Where is the Value Added?
Trade Liberalization and Production Networks*

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Abstract

Fragmentation of the global value chain makes it difficult to assess the effects of trade liberalization on the global pattern of production. Gross bilateral trade flows no longer reveal a country's or a sector's value added contribution. Yet, it is value added that matters for employment and welfare. We derive a structural equation for value added trade flows and theory-based measures for production networks from a multi-sector gravity model with inter-sectoral linkages to analyze the effects of trade liberalization in the presence of globally fragmented value chains. We estimate the model's key parameters, calibrate it to the year 2000 using the World Input-Output Database, and perform a counterfactual analysis of China's WTO accession. We find that the tariff changes associated with China's WTO entry spurred global production fragmentation, explaining about 7 percent of the decrease in the ratio of world value added exports to gross exports as observed between 2000 and 2007. Furthermore, our results imply that China's WTO accession was the driving force behind the strengthening of production networks with its neighbors and led to significant welfare gains for China, Australia, and the proximate Asian economies.

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1 Introduction

The global value chain is increasingly fragmented. Single stages of a good's production may each be performed in a different country and trade along the production chain is surging. Value added from early stages of production may thus cross borders multiple times and is then "double-counted" in export statistics. This implies that gross export flows do not accurately measure the value added a country transfers to a trade partner. Xing and Detert (2010) document that only about 4 percent of the value of an iPhone assembled in China and exported to the United States is Chinese value added. Linden et al. (2009) come to similar results for the iPod. On the world level, the ratio of value added exports to gross exports as measured in official trade statistics, has declined dramatically. Johnson and Noguera (2016) document that between 1970 and 2009 the ratio fell from 87 percent to 79 percent for total exports and from 65 percent to 47 percent for manufacturing exports.

Fragmentation of the global value chain makes it increasingly difficult to track who produces for whom, which, in turn, makes it difficult to disentangle the effects of trade liberalization on the global pattern of production. Moreover, production linkages imply that the welfare effects of regional trade policies on third countries can be very diverse. Production fragmentation multiplies the potential gains from specialization and magnifies the importance of fundamental determinants of trade relationships such as relative productivity differences and geographical proximity. It renders the effect of a decrease in trade barriers heterogeneous and non-linear, depending on the initial level of and the potential for production fragmentation, as shown first by Yi (2003). Johnson and Noguera (2016) and Baldwin and Lopez-Gonzalez (2015) document that the current engagement in trade along the production chain is very unevenly distributed across the globe. It is highly concentrated and takes place within networks among geographically close nations, especially in North America, East Asia, and Europe.

In this paper, we analyze how trade liberalization has shaped the pattern of who produces for whom, how much it contributed to global production fragmentation, and whether it facilitated the formation of production networks. We focus on a major event of trade liberalization in the past decade: China's accession to the WTO in 2001. We simulate the impact of the associated tariff cuts on China's trade and value added trade relationships on the sectoral bilateral level and analyze the change in the composition of China's trade, the value added and welfare effects across the globe, and their interaction with fundamental determinants of trade relationships.

To that end, we derive a structural expression for value added trade in a general equilibrium multi-country multi-sector trade model of the Eaton and Kortum (2002)-type with input-output linkages, building on the work of Caliendo and Parro (2015) and Johnson and Noguera (2012a). Using the model, we derive a definition for international supply and demand networks between value added source sectors and final goods producing downstream sectors that can be compared across sectors, countries, and time. Based on the World Input-Output Database (WIOD), we construct a panel dataset of value added trade for 40 countries and decompose exports into value added exports, exports of foreign value added, and double-counting, following the methodology developed by Koopman et al. (2014). Combining WIOD with tariff data, we estimate the model's structural parameters and calibrate it to 2000, the year preceeding China's accession to the WTO. This forms the basis for our counterfactual analysis of a change in the tariff structure to the level in 2007.

To preview our results, we find that China's WTO entry can account for large parts of the structural changes in China's sectoral bilateral sourcing patterns, such as the disproportional strengthening of production networks with its neighboring countries, as well as its aggregate level of production fragmentation. The change in the composition of world exports predicted by the change to the counterfactual equilibrium accounts for about 7 percent of the actual decrease in the world value added exports to exports ratio between

2000 and 2007. Moreover, we find that China's WTO accession was the driving force behind the strengthening of supply and demand networks with Japan, Korea, and Australia, and significantly shaped its value added trade relationships with the United States. China gained in importance as a location for processing value added into final goods for almost all countries, but particularly for the nearby Asian economies, which could, at the same time, foster their positions as major sources of foreign value added in China's final goods production. Even conditional on geographical proximity, we find that initially stronger networks became even more intense, suggesting that a magnification effect of trade costs is at work. With respect to welfare, we find that the WTO accession led to a 0.6 percentage point increase in real income for China. The largest gains (2.6 percentage points) accrued to Australia, which was also among the countries facing the highest tariff cuts on imports from China. We find positive welfare effects for China's neighboring countries and no evidence of negative welfare consequences for the United States. In fact, only a few countries, primarily European, appear to have been marginally adversely affected.

Our results are interesting in view of related literature that evaluates the welfare effects of trade with China and the impact of the WTO accession. di Giovanni et al. (2014) estimate the gains from trading with China relative to a situation where China is in complete autarky using a variant of the model developed by Caliendo and Parro (2015). Their qualitative results strongly resemble the pattern we find for the WTO accession. Ghosh and Rao (2010) find a similar pattern in an evaluation study of China's WTO entry based on a CGE model and GTAP data. Those studies, as well as ours, complement micro-level evidence that has drawn a more pessimistic picture of the consequences of trading with China, particularly for the United States (see, e.g., Autor et al., 2013). Given their short-term perspective on local employment, those results are not necessarily contradictory to ours. Our results reflect long-run effects and include general equilibrium adjustments, allowing for sectoral labor mobility to facilitate the value added increases on the national level, and for lower prices to increase real income. Our study also complements recent research on the firm-level and industry-level effects of China's WTO entry (Brandt et al., 2015; Kee and Tang, 2016). Rather than aiming to explain the observed changes in the data, we isolate the direct effect of tariff changes with the help of a counterfactual experiment. That is, we hold constant, among other things, technological parameters and market structure to analyze the effects of tariff cuts in a general equilibrium model that captures tariff-change-induced adjustments in the global pattern of factor prices, production, and expenditures.

Our paper is also related to structural gravity applications. To take into account general equilibrium effects of trade liberalization, this strand of literature resorts to counterfactual policy experiments, simulating effects of trade cost changes on (gross) trade patterns and welfare in general equilibrium. Several studies investigate the effects of abolishing the Canada-U.S. border, (e.g., Anderson and van Wincoop, 2003; Bergstrand et al., 2013). Other studies simulate the gains from trade versus autarky (see, e.g., Eaton and Kortum, 2002) or free trade agreement (FTA) formation (Egger et al., 2011; Egger and Larch, 2011) or assess the effects of trade imbalances on welfare (Dekle et al., 2007). Caliendo and Parro (2015) introduce input-output linkages in a multi-sector Eaton and Kortum (2002)-type gravity model and simulate the welfare effect of tariff cuts in the wake of the North American Free Trade Agreement (NAFTA).[4] We contribute to this strand of literature by making explicit the value added flows between countries and sectors, both theoretically and empirically, and by analyzing how they were affected by a major event of trade liberalization.

A growing body of literature documents value added trade flows (see, e.g., Johnson and Noguera, 2012a,b, 2016; Baldwin and Lopez-Gonzalez, 2015). Hummels et al. (2001), Daudin et al. (2011), and Johnson and Noguera (2012a) develop measures of vertical specialization, which are incorporated into a general accounting formula for value added in

[4]A comprehensive summary of the welfare implications of trade liberalization in different formulations of the gravity model (single vs. multi-sector, input-output linkages, homogenous vs. heterogeneous firms, etc.) is provided by Costinot and Rodriguez-Clare (2014).

trade developed by Koopman et al. (2014) and Wang et al. (2013).[5] Vertical specialization changes the perspective on many aspects of trade, such as revealed comparative advantage (Koopman et al., 2014; Wang et al., 2013), exchange rates (Bems and Johnson, 2012), business cycle co-movements (di Giovanni and Levchenko, 2010), the elasticity of trade with respect to tariff cuts (Yi, 2003; Johnson and Noguera, 2016), and the home bias in trade (Yi, 2010). Vertical specialization can also explain why trade collapsed relatively stronger than GDP during the recent global financial crisis (Bems et al., 2011; Bénassy-Quéré et al., 2009).

Johnson and Noguera (2012b) provide first empirical evidence on how the global value chain reacts to changes in trade costs. They employ a gravity equation to study the effects of distance on trade in value added. However, due to omitted third-country effects, which, from a structural gravity point of view, cannot be taken care of by means of country fixed effects, the estimates from this empirical model must be interpreted with care. Noguera (2012) derives a gravity equation for bilateral value added trade from an Armington model with final and intermediate goods trade using a first-order approximation to the highly non-linear relationship between bilateral value added flows and the standard gravity variables. In a companion paper to the present one (Aichele and Heiland, 2016) we show that even if one acknowledges all higher-order relationships, a gravity relationship holds on the bilateral cross-sectoral level. Moreover, in Aichele and Heiland (2016) we also show why, in a multi-sector setting, gravity fails to hold at the aggregate bilateral or sectoral bilateral level. These results strongly suggest that the effects of trade costs (and other gravity variables of interest) on value added trade need to be assessed using a structural model and counterfactual simulation rather than reduced form gravity estimations. To the best of our knowledge, Johnson and Noguera (2016)'s analysis of the role of distance and PTA formation in shaping global value chains is the only paper besides our

[5]The methodology for tracing value added in foreign consumption builds on methods developed for multi-regional input-output analysis, which are also used in the literature on the factor content of trade (see, e.g., Trefler and Zhu, 2010).

own work pursuing such a strategy. Our paper seeks to contribute to this literature by providing model-based expressions for value added trade flows and production networks, and by providing a quantification the global effect of one of the major instances of tariff liberalization in the past decade – China's entry into the WTO.

Building on the insight of Yi (2003), who shows that both the initial degree of and the potential for production fragmentation render the effects of tariff liberalization non-linear and heterogeneous, we analyze the regional and global trade and value added effects of China's entry into the WTO. In our model, production fragmentation across borders arises as a consequence of Ricardian productivity advantages in the production of differentiated varieties that serve as inputs for a sectoral composite good. Regardless of the possibly infinite number of travel routes through other sectors in other countries where value added can occur before the good is assembled into its final form, the pattern and intensity of value added trade relationships are determined by the well-known fundamental factors of the Eaton-Kortum world – productivity and geography – as well as by differences in production technology with respect to cross-sectoral intermediate input usage.

Our analysis of the impact of trade liberalization involves an implicit comparison with alternative explanations for the increase in trade along the value chain over time that have been put forward by the literature on production fragmentation. One strand of this literature revolves around the idea that production of a good can be characterized as the completion of a set of tasks. Tasks are either performed sequentially (Costinot et al., 2013) or ordered according to a specific criterion, such as tradability (Grossman and Rossi-Hansberg, 2008). Differences in country characteristics, for example, in the level of development or in relative factor prices, lead to a pattern of specialization based on comparative advantage. Another strand of literature focuses on production fragmentation as a problem of firms' internal organization (for an overview, see Helpman, 2006). Recent work in this field highlights the role of contractual frictions (Antrás and Chor, 2013) and communication costs (Keller and Yeaple, 2013). Improvements in communication technology have facilitated the unbundling of production processes into finer steps and eased the flow of knowledge across borders. Moreover, improvements in institutional quality and property rights protection have lowered the cost of production relocation. Finally, increased demand for technologically more complex goods, in conjunction with economic growth and non-homotheticity of preferences, provide a demand-driven explanation. The importance of each of these explanations is an empirical question. We seek to contribute by quantifying the effect of a major event of trade liberalization on the observed regional and global trends in the 2000s.

The paper proceeds as follows. In Section 2 we describe the gravity model with input-output linkages developed by Caliendo and Parro (2015) and derive structural expressions for value added trade on different levels of aggregation. We show how trade liberalization affects gross exports and value added trade differently. In Section 3 we propose a definition for supply and demand networks in the context of the model and provide summary statistics on those measures based on the WIOD. Section 4 explains how we identify the model's key parameters, namely, value added and input-output coefficients, as well as a sectoral measure of productivity dispersion. In Section 5 we describe the counterfactual experiment, present simulation results for the impact of China's WTO accession on gross exports, value added trade, production networks, and welfare, and discuss our results in view of the model's assumptions and the extant literature. Section 6 concludes.

2 A Model for Trade in Value Added

We begin with a brief description of production and trade in the multi-sector input-output gravity model developed by Caliendo and Parro (2015). Based on this framework, we then derive a structural expression for bilateral value added trade flows and decompose gross exports into value added components from different sources and production stages.

2.1 Production and Gross Exports

There are N countries indexed by i or n and J sectors indexed by j or k. The representative consumer derives utility from consumption of final goods from all sectors. Each sectoral final good is a composite of differentiated varieties that are sourced from different countries. We assume that preferences for sectoral composites are Cobb-Douglas and we denote with α_n^j the corresponding constant sectoral expenditure share. Household income I_n comprises labor income and lump-sum tariff rebates. The labor force, L_n, of a country is mobile across sectors, but not across countries.

In each sector j a continuum of varieties ω^j is produced with labor $l_n^j(\omega^j)$ and composite intermediate inputs $m_n^{k,j}(\omega^j)$ from other sectors according to the following production function:

$$q_n^j(\omega^j) = x_n^j(\omega^j)^{-\theta^j} \left[l_n^j(\omega^j)\right]^{\beta_n^j} \left[\prod_{k=1}^{J} m_n^{k,j}(\omega^j)^{\gamma_n^{k,j}}\right]^{(1-\beta_n^j)}, \tag{1}$$

where $\beta_n^j \in [0,1]$ is the cost share of labor and $(1-\beta_n^j)\gamma_n^{k,j}$ denotes the cost share of intermediates from source sector k, with $\gamma_n^{k,j} \in [0,1]$ and $\sum_{k=1}^{J} \gamma_n^{k,j} = 1$. $x_n^j(\omega^j)$ denotes the inverse efficiency of variety producer ω^j and θ^j governs the dispersion of efficiency across varieties in sector j. A higher θ^j implies greater dispersion. All varieties ω^j are aggregated to sector j's composite good q_n^j with a Dixit-Stiglitz CES technology. This composite is either used as intermediate input in other sectors or consumed as a final good.

