Changing Global Input-Output Linkages and Demand Spillover*

Wataru Miyamoto† Thuy Lan Nguyen‡

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May 30, 2023

Abstract

This paper examines the effects of changing input-output linkages within and across countries in transmitting shocks across countries between 1965 and 2011. We apply the global input-output framework with the time series for the world input-output tables to examine the spillover of shocks to final demand in 23 countries over the last 47 years. We document that the spillover to foreign countries associated with exogenous changes in final demand in domestic economy is about twice as large now as that in 1965. Moreover, demand spillover is even larger when final demand for more open sectors or foreign goods increases, suggesting the importance of sectoral demand composition. Finally, the foreign spillover in the 2008–2009 Great Recession is large due to both input-output structure changes and sectoral composition of demand.

JEL classification: E32, F31.

Keywords: International business cycles, trade linkages, volatilities, input-output, shock spillovers.

*This paper is prepared for the *IMF Economic Review* Summer Conference in June 2023 in Oslo, Norway. We thank the editors and the organizers for the invitations. The views expressed in this paper are those of the authors and do not represent the view of the San Francisco Fed or the Federal Reserve Bank system.

†University of Hong Kong. wataru.miyamoto1@gmail.com.

‡Federal Reserve Bank of San Francisco and Santa Clara University. thuylan.nguyen00@gmail.com.

1 Introduction

Input-output linkages within and across countries have changed substantially in the last 50 years. Volumes of trade is much larger now than 40 years ago: As plotted in Figure 1, both intermediate and final goods trades as a share of gross output have increased two folds in a median country of 23 countries between 1965 and 2011. In addition, all sectors in the economy trade more over time, with some sectors experiencing much larger change, reflecting a more vertical production network. As plotted in Figure 2, the largest increase in trade happens in manufacturing sectors: total exports and imports as a share of gross output in the Chemicals and Chemical Product sector increase from 20% to 100%, while that in the Post and Telecommunication sector or the Financial Intermediation sector increases from 5% to nearly 10% only in a median country.

Economic theory suggests that production networks within and across countries are an important channel through which shocks are transmitted across countries. Therefore, these observed changes in patterns of trade linkages are likely to have altered shock transmission and global business cycle synchronization in the last 50 years. While there are several papers, such as the recent Caselli et al. (2020) and Miyamoto and Nguyen (2022), analyzing the effects of changing input-output linkages on business cycle volatilities, only few papers analyze how structural changes have affected cross-country business cycle transmission. This paper tries to fill this gap by providing an empirical analysis on how changing input-output within and across countries have altered the strength of the shock spillover across countries. We take an agnostic approach to focus on the production network role in shock spillover, disentangling different spillover channels such as through intermediate and final goods trade. We use a global input-output framework that links demand to production through intermediate and final goods and service flows to trace the impact of demand changes in each economy on its domestic economy as well as the entire world economy through production linkages. This framework simplifies the many frictions often assumed in a dynamic stochastic general equilibrium model. The main contribution of our paper is that we exploit the time variation in the world input-output (IO) tables between 1965 and 2011 to highlight how changes in the global input-output structure have altered the transmission of demand spillover through final and intermediate trade channels in this long time span. In addition, we seek to understand the role of sectoral heterogeneity in altering the spillover strength over time.

We conduct three exercises. In the first exercise, we consider an "aggregated" world where each of the 24 countries have only one sector. We compute a domestic value added response to a $1

increase in final demand for each country. Then, the foreign value added response is computed as the sum of the responses of the rest of 23 countries. The foreign response measures the spillover of exogenous final demand changes to foreign countries. In this case, the mechanism through which changes in demand for domestic final goods to other countries is only through intermediate trade across countries. We find that the domestic value added response is declining over time, while the foreign value added response increases substantially. The demand spillover to foreign output is 0.16 with the IO linkages in 2011, twice as large as that with the 1965 IO linkages. Since final demand in each country can consist of both domestic and foreign imported goods, we compute the spillover of shocks to the final demand in each country where *both* domestic and foreign goods change by their shares in final demand in each country. The main difference between this case and the previous case is that both intermediate and final demand channels are at work. We find that the response of value added in the rest of 23 countries are larger than the previous case, and also increases significantly over time—by nearly 70% as much with the 2011 IO linkages as that with the 1965 IO linkages

In the second exercise, we examine the role of heterogeneous demand and sectoral composition in the transmission of demand changes to domestic and world economy. We focus on the multi-sector set up where each country has 24 sectors. We motivate our analysis by documenting three facts: First, the standard deviations of value added for these 23 sectors are vastly different, with some sectors in manufacturing being three to four times more volatile than those in services. Second, volume of trade changes over the last 47 years have been larger for manufacturing sectors than for services sectors. Third, the spillover of a shock to final demand for each sectoral good is larger and more significant for some sectors such as manufacturing sectors than for others such as services sectors. In this multi-sector setup, we compute the foreign spillover of final demand in a similar manner as in the aggregate analysis. When the final demand for domestic goods increases by $1 with demand for each sectoral good changing by its share in total final domestic demand, we find that the spillover of this final demand change to foreign value added are twice as large with the 2011 IO linkages as that with the 1965 IO linkages. We further examine the spillover when the final demands for both domestic and foreign goods increase by a total of $1, with demand for each sectoral good changing by its share in total final demand in each country. Similar to our aggregate analysis, we find that the international transmission is higher than when only final demand for domestic goods increases. This result reflects the final good trade channels, and is larger with the 2011 IO linkages than that with the 1965 IO linkages. Taken together, our analyses suggest a

substantial role of IO linkages in shaping international transmission of demand spillover.

To further understand the extent to which demand composition plays a role in the changing international transmission of shocks over time, we consider the international transmission of demand spillover when changes in final demands for foreign goods are large. To motivate, we compute the standard deviations of HP-filtered real GDP, exports and imports for our 23 countries between 1960 and 2019. Consistent with the documentation in Engel and Wang (2011), we find that real exports and imports are between two and three times more volatile than real GDP. We then compute the spillover effect from a \$1 increase in final demand in each country, where the final demand for foreign goods in the composition to be two to three times larger than the final demand for domestic goods in percent change. In this case, the impact of a \$1 increase in final demand on all foreign countries at median is higher than our previous exercise, where changes in the final demand for domestic and foreign goods are proportional. Moreover, the spillover effect at a median country is now more than 50% higher than in when the IO linkages are at the 1965 level.

We further explore the implication of sectoral heterogeneity in demand composition in the multi-sector framework. While our baseline considers the case where changes in the final demand for all 23 sectors are proportional, the actual standard deviations of the value added for these sectors are substantially different, suggesting that changes in the final demand may not be proportional across sectors. Motivated by this observation, we compute the international spillover in the last 47 years when final demand changes for some sectors such as machineries are larger than those for service sectors. We find that the foreign spillover of a shock to final demand in each country is also larger with the 2011 IO linkages than that with the 1965 IO linkages Importantly, the size of the international transmission can be twice as large as the international spillover when final demand changes for 23 sectoral goods are proportional. We note that while these adjustments are an imperfect way to capture the relative changes in domestic and foreign good composition when final demand changes, it sheds light on the role of demand composition in shock transmission through production network, and provides us a range of the strength of demand transmission across countries over time.

