN SECTORAL DEMAND

This appendix explains the procedure used to split observed changes in total demand into sector-specific demand changes for durable goods (d), nondurable goods (n), and services (s).

In the static global input-output framework, the value of output in country i and sector j in the pre-crisis period ($t = 2008Q1$) can be written as:

$$Y_t^{i,j} = A_t^{i,j} + NX_t^{i,j} + dV_t^{i,j}, \tag{19}$$

where Y denotes the level of output, A denotes the level of domestic demand, NX denotes the level of net trade and dV denotes change in inventories between the beginning and the end of the period. The goal of the procedure is to estimate post-crisis levels of sectoral demand, A_{t+1}^s, A_{t+1}^d and A_{t+1}^n, where $t+1 = 2009Q1$ (to simplify notation, we drop the superscript i from here forward).

Estimated sector-specific demand changes are constructed to be consistent with observed changes in total demand in each country. To achieve this, we take initial pre-crisis levels of sectoral demand and output from the input-output model and compute post-crisis levels by multiplying the pre-crisis levels in the model by the proportional change observed in data. The variables that need to be estimated can then be expressed as:

$$A_{t+1}^j = \Delta\widetilde{A}^j A_t^j, \tag{20}$$

where $\Delta\widetilde{A}^j \equiv \widetilde{A}_{t+1}^j / \widetilde{A}_t^j$ are proportional changes and $\widetilde{\ }$ indicates that values are obtained from data.

In the first step, we take realized changes in total domestic demand, $\Delta\widetilde{A} \equiv \sum_j \widetilde{A}_{t+1}^j / \sum_j \widetilde{A}_t^j$, from IMF Global Data Source, which contains quarterly, local currency, constant price data for 55 countries. For the EU15 composite, we retrieve total demand data from Eurostat. The post-crisis level of aggregate demand can then be computed as:

$$A_{t+1} = \Delta\widetilde{A} A_t. \tag{21}$$

Next, to compute post-crisis demand levels for goods, $A_{t+1}^d + A_{t+1}^n$, and services, A_{t+1}^s, we assign aggregate demand changes to the two sectors using the following sequential procedure:

$$A_{t+1}^s = Y_{t+1}^s = \Delta\widetilde{Y} Y_t - \Delta\left(\widetilde{Y}^d + \widetilde{Y}^n\right)\left(Y_t^d + Y_t^n\right), \tag{22}$$

$$A_{t+1}^d + A_{t+1}^n = \Delta\widetilde{A} A_t - A_{t+1}^s, \tag{23}$$

where $\Delta\left(\widetilde{Y}\right)$ is change in GDP obtained from IMF Global Data Source and $\Delta\left(\widetilde{Y}^d + \widetilde{Y}^n\right)$ is set equal to the change in the index of industrial production for each country, which we also take from the IMF Global Data Source. This procedure assumes that assumes that in the service sector trade balance did not change during the crisis ($\Delta NX^s = 0$), nor did the stock of services ($\Delta V^s = 0$).

Finally, the estimated post-crisis level of domestic demand for goods, $A^d_{t+1} + A^n_{t+1}$, needs to be separated into A^d_{t+1} and A^n_{t+1}. To do this, we turn to data on durables demand changes to back out the demand for non-durables that is consistent with changes in aggregate demand. Formally:

$$A^d_{t+1} = \Delta\widetilde{A}^d A^d_t, \qquad (24)$$

$$A^n_{t+1} = A_{t+1} - A^s_{t+1} - A^d_{t+1}. \qquad (25)$$

Since detailed expenditure data separating durables and nondurables is not available for all across countries, we combine several types of data to perform this calculation (i.e., estimate $\Delta\widetilde{A}^d$). For the U.S. and EU15, we use data from the BEA and Eurostat on machinery and equipment investment. For other countries, our preferred series is investment expenditures on machinery and equipment from OECD quarterly national accounts.[32] For select countries (e.g., Chile, U.K.) we prioritize national data sources. Finally, for a few countries (e.g., Brazil), we use industrial production data for capital goods and consumer durables to proxy for demand changes. This supply-side data will yield a good estimate of demand changes if we assume that $\Delta V^d = 0$ and $\Delta NX^d = 0$. For one major country, China, we were unable to locate any usable data to perform this durables/nondurables split. We therefore assume that demand changes are symmetric across durables and nondurables sectors in China.

[32] We do not use consumer expenditures on durables, since around 50% of such expenditures are spent on trade and transportation services. For investment expenditures such services account for less than 10% of expenditures (see Bems (2008)).

APPENDIX D. FIT OF THE 3 SECTOR, 55 COUNTRY MODEL WITH DATA

For a variety of reasons, projections of trade and output obtained by feeding demand changes through our input-output framework will not match actual changes in trade and output calculated in the data exactly. As a diagnostic exercise, this appendix documents the "fit" between computed outcomes from our three sector input-output framework and data. Table 9 presents summary statistics quantifying model "fit" and documents how those statistics change across one, two, and three sector specifications. Figure 3 plots changes in GDP, exports and imports computed in the three sector, 55 country framework versus data.