The minimum cost c_n^j of an input bundle for a typical variety producer from sector j in country n depends on the wage rate w_n and the prices of composite intermediate goods p_n^k according to

$$c_n^j = \Upsilon_n^j \, {w_n}^{\beta_n^j} \left[\prod_{k=1}^{J} {p_n^k}^{\gamma_n^{k,j}}\right]^{(1-\beta_n^j)}, \tag{2}$$

where Υ_n^j is a constant.[6]

[6]Note that the minimum costs of an input bundle are identical for all variety producers within a given

Let κ_{in}^j denote the trade costs of delivering good j from country i to country n. We assume that these costs consist of iceberg trade costs $d_{in}^j \geq 1$, with $d_{nn}^j = 1$, and ad-valorem tariffs $\tau_{in}^j \geq 0$ such that $\kappa_{in}^j = (1 + \tau_{in}^j)d_{in}^j$. Perfect competition and constant returns to scale imply that firms charge prices equal to unit costs, that is, the price of variety ω^j from country i in country n is given by $p(\omega^j) = x(\omega)^{\theta_j} c_i^j \kappa_{in}^j$. Producers search across all countries for the lowest-cost supplier. We assume that productivity levels $x(\omega^j)$ are independent draws from an exponential distribution with a country- and sector-specific location parameter λ_n^j. Solving for the distribution of prices and integrating over the sets of goods for which any country is the lowest-cost supplier to country n, we obtain the price of the composite intermediate good in country n as

$$p_n^j = A^j \left(\sum_{i=1}^{N} \lambda_i^j \left(c_i^j \kappa_{in}^j \right)^{\frac{-1}{\theta^j}} \right)^{-\theta^j}, \tag{3}$$

where A^j is a constant.[7] Note that p_n^j depends on the prices of composites from all other sectors (via c_i^j). The strength of the correlation is governed by the cross-sectoral intermediate cost shares $\gamma_n^{k,j}$.

Ultimately, the model delivers a gravity equation. Country n's expenditure share π_{in}^j for source country i's goods in sector j depends on i's price relative to the price index and can be written as

$$\pi_{in}^j = \frac{\lambda_i^j \left[c_i^j \kappa_{in}^j \right]^{\frac{-1}{\theta^j}}}{\sum_{i=1}^{N} \lambda_i^j \left[c_i^j \kappa_{in}^j \right]^{\frac{-1}{\theta^j}}}. \tag{4}$$

This trade share corresponds to the probability that i is the lowest cost supplier of a variety in sector j for country n. Equation (4) differs from the standard gravity equation in that unit costs c_i^j depend on the costs of all sectoral composites and thus also on trade costs and tariffs in other sectors and between other country pairs.

sector and country since these costs differ only with regard to Hicks-neutral productivity shifters $x_n^j(\omega^j)$.

[7]Specifically, $A^j = \Gamma\left[1 + \theta(1 - \eta_j)\right]^{\frac{1}{1-\eta_j}}$ where $\Gamma(\cdot)$ is the gamma function and η_j is the elasticity of substition between any two of all varieties that are bundled into the sectoral composite good.

2.2 General Equilibrium

Let Y_n^j denote the value of gross production of varieties in sector j. For each country n and sector j, market clearing requires that Y_n^j be equal to the sum of intermediates and final goods demand from all countries $i = 1, \dots, N$. Hence, goods market clearing conditions are given by

$$\begin{aligned} Y_n^j &= \sum_{i=1}^{N} \sum_{k=1}^{J} \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} \gamma_i^{j,k} (1-\beta_i^k) Y_i^k + \sum_{i=1}^{N} \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} \alpha_i^j I_i \\ &= \sum_{i=1}^{N} \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} \left(\sum_{k=1}^{J} \gamma_i^{j,k} (1-\beta_i^k) Y_i^k + \alpha_i^j I_i \right) \\ &= \sum_{i=1}^{N} \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} X_i^j, \end{aligned} \tag{5}$$

where national income I_i consists of labor income, tariff rebates R_i, and the (exogenous) trade surplus S_i, that is, $I_i = w_i L_i + R_i - S_i$. X_i^j denotes country i's expenditure on sector j goods. The first term on the right-hand side equals demand of all sectors in all countries for intermediates from sector j produced in n. The second term is final demand.[8] Both intermediates and final goods demand are divided by $(1 + \tau_{ni}^j)$ to convert values from purchaser prices to producer prices. Tariff rebates are $R_i = \sum_{j=1}^{J} X_i^j \left(1 - \sum_{n=1}^{N} \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)}\right)$.

The model is closed with an income-equals-expenditure condition for each country n that takes into account trade imbalances. This condition mandates that the value of total imports plus the trade surplus equal the value of total exports plus domestic sales, which

[8]Our exposition differs from that of Caliendo and Parro (2015), who use total expenditure on composite goods instead of total production of varieties as an endogenous variable. Hence, in Caliendo and Parro (2015), the value of gross production comprises all foreign varieties that are bundled into the composite good without generation of value added. However, we belief that the value of production of sectoral varieties is a more natural choice.

is equivalent to GDP Y_n:

$$\sum_{j=1}^{J}\left(\sum_{k=1}^{J}\gamma_n^{j,k}(1-\beta_n^k)Y_n^k+\alpha_n^j I_n\right)\sum_{i=1}^{N}\frac{\pi_{in}^j}{(1+\tau_{in}^j)}+S_n=\sum_{j=1}^{J}Y_n^j\equiv Y_n,$$
$$\sum_{j=1}^{J}X_n^j\sum_{i=1}^{N}\frac{\pi_{in}^j}{(1+\tau_{in}^j)}+S_n=Y_n \tag{6}$$

2.3 Comparative Statics in General Equilibrium

In this section, we describe how the model can be solved for changes in equilibrium outcomes induced by an exogenous change in the tariff structure, thus paving the way for our counterfactual analysis of China's WTO entry and its effect on exports, value added flows, and welfare. As suggested by Dekle et al. (2008), instead of solving the model for the new equilibrium, one can solve for equilibrium changes. This approach has the advantage that we do not need data on prices, iceberg trade costs, or productivity levels.

Denote with $\hat{x}\equiv x'/x$ the relative change in any variable x from its initial level x to the counterfactual level x'. The equilibrium change in input costs induced by a change in tariffs is then given by

$$\hat{c}_n^j=\hat{w}_n^{\beta_n^j}\left(\prod_{k=1}^{J}\left[\hat{p}_n^k\right]^{\gamma_n^{k,j}}\right)^{1-\beta_n^j}. \tag{7}$$

The change in the price index is

$$\hat{p}_n^j=\left(\sum_{i=1}^{N}\pi_{in}^j\left[\hat{\kappa}_{in}^j\hat{c}_i^j\right]^{-1/\theta^j}\right)^{-\theta^j} \tag{8}$$

and bilateral trade shares change according to

$$\hat{\pi}_{in}^j=\left(\frac{\hat{c}_i^j}{\hat{p}_n^j}\hat{\kappa}_{in}^j\right)^{-1/\theta^j}. \tag{9}$$

The counterfactual expenditure in each country and sector is

$$X_n^{j'} = \sum_{k=1}^{J} \gamma_n^{j,k}(1-\beta_n^k)\left(\sum_{i=1}^{N} \frac{\pi_{ni}^{k'}}{1+\tau_{ni}^{k'}} X_i^{k'}\right) + \alpha_n^j I_n', \tag{10}$$

where $F_n^j \equiv \sum_{i=1}^N \frac{\pi_{in}^j}{(1+\tau_{in}^j)}$ and $I_n' = \hat{w}_n w_n L_n + \sum_{j=1}^J X_n^{j'}(1-F_n^{j'}) - S_n$ and subject to the trade balance that requires

$$\sum_{j=1}^{J} F_n^{j'} X_n^{j'} + S_n = \sum_{j=1}^{J}\sum_{i=1}^{N} \frac{\pi_{ni}^{j'}}{1+\tau_{ni}^{j'}} X_i^{j'}. \tag{11}$$

This system of equations can be solved with the searching algorithm proposed by Alvarez and Lucas (2007).[9]

The welfare effects of a change in the tariff structure can be assessed by looking at the change in real income, which is given by

$$\widehat{W}_n = \frac{\hat{I}_n}{\Pi_{j=1}^J (\hat{p}_n^j)^{\alpha_n^j}} \tag{12}$$

2.4 Value Added Trade

We use the model to derive an expression for value added trade flows based on the methodology developed by Johnson and Noguera (2012a). To compute value added trade flows between countries i and n we need information on bilateral final goods exports, a world input-output table, and labor cost shares (value added coefficients) in all countries and sectors. Expenditure on final goods from sector j is $C_n^j = \alpha_n^j I_n^j$. As established above, a fraction π_{hn}^j of this expenditure is devoted to varieties from country h. Then, expenditure

[9]The algorithm starts with an initial guess about a vector of wage changes, then computes price and trade share changes and the new expenditure levels based on those wage changes, then evaluates the trade balance condition, and then updates the wage change based on the error in the trade balance. This algorithm is also used by Dekle et al. (2008). Caliendo and Parro (2015) extend it to a multi-sector input-output version.

in country n on final goods from country h (net of tariffs) is

$$C_{hn}^{j} = \frac{\pi_{hn}^{j}}{(1+\tau_{hn}^{j})} C_{n}^{j} = \frac{\lambda_{h}^{j}\left[c_{h}^{j}\kappa_{hn}^{j}\right]^{\frac{-1}{\theta^{j}}}}{(1+\tau_{hn}^{j})\sum_{h=1}^{N}\lambda_{h}^{j}\left[c_{h}^{j}\kappa_{hn}^{j}\right]^{\frac{-1}{\theta^{j}}}}\alpha_{n}^{j} I_{n}. \tag{13}$$

The value added share $V_i^j(\omega^j) = \frac{l_i^j(x_i^j(\omega^j))w_i}{x_i^j(\omega^j)^{\theta^j} c_i^j}$ in the production value of a typical variety in country i follows from Shepard's lemma:

$$V_i^j(\omega^j) = x_i^j\left(\omega^j\right)^{\theta^j}\frac{\partial c_i^j}{\partial w_i}\frac{w_i}{x_i^j\left(\omega^j\right)^{\theta^j} c_i^j} = \beta_i^j. \tag{14}$$

Note that this share is independent of the producer's efficiency level. Similarly, we can derive input-output coefficients, that is, the cost share of intermediates from sector k in country n in the production of goods in country i's sector j as

$$(1+\tau_{in}^{k})a_{i,n}^{k,j} = \frac{\partial c_i^j}{\partial p_{in}^k}\frac{p_{in}^k}{c_i^j} = \pi_{in}^k(1-\beta_i^j)\gamma_i^{k,j}. \tag{15}$$

We define $a_{in}^{k,j}$ as the cost share net of tariffs because input-output coefficients are usually denoted in producer prices.

We collect all bilateral input-output coefficients $a_{in}^{k,j}$ in a $NJ \times NJ$ world input-output table $\mathbf{A}$. Input coefficients are arranged in $N \times N$ submatrices of dimension $J \times J$, each of which comprises all cross-sectoral relationships of a country pair, that is, we write

$$\mathbf{A} = \begin{pmatrix} \mathbf{A}_{11} & \dots & \mathbf{A}_{1N} \\ \vdots & \ddots & \vdots \\ \mathbf{A}_{N1} & \dots & \mathbf{A}_{NN} \end{pmatrix}, \text{ where } \mathbf{A}_{in} = \begin{pmatrix} a_{in}^{1,1} & \dots & a_{in}^{1,J} \\ \vdots & \ddots & \vdots \\ a_{in}^{J,1} & \dots & a_{in}^{J,J} \end{pmatrix}.$$

Within each submatrix the row index k of $a_{in}^{k,j}$ corresponds to the supply sector and the column index j denotes the demand sector, while the indices i and n of the submatrix denote the source country and destination country, respectively. Elements $b_{ih}^{k,j}$ of the

Leontief inverse of the input-output matrix, $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$, inform about the value of output that is generated in sector k in country i per unit (value) of final goods production in sector j in country h. $\mathbf{B}$ takes into account the world-wide fragmentation of the value chain and intermediates trade.

Let $\mathbf{C}_n$ be a column vector collecting sectoral final goods imports of country n from all countries $i = 1, \ldots, N$

$$\mathbf{C}_n \equiv \begin{pmatrix} \mathbf{C}_{1n} \\ \vdots \\ \mathbf{C}_{Nn} \end{pmatrix}, \text{ where } \mathbf{C}_{hn} \equiv \begin{pmatrix} C_{hn}^{1} \\ \vdots \\ C_{hn}^{J} \end{pmatrix}.$$

Then, $\mathbf{B} \cdot \mathbf{C_n}$ is a $J \cdot N$ column vector that collects the amount of production in country i and sector k for final demand in country n. An element of this vector is $\sum_{h=1}^{N} \sum_{j=1}^{J} b_{ih}^{k,j} C_{hn}^{j}$, which takes into account that sector k's output can reach country n embodied in final goods imports from all sectors j from all countries h.[10] Value added generated in country i's sector k that is assembled into a final good in country h's sector j and finally consumed in country n is

$$VA_{ihn}^{k,j} = \beta_i^k b_{ih}^{k,j} C_{hn}^{j} = \beta_i^k b_{ih}^{k,j} \pi_{hn}^{j} \alpha_n^j I_n. \tag{16}$$

By summing over h we obtain the total value added from sector k in country i that reaches country n embodied in final goods from sector j:

$$VA_{in}^{k,j} = \beta_i^k \alpha_n^j I_n \sum_{h=1}^{N} b_{ih}^{k,j} \pi_{hn}^{j}.$$

Finally, summation over all final goods sectors yields the total value added from sector k

[10]Note that it is not possible to find an explicit closed-form solution for $b_{ih}^{k,j}$.

in country i that is consumed in country n:

$$VA_{in}^{k} = \beta_i^k \sum_{j=1}^{J} \alpha_n^j I_n \sum_{h=1}^{N} b_{ih}^{k,j} \pi_{hn}^j \tag{17}$$

To assess how bilateral value added flows change in response to a change in tariffs we proceed as follows: Once the equilibrium trade share changes are determined by (9), we can compute the counterfactual Leontief inverse and then the counterfactual bilateral value added flows. The counterfactual input-output coefficients are

$$a_{hi}^{k,j'} = \frac{\hat{\pi}_{hi}^k}{\widehat{(1+\tau_{hi}^k)}} a_{hi}^{k,j}. \tag{18}$$

We collect them in the counterfactual input-output table $\mathbf{A'}$. The counterfactual Leontief inverse is then simply $\mathbf{B'} = (\mathbf{I} - \mathbf{A'})^{-1}$. Final goods trade in the counterfactual experiment is

$$C_{hn}^{j'} = \frac{\hat{\pi}_{hn}^j \pi_{hn}^j}{(1+\tau_{hn}^{j'})} \alpha_n^j I_n'. \tag{19}$$

The counterfactual value added flow corresponding to Equation (17) results as

$$VA_{in}^{k'} = \beta_i^k I_n' \sum_{j=1}^{J} \alpha_n^j \sum_{h=1}^{N} b_{ih}^{k,j'} \hat{\pi}_{hn}^j \pi_{hn}^j. \tag{20}$$

Note that the value added flows in Equations (17) and (20) are tied to the value added content of final goods consumption. In the next subsection, we look at the value added content of exports. In particular, we show how a connection between value added trade flows as given in Equations (17) and (20) and exports can be established using the accounting methodology put forward by Koopman et al. (2014).