Finally, to highlight how international IO structure changes over time and sectoral composition play an important role in the international transmission of demand changes, we conduct counterfactual analysis taking the actual final demand changes in the 2008–2009 Great Recession period. We first document that shocks to final demand in the United States between 2008 and 2009 have large spillover to the rest of the countries: larger when the input-output linkages follow the 2008 world

IO table than when the input-output linkages are at the 1965 level. This result is consistent with our analyses that the world IO structure has enhanced the spillover of shocks across countries. In addition, we also find that the spillover with the sectoral composition of US final demand changes in the 2008–2009 period is three times larger than the demand composition with the proportional change. In fact, there is a large increase in spillover contributed by sectors such as Machineries and Transport Equipment. Final demands for foreign goods in the United States also fell by more than that for domestic goods in many sectors. These results demonstrate that sectoral composition of demand changes can be an important factor driving the magnitude of international transmission, in addition to changes in the world IO structure over time.

We note that our paper focuses on demand changes, rather than specific types of shocks in a general equilibrium model. Our motivation is that Behrens, Coreos, and Mion (2013) and Bems, Johnson, and Yi (2010) find that the 2008-2009 trade collapse is due to a fall in demand, especially in durable and capital goods. Our framework can help us understand how propagation of demand changes in different sectors have changed over time. Overall, our analyses suggest that input-output linkages within and across countries may have altered the transmission of shocks across countries substantially in the last 47 years. An important implication is that we need to consider the structural changes in input-output linkages seriously.

Related Literature First, our paper contributes to the literature understanding the changing input-output network in driving business cycle volatilities and comovements across countries. For example, Caselli et al. (2020) and Miyamoto and Nguyen (2022) use a multi-country multi-sector model to analyze the implications on output volatility when there are changes in trade and input-output linkages. Bonadio et al. (2020) also employ a multi-country model to quantify the changing input-output linkages on business cycle comovements between 1979 and 2007 for several countries in the Organisation for Economic Co-operation and Development (OECD). We instead use a global input-output framework focusing on final demand changes to study how shock spillover have changed between 1965 and 2011 for 24 countries with 23 sectors and how sectoral heterogeneity affect demand spillover over time. The main difference between the global input-output framework and a general equilibrium model as in those papers is that the global input-output framework abstracts from the household side. However, the tractability of this approach can help clarify transmission mechanism through the production side, potentially distinguishing between the final and intermediate good channels.

Second, we add into the literature on understanding the connection between trade including intermediate goods trade in propagating shocks across countries. Di Giovanni and Levchenko (2010), Burstein, Kurz, and Tesar (2008) among others highlight the importance of bilateral intermediate trade in generating large correlation of sectoral outputs across countries, while Johnson (2013) suggests that in a two-sector two-country model, the existence of intermediate trade cannot explain the correlation of bilateral trade and output correlation across countries. A closer paper to us is Bems, Johnson, and Yi (2010), who study the role of intermediate trade in demand spillover during the 2008-2009 Great Recession. Unlike these papers, we focus on the time-varying features of the input-output network within and across countries to examine how demand spillover across countries have changed over time and its implication for studying business cycle comovements. Our paper argues that studies using international business cycle models need appropriate calibration of the steady state, instead of relying on an average input-output structure. We also suggest that a time-invariant VAR to study transmission of shocks across countries may need more careful interpretation.

Finally, our work also contributes to understanding how demand heterogeneities at the aggregate level and the sectoral level combined with changes in IO linkages within and across sectors amplify the transmission of shocks across countries. While recent work on international business cycles such as Huo, Pandalai-Nayar, and Levchenko (2020) among others employ multi-country multi-sector models to analyze business cycle comovements, we highlight how sectoral heterogeneity may amplify structural changes in the last 47 years.

The rest of the paper is organized as follows. In Section 2, we describe in detail our global input-output framework. Section 3 summarizes the data we use for our analysis. The next three sections present our main findings on the demand spillover to foreign countries in the last 47 years. We conclude in Section 8.

2 Empirical Framework

Our framework is based on classic input-output analyses. This framework is similar to Bems, Johnson, and Yi (2010). There are N countries with S goods-producing sectors in each country. Each sector in each country produces a differentiated good that can be used as an intermediate input in the production of all sectors in all countries, or as a final good to satisfy final demand. Output in each sector in each country is produced by combining all sectoral intermediate inputs

from all countries. Let M be an $NS \times NS$ matrix containing all the intermediate inputs for each sector s country i, F be an $NS \times N$ matrix of the final demand in country j for goods in sector i country j, and Q and V be $NS \times 1$ vectors of gross output and value added in sector s country i, i.e.

$$Q = \begin{bmatrix} Q(1,1) \\ \vdots \\ Q(1,S) \\ Q(2,1) \\ \vdots \\ Q(N,S). \end{bmatrix}$$

For each country i and sector s, the market clearing condition at each year requires:

$$Q(i,s) = \sum_{j=1}^{N} \sum_{k=1}^{S} m((i,s),(j,k)) + \sum_{j=1}^{N} f((i,s),j), \tag{1}$$

where $m((i,s),(j,k))$ is the intermediate goods from country j sector k, and $f((i,s),j)$ is the final goods from country j. Gross output is determined by demand for intermediate inputs and final goods. In a matrix form, the equation above can be rewritten as

$$Q = M \times I_{NS} + F \times I_N,$$

where I_{NS} and I_N are column vectors of ones with length NS and N, respectively. We add up final demand across countries, and define $\widetilde{F} \equiv F \times I_N$. Then, gross output is simply expressed as $Q = M \times I_{NS} + \widetilde{F}$. We assume final demand $\tilde{F}$ to be exogenous, and analyze how changes in $\tilde{F}$ affects Q and V.

Intermediate good demands are determined as follows. Define matrix A that contains the share of intermediate inputs used in each sector as follows:

$$A = M\bar{Q}^{-1}, \tag{2}$$

where $\bar{Q}$ is a diagonalized matrix of Q, i.e.

$$\bar{Q} = \begin{pmatrix} Q(1,1) & 0 & 0 & ... & 0 \\ 0 & Q(1,2) & 0 & ... & 0 \\ ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & Q(N,S) \end{pmatrix}.$$

A is assumed to be fixed. We also assume fixed value added share as $v' = V'\bar{Q}^{-1}$. The assumption for these analyses is that the production function is Leontief in its inputs, which is consistent with the estimate of the elasticity of substitution between inputs in Boehm, Flaaen, and Pandalai-Nayar (2019) in the short run. We then rewrite the equation for gross output as $Q = AQ + \tilde{F}$. Define the Leontief inverse $B \equiv (I - A)^{-1}$, then gross output is expressed in terms of final demand as follows

$$Q = (I - A)^{-1}\tilde{F} = B\tilde{F}. \tag{3}$$

The effects of changes in $\tilde{F}$ on value added V can be computed as follows:

$$V = \bar{v}Q = \bar{v}B\tilde{F},$$

where $\bar{v}$ is a diagonalized matrix of v:

$$\bar{v} = \begin{pmatrix} v(1,1) & 0 & 0 & ... & 0 \\ 0 & v(1,2) & 0 & ... & 0 \\ ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & v(N,S) \end{pmatrix}.$$

In the exercises below, we use level changes, i.e. $\Delta Q = B\Delta\tilde{F}$.

To understand how transmission of shocks have changed over time due to IO linkage changes, we perform the following procedure. For each version of the world IO table at time t, we compute B, v, denoted as $B(t), v(t)$. Using these shares, we compute the responses of gross output and value added to a change in final demand $\Delta\tilde{F}$. Changes in the responses of gross output and value added to the same change in final demand when $B(t), v(t)$ change over time are the impact of changing global input-output linkages. Note that for some of the exercises, changes in $\tilde{F}$ are also different over time based on the world IO tables, which we explain in details below.