The three sector input-output model matches changes in output quite closely. The model's implied fall in global GDP amounts to 98% of the fall in data, and the cross-country correlation in growth rates between the model and data is 0.91. Our ability to match the decline in global GDP is not particularly surprising given that we calibrate the fall in global demand to match the data. Our ability to match the distribution of GDP changes across countries is of interest because changes in domestic output need not match changes in domestic demand in our open economy framework. Because we assume that changes in demand fall symmetrically on domestic and imported goods, a fraction of the change in demand spills over to the rest of the world. By construction, changes in GDP are a weighted average of demand changes at home and in the rest of the world. As depicted in Panel A of Figure 4**,** this means that variation in GDP changes within the framework will be smaller than the variation in domestic demand. Panel B of Figure 4 shows that this relationship between domestic demand and GDP holds not just in our framework, but also in the data.

Turning to trade flows, the three sector model generates two-thirds of the global trade collapse in data. Interestingly, the model captures a larger share of the cross-section variation in imports than exports. The correlations between the model-implied change and the actual change in exports and in imports are 0.48 and 0.79, respectively. Further, the standard deviation of the model's export response is 3.0, considerably smaller than in data (7.8) or when compared to the standard deviation of the import response (9.3). The underpinnings of this result are conveyed by equations (11) and (12), which show the role of changes in demand in determining outcomes for exports and imports in the three country example. As depicted in Panel A of Figure 4, for most countries change in GDP deviates only slightly from the change in domestic demand. Then equation (11) implies that changes in imports in the model are approximately proportional to changes in domestic demand, while export flows are a weighted average of demand changes in partner countries, leading to more limited cross-country variation in the response of exports.

The input-output's inability to generate wide variation in export changes could at least partly stem from our assumption that changes in demand affect imports from all sources proportionally. This assumption is appropriate if countries are not specialized in the goods they export within our broad sector classifications. That is, with more disaggregate data on demand changes, we believe the model would better match the cross-country distribution of export changes. One can see the effects of disaggregation by comparing our results for the one, two, and three sector version of

	Mean Square Error	Correlation	Change in global volume, % of data	St. dev. of growth rates, % of data
		1-SECTOR MODEL		
Exports	16.0	-0.24	26	14
Imports	11.9	0.68	26	72
GDP	0.8	0.76	97	113
		2-SECTOR MODEL (goods and services)		
Exports	8.5	0.03	56	24
Imports	4.3	0.74	56	97
GDP	0.7	0.81	98	92
		3-SECTOR MODEL (durables, nondurables and services)		
Exports	5.0	0.48	68	38
Imports	3.0	0.79	68	108
GDP	0.4	0.91	98	87

Table 9. Selected statistics for the fit of growth rates in the model and data in a cross-section of 55 countries. Notes: Mean square error and correlation based on GDP-weighted growth rates. "Change in global volume" refers to the sum of changes in the model, as percent of corresponging changes in data.

the framework. As statistics of fit in Panels A-C of Table 9 show, the "fit" for exports (as well as other variables) improves considerably as the number of sectors increases.

Finally, we note that the model does not explain changes in Chinese imports well during the crisis. In the data, China experienced growth in both GDP and domestic demand, while exports and imports contracted. Because imports are driven by domestic demand changes in our framework, we predict that imports in China should have increased proportionally with Chinese economic activity, while in fact they fell in the data. This is a puzzle for future, likely China-specific, work.