2.5 Decomposition of Exports into Value Added Components

The total value of a country's exports consists of domestic value added, value added generated in other countries that is re-exported, and some double-counting of those values associated with multiple border crossings by the same piece of value added. The value of the latter is a pure statistical artifact. We use the methodology developed by Koopman et al. (2014) to decompose a country's exports as follows.

$$
\begin{aligned}
\mathbf{1} \cdot \mathbf{EX}_i = & \underbrace{\boldsymbol{\beta}_i \sum_{n \neq i}^{N} \mathbf{B}_{ii} \mathbf{C}_{in} + \boldsymbol{\beta}_i \sum_{n \neq i}^{N} \mathbf{B}_{in} C_{nn} + \boldsymbol{\beta}_i \sum_{n \neq i}^{N} \sum_{m \neq i,n}^{N} \mathbf{B}_{in} \mathbf{C}_{nm} +}_{i'\text{s VA consumed in } n \neq i \text{ or passed on to } m \neq i,n} \\
& \underbrace{+ \boldsymbol{\beta}_i \sum_{n \neq i}^{N} \mathbf{B}_{in} \mathbf{C}_{ni} + \boldsymbol{\beta}_i \sum_{n \neq i}^{N} \mathbf{B}_{in} \mathbf{A}_{ni} (\mathbf{I} - \mathbf{A}_{ii})^{-1} \mathbf{C}_{ii} +}_{i'\text{s VA returning home}} \\
& \underbrace{+ \sum_{n \neq i}^{N} \sum_{m \neq i}^{N} \boldsymbol{\beta}_m \mathbf{B}_{mi} \mathbf{C}_{in} + \sum_{n \neq i}^{N} \sum_{m \neq i}^{N} \boldsymbol{\beta}_m \mathbf{B}_{mi} \mathbf{A}_{in} (\mathbf{I} - \mathbf{A}_{nn})^{-1} \mathbf{C}_{nn} +}_{\text{Foreign VA in } i\text{'s exports}} \\
& \underbrace{+ \boldsymbol{\beta}_i \sum_{n \neq i}^{N} \mathbf{B}_{in} \mathbf{A}_{ni} (\mathbf{I} - \mathbf{A}_{ii})^{-1} \mathbf{EX}_i + \sum_{m \neq i}^{N} \boldsymbol{\beta}_m \mathbf{B}_{mi} \sum_{n \neq i}^{N} \mathbf{A}_{in} (\mathbf{I} - \mathbf{A}_{nn})^{-1} \mathbf{EX}_n,}_{\text{Pure double counting}} \quad (21)
\end{aligned}
$$

where $\mathbf{1}$ is a unit vector and $\mathbf{EX_i}$ is a vector collecting country i's total sectoral exports. $\boldsymbol{\beta}_i$ is a $J \times J$ diagonal matrix with diagonal elements corresponding to country i's sectoral value added coefficients β_i^k.

The first three terms in Equation (21) make up country i's value added exports to other countries, that is, value added from country i that is consumed in other countries $n \neq i$. This is identical to the value added flows in Equations (17) and (20), when summing over destination countries $n \neq i$. The second line represents value added generated in country i that first leaves the country in the form of intermediate goods but is eventually re-imported (as final or intermediate good) and consumed in i. These flows show up in country i's export statistic but do not constitute value added exports. The third line shows the part of country i's export value that is foreign value added, embodied either in final or in intermediate goods exports. The last line shows value added (originating either in the home country or in the foreign country) that appears several times in i's export statistic.

This decomposition also helps categorize countries according to their engagement in production fragmentation. For countries heavily involved in the global value chain we expect double-counting to be relatively more important. A country's position in the global value chain is indicated by the importance of final, compared to intermediate, value added exports. The more upstream a country's position in the value chain, the more important are domestic value added exports (the first term in Equation (21)) compared to value added re-imports and foreign value added exports (second and third terms in Equation (21), respectively). With the help of the model, we are able to conduct counterfactual analyses of those quantities and their relative importance in order to assess how a country's position in the global value chain is affected by trade liberalization.

3 Production Networks

Countries can multiply the gains from specialization in production by relocating production stages across borders. In addition to trade costs, geography, and sectoral productivity differences, which shape the pattern of trade in final goods, intersectoral linkages are the key determinants of trade flows along the value chain. The input-output-based view on interlinkages has advantages and disadvantages, however. Leontief coefficients provide a measure of the depth of a production relationship, taking into account all possible linkages between countries, and thus capture all countries' relative productivity differences and geographical characteristics. However, by summarizing all indirect production relationships, the method does not allow for a step-by-step analysis of all sequential production stages.[11] Nor can it capture differences in the structure of the value chain, as discussed by Baldwin and Venables (2013).[12]

With these limitations in mind, we propose a measure that can be used to identify production networks. The measure is based on the relationship between a source sector in one country, which we call the upstream sector, and a final goods producing downstream sector in another country. All the intermediate travel routes, including the second to last location from which the downstream sector imports the upstream sectors' value added, enter through the Leontief coefficients. To separate value added in intermediate and final goods production, we first define modified Leontief coefficients. Let $b_{ih}^{k,j}$ be any Leontief coefficient, that is, any element of $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1} = \sum_{k=0}^{\infty} \mathbf{A}^k$ and denote with $\tilde{b}_{ih}^{k,j}$ the corresponding element of $\widetilde{\mathbf{B}} = \sum_{k=1}^{\infty} \mathbf{A}^k$. Then,

$$
\begin{aligned}
b_{ih}^{k,j} &= \tilde{b}_{ih}^{k,j} && \text{if} \quad i \neq h \vee k \neq j \\
b_{ih}^{k,j} &= \tilde{b}_{ih}^{k,j} + 1 && \text{if} \quad i = h \wedge k = j.
\end{aligned}
$$

$\tilde{b}_{ih}^{k,j}$ is the output created through *intermediate* goods production per unit of final goods output. This is identical to the Leontief coefficient if the demanding and supplying sectors are not identical (or not in the same country), because in those cases all output generated

[11] As Koopman et al. (2014) and Wang et al. (2013) propose, we can decompose a country's export separately for goods differentiated by their purpose in the destination country. Yet, due to the assumption inherent to the input-output analysis that within each sector the technologies for production of final and intermediate goods are identical, differences between the value added content of final and intermediate goods flows are exclusively due to differences in the demand structure.

[12] These authors highlight the importance of engineering details of the production process for the effect of a decrease in trade costs on trade flows and location decisions. They describe two extreme cases, one in which production takes place in a chain of subsequent steps (a "snake" in their terminology), the other in a two-stage process in which a number of intermediate goods are produced independently in a first step and assembled into one final good in the second stage (a "spider"). Our model has features of both processes. Varieties are assembled to sectoral composites in a spider-like process, but since composites are used as intermediates for variety production, a change in the range of varieties sourced from one country has a direct impact on the varieties sourced from other countries. A true spider-like process is instead characterized by independent intermediate production processes.

in the supplying sector through final goods production of the demanding sector must be through intermediates production. If the two sectors are identical, then the value of the final good itself is included in $b_{ih}^{k,j} = b_{ii}^{k,k}$, given by the 1 that is added to $\tilde{b}_{ih}^{k,j}$.

The total value added from upstream sector k that is processed into a final good by the downstream sector j in country h and from there exported to the world or consumed in h can be obtained by summing up the expression for value added flows in Equation (16) over destination countries n

$$\widetilde{VA}_{ih}^{k,j} = \beta_i^k \tilde{b}_{ih}^{k,j} \pi_{hW}^j C_W^j, \tag{22}$$

where $\pi_{hW}^j = \sum_n^N \frac{C_{hn}^j}{C_W}$ is processing country h's share in world demand for final goods from sector j. Note that here we use the modified Leontief coefficients $\tilde{b}_{ih}^{k,j}$ that do not include value added generated in final goods production.

To evaluate the intensity of such a value added trade relationship, we can focus on either the upstream or the downstream industry, which are, respectively, tied to the source country of value added and to the final goods producing country. Furthermore, we can look at the value added trade relationship from either the demand side or the supply side by comparing any flow given by Equation (22) to the total value from the upstream sector that is processed elsewhere, or to the total value added processed by the downstream sector. We call the former a "demand network" and the latter a "supply network."

3.1 Supply Networks

We first look at a supply network and focus on the downstream sector j_d. Sector j_d uses value added from all upstream sectors in country i to produce final goods for the world. We define such a value added trade relationship between j_d in h and all sectors k in country i as intense if the share of value added from country i processed by j_d relative to the total value added from all sources that j_d processes is large. This measure is given by[13]

$$\frac{\widetilde{VA}_{ih}^{\cdot j_d}}{\widetilde{VA}_{.h}^{\cdot j_d}} = \sum_{k=1}^{J} \frac{\beta_i^k \tilde{b}_{ih}^{k,j_d}}{\sum_i^N \sum_k^J \beta_i^k \tilde{b}_{ih}^{k,j_d}}. \tag{23}$$

We can decompose Equation (23) into two terms, each highlighting a different aspect of such a supply network:

$$\frac{\widetilde{VA}_{ih}^{\cdot j_d}}{\widetilde{VA}_{.h}^{\cdot j_d}} = \sum_{k}^{J} \pi_{ih}^{k,j_d,VA} \cdot \gamma_h^{k,j_d,VA}, \quad \text{where} \tag{24}$$

$$\pi_{ih}^{k,j_d,VA} = \frac{\beta_i^k \tilde{b}_{ih}^{k,j_d}}{\sum_i^N \beta_i^k \tilde{b}_{ih}^{k,j_d}} \qquad \text{and} \qquad \gamma_h^{k,j_d,VA} = \frac{\sum_i^N \beta_i^k \tilde{b}_{ih}^{k,j_d}}{\sum_k^J \sum_i^N \beta_i^k \tilde{b}_{ih}^{k,j_d}}.$$

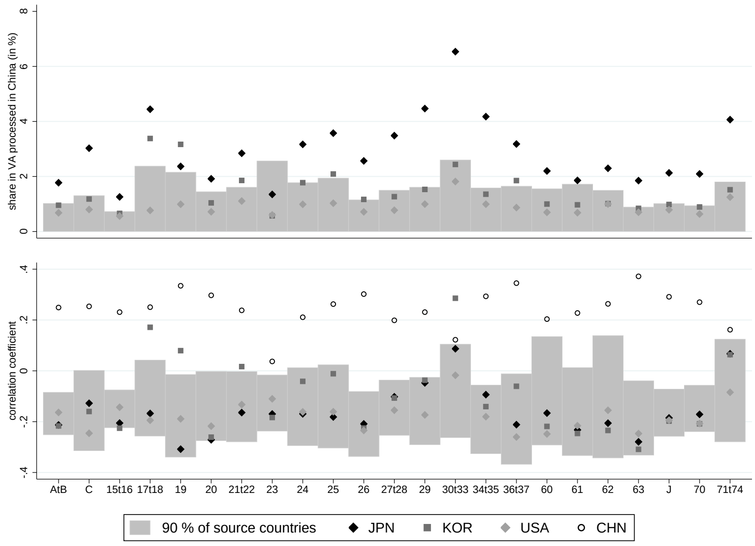
The first term captures country i's share of value added used by j_d and originating in sector k. We call it $\pi_{ih}^{k,j,VA}$ to highlight the conceptual similarity of this value added-based import share to the import trade share π_{ih}^k. $\pi_{ih}^{k,j,VA}$ is a measure of country i's competitiveness relative to other countries that send value added from sector k to h. Note, however, that due to different production technologies across demand sectors, $\pi_{ih}^{k,j,VA}$ varies across j. The second term, $\gamma_h^{k,j_d,VA}$, is conceptually similar to the input cost share $\gamma_n^{k,j}$. It denotes the share of value added from sector k (from all source countries) in the total amount of value added from all sectors processed by j_d, and hence measures the importance of sector k for j_d in terms of value added. Using the fact that $\overline{x \cdot y} = \bar{x} \cdot \bar{y} + cov(x,y)$ for $\bar{x} = \frac{1}{J}\sum_j^J x_j$ we can rewrite Equation (24) as

$$\frac{\widetilde{VA}_{ih}^{\cdot j_d}}{\widetilde{VA}_{.h}^{\cdot j_d}} = \frac{1}{J}\sum_{k}^{J} \pi_{ih}^{k,j_d,VA} + J \cdot Cov\left[\pi_{ih}^{k,j_d,VA}, \gamma_h^{k,j_d,VA}\right] \tag{25}$$

in order to highlight two distinct aspects of a strong supply network as we define it. First, the value added trade relationship is stronger if country i is more competitive,

[13] Dots in subscripts and superscripts indicate that we have summed up over the respective dimension.

Figure 1: Supply networks with China, 2000



Note: The figure plots the measure of supply networks as given in Equation (23) (upper panel) and the correlation coefficient corresponding to the covariance in Equation (25) (lower panel). Calculations based on WIOD. Sectors on x-axis in Isic Rev. 3.

on average, in supplying value added to country h. Second, the relationship will be particularly strong if country i is competitive in those sectors k that are used intensively by sector j_d, as measured by the covariance. Standardization by the product of the standard deviations of π^{VA} and γ^{VA} makes this measure of complementarity comparable across sectors, countries, and time.

Based on the World Input-Output Database we can compute the supply network measure and its components for all countries and sectors at various points in time. Here, we focus on China and the period 2000 to 2007, as we will later seek to quantify the contribution of China's WTO entry to observed changes in the production network structure.

Figure 1 shows the supply network measure (Equation (23)) in the upper panel and the correlation coefficient as implied by Equation (25) in the lower panel for a selection of downstream sectors in China. The gray bars capture the range of values of the network measure across all sourcing countries up to the $90th$ percentile; Japan, Korea, and the United States are shown explicitly. In the upper panel, each dot indicates the share of the respective source country in the total value added processed by the respective downstream sector in China. It is apparent that Japan was a major source of value added for almost all sectors in 2000. In fact, with an average share of about 3 percent across sectors, Japan was the third most important value added source, following China (78 percent) and the rest-of-the-world aggregate (4 percent) (not shown). Korea ranked fourth with an average share of 1.5 percent. The United States is in the middle of the distribution of countries, but tends to have slightly higher shares in the service sectors.