3 Data

The main data series we use come from the world IO database (WIOD). The long-run WIOD, released in March 2022, covers the 1965–2000 period, encompassing the period with increasing integration of production and consumption in the world economy. The second WIOD covers the 1995–2011 period. As we focus on the changes of the world IO linkages over time, we combine these two WIODs into one, spanning from 1965 to 2011. We consider 23 countries: Australia, Austria, Belgium, Brazil, Canada, China, Germany, Denmark, Spain, Finland, France, the United Kingdom, Greece, India, Ireland, Italy, Japan, Korea, Mexico, the Netherlands, Portugal, Sweden, and the United States. The rest of the countries are aggregated into a composite rest-of-the-world (ROW). Each country has 23 sectors as listed in Table 1.[1] To smooth out fluctuations that may be due to business cycles and possibly measurement errors, we take a rolling 10-year average for the 1965-2011 world IO table time series.

We summarize the changes of international trade in the 1965-2011 world IO time series. Figure 1 plot the shares of intermediate and final trade in gross output for a median country in our sample and the 25-75 percentile bands. Consistent with the well-documented fact about international trade, intermediate good trade is much larger than final good trade: in the entire time period, intermediate trade is about twice as much as final trade. Both intermediate and final trade as a share of gross output increase two fold between 1965 and 2011 in a median country in our sample. We next plot in Figure 2 the shares of intermediate and final trade in each of the 23 sectors over the same period. There are three main observations. First, while trade as a share of sectoral gross output increase in all sectors, trade openness, or exposure, measured by the shares of trade, in the non-manufacturing sectors and services sectors (sectors 15 to 23) are small. Second, final good trade is as large as intermediate good trade in some sectors such as the Food, Beverage and Tobacco sector, the Textiles, Leather and Footwear sector, the Machinery sector. Third, trade exposure changes happen in different periods within the last 50 years: while some sectors, such as the Chemical and Chemical Products and Manufacturing, Nec Recycling sectors, experience a large increase in trade in the 1990s and small changes in the 2000s period, other sectors have more even changes over time. Given the complex input-output linkages across sectors, the different patterns of trade across sectors over time suggest that shocks hitting a service sector in one country may

[1] There are some discrepancies between the two WIODs in the overlapping years. To construct the world IO table for the overlapping years between 1995 and 2000, we take a weighted sum of the two WIODs, with the weights based on world gross output in the two WIODs, which turn out to be close to 0.5.

have substantially different consequences than shocks hitting the Construction or Textile sector in the same country, in addition to the time dimension. We use our framework to study this question next.

4 Aggregate demand spillover over time

We first examine how spillover of a change in aggregate final demand to domestic and foreign economies has evolved over time due to global IO linkage changes. To that end, we consider an aggregate world IO table where each country has only one sector. When final demand for goods of country i increases by \$1, we compute the domestic value added response, which is the response of total value added in country i, as well as the other 23 countries. To fix idea, suppose final demand for US goods increase by \$1, the Leontief inverse helps us pin down the change in gross output, then value added in the United States and 23 other countries.[2] For ease of exposition, we use "domestic" response to note the response of US value added, and sum up the changes in the other 23 countries into an aggregate statistic called "foreign" response. For each IO table in time t, we have a set of domestic and foreign responses to a change in final demand for each country in the sample. Note that the sum of the foreign and home value added responses is \$1.

4.1 Changes in final demand for domestic goods only

Figure 3 plots the domestic responses (on the left) and the foreign responses (on the right) to a \$1 increase in final demand for country i as global IO changes between 1965 and 2011. The responses are plotted at median, 25 and 75 percentiles across countries in each point in time. There are three main observations: First, domestic responses to a \$1 increase in final demand for domestic goods are getting smaller over time, so on the flip side, the foreign responses are larger. The foreign responses in a median country almost double between 1965 and 2011: from \$0.09 to \$0.16. This suggests that increase in global linkages lead to larger spillover of demand to other countries. Second, while spillover of demand changes to foreign countries has increased over time, domestic responses are still much larger than foreign responses. In particular, a \$1 increase in final demand for goods in a median country leads to \$0.91 increase in domestic value added and only \$0.09 increase in foreign value added when steady state input-output linkages are in 1960s level. The intuition is that final demand for goods directly affect the domestic economy, while it only affects other foreign countries

[2] This framework does not distinguish the origin of the increase in final demand.

through intermediate input linkages and often with a home bias, the spillover of a demand change is larger in the domestic economy than in foreign countries. Third, changes in the magnitude of the demand spillover to foreign countries are heterogeneous across countries. To demonstrate this point, we include in the same figure the domestic and foreign responses to a \$1 increase in final demand for US goods and Chinese goods. In both cases, while foreign responses when the global IO linkages are in 2011 are larger than when IO linkages are in the 1960s, foreign spillover of demand for Chinese goods is about five times larger now than in the 1960s (\$0.17 compared to \$0.03) and for US goods is less significant (\$0.07 compared to \$0.03). This result reflects the increasing large presence of China in international trade and the world economy.

4.2 Changes in final demand for both domestic and foreign goods

Since changes in the final demand often consist of both foreign and domestic goods, we consider the case when both home and foreign final demand changes. The percent changes in the final demand for domestic and foreign goods are by the same proportion. To make the results comparable across different cases, we normalize the level changes so that the total changes in the final demand for both domestic and foreign goods sum up to \$1. Another interpretation for this scenario is that there are some correlated final demand changes when the shock happens in country i. In particular, the \$1 final demand change in country i is allocated to final demand for all country based on the domestic and foreign final demand shares in country i, i.e. final demand for each country increases by $\frac{f(i,j)}{\sum_j f(i,j)}$, where $f(i,j)$ denotes the final demand of country i for goods from country j. For example, final demand in the United States, using the world IO table in 1965, consists of 0.8 US goods and 0.2 goods from other countries. Then, our exercise assumes $\Delta\tilde{F}$ in the United States includes \$0.80 increase in final demand for US goods and \$0.20 increase in final demand for other countries' goods. Each world IO table in time t is associated with a set of steady states, so we can compute the effects on domestic and foreign value added when final demand in each country changes.

Figure 4 plots the responses of domestic and foreign value added to a change in final demand in each country as the global IO linkages change between 1965 and 2011. As before, we include the responses in the median and 25–75 percentile countries. There are two main observations. First, the responses of domestic (foreign) value-added are smaller (larger) than those in the case above when only final demand for goods in country i changes. This result makes sense since there is a direct effect of the final demand for foreign goods on foreign value added in addition to the spillover

through intermediate goods channel in the case above. At the same time, since the changes in the final demand for foreign and domestic goods are proportional, the weight of the change in the final demand for foreign goods is relatively small. Consequently, the response of foreign value-added with the 1965 IO linkages is larger than that in the first exercise ($0.14 compared to $0.09 in 1965). Second, the response of foreign value added in the rest of 23 countries with the 2011 IO linkages is nearly 80% higher than that with the 1965 IO linkages ($0.25 from $0.14). This result is consistent with our previous case where final demand changes have much larger spillover to other countries now than 40 years ago.

5 Multi-sector demand spillover over time

This section analyzes the spillover of final demand shocks over time in a multi-sector framework. We make use of the full input-output data where each country has 23 sectors, and examine the role of heterogeneous demand and sectoral composition in the transmission of demand changes across countries over time. We show that demands for final sectoral goods have different spillover effects, and that spillover effect also increases substantially over the last 40 years due to world IO linkage changes. We then decompose the changes into intermediate and final demand channels to understand which channel contributes more to the changes in spillover effects.