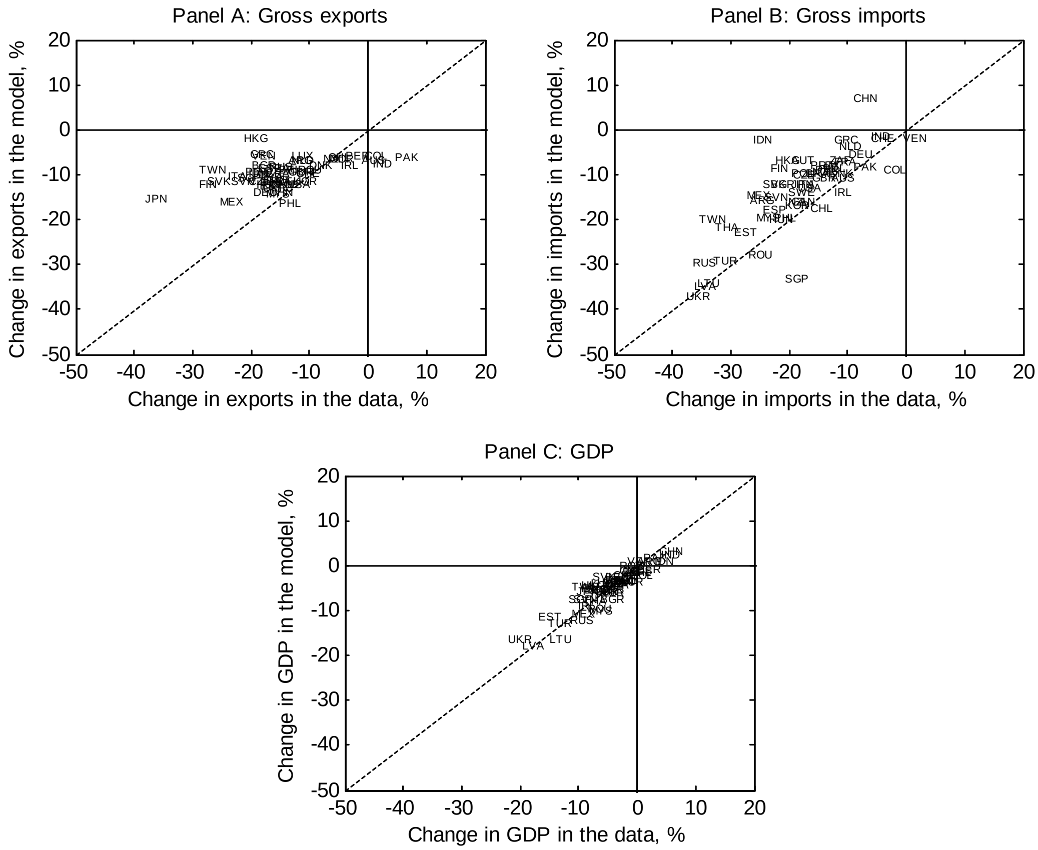

Figure 3. Comparison of the contraction in trade flows and GDP in the global 3-sector I-O model and data (%, 2009Q1/2008Q1). Source: IMF Global Data Source.

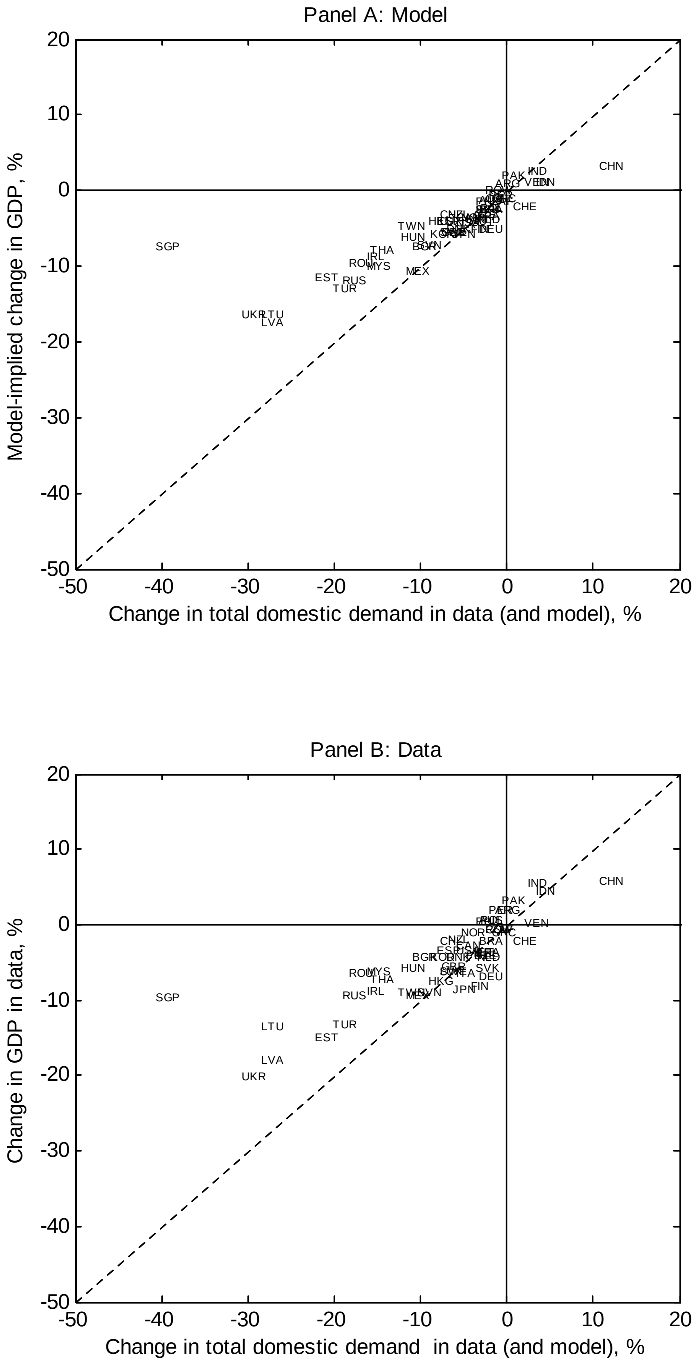

Figure 4. Comparison of changes in real GDP and real total domestic demand in the 3-sector model and data (%, 2009Q1/2008Q1). Source: IMF Global Data Source.