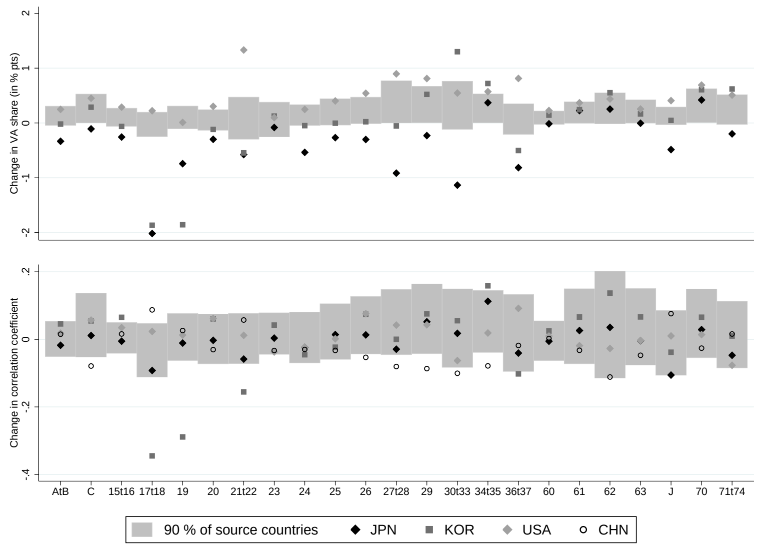
The lower panel presents for each of the networks the degree of complementarity between the relative importance of the source sectors for the downstream sector in China and the competitiveness of the source country in those sectors. As the 90 percent range indicates, most source countries exhibit a negative correlation. A strongly positive correlation exists for China itself.[14] Some foreign source countries stand out: Korea exhibits strong complementarities with the textiles (Isic 17t18) and leather (19t20) sectors, as well as in manufacturing of optical equipment (30t33) and the service industry supplying business activities (71t74). In the latter two sectors, we find strong complementarities for Japan as well, which otherwise, like the United States, ranges in the middle of the distribution of all source countries.

Figure 2 displays the change in the supply networks and the measure of complementarity from 2000 to 2007. As shown in the upper panel, the majority of countries gained shares in the value added processed by China's final goods producing sectors. Generally, this was achieved at the expense of China's own share, which decreased in all sectors except for textiles (17t18) and leather (19t20).[15] We also find that the United States significantly increased its share in almost all sectors, whereas for Korea this was the case

[14]This pattern of high complementarity of domestic sectors is consistent across all countries in the sample and is chiefly due to the restricted tradability of services, which are intensively used inputs in many downstream sectors.

[15]For expositional purposes China is not shown in the upper panel of Figure 2. The negative changes range between -3 and -10 percentage points.

Figure 2: Supply networks with China, change 2000 – 2007



Note: The figure plots changes in the supply networks as given in Equation (23) (upper panel) and the correlation coefficient corresponding to the covariance in Equation (25) (in units, lower panel). Calculations based on WIOD. Sectors on x-axis in Isic Rev. 3.

only in the sectors producing machinery (29), optical and electronic equipment (30t33), and transport equipment (34t35), as well as for a few service sectors. Korea lost a significant share (2 percentage points) in the textiles (17t18) and leather (19t20) industries. Japan, which was a major source of foreign value added in 2000, lost value added shares in almost all sectors, with the exception of transport equipment (34t35) and some of the service sectors, most prominently those associated with transportation (60 – 62).

The lower panel of Figure 2 shows that Japan's and Korea's gains in value added shares in the transport equipment sectors were accompanied by an increase in complementarity. This implies that these countries gained relatively more in sectors that are important inputs for transport equipment producers in China. The figure also reveals that Korea's loss in value added shares in China's textiles and leather industry was accompanied by a strong decline in the degree of complementarity, which initially had been exceptionally high.

3.2 Demand Networks

Next, we look at a demand network of the upstream sector k_u with all final goods producing sectors in country h. We define this sort of value added trade relationship as intense if the share of k_u's value added processed in country h (by any sector) relative to the total value added from k_u processed elsewhere is large. This measure is given by

$$\frac{\widetilde{VA}_{ih}^{k_u \cdot}}{\widetilde{VA}_{i.}^{k_u \cdot}} = \sum_{j=1}^{J} \frac{\tilde{b}_{ih}^{k_u,j} \pi_{h,W}^{j} C_W^j}{\sum_h^N \sum_j^J \tilde{b}_{ih}^{k_u,j} \pi_{h,W}^{j} C_W^j}. \tag{26}$$

Analogously to the supply network, we can decompose Equation (26) into two components

$$\frac{\widetilde{VA}_{ih}^{k_u \cdot}}{\widetilde{VA}_{i.}^{k_u \cdot}} = \sum_{j=1}^{J} s_{ih}^{k_u,j} \cdot r_i^{k_u,j}, \qquad \text{where} \tag{27}$$

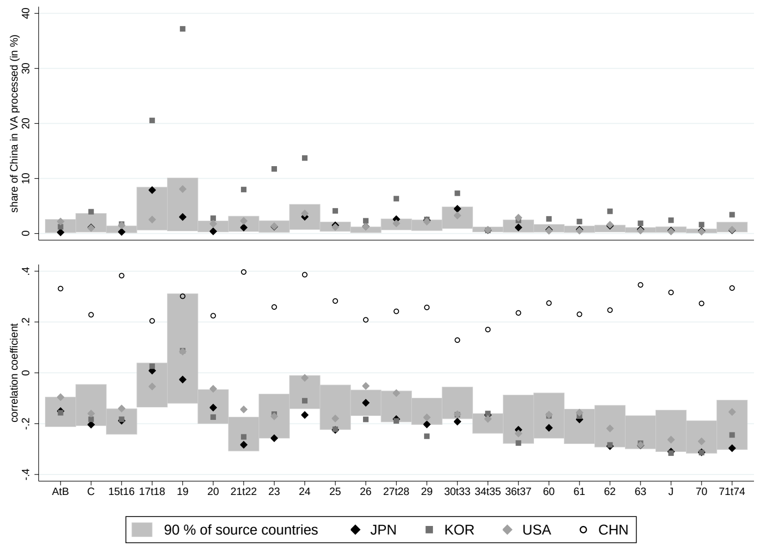
$$s_{ih}^{k_u,j} = \frac{\tilde{b}_{ih}^{k_u,j} \pi_{h,W}^{j}}{\sum_h^N \tilde{b}_{ih}^{k_u,j} \pi_{h,W}^{j}} \qquad \text{and} \qquad r_i^{k_u,j} = \frac{\sum_h^N \tilde{b}_{ih}^{k_u,j} \pi_{h,W}^{j} C_W^j}{\sum_j^J \sum_h^N \tilde{b}_{ih}^{k_u,j} \pi_{h,W}^{j} C_W^j}.$$

Here, the first component $s_{ih}^{k_u,j}$ denotes a value added export share, that is, country h's share in total value added from sector k_u that is processed by sector j in any country. This depends on how large a trade share country h has in world final goods consumption and how much output this generates in sector k_u relative to all other final goods producers. The second term captures the importance of sector j for sector k_u from a demand perspective. More specifically, r_{ih}^{j} is the share of sector j inputs in total value added from sector k_u that is processed in final goods consumption by all sectors in all countries. As for the supply network, we can distinguish between two determinants of demand network strength based on

$$\frac{\widetilde{VA}_{ih}^{k_u \cdot}}{\widetilde{VA}_{i.}^{k_u \cdot}} = \frac{1}{J} \sum_{j}^{J} s_{ih}^{k_u,j} + J \cdot Cov\left[s_{ih}^{k_u,j}, r_i^{k_u,j}\right]. \tag{28}$$

This decomposition shows that the value added trade relationship is strong if country h is an important destination for country i on average, and particularly strong if, on average,

Figure 3: Demand networks with China, 2000

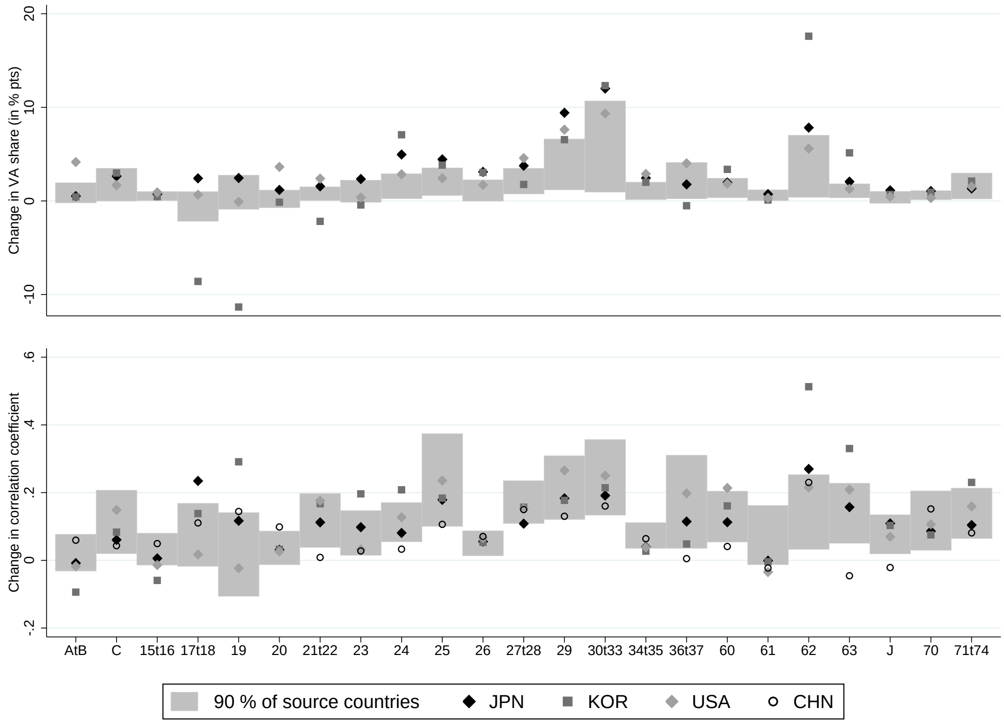


Note: The figure plots demand networks as given in Equation (26) (upper panel) and the correlation coefficient corresponding to the covariance in Equation (28) (lower panel). Calculations based on WIOD. Sectors on x-axis in Isic Rev. 3.

country h captures a large share of sector k_u's value added in sectors that absorb a large share of value added from sector k_u due to either technological reasons or to high demand for this sector's final goods.

We now describe demand networks with China. A demand network, as defined in Equation (26), captures the relative importance of a final goods producing country, here China, for an upstream sector in a specific source country. The upper panel of Figure 3 shows that in 2000, for most countries, China was an important location for processing value added from the textiles (17t18) and leather (19t20) sectors, as well as from chemical products (24) and electronic and optical equipment (30t33), into final goods. It also shows the remarkable importance of China as a final goods producer for Korean upstream sectors. With an average share of 5 percent across sectors, Korea was in fact the country relying most heavily on processing in China, followed by Indonesia and Australia, both having shares of about 2.5 percent. Japan is found in the middle or at the lower end of the distribution of source countries in most sectors, except for textiles (17t18), metals (27t28) and electrical and optical equipment (30t33), in which sectors its reliance on China as a

Figure 4: Demand networks with China, change 2000 – 2007



Note: The figure plots changes in supply networks as given in Equation (26) (upper panel) and the correlation coefficient corresponding to the covariance in Equation (28) (in units, lower panel). Calculations based on WIOD. Sectors on x-axis in Isic Rev. 3.

final goods producer was relatively strong.

The lower panel of Figure 3 reveals that the complementarities in demand networks are similar to those found for supply networks. Chinese upstream sectors exhibit strong complementarities with the sourcing structures of its downstream sectors, while for the upstream sectors in foreign countries, the correlation tends to be negative. This suggests that China's reliance on domestic value added from the upstream sectors that are intensively used in important final goods industries was still relatively high. The limited tradability of service sectors plays a crucial role here as well.

Figure 4 shows the changes in the demand networks and in complementarity. Between 2000 and 2007, China's importance as a processing location grew for almost all countries and in almost all sectors. The electronic and optical equipment sector (30t33), as well as the machinery sector (29), are particularly noteworthy in this regard. Furthermore, we find that for both Japan and Korea, reliance on China increased particularly strongly for most sectors. China lost importance for Korea's value added from the textiles (17t18) and leather (19t20) sectors. The figure's lower panel shows increasing complementarity between foreign source sectors and the demand structure of China's final goods sectors. This means, for example, that for the electrical and optimal equipment sector, stronger reliance on China as a processing location was particularly pronounced in sectors that use relatively more electrical and optical equipment as an input to production.

The deepening of networks with China suggests that China's integration into the global economy brought about a shift toward more foreign value in Chinese final goods and towards all countries processing relatively more value added in China than elsewhere. Moreover, the increase in the complementarity measures indicates a change in the relative supply structure toward more competitive sources and a change in the relative demand structure toward more competitive final goods sectors. These findings highlight the scope for gains achievable from specialization along the global value chain and, furthermore, illustrate that cross-sectoral dependencies play a crucial role in understanding how structural changes affect countries' relative competitiveness and how the effects of trade policy spread across all countries involved in global production sharing.

Before we evaluate China's accession to the WTO by means of a counterfactual experiment, we first describe our data sources and how we identify the parameters of the model.

4 Data and Parameter Identification

To simulate the effects of changes in tariffs, we need to identify the model parameters α, β, γ, and θ, and collect data on bilateral trade shares, tariff levels, countries' total value added, and trade surpluses. The expenditure shares α and the cost shares β and

γ are obtained from input-output tables. θ is estimated as a trade cost elasticity based on a structural equation that follows from the model. We obtain an alternative set of estimates based on a standard gravity equation.

4.1 Data Sources

Our main data source is the World Input-Output Database (WIOD), which provides harmonized international input-output tables as well as production values, final and intermediate goods trade, and consumption by use categories. The database contains data for 40 countries (mainly members of the OECD) and a rest-of-the-world aggregate (RoW) for the years 1995-2011, with a sectoral breakdown at roughtly the two-digit level of ISIC, resulting in 35 industries.[16] The WIOD contains information on trade by sector, including services industries. The WIOD does not have information on actual bilateral input-output coefficients. These coefficients are imputed from national input-output tables based on a proportionality assumption. Accordingly, a sector's usage of a certain intermediate input is split between trade partners according to their respective shares in total intermediate goods imports. See Timmer (2012) for an in-depth description of methods and assumptions used to construct the WIOD.

Data on bilateral tariffs for manufacturing sectors are taken from UNCTAD's TRAINS database.[17] We use effectively applied tariffs at the six-digit level of the Harmonized System goods classification and aggregate them to the WIOD sectoral level using import values as weights. Other trade cost variables for our auxiliary gravity estimation, that is, bilateral distance and a dummy for contiguity, are obtained from the CEPII database. A FTA dummy is constructed based on the RTA database of the WTO.

[16] Due to lack of tariff data for Taiwan, we merge it with RoW and are thus left with 39 countries plus the RoW aggregate.

[17] The database can be accessed via the World Bank's World Integrated Trade Solution (WITS) project, `https://wits.worldbank.org/WITS/WITS/Restricted/Login.aspx?AspxAutoDetectCookieSupport=1`.

4.2 Identification of Sectoral Productivity Dispersion

The sectoral productivity dispersion parameters are identified with the method proposed by Caliendo and Parro (2015). The estimation equation is based on a structural expression for gross trade flows derived from the model. By dividing a country-pair's trade flow with trade flows of other trade partners, importer, exporter, and pair-specific symmetric effects are canceled out. The corresponding estimation equation is

$$\ln \frac{X_{in}^j X_{hi}^j X_{nh}^j}{X_{ni}^j X_{ih}^j X_{hn}^j} = -\frac{1}{\theta^j} \ln \left(\frac{(1+\tau_{in}^j)(1+\tau_{hi}^j)(1+\tau_{nh}^j)}{(1+\tau_{ni}^j)(1+\tau_{ih}^j)(1+\tau_{hn}^j)} \right) + \varepsilon_{inh}^j, \tag{29}$$

where ε_{inh}^j is an i.i.d. error term. Identification rests on the assumption that unobserved trade costs are exogenous to tariffs after differencing out all importer-sector-, exporter-sector-, and importer-exporter-specific effects.