5.1 Sectoral transmission

To motivate our multi-sector analysis, we first describe the spillover effects of a change in the final demand for each sectoral good over time. In particular, we study how foreign value added responds when there is a $1 increase in final demand for a sector s in country i. Figure 5 plots the median responses of all foreign countries with the 25-75 percentile bands. As above, we sum up the responses of all country $j \neq i$ to get the foreign response to a $1 increase in final demand for goods in sector s in country i. The foreign responses for all sectors have increased persistently over time. Comparing the foreign responses in 2011 to those in 1965, the spillover effects are about twice as large. At the same time, the sectoral final demand spillover is quite different across sectors. For example, Real Estate, Communication, Social and Personal Services have little spillover to other countries (less than $0.10 response in 2011), while manufacturing sectors such as the Coke, Refined Petroleum and Nuclear Fuel sector and the Electrical and Optical Equipment sector have much larger spillover (up to $0.6 in 2011) and larger spillover increase. This result makes sense as we show above that

the Real Estate sector, as well as the Communication, Social and Personal Services sector have small trade exposure with less than 10% total trade share out of gross output, while manufacturing sectors are much more open. However, note that while Real estate or Communication sectors are almost closed, the increase in final demand for those sectors can still have a non-negligible spillover as we document here, due to the input-output structure of the economy. This same pattern is clear for the Construction sector: while its total trade share in gross output is less than 15% over time, a $1 increase in the final demand for the Construction goods generates $0.20 increase in foreign value added, suggesting that a sector that may not directly import intermediate but is connected to other sectors which import foreign goods can have large international spillover.

5.2 Spillover of final demand changes

Since spillover effects from sectoral final demand are substantially different across sectors, it is important to understand how the changing sectoral composition of final demand changes have affected international spillover. To that end, we consider two scenarios, similar to the aggregate analysis. In the first case, only final demand for domestic goods goes up by $1, with final demands for domestic sectoral goods changing by proportionally in percent. In the second case, changes in the final demand for both domestic and foreign goods sum up to $1.

Changes in final demand for domestic goods only The left figure of Figure 6 plots the foreign responses to $1 increase in domestic demand for final goods for each year corresponding to that year's world input-output structure. We assume that the changes in each sector's final demand are proportional in percent, so in level, the change in the final demand for each sectoral good is equal to its share. With the 1965 IO structure, a $1 increase in final demand for domestic goods only leads to $0.08 increase in foreign value added (and the rest, $0.92, is domestic value added increase). The spillover is more than 50% larger with 2011 IO structure ($0.13). Similar to the aggregate analysis, the increase of the international spillover has been gradual over time. In terms of magnitude, it is slightly lower than the transmission in the aggregate analysis (the left figure of Figure 3).[3]The difference comes from the disaggregated nature of the multi-sector analysis: while the total final demand for country i changes by $1 in both cases, the demand is allocated to each sector by its share in total domestic demand. In addition, with changing IO structures, these shares

[3]The spillovers in the aggregate analysis and in the multi-sector analysis are the same if we only consider world final demand changes with proportionality.

change over time, i.e. sectoral composition of final demand changes in addition to the linkages. Therefore, some discrepancies exist between the aggregate analysis and the multi-sector analysis.

Changes in final demand for both domestic and foreign goods The right figure of Figure 6 plots the foreign responses to \$1 increase in domestic demand for both domestic and foreign final goods for each year corresponding to the world input-output structure. As before, the domestic and foreign final demand for each sector increases by its share in the final demand, so that their sum is \$1. We find that international spillover has also increased by over 70% over time in this case, from \$0.13 in a median country with the 1965 IO structure to \$0.23 with the 2011 IO structure. This larger increase compared to when all \$1 is spent on domestic final demand reflects the difference of intermediate and final good channels, in addition to the composition of sectoral final demand change over time. In particular, when there is a \$1 increase in final demand for domestic goods only, the only transmission mechanism goes through intermediate linkages. In contrast, the international spillover of \$1 increase in final demand for both domestic and foreign goods goes through both final and intermediate good linkages. We decompose the transmission into these two channels next.

Intermediate and final good channels To see how much the roles of intermediate and final good channels have changed over time, we decompose the demand spillover to foreign countries into intermediate and final good channels. To explain based on our framework above:

$$\begin{aligned}\Delta V &= \bar{v}(I-A)^{-1}\Delta\tilde{F} \\ &= \bar{v}(I-A)^{-1}(\Delta\tilde{F}_{foreign} + \Delta\tilde{F}_{domestic}) \\ &= \bar{v}(I+A+A^2+...)(\Delta\tilde{F}_{foreign} + \Delta\tilde{F}_{domestic}).\end{aligned}$$

Intuitively, there are two ways to separate intermediate and final good channels. To fix idea, consider the simple example above where $\hat{F}$ in the United States includes \$0.80 increase in final demand for US goods and \$0.20 increase in final demand for other countries' goods. Then, the international spillover coming from the final good channel is simply \$0.2, which is the direct effect, and the rest of the foreign responses comes from the intermediate good channel. Alternatively, the international transmission of demand coming from the intermediate channel is the spillover when only \$0.80 increase in final demand for US goods, and the rest is the final good channel. The main difference between the two decomposition methods is that the final good channel in the second method includes both the direct and indirect effects of \$0.2 changes, i.e. all the subsequent

propagation of demand for foreign countries' final goods, while the final good channel in the first method only includes the direct increase in final demand for foreign goods. We employ both decomposition methods.

The left figure in Figure 7 shows the decomposition using the first method. In this case, when domestic economy demands \$1 more of goods from both home and abroad, where each country's final demand changes by a fraction of \$1. Since countries often have a strong home bias, final demand for foreign goods is relatively small (less than \$0.30 in 1965), the final good channel in this decomposition method is small, less than 20% of the total increase in value added in the foreign countries in 1965. Over time, the final good channel increases in the level, due to an increase in foreign shares in the final demand, but it remains small, less than \$0.05. Therefore, the majority of the increase in the foreign value added responses between 1965 and 2011 is driven by the intermediate good channel.

The decomposition of intermediate and final good channels using a second method is plotted in the right figure in Figure 7. In this case, both final and intermediate good channels are important in driving the larger spillover of final demand changes over time. The final good channel is now more important than in the first decomposition method, as the propagation of demand for foreign final goods is included in the final good channel. By 2011, final good channel contributes to about half of the transmission of final demand changes to the rest of the countries.

Overall, our decomposition suggests that both intermediate and final good channels are important in driving larger international spillover over time.

6 The role of demand heterogeneity

We further explore the importance of demand composition in the multi-sector framework. While our exercises so far suggest that demand spillover to foreign countries can be large and has increased over time, the magnitude of the spillover may be underestimated. The intuition is as follows: we have assumed that the change in final demand for each sector is proportional, so in level, they are a simple share in the total final demand. At the same time, since each sector has different international spillover as shown above, and demand for foreign goods tend to fluctuate more than demand for domestic goods, how much final demand for each sector changes can matter substantially for the spillover strength.

To provide insight on how much demand composition can change the spillover strength and

pattern over the last 47 years, we again compute the international spillover over time when final demand increases by \$1, but this time we adjust final demand changes for volatility differences across home and foreign goods and sectoral goods. As in the previous section, final demand for home and foreign goods are changed by a fraction of \$1, equal its share in total final demand in each country. At the same time, as in Engel and Wang (2011), we find that real exports and imports are between two and three times more volatile than real GDP. So, we consider the spillover where the demand for foreign goods in the composition to be disproportionately larger than the same exercise in the previous section. In particular, we adjust the changes in final demand as follows. Suppose in the baseline case, a \$1 increase in final demand in the United States includes \$0.80 increase in the final demand for US goods, and \$0.20 for foreign goods. To adjust for final demand for foreign goods to account for the fact that imports can be twice as volatile as final demand for domestic goods, we normalize the increase for US goods to be $\$0.80/(0.80+0.20\times 2) = \$0.67$ and for foreign goods to be $\$0.2\times 2/(0.80+0.20\times 2) = \$0.33$. The left plot of Figure 8 presents the spillover effect to foreign value added when changes in final demand for foreign goods are 1.5 to 2.5 times more volatile than final demand for domestic goods. Similar to the baseline, international spillover has increased substantially over time: the spillover effect at a median country is now close to 75% higher than in when the IO linkages are at the 1965 level. More importantly, the impact of a \$1 increase in final demand on all foreign countries at median is higher than baseline (proportional) case. In the case where changes in final demand for imported goods are 2.5 times more volatile, transmission is substantial: foreign value added increases by \$0.35 with the 2011 IO linkages, compared to \$0.23 in the baseline.

We next examine how sectoral composition affects the international spillover strength over time. In this case, we adjust final demand changes for each sectoral goods according to the relative volatilities of 23 sectors. For simplicity, we group the first 16 sectors (up to the Construction sector) to be "tradable" and the rest of the sectors "nontradable". Again, we compare the international spillover in the last 47 years with that in the baseline where the changes in final demand for each country sectoral goods are unadjusted shares in total final demand in each country. We adjust the changes in final demand for differences in volatilities of final demand for tradable and nontradable goods. in the same way as in the aggregate analysis. The right figure of Figure 8 plots the results in several cases: the baseline median, the case where nontradable sectors are 50%, 75% and 90% as volatile as the tradable sectors. In all of these cases, the foreign spillover of a shock to final demand in each country is also larger with the 2011 IO linkages than that with the 1965 IO linkages

Moreover, the size of the international transmission with adjusted sectoral demand can be much larger than the baseline: adjusting for sectoral volatility can increase foreign spillover by about 30%, from \$0.22 (with the 2011 IO linkages) to \$0.3. This is large spillover to foreign countries, as the sum of domestic and foreign value added changes is only \$1. This exercise highlights the importance of sectoral composition in spillover of final demand through input-output relationship.

We note that while these adjustments are an imperfect way to capture the relative changes in domestic and foreign good composition when final demand changes, it sheds light on the role of demand composition in shock transmission through production network, and provides us a range of the strength of demand transmission across countries over time.

7 Great Recession 2008-2009

In this section, we use the actual changes in final demand in the United States during the 2008-2009 Great Recession period to demonstrate the extent to which sectoral composition and changes in IO linkages over the 1965-2011 period affect the magnitude of international spillover. We focus on the United States, but our findings, included in the Appendix Figure 10, for a median country are similar.

To understand how world IO linkages have altered the impact of final demand changes in the 2008-2009 period, we first find the actual changes in final demand in the United States. The time series of the world IO table provide the information for the changes in the final demand of the United States between 2008 and 2009. We then compute the spillover of the actual changes to foreign value added using the 1965–2011 world IO tables. Figure 9a plots the spillover in the Great Recession coming from the United States. To make it comparable to the spillover analysis above, we normalize the demand changes in the United States so that the total change is \$1, and also include the spillover from the median country in the baseline and the spillover from US proportional final demand change (baseline US). There are two observations. First, the international spillover for US demand changes is larger now (\$0.36) than if it had happened in 1965 (\$0.27), suggesting structural changes play an important role in the magnitude of the transmission of shocks across countries. Second, the spillover of the actual changes in final demand in the Great Recession is three times larger than our exercise using proportional changes in the US final demand. This result demonstrate that the composition of final demand change matters significantly for the strength of the spillover to foreign countries.

To further understand what contributes to the larger spillover of US demand changes in the Great Recession than that in the baseline proportional change, we plot in Figure 9b the spillover to foreign value added by sector in the Great Recession as well as in the baseline where the final demand changes are based on the proportional share in 2008. Compared to our baseline, the large spillover in the Great Recession is driven by Coke, Refined Petroleum and Nuclear Fuel, Machinery, Electrical and Optical Equipment and Transport Equipment sectors. This result is consistent with Bems, Johnson, and Yi (2010) that durable sector contributes to the large change in trade during the Great Recession. Construction also plays a relatively large role in driving the larger spillover in this period, suggesting that its connection with other sectors in the economy is important.

Finally, further understand how the composition of final demand for home and imported goods may have contributed to the large spillover during the Great Recession, we plot in Figure 9c the changes in US final demand in different sectors in the Great Recession broken down by domestic and imported demand. In many sectors, the changes in final demand for foreign imported goods are larger than those for domestic goods. The large spillover to foreign countries in Transport Equipment sector that we observe above is also driven by the large change in final demand for imported goods, which is more than twice as much as that for domestic goods. Overall, these observations are consistent with the analyses for domestic and foreign demand as well as sectoral composition above.

8 Conclusion

This paper explores the importance of domestic and international input-output linkages on the spillover of final demand between 1965 and 2011. In both one-sector and multi-sector frameworks, a $1 change in final demand leads to twice as much foreign value-added change using the world IO relationship in 2011 as that using the world IO relationship in 1965. This result suggests that it is important to consider structural changes in input-output relationship seriously when modeling international transmission of shocks across countries—we may capture the average, which can be significantly different from the actual period. Furthermore, the strength of the international spillover from a final demand change depends crucially on sectoral composition, and international transmission depends on which sector is hit by a shock, which may not be adequately captured in a single sector model.

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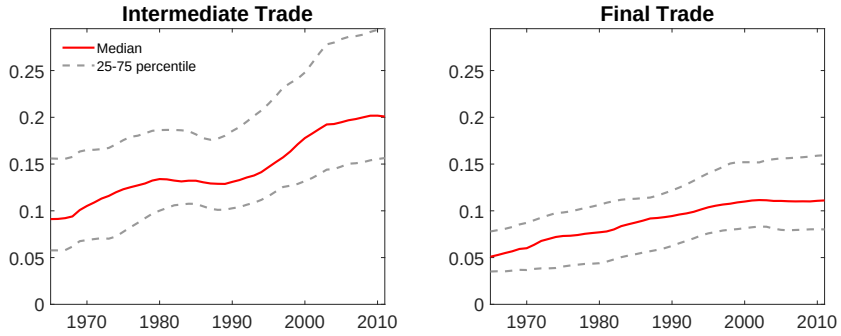
Figures and Tables