Alternatively, we can identify θ from a standard gravity equation; the coefficient of tariffs in the gravity equation is $-1/\theta^j$ (see Equation (4)). Tariff data is directly observable, but iceberg trade costs are not. To estimate Equation (4), the gravity literature typically assumes a functional form for iceberg trade costs based on proxies such as bilateral distance and dummies for contiguity and joint membership in a free trade agreement (FTA). We proceed accordingly by assuming that $d_{in}^j = {D_{in}}^{\rho^j} e^{\delta^j \mathbf{Z}_{in}}$, where D_{in} is bilateral distance and $\mathbf{Z}_{in}$ is a vector collecting dichotomous trade cost proxies (contiguity and FTAs). Plugging this functional form into the trade share equation (4) and multiplying by X_n^j, results in the following log-linearized estimable gravity equation for each sector j:

$$\ln(\pi_{in}^j X_n^j) = -\frac{1}{\theta^j} \ln(1+\tau_{in}^j) - \frac{\rho^j}{\theta^j} \ln D_{in} - \frac{\delta^j}{\theta^j} \mathbf{Z}_{in} + \nu_i^j + \mu_n^j + \varepsilon_{in}^j, \tag{30}$$

where $\nu_i^j \equiv \ln(\lambda_i^j c_i^j)$ is an exporter fixed effect, $\mu_n^j \equiv \ln(X_n^j / \sum_{i=1}^N \lambda_i^j \left[c_i^j \kappa_{in}^j\right]^{\frac{-1}{\theta^j}})$ is an importer fixed effect, and ε_{in}^j an i.i.d. error term.

Table 1 displays the results from both estimation strategies. Each row corresponds to a separate estimation. Columns (1) and (2) show the estimates for the (inverse) productivity dispersion, $1/\theta^j$, from the Caliendo and Parro (2015) methodology; in column (2) we drop from the sample the 0.5 percent of observations with the highest tariffs. Column (3) applies a gravity equation where importer and exporter fixed effects control for unobserved country-level heterogeneity and the log of distance and dummies for FTAs and for contiguity proxy trade costs. Sectors are sorted in descending order of the estimated coefficient on tariffs. The higher $1/\theta^j$ (in absolute terms), the smaller the productivity dispersion in the respective sector. The coefficients are fairly stable across the different estimation procedures. Not surprisingly, "basic metals and fabricated metal," "mining and quarrying," and "coke, refined petroleum, and nuclear fuel" are at the top of the list. These sectors are characterized by more homogeneous products. At the lower end of the table are sectors such as "transport equipment" and "manufacturing nec." which tend to produce more heterogeneous goods. All in all, the sorting of sectors seems plausible.[18] Also, the order of magnitude of the estimated coefficients seems plausible, except for three (two) estimates that are smaller than one in Column (1) (Column (2)). For our counterfactual analysis we use the estimates from Column (2), since Caliendo and Parro (2015)'s methodology relies on weaker identification assumptions. For "manufacturing nec." we use the gravity estimate.

Data on bilateral tariffs are not available for service sectors. Therefore, we cannot apply our estimation strategy for sectors listed in ISIC Chapters E-Q. Instead, we rely on an average value obtained by Egger et al. (2012), who estimate a trade cost elasticity for services of 5.959.

[18]The estimates indicate that the agricultural sector has a rather high productivity dispersion. This is unexpected. However, given that this sector aggregates agriculture, hunting, forestry, and fishing, this result might be due to an aggregation bias.

Table 1: Gravity estimates of sectoral dispersion parameter

ISIC Rev. 3	Sector	(1)	(2)	(3)
		Estimates of $-1/\theta$		
		CP	CP (99.5)	FE
27-28	Basic metals	-12.3572***	-14.5695***	-12.7967***
		(0.2050)	(0.2232)	(0.9444)
C	Mining, quarrying	-12.0365***	-13.7911***	-12.2792***
		(0.7800)	(0.8951)	(1.8261)
23	Coke, petroleum	-11.0537***	-11.4946***	-7.5495***
		(1.4409)	(1.6248)	(2.5559)
24	Chemicals	-9.7762***	-11.2670***	-9.3409***
		(0.2220)	(0.2416)	(0.8369)
20	Wood	-11.1967***	-10.7237***	-10.7012***
		(0.2924)	(0.3026)	(0.9028)
26	Non-metallic minerals	-2.8295***	-6.1282***	-6.1251***
		(0.2866)	(0.2397)	(1.5628)
19	Leather	-3.9975***	-5.5967***	-5.6334***
		(0.1529)	(0.1798)	(0.7012)
17-18	Textiles	-5.2900***	-5.2978***	-5.1851***
		(0.1191)	(0.1205)	(0.5769)
21-22	Paper	-4.4812***	-4.4347***	-5.3701***
		(0.2177)	(0.2333)	(0.7306)
29	Machinery nec.	-4.6152***	-4.2234***	-4.5264***
		(0.2201)	(0.2365)	(0.7764)
15-16	Food	-1.7676***	-2.8780***	-2.0467***
		(0.0600)	(0.0669)	(0.3212)
30-33	Electrical equip.	-3.2876***	-2.5285***	-4.4546***
		(0.1847)	(0.1910)	(0.7313)
25	Rubber	-1.5353***	-2.0934***	-2.6653***
		(0.2094)	(0.2286)	(0.7344)
A-B	Agriculture	-0.4081***	-1.4012***	-1.4457***
		(0.0606)	(0.1043)	(0.3115)
34-35	Transport equip.	-0.8259***	-0.9790***	-1.9491***
		(0.1831)	(0.2190)	(0.6332)
36-37	Manufacturing nec.	-0.7979***	-0.6021***	-2.7715***
		(0.1579)	(0.1621)	(0.6876)
# Observations		1,146,618	1,126,494	93,691
# Exporters/ # Importers		212/120	212/120	212/120

Note: The table shows estimates for the (inverse) sectoral productivity dispersion $1/\theta$ as identified by a cross-sectional gravity estimation for the year 2007. Columns (1) and (2) apply the Caliendo-Parro (CP) method as given in Equation (29), Column (3) applies the gravity equation with importer and exporter fixed effects (FE) and controls for bilateral trade costs as given in Equation (30). Column (2) drops from the sample the 0.5 % highest tariffs. Sectors are sorted in descending order of the estimated coefficient in Column (2). Standard errors (in parentheses) are heteroskedasticity-robust. *, ** and *** indicate statistical significance at the 10, 5, and 1% level, respectively.

4.3 Expenditure and Cost Shares

The remaining parameters, α, β, and γ, and the trade shares π, are obtained from WIOD in conjunction with the tariff data described above. We match production values, the sectoral bilateral trade flows (aggregating intermediate and final goods trade), and the cost shares for intermediates from the WIOD as well as the tariff structure in 2000. We calculate value added, final goods expenditure, and the trade surplus by applying the equilibrium conditions of the model. We show below that deviations from the empirical counterparts are not substantial.

The WIOD data are valued in producer prices; we obtain bilateral imports in purchaser prices by applying the add-valorem tariffs to the reverse export flows so that $X_{in}^k = Z_{in}^k(1+\tau_{in}^k)$. Trade shares are then computed as

$$\pi_{in}^k = \frac{X_{in}^k}{\sum_{i=1}^N X_{in}^k}.$$

Sectoral value added for each country is obtained by subtracting the total cost of intermediate usage from the sector's production value. To that end, we first need to convert sector j's usage of intermediate inputs to purchaser prices by adding the expenses for tariffs to the fob value. Tariff expenses can be calculated as follows:

$$TF_n^j = \sum_i \sum_k \pi_{in}^k \frac{\tau_{in}^k}{\tau_{in}^k + 1}(1-\beta_n^j)\gamma_n^{k,j} Y_n^j$$

where $(1-\beta_n^j)\gamma_n^{k,j} = \frac{\sum_i a_{in}^{k,j}}{F_n^k}$ and the value of production observes $Y_n^j = \sum_i^N Z_{ni}^k + \Delta Inv_n^j$, that is, it is given by the sum over exports plus changes in the stock of inventory. Value added then results from subtracting the total cost of intermediate usage from the sector's production value, that is,

$$VA_n^j = Y_n^j - \sum_k^J \sum_i^N a_{in}^{k,j} Y_n^j - TF_n^j.$$

Value added shares β follow as $\beta_n^j = \frac{VA_n^j}{Y_n^j}$. The cost shares for intermediate inputs, $\gamma_n^{k,j}$, can be backed out from $(1-\beta_n^j)\gamma_n^{k,j} = \frac{\sum_i a_{in}^{k,j}}{F_n^k}$ using the β_n^j's.

The share of expenditure on goods from sector k in total final goods consumption, α_n^k, is derived from the sectoral goods market clearing condition, which requires total expenditure on goods from sector k, $X_n^k = \sum_{i=1}^N X_{in}^k$, to be equal to the sum of expenditure on intermediate and final goods and thus results as

$$\alpha_n^k = \frac{X_n^k - \sum_j^J (1-\beta_n^j)\gamma_n^{k,j} Y_n^j}{I_n}.$$

Finally, income is pinned down by a macroeconomic closure condition that requires income to be equal to final goods expenditure, $I_n = \sum_k X_n^k - \sum_k \sum_j (1-\beta_n^j)\gamma_n^{k,j} Y_n^j$, and follows as

$$I_n = VA_n + R_n - S_n - \Delta Inv_n,$$

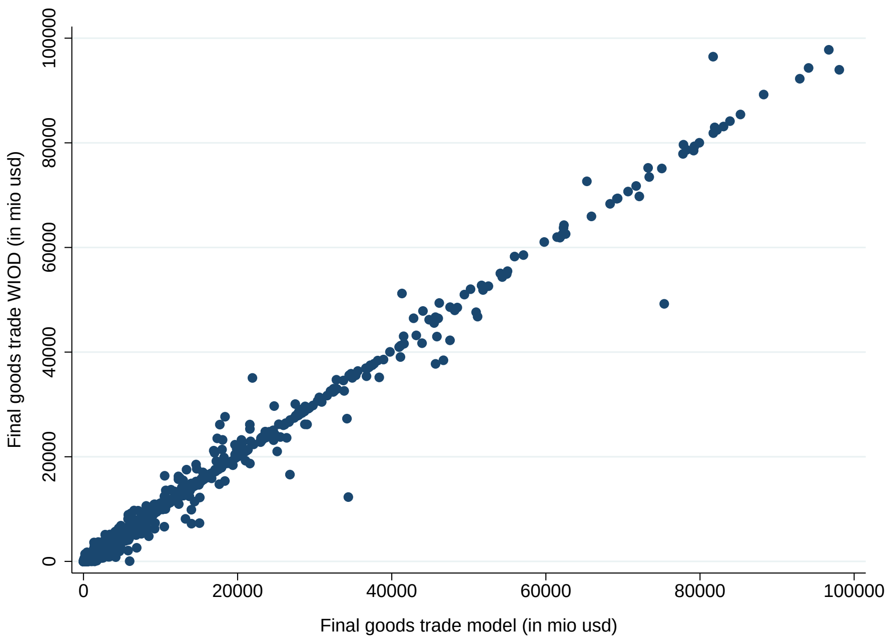
where S_n is the aggregate trade surplus (net exports) $\sum_i^N Z_{ni}^k - \sum_i^N Z_{in}^k$ and ΔInv_n is the net change in inventories. Both terms appear as a mere transfer of income in our one-period setting. The trade surplus is valued in producer prices, since tariff income is captured separately in R_n.

To compute final goods consumption and trade we imposed the assumption inherent to the model that bilateral trade shares are the same for final and intermediate goods. Figure 5 plots the model-based sectoral bilateral final goods expenditures versus the actual data from WIOD (56,000 observations).[19] The deviations are minor, suggesting that the assumption is not problematic.[20]

[19] The largest .01 percent of observations have been omitted from Figure 5 for display purposes.

[20] The largest outlier is the U.S. domestic expenditure share for textiles, where the model overestimates the data by 35 percent. The other apparent outliers all involve RoW.

Figure 5: Model fit: Final goods trade



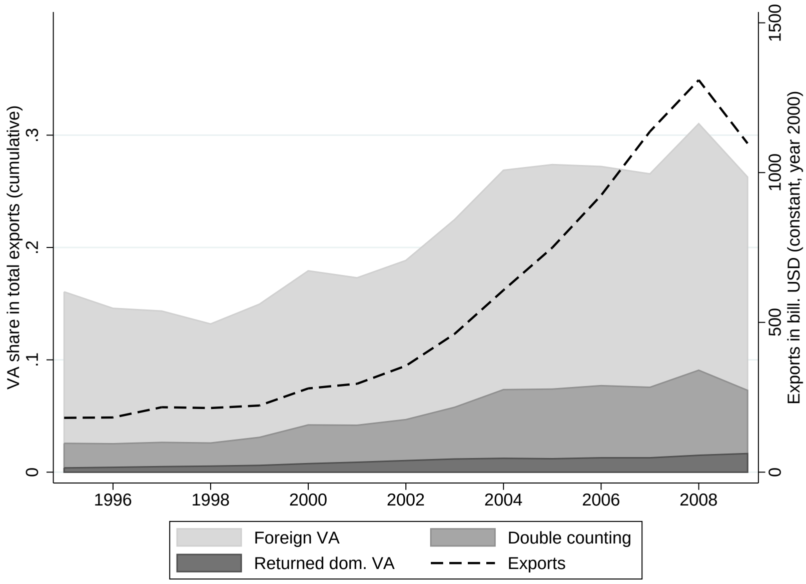
Note: The figure plots bilateral sectoral final goods expenditures in 2000 implied by the model (x-axis) against their counterpart in the data (y-axis, WIOD).

5 Counterfactual Analysis: China's WTO Accession

5.1 Developments in China's Export Composition and Bilateral Value Added Trade Relationships in the 2000s

China's accession to the World Trade Organization (WTO) in 2001 was a major trade shock. It is widely believed that it significantly changed global sourcing structures and has spurred formation of production networks with China. Most notable in the latter regard is the evolution of an Asian production network in which Japan and Korea and other Asian countries supply intermediates to China where they are assembled into final goods. China then exports the final goods, predominantly to the United States, but also to the European Union. Between 2000 and 2008, China's real exports increased by a factor of 4.7, which implies an increase in the share in world exports from 4 to almost 10

Figure 6: China's exports to the world and their value added composition



Note: The figure shows the evolution of China's export (dashed line, right scale) and the cumulated shares of returned domestic value added, double counted value added, and foreign value (left) scale. Shares were computed based on methodology developed by Koopman et al. (2014).

percent. This surge in exports was accompanied by an almost concurrent decline in the domestic value added content. Figure 6 shows China's total exports (right scale) and the value added composition (left scale). The share of value added contributed by China to its own exports decreased in the long run.[21] In 2000, foreign value added accounted for 14 percent of the value of Chinese exports; in 2008 its share was 22 percent. The increase in the share of double-counted trade from 3 to 7.5 percent over the same period is further evidence of China's deepening integration into the global value chain.[22]

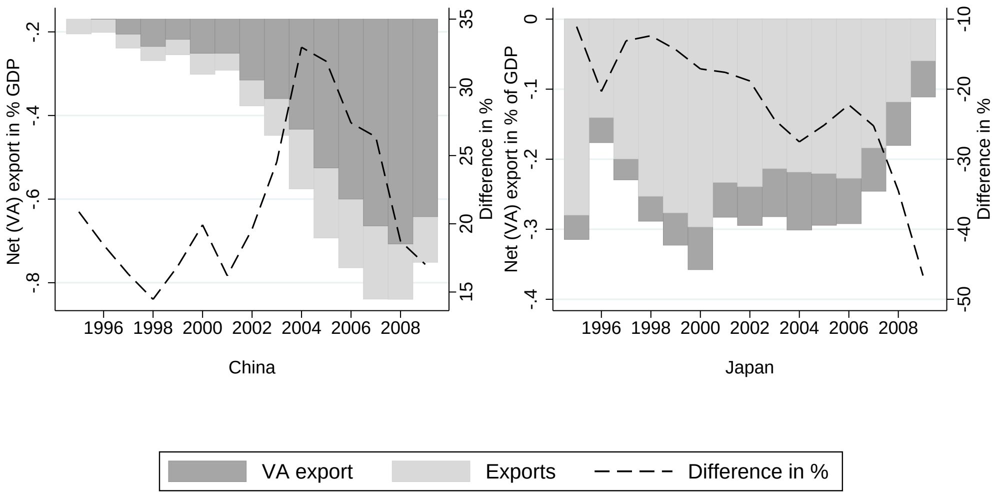
[21] Note that in the later 2000s, the domestic value added of exports inclusive returned and double-counted domestic value added (DVAR) actually increased; compare Figure 13 in the Appendix. This finding is broadly consistent with the trends shown by Koopman et al. (2012) based on a single region input-output framework that distinguishes export-processing zones from the "normal" China and by Kee and Tang (2016) using firm-level data. We find a similar trend in our global input-output framework, however, it is less pronounced and starts only in 2005.

[22] We use Koopman et al. (2014)'s methodology (described above) to compute those shares using data from the WIOD. The share of domestic value added in exports that is consumed abroad is given by one minus the cumulated shares of foreign value added, double-counting, and domestic value that returns home.

The increase in the foreign value added content of China's exports is reflected in large deviations of bilateral trade balances from net value added trade flows. The left panel of Figure 7 shows the U.S. trade balance with China. During the whole period 1995 to 2009, the U.S. ran a trade deficit with China. With China's accession to the WTO, this deficit greatly increased. Starting at about 0.5 percent of U.S. GDP in 2001, U.S. net imports from China almost quadrupled to 2 percent of U.S. GDP by 2007. However, the increase in net value added transfers from China to the United States was much smaller. In the same time period, these increased from around 0.5 percent of U.S. GDP to only 1.5 percent. This implies that the U.S. trade deficit with China is considerably overstated when measured in gross terms instead of value added terms. In 2007, the trade deficit was overestimated by about 25 percent. Over the same period, Japan's net direct export to the United States decreased, while net value added transfers went up (see right panel of Figure 7). In value added terms, the U.S. trade deficit with Japan was understated by around 35 percent in 2007. Those patterns are consistent with the findings of Dean et al. (2009), who show that China's exports of processed goods to the U.S. grew much stronger than exports of processed goods to Japan, while China's imports for processing from Japan grew much stronger than the same type of imports from the U.S..

As shown in our empirical section on networks, China was by far the most important foreign destination for Japan and Korea in terms of processing their value added into final goods and, at the same time, these countries were among the most important sources of foreign value added for China. Korea also experienced disproportionally strong growth in the demand and supply networks, and even though Japan lost in terms of relative importance as a source country for China, the latter's importance as a processing country for Japanese value added increased disproportionately.

Figure 7: U.S. trade deficit with China and Japan



Note: The figure shows the evolution of U.S. net exports (light gray bars) and net value added exports (dark gray bars) to China (left panel) and Japan (right panel) as a share of U.S. GDP for the period 1995-2009. The figure also shows the adjustment of the deficit from value added terms to nominal exports terms (dashed line, right scale).

5.2 China's Accession to the WTO in 2001

To what extent can we attribute these observations to China's accession to the WTO? Can the WTO entry explain the increase in production fragmentation, China's rise as a final goods exporter, and the network formation with its neighboring countries?

To answer these questions, we calibrate the model to the year prior to the accession (2000) and then simulate China's entry by changing China's inward and outward tariff rates with respect to all other countries to the level observed in 2007. Table 2 shows the magnitude of the tariff cuts for the countries in our sample.[23] The cuts were substantial, but very heterogeneous across countries; import tariffs on goods from China decreased

[23]Note that Chinese inward tariff changes are national sectoral averages that mask potential treatment heterogeneity across processing zones – which receive their foreign inputs duty free – and the "normal" Chinese industries. Kee and Tang (2016) show with Chinese firm-level data that this heterogeneity leads to diverging patterns of import changes and rising domestic content levels for China in the years 2000-2007.

Table 2: Inward and outward tariffs with China in 2000 and changes to 2007

	Inward		Outward			Inward		Outward	
Country	Tariff %	Cut	Tariff %	Cut	Country	Tariff %	Cut	Tariff %	Cut
BRA	13.1	-2.7	35.7	-17.2	NLD	0.9	-0.1	6.0	-3.1
USA	4.1	-0.4	15.4	-7.1	POL	2.5	-0.3	5.9	-3.0
MEX	17.0	-6.4	11.7	-6.7	TUR	7.8	-4.5	10.2	-3.0
IDN	4.7	-1.5	11.8	-6.6	GBR	2.3	-0.2	5.0	-2.8
JPN	3.2	0.0	14.1	-6.5	AUT	2.2	-0.2	4.6	-2.5
RoW	8.2	-5.2	11.9	-6.4	ITA	2.9	-0.2	5.0	-2.5
KOR	5.8	-1.6	13.5	-6.0	RUS	11.1	-0.8	5.9	-2.5
CAN	4.8	-0.3	11.3	-5.9	BEL	2.1	-0.2	5.3	-2.5
DNK	2.4	-0.1	10.4	-5.5	CZE	2.9	-0.3	5.1	-2.0
CYP	3.5	-0.2	10.8	-5.0	SVK	2.6	-0.2	4.9	-2.0
LTU	2.8	-0.2	8.3	-4.2	LVA	2.9	-0.2	4.6	-1.9
IND	26.6	-1.3	11.2	-3.9	BGR	1.8	-0.4	4.8	-1.9
FIN	1.7	-0.3	5.8	-3.7	SVN	2.5	-0.3	3.0	-1.4
IRL	1.5	-0.3	5.9	-3.5	ESP	2.8	-0.2	2.6	-1.3
EST	2.1	-0.4	6.7	-3.3	GRC	2.9	-0.2	3.4	-1.2
FRA	2.5	-0.3	5.9	-3.2	MLT	3.1	-0.2	1.5	-1.0
HUN	1.7	-0.4	5.2	-3.2	ROU	3.1	-0.3	1.9	-0.8
AUS	22.0	-5.1	12.9	-3.2	PRT	2.4	-0.2	1.2	-0.6
SWE	3.0	-0.3	4.6	-3.1	LUX	1.0	0.0	0.4	-0.2
DEU	2.5	-0.3	5.4	-3.1					

Note: The table shows trade-weighted average tariffs and tariff changes for all countries with respect to China.

most strongly for Mexico and Australia, where initial levels were also very high. On the other hand, China had to drastically cut its tariffs on imports from the North American economies (the United States, Mexico, and Canada) and on those from its neighboring countries Japan and Korea, as well as those from the emerging economies of Brazil, Indonesia, and India, and the mostly developing countries grouped in the RoW aggregate.

As regards sectoral heterogeneity, Table 3 shows that tariff cuts were particularly deep in the “food, beverages and tobacco” sector and in agriculture, but also for “transport equipment,” “manufacturing, nec.” and “electrical and optical equipment.” For those sectors, the magnitude of tariff cuts also varied substantially across trade partners. Given the large heterogeneity across both sectors and countries, we do not expect all countries to benefit equally from China’s WTO entry.

Table 3: Sectoral tariff changes, 2000-2007

ISIC	Sector	Tariff Cut (in %)	Std.Dev.
15+16	Food, beverages and tobacco	-21.1	66.1
A+B	Agriculture, hunting, forestry and fishing	-11.6	25.7
34+35	Transport equipment	-6.6	8.5
36+37	Manufacturing, nec; recycling	-6.2	6.2
30-33	Electrical and optical equipment	-5.1	3.5
17+18	Textiles and textile products	-4.9	5.3
25	Rubber and plastics	-4.6	3.8
21+22	Pulp, paper, printing and publishing	-4.4	3.5
24	Chemicals and chemical products	-4.0	4.1
29	Machinery, nec.	-4.0	3.5
23	Coke, refined petroleum and nuclear fuel	-3.8	11.1
20	Wood and products of wood and cork	-3.6	4.2
19	Leather and footwear	-3.3	3.1
26	Other non-metallic mineral	-3.3	3.7
27+28	Basic metals and fabricated metal	-3.0	2.9
C	Mining and quarrying	-0.8	1.1

Note: The table shows average tariff changes by sector (in %) with respect to China between 2000 and 2007 and the corresponding standard deviation.

5.3 Results: The Effect of China's WTO Entry

5.3.1 Aggregate Trade and Welfare Effects

Our counterfactual analysis predicts that world real exports increased by 2.1 percent due to China's WTO entry and that world trade over world production went up by .23 percentage points, as we show in Table 4. The driving force behind this overall increase was, of course, China itself, for which we find an increase in total exports of 28 percent. A sizeable effect can also be attributed to Australia (19 percent). Much smaller but still significant increases were experienced by China's neighboring countries Korea, Indonesia, and Japan. We find positive but small trade effects for the United States and negligible or even slightly negative effects for most of the European economies. Furthermore, the results show that China's WTO entry did indeed spur production fragmentation. China's value added exports increased by much less than its total exports. This is indicated by

Table 4: Aggregate trade effects

Country	Rank $\widehat{X}$	Counterfactual Change $\widehat{X}$ %	$\widehat{X/Y}$ % pts	$\widehat{VAX/X}$ % pts	Actual Change 2000-2007 $\widehat{X}$ %	$\widehat{X/Y}$ % pts	$\widehat{VAX/X}$ % pts
CHN	1	28.35	2.49	-3.87	307	3.55	-9.13
AUS	2	19.28	2.47	-1.92	83	-0.83	-1.69
KOR	3	3.34	0.44	-0.71	87	0.68	-4.04
RoW	4	2.39	0.37	-0.60	100	3.04	-6.08
IDN	5	1.73	0.30	-0.34	62	-4.44	2.93
JPN	6	1.52	0.08	-0.20	28	3.19	-7.19
BRA	7	1.38	0.08	-0.05	140	1.81	-0.37
USA	8	0.42	0.02	0.01	32	0.57	0.32
IND	9	0.39	0.04	-0.12	204	2.87	-5.63
RUS	10	0.17	0.04	-0.04	182	-7.31	1.64
ROU	31	-0.18	-0.01	0.05	257	-0.67	-1.23
EST	32	-0.19	-0.02	0.02	154	-4.04	5.50
POL	33	-0.19	-0.01	0.01	218	5.87	-7.52
CZE	34	-0.19	-0.02	0.02	236	5.18	-7.66
MLT	35	-0.20	-0.01	0.03	58	-2.71	7.12
ESP	36	-0.20	-0.01	0.00	101	-0.97	-3.03
SVN	37	-0.22	-0.02	0.02	152	5.05	-4.69
ITA	38	-0.23	-0.01	0.01	79	0.93	-4.46
PRT	39	-0.34	-0.03	0.02	89	1.51	-2.09
LTU	40	-0.58	-0.08	-0.03	237	2.60	1.59
WLD		2.10	0.23	-0.28	86	2.49	-3.81

Countries ranking 11-30 in terms of changes in exports not shown.

China's value added to export ratio, which decreased by 4 percentage points. On the world level, the VAX ratio decreased by 0.3 percentage points. We find decreasing ratios also for the other countries that had positive export changes. Interestingly, for many countries with negative export effects, value added exports increased by less.

How big are these predicted changes in relation to the actual changes that occurred between 2000 and 2007? The answer to this question depends very strongly on the particular numbers at which we look. On the world level, we find that China's WTO entry explains about 9 percent of the increase in world exports relative to world GDP and about 7 percent of the decline in the world VAX ratio. These are sizeable effects if one takes into account that the only difference between the baseline scenario and the counterfactual is the tariff schedule of one country. The scenario does not consider growth in world GDP or growth in China due to anything other than the tariff changes, which explains why the counterfactual changes in total world exports or China's exports explain only a marginal fraction of the actual change (about .25 percent for the world and 10 percent for China). As regards China's growth in exports over GDP or value added exports over exports, the contribution of the WTO entry is much larger. About 2.5 percentage points (70 percent) of the 3.5 percentage point increase in exports over GDP and 4 percentage points (45 percent) of the 9 percentage points decrease in the VAX ratio can be attributed to the change in the tariff structure.

China's WTO entry also explains a large share of the actual developments in Australia. About one-fourth of Australia's increase in total exports and almost 90 percent of the decline in its VAX ratio can be explained by the WTO entry, although the fact that exports over GDP actually declined implies that other significant changes were happening in Australia that cannot be explained by China's trade integration. For Japan's and Korea's aggregate statistics we find that the changes implied by our counterfactual point in the same direction as the actual changes, but the share explained by the counterfactual is small, especially for Japan. Not surprisingly, the farther away we move from China, the less of the actual development is explained. However, as we show below, on a more disaggregated level we find that China's WTO entry significantly influenced the bilateral and sectoral pattern of trade in value added.