Table 1: Data Summary

			$\sigma\Delta \ln Y$	σY_HP
AtB	Sector 1	Agriculture, Hunting, Forestry and Fishing	4.60	3.78
C	Sector 2	Mining and Quarrying	7.05	6.83
D15t16	Sector 3	Food, Beverages and Tobacco	2.94	3.33
D17t19	Sector 4	Textiles, Textile, Leather and Footwear	5.17	4.82
D21t22	Sector 5	Pulp, Paper, Paper, Printing and Publishing	4.63	4.54
D23	Sector 6	Coke, Refined Petroleum and Nuclear Fuel	9.21	9.82
D24	Sector 7	Chemicals and Chemical Products	6.07	4.97
D25	Sector 8	Rubber and Plastics	6.08	5.76
D26	Sector 9	Other Non-Metallic Mineral	5.76	6.32
D27t28	Sector 10	Basic Metals and Fabricated Metal	5.65	4.85
D29	Sector 11	Machinery, Nec	6.83	6.14
D30t33	Sector 12	Electrical and Optical Equipment	7.64	7.13
D34t35	Sector 13	Transport Equipment	7.29	6.63
Dnec	Sector 14	Manufacturing, Nec; Recycling	6.01	6.51
E	Sector 15	Electricity, Gas and Water Supply	5.27	4.15
F	Sector 16	Construction	5.31	6.40
G	Sector 17	Wholesale and Retail Trade	3.75	3.45
H	Sector 18	Hotels and Restaurants	3.60	3.52
I60t63	Sector 19	Transport and Storage	3.85	3.45
I64	Sector 20	Post and Telecommunications	5.48	5.89
J	Sector 21	Financial Intermediation	4.68	4.65
K	Sector 22	Real Estate, Renting and Business Activities	2.45	2.60
LtQ	Sector 23	Community Social and Personal Services	1.97	1.65

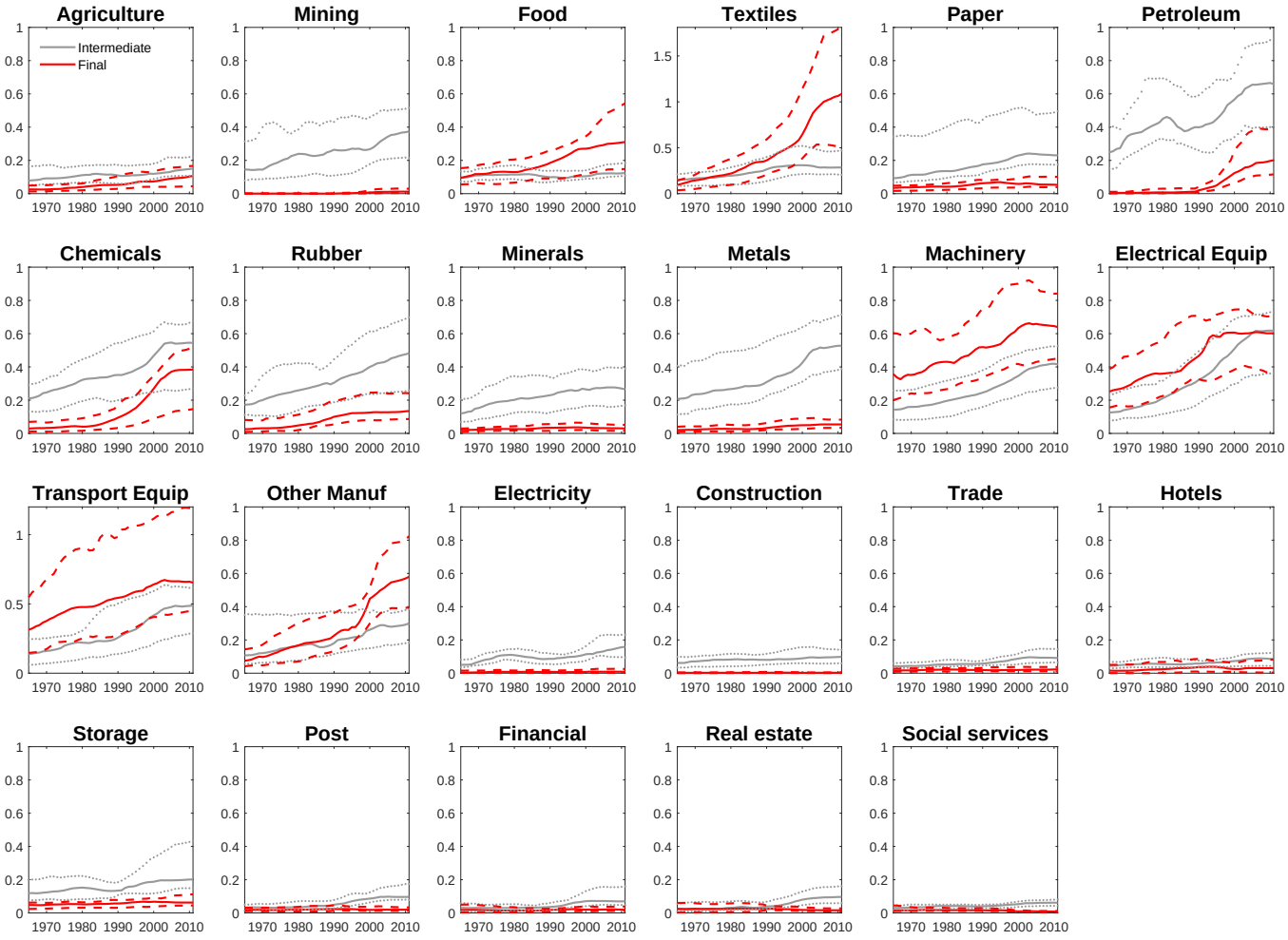
Note: The standard deviations of the growth rates of value added for each sector are taken at median across countries available between 1970 and 2009.

Figure 1: Intermediate and Final Trade as a Share of Gross Output between 1965 and 2011.



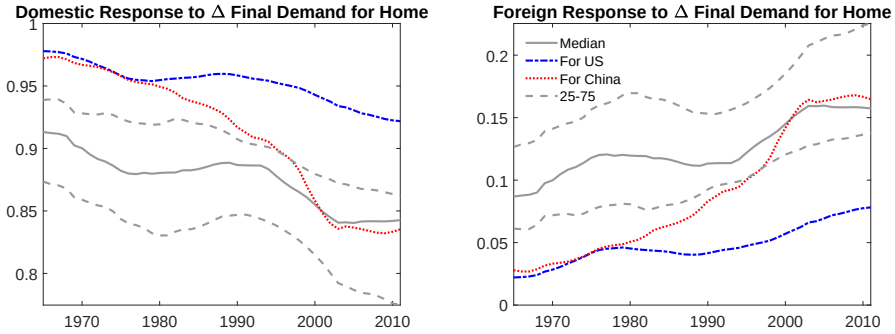
Note: The red solid and dotted lines are shares of final trade in sectoral gross output at median, 25 and 75 percentiles across 23 countries and a composite rest-of-the-world. The gray solid and dashed lines are shares of intermediate trade in sectoral gross output at median, 25 and 75 percentiles. The 23 sectors are listed in the paper.

Figure 2: Total Trade as a Share of Gross Output in 23 sectors for 24 countries between 1965 and 2011.



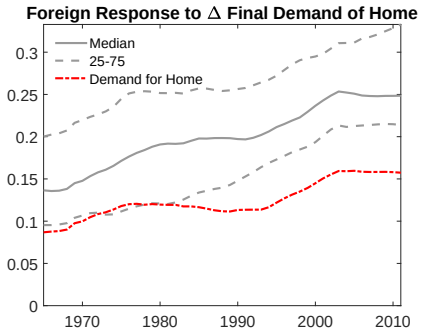
Note: The red lines are the median across 23 countries and a composite rest-of-the-world. The dashed lines are the 25 and 75 percentile band. The 23 sectors are listed in the paper.

Figure 3: Domestic and foreign value added responses to $1 increase in final demand for each country between 1965 and 2011.



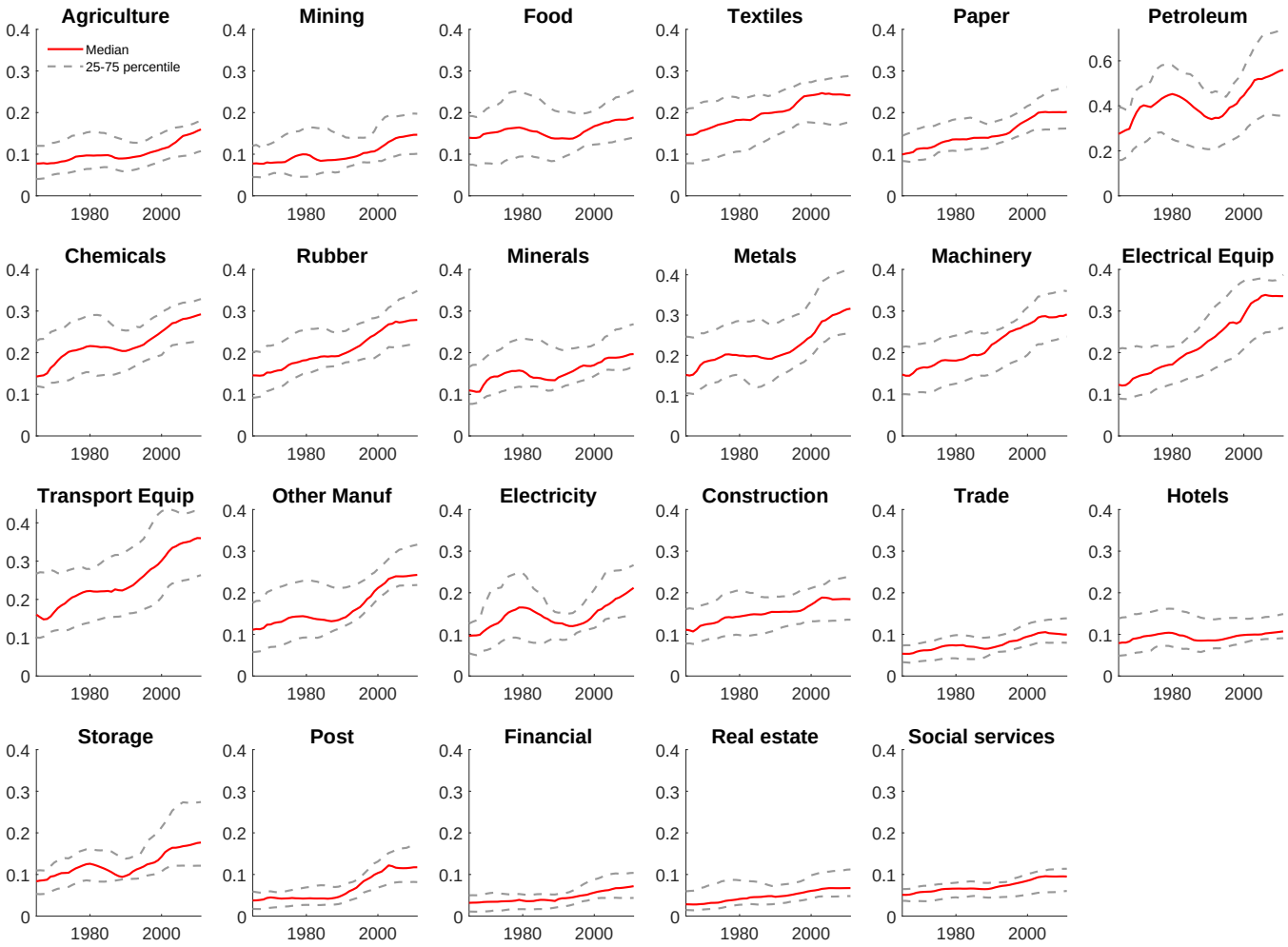
Note: The solid gray lines are the median across 23 countries and a composite rest-of-the-world. The dashed lines are the 25 and 75 percentile band. The red dotted line is the response to an increase in demand for Chinese goods and the blue dashed line is the response to an increase in demand for US goods.

Figure 4: Domestic and foreign value added responses to $1 increase in final demand in each country between 1965 and 2011.



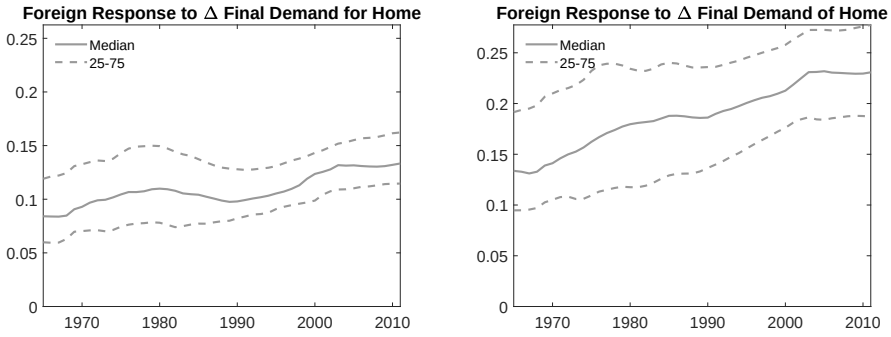
Note: The solid gray lines are the median across 23 countries and a composite rest-of-the-world. The dashed lines are the 25 and 75 percentile band. The red line is the response to a $1 increase in final demand for domestic goods only.

Figure 5: Median foreign value added responses to final demand increases in each of the 23 sectors for 24 countries between 1965 and 2011.



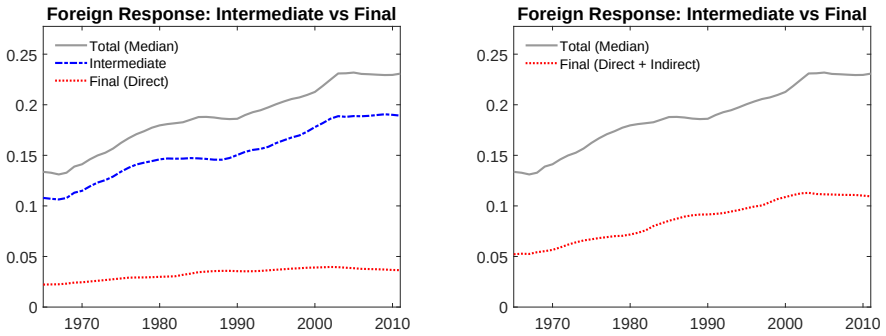
Note: The red lines are the median across 23 countries and a composite rest-of-the-world. The dashed gray lines are the 25 and 75 percentile band. The 23 sectors are listed in the paper.

Figure 6: Foreign value added responses to $1 increase in final demand in a multisector framework between 1965 and 2011.



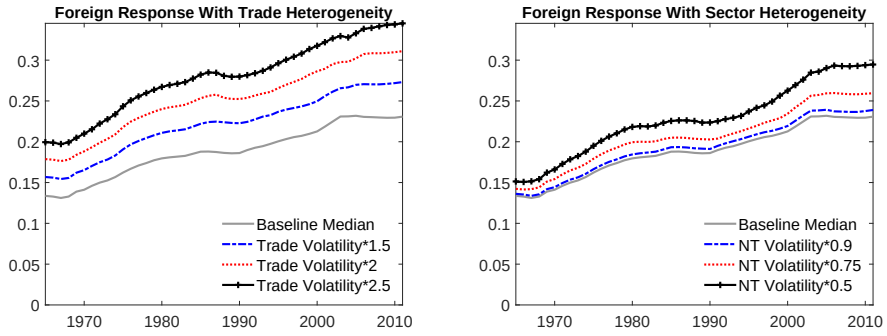
Note: The left figure shows the responses when there is $1 increase in final demand for domestic goods only, and the right figure shows the responses when there is $1 increase in final demand for both domestic and foreign goods. The solid gray lines are the median across 23 countries and a composite rest-of-the-world. The dashed lines are the 25 and 75 percentile band.