Next, we use the decomposition method outlined above to analyze how China's WTO entry affected the composition of countries' exports. In Table 5 we show the world aggregate for comparison and the countries with the largest declines in their VAX ratios, which are, except for RoW, all countries geographically close to China. We find for China that the largest part of the decline in the domestic value content was due to an increase in the

Table 5: Changes in export composition (in % pts)

Exporter	$\widehat{VA\ Exports}$	$\widehat{VA\ Reimports}$	$\widehat{Foreign\ VA}$	$\widehat{Double\ Counting}$	$\widehat{Tariffs}$
CHN	-3.87	0.31	1.26	3.08	-0.78
AUS	-1.92	0.11	0.40	1.70	-0.30
KOR	-0.71	0.03	0.52	0.21	-0.05
RoW	-0.60	0.08	0.32	0.29	-0.08
IDN	-0.34	0.00	0.20	0.16	-0.02
JPN	-0.20	0.05	0.10	0.06	-0.01
IND	-0.12	0.00	0.09	0.02	0.01
WLD	-0.28	0.01	0.15	0.18	-0.05

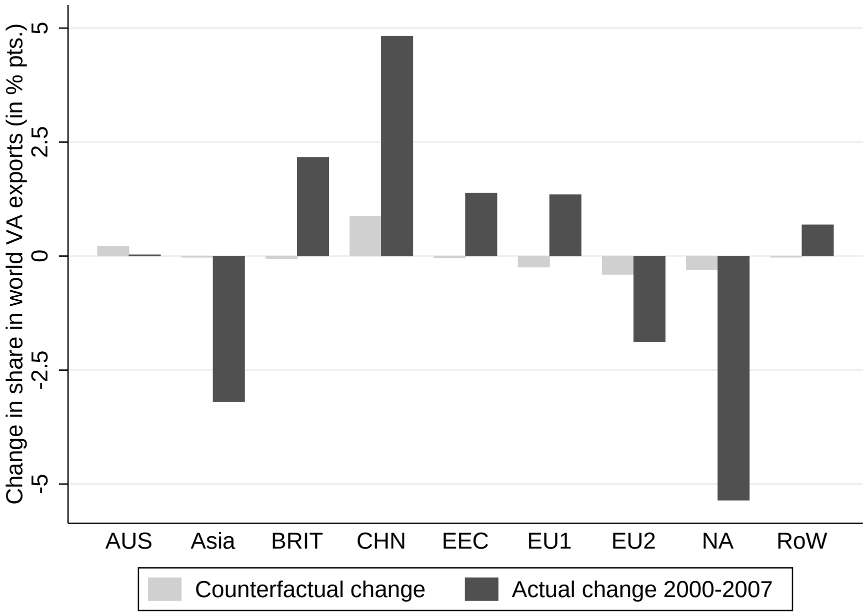
Note: The table shows the changes in the composition for the seven countries with the largest declines in the VAX-ratio and for the world as a whole.

share of double-counted value added, which increased by 3 percentage points.[24] In comparison, the share of foreign value added increased by 1.7 percentage points. Australia's exports experienced similar changes in composition; for the other countries, the increase in the share of foreign value added exceeded the increase in double-counting.

Figure 8 shows how the pattern of world wide value added sourcing changed between 2000 and 2007 and what part of this can or cannot be explained by China's WTO accession. The dark gray bars show the actual changes and the light gray bars show the changes to the counterfactual equilibrium. We group the countries that exhibited qualitatively similar changes both in the counterfactual and in the actual data and we find that this scheme is in good accordance with a grouping based solely on geography. Between 2000 and 2007, China gained a significant share in total world value added exports, reaching 9.5 percent in 2007. Furthermore, Australia, a group of western European countries (EU1), and the central and eastern European countries (EEC), as well as the emerging countries (BRIT) and the primarily developing countries in RoW, were able to increase their shares in world value added exports. This came at the expense of a second set of

[24]Note that we do not treat tariff payments on intermediate imports as value added, hence the accounting equation capturing features an additional term capturing the sum of changes in tariff payments in all upstream production stages.

Figure 8: Changes in world value added export shares



Countries are grouped as follows: *Asia*: IDN, JPN, KOR; *BRIT*: BRA, RUS, IND, TUR; *EEC*: Eastern Europe; *EU1*: AUT, DEU, LUX, IRL, ESP, POR; *EU2*: BEL, DNK, FIN, FRA, GBR, ITA, NLD, SWE; *NA*: CAN, USA, MEX

western European countries and the North American and Asian industrialized economies. We find that China's WTO entry can account for about 20 percent of its increase in the share of world value added. The country's WTO entry did not significantly affect the shares of the other Asian economies, those of the emerging and eastern European countries, nor those of RoW. Apparently, the dynamics of those regions were due to something else. However, China's WTO accession did contribute to the loss in value added export shares by the northern American and western European countries and the slight gains in Australia's share.

To assess the welfare implications of China's accession to the WTO we look at changes in real income as given in Equation (12). The two determinants of welfare changes are real wages and tariff income. Due to global production linkages, real wages in all countries are much more directly affected than just through the equilibrium price indices, as is the

Table 6: Welfare changes (in %)

Country	$\widehat{W}$	$\widehat{(w/P)}$	$\hat{P}$	$\widehat{R}$	Rank $\widehat{W}$
AUS	2.62	3.18	-3.94	-28.23	1
CHN	0.56	1.52	-1.27	-41.12	2
KOR	0.24	0.23	0.31	-0.33	3
IDN	0.13	0.14	-0.09	-1.65	4
RoW	0.07	0.15	-0.08	-5.34	5
JPN	0.04	0.03	0.11	2.71	6
CYP	0.04	0.02	-0.07	-0.10	7
MLT	0.04	0.02	-0.13	0.45	8
BRA	0.03	0.03	0.09	0.39	9
RUS	0.03	0.03	-0.05	0.11	10
USA	0.02	0.02	-0.06	-0.50	13
SVK	0.00	0.00	-0.11	-0.75	31
FRA	0.00	0.01	-0.10	-0.69	32
SVN	0.00	0.00	-0.12	-0.61	33
ITA	0.00	0.00	-0.13	-0.09	34
LUX	-0.01	0.01	-0.09	-0.20	35
BEL	-0.01	0.00	-0.11	-0.66	36
TUR	-0.01	0.00	-0.22	-3.25	37
IRL	-0.01	0.02	-0.14	-1.28	38
MEX	-0.02	0.02	-0.11	-1.04	39
LTU	-0.04	-0.06	-0.20	-0.81	40

Note: The table shows counterfactual changes in welfare $\widehat{W}$ (real income), real wages $\widehat{(w/P)}$, the price level $\hat{P}$, and tariff revenue $\widehat{R}$ for the 10 most positively and most negatively affected countries in terms of welfare as well as for the U.S..

case in the standard gravity model. Even countries that experienced little or no tariff changes with respect to China can witness an increased demand for their labor if they are an important input supplier either for China or for some other country that experienced significant changes in the tariff structure. Similarly, production linkages imply that other countries' production costs show up directly in a country's own price index. Hence, we expect that the welfare consequences are much more complex than in a standard general equilibrium gravity framework without input-output linkages.

China's WTO entry resulted in positive welfare gains in terms of a positive change in aggregate real income for China itself, and also for most other countries. Table 6 shows welfare changes for the 10 most and least positively affected countries and for the United

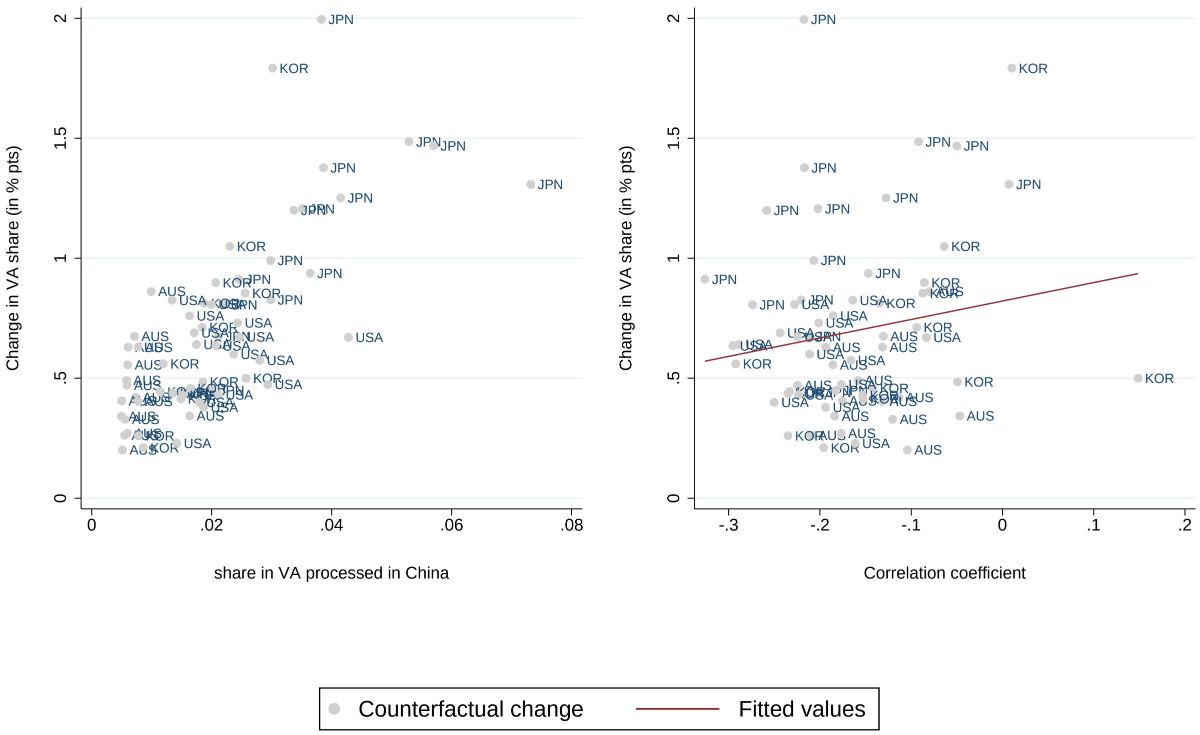
States. Remarkably, Australia experienced the largest real income gain – 2.6 percentage points – more than four times the increase for China. Australia benefited from a strong decrease in the price index, which compensated for the significant 28 percent decline in tariff revenue. Similarly, China lost 41 percent of its tariff revenue, but also experienced a significant reduction in prices and higher demand for its labor, resulting in a net real income gain of .6 percent. The other countries with sizeable positive effects are China's neighbors and the mostly developing countries in the RoW aggregate. We find that in most countries prices decreased, with the noteworthy exceptions of Japan and Korea, where the increased demand for labor drove up nominal wages and prices. Nevertheless, these two countries still experienced real wage gains. The increased demand for labor in Korea and Japan suggests that the relocation of production to China (which we document below for final goods production) was overcompensated by an increase in total demand. We also find positive but small welfare effects for the United States, where the decline in the price index was sufficiently large to make up for the loss in nominal wages and tariff income. We find small negative welfare effects for only six countries, with Lithuania, the most adversely affected country, experiencing a decline in real income of .04 percent.

5.3.2 Effects on Bilateral Trade in Value Added and Networks

Supply Networks. China's WTO accession facilitated easier access to inputs for Chinese final goods producers. The sectoral and bilateral heterogeneity suggests that input suppliers were differentially affected, yet the sectoral and global interlinkages make it hard to predict ex-ante how value added flows change as a consequence of trade cost changes. We use our measure of supply networks to shed light on the question of which countries and sectors intensified their production linkages with China.

Three features of value added trade relationships, when present, tended to make these relationships particularly affected by China's WTO entry. First, geographical proximity was a major determinant. Following the RoW aggregate, Japan, Korea, Indonesia, and

Figure 9: Changes in the intensity of supply networks for selected countries



Note: The figure plots changes in supply network intensity as defined in Equation (23) against values (left panel) and against the inital degree of complementarity (right panel), given by covariance term in Equation (25) standardized by the product of the standard deviations of $\pi_{ih}^{k,j_d,VA}$ and $\gamma_h^{k,j_d,VA}$.

Australia were the countries that on average experienced the strongest increases in their shares of foreign value added processed by final goods sectors in China. Second, the scope and the depth of existing supply networks mattered. Figure 9 shows for China's neighboring countries and the United States that the initial value added share was a strong predictor of the change in the share (left panel). Each dot is a supply network between the country as labeled and one downstream sector in China. Likewise, a deeper network facilitated a stronger increase in the value added share (right panel), where the depth of a supply network is measured by the correlation between the source country's relative competitiveness in an upstream sector and the importance of that upstream sector in general for the downstream sector in China.

Table 7 presents the correlations for all source countries and all downstream sectors in

Table 7: Determinants of changes in supply networks

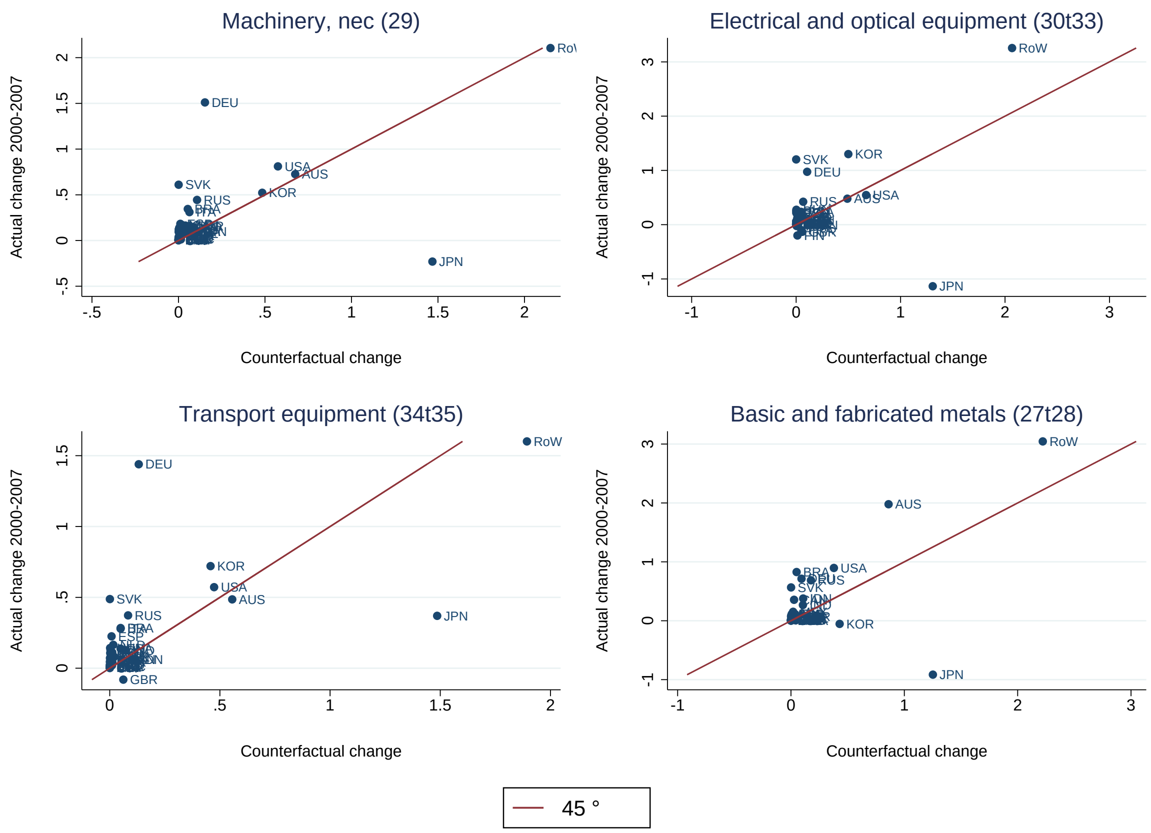
Dep. var: $\Delta\frac{VA_{ih}^{\cdot j_d}}{VA_{i.}^{\cdot j_d}}$	Counterfactual		Actual Change	
$VA_{ih}^{\cdot j_d}/VA_{i.}^{\cdot j_d}$	26.46***		17.72***	
	(0.354)		(0.884)	
$\pi_{ih}^{k,j_d,VA}$		22.60***		12.25***
		(0.307)		(1.037)
$\rho(\pi_{ih}^{k,j_d,VA}, \gamma_h^{k,j_d,VA})$		0.289***		0.480***
		(0.0397)		(0.0740)
N	1287	1287	1287	1287
R^2	0.813	0.819	0.238	0.153

Note: The table shows OLS regression results for changes in supply network intensity for all source countries with all downstream sectors in China. Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. ρ denotes the correlation coefficient; the other variables are as defined in Equation (28).

China and compares the counterfactual changes to the actual changes. Columns (1) and (3) show the relationship of the change in the share with the initial level. Columns (2) and (4) display the relationship with each of the components of the supply network and confirm that both affect the intensity of the network. The counterfactual changes strongly resemble the pattern in the data. In terms of magnitudes, we find for the counterfactual that a 1 percentage point higher initial value added share is associated with a .26 percentage point stronger increase. The actual data predict a .18 percentage point increase. An increase in the correlation coefficient by .01 units is associated with a .29 percentage point higher increase in the counterfactual and .48 in the data. It is noteworthy that the initial strength of the network is a remarkably strong predictor of the counterfactual change, as indicated by an R^2 larger than .8, and also has substantial explanatory power for the changes that we observe in the data over a period of seven years.

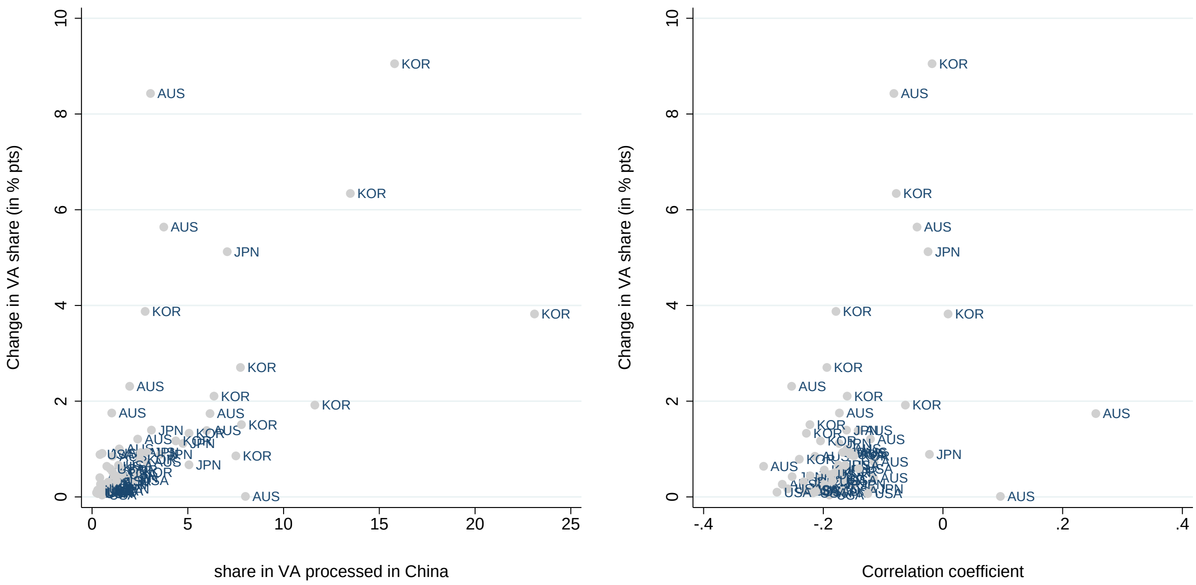
We find a strong resemblance between the counterfactual changes and the actual data within sectors, too. Figure 10 plots for all source countries the changes in supply network intensity with China's manufacturing sectors (29-36) in the counterfactual against the

Figure 10: Changes in the intensity of supply networks for selected sectors



Note: The figure plots actual vs. counterfactual changes in supply network intensity as defined in Equation (23) for selected sectors.

Figure 11: Changes in the intensity of demand networks for selected countries



Note: The figure plots changes in supply network intensity as defined in Equation (26) against values (left panel) and against the inital degree of complementarity (right panel), given by covariance term in Equation (28) standardized by the product of the standard deviations of $s_{ih}^{k_u,j}$ and $r_i^{k_u,j}$.

change in the data. The majority of countries are clustered at zero both in our counterfactual and in the data. Countries that repeatedly stand out are Japan, Korea, Australia, the United States, Germany, and RoW. In many cases, the changes in the data are very well explained by our counterfactual, especially so in the case of RoW, Australia, the United States, and Korea. These countries are aligned on or close to the 45-degree line, which is the most challenging benchmark. Apparently, the counterfactual does not do well at explaining the developments in Japan, which lost value added shares in those sectors or gained only a little, whereas our simulation suggests that China's WTO entry enhanced Japan's supply networks. Also, the significant changes that occurred for Germany, Slovakia, and Russia are at most only partly – as regards the direction of the change – explained by China's WTO entry.

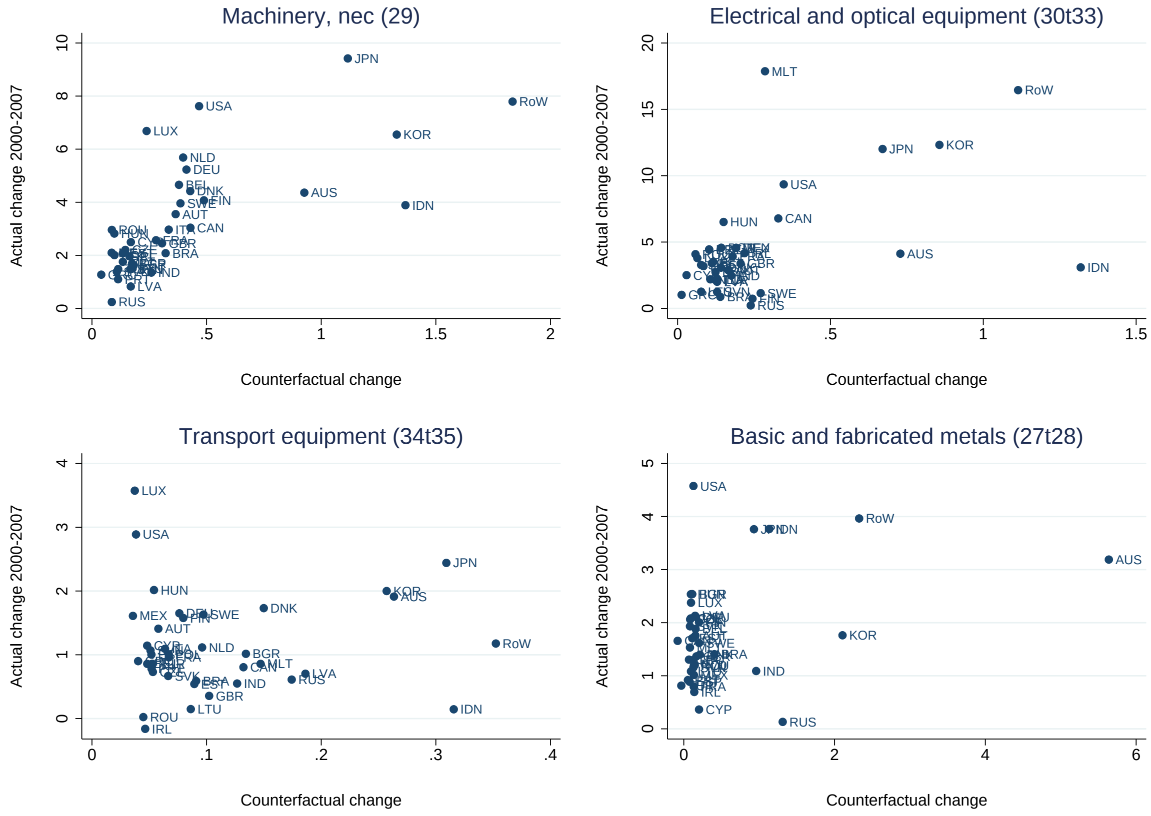
Table 8: Determinants of changes in demand networks

Dep. var: $\Delta\frac{VA_{ih}^{k_u\cdot}}{VA_{i.}^{k_u\cdot}}$	Counterfactual change			Actual change		
$VA_{ih}^{k_u\cdot}/VA_{i.}^{k_u\cdot}$	25.01***	24.89***		-14.06***	33.53***	
	(1.349)	(1.584)		(3.784)	(6.182)	
$\overline{s_{ih}^{k_u\cdot}}$			22.62***			27.07***
			(1.425)			(4.615)
$\rho(s_{ih}^{k_u,j}, r_i^{k_u,j})$			0.0440			2.762*
			(0.361)			(1.457)
N	622	545	545	621	544	544
R^2	0.357	0.313	0.332	0.0218	0.0515	0.0699

Note: The table shows OLS regression results for changes in demand network intensity for all the agricul-teral, mining and manufacturing sectors in the source countries with all downstream sectors in China. Columns 2 and 4 exclude textiles (17t18) and leather (19t20). Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. ρ denotes the correlation coefficient, the other variables are as defined in Equation (27).

Demand Networks. We next focus on the upstream sectors in the source countries and investigate how China's WTO entry changed the pattern of demand for their value added. We find forces similar to those affecting the supply network to be at work in shaping changes in demand network intensity. That is, geographically close countries had the strongest effects, and initially strong networks were disproportionately intensified. Since service sector networks are very small throughout and do not change by much, we restrict the analysis to the agricultural and manufacturing sectors plus mining (A-36). Figure 11 (left panel) shows for China's neighboring countries and for the United States that the increase in the share of value added from a given upstream sector that was processed into final goods in China (rather than elsewhere) was stronger for source countries/sectors where China's share was initially high. The right panel shows that a higher complementarity with the demand structure of China's final goods producers was also associated with a stronger effect on China's demand share. Table 8, Column (1) confirms that the correlation with the initial value added share holds for the full set of countries. The effect of the complementarity measure on the change in the value added

Figure 12: Changes in the intensity of demand networks for selected sectors



Note: The figure plots actual vs. counterfactual changes in supply network intensity as defined in Equation (23) for selected sectors.

share is small and not significant for the full sample (Column (3)); however, we find a strongly significant and positive coefficient when repeating the regression for the subset of countries displayed in Figure 11.

Columns (5) and (6) of Table 8 show that the pattern of the counterfactual changes is well aligned with the actual pattern in the data once we exclude the textiles and leather industries (17t20). Comparing Column (4) to Column (5) shows that excluding textiles and leather reverses the coefficient on the initial share, indicating that those two sectors underwent changes that were significantly different from those experienced by the other sectors. We also find that the developments in textiles and leather also cannot be explained by our counterfactual experiment. Excluding these sectors in the regression with the counterfactual changes (Column (2)) hardly affects the coefficient on the initial share. The magnitude of the effect of the initial share on the change is in a range similar to that seen for the supply networks. A 1 percentage point increase in the initial share implies a .25 and .34 percentage point higher increase in the counterfactual and the data, respectively.

Figure 12 zooms in on four manufacturing sectors to show the extent to which China's WTO entry explains the dynamics within sectors between 2000 and 2007. For all sectors it holds that the actual changes exceed the counterfactual predictions, in some cases by a factor of 10. We attribute this to the exceptional growth taking place in China generally, most of which was unrelated to its WTO accession. The benchmark of the 45-degree line is thus out of reach, but we still find that our counterfactual changes do a good job of predicting developments for the countries located close to China as well as for RoW and the United States, which are the countries that most often exhibit significant changes in the data. In the machinery (29) and electrical and optical equipment (30t33) sectors, the relative changes are explained well for all countries except Indonesia and Malta. In transport equipment (34t45) and basic and fabricated metals (27t28), the northern American and European economies exhibit different dynamics, but for China's neighbors and RoW, the counterfactual changes explain a substantial part of the actual developments.

5.4 Discussion

A few comments are in order in regard to the effects of our counterfactual experiment. First, our analysis rests on the assumption that labor is perfectly mobile across sectors within a country. Since sectors are affected very differently, owing both to heterogeneous tariff cuts and different sourcing structures, the assumption of labor mobility clearly matters for whether countries can actually realize the real wage gains predicted by the model, and over what time horizon. Second, in our static framework trade deficits appear as one-time net income transfers that are treated as exogenous and held constant when moving to the counterfactual equilibrium. Third, as mentioned before, the consequences of China's WTO accession were much broader than those we discuss here. Our welfare effects reflect only the changes induced by the tariff cuts directly. We do not take into account indirect effects of the tariff reductions, such as changes in productivity induced by the reallocation of resources among firms or changes in the degree of competition. As shown by Brandt et al. (2015), the tariff cuts associated with China's WTO entry brought about significant productivity gains and reduced markups. Kee and Tang (2016) show that trade and investment liberalization facilitated an increase in the availability of domestic varieties in upstream sectors with important consequences for the value chain of exporters.

Concurrent with trade liberalization, foreign direct investment (FDI) also underwent substantial liberalization in the 2000s (see, for example Mattoo, 2003). An increase in horizontal FDI may imply that we are overestimating the effects of the tariff cuts, if these investments substitute for trade. Greaney and Li (2009) show that China experienced average annual growth in FDI inflows of 9.3 percent between 2000 and 2006, which was however, significantly smaller than the annual growth of 27.9 percent during the 1990s. FDI inflows relative to GDP stayed almost constant between 2000 and 2006, FDI stocks relative to GDP actually decreased.[25] In contrast, exports and imports over GDP surged during that time. These figures suggest that trade liberalization was the dominant effect of China's WTO entry. Moreover, in a descriptive analysis of the sales structure of U.S.-owned and Japanese-owned foreign affiliates in China, Greaney and Li (2009) find that the share of sales directed to the Chinese market grew, respectively, by only .2 and 2.7 percentage points between 2002 and 2005, notwithstanding China's exceptional GDP growth during that time. Hence, trade cost saving horizontal FDI appears not to have

[25] See Figure 1 and Table 1 in Greaney and Li (2009) for details.

been a major constituent of foreign investment in China in the first half of the 2000s.

Lastly, our analysis is based on the Chinese sectoral input-output table as provided in the WIOD database. However, production in China is divided between two very different systems: (i) export processing zones which receive their foreign inputs duty free and only serve foreign markets and (ii) the normal domestic industries. Koopman et al. (2014) split the Chinese input-output table for these two systems. We do not follow their approach here since this would require a substantial manipulation of the WIOD data with potentially far-reaching consequences, given that the world input-output framework has to be balanced and further assumptions and constraints on the system would be needed. Yet, our results have to be taken with a pinch of salt since export processing zones could react very differently to