Figure 7: Foreign responses to $1 increase in final demand: Final and intermediate good channels.



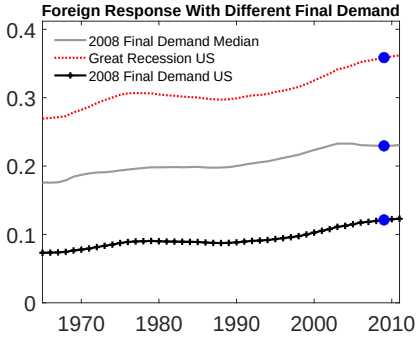
Note: We decompose the foreign responses to $1 increase in final demand in each country into intermediate input-output channel and final goods channel. The plot on the left follows the decomposition that final good channel is the direct change in final good demands for abroad. The plot on the right uses the decomposition that intermediate good channel comes from the increase in final demand for domestic goods.

Figure 8: Median domestic and foreign value added responses to $1 increase in final demand with heterogenous domestic and foreign demand and sectors between 1965 and 2011.

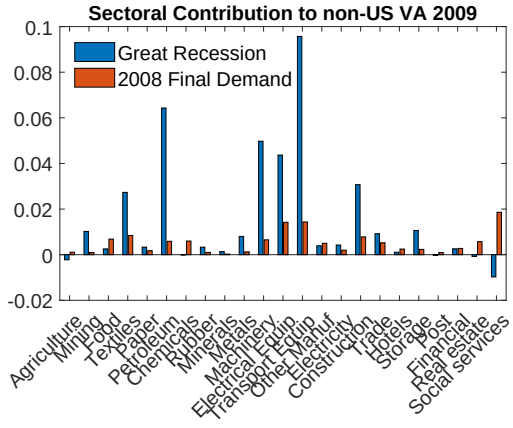


Note: The left figure is the response when there is $1 increase in final demand in a multi-sector framework: we adjust the changes in foreign demand so that it is 1.5 to 2.5 times more volatile than domestic demand. The right figure is the response when there is $1 increase in final demand in the multi-sector framework where sectoral responses are adjusted.

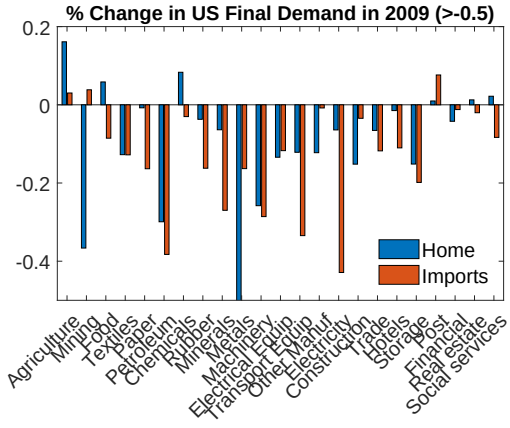
Figure 9: International spillover of final demand changes in the United States in the Great Recession 2008–2009.



(a) Spillover of final demand changes in the Great Recession



(b) Sectoral spillover contribution



(c) Sectoral demand changes

Appendix (not for publication)

Our framework is consistent with the framework in Bems, Johnson, and Yi (2010). Market clearing requires that output in sector s in each country i has to satisfy the following condition:

$$Q_t(i,s) = \sum_{j=1}^{N} f_t((i,s),j)) + \sum_{j=1}^{N}\sum_{k=1}^{S} m_t((i,s),(j,k)), \tag{4}$$

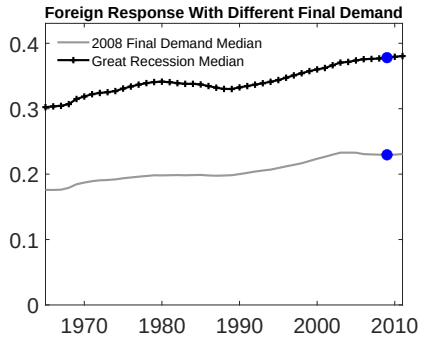
where $f_t((i,s),j)$ is the final goods shipped from sector s country i to country j, and $m_t((i,s),(j,k))$ is the intermediate good shipment from sector s country i to sector k in country j. Then, the changes in gross output in sector i can be computed as a weighted sum of changes in gross output in other sectors in all countries and changes in final demand as follows:

$$\hat{Q}_t(i,s) = \sum_{j=1}^{N} \frac{f((i,s),j))}{Q(i,s)} \hat{f}_t((i,s),j) + \sum_{j=1}^{N}\sum_{k=1}^{S} \frac{m((i,s),(j,k))}{Q(i,s)} \hat{m}_t((i,s),(j,k)), \tag{5}$$

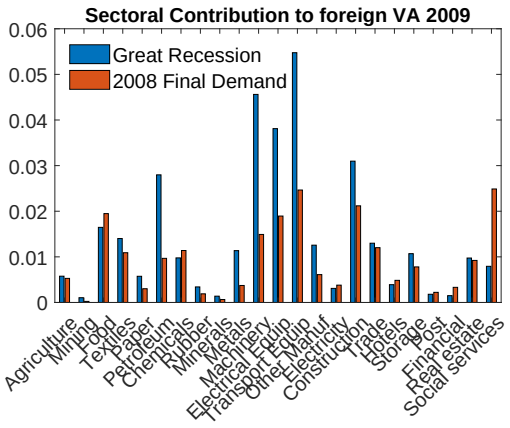
where hatted variables denote log deviation from steady state. The weights are the shares of intermediate and final goods shipments in gross output.

The production function is Leontief in its inputs, so the changes in the input shipped from sector s in country i to sector k in country j are proportional to the changes in output in sector k. This assumption is consistent with the estimate of the elasticity of substitution between inputs in Boehm, Flaaen, and Pandalai-Nayar (2019). We further assume that preferences are also Leontief, so the change in the final good shipment from sector s country i to country j is proportional to the change in final demand in country j. These assumptions are similar to Bems, Johnson, and Yi (2010). The advantage of this approach is that we can use the information on quantities of final demand, gross output, intermediate shipments in each sector and country to trace out the impact of demand changes on domestic and foreign countries. Besides, this framework helps us to isolate the transmission mechanism through the production side. The main shortcoming of this framework is that we do not consider the household side. With these assumptions, the weights in equation 5 can be computed using data in the world IO table.

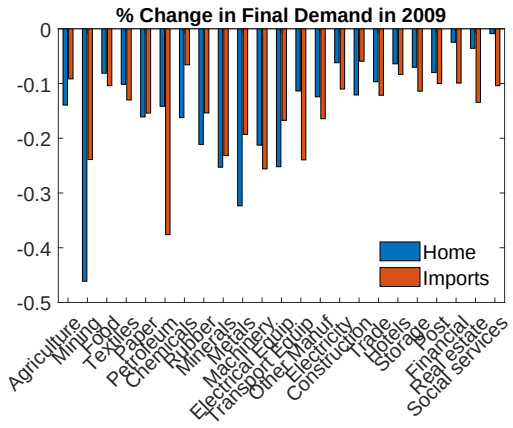
Figure 10: International spillover of final demand changes in median country in the Great Recession 2008–2009.



(a) Spillover of final demand changes in the Great Recession



(b) Sectoral spillover contribution



(c) Sectoral demand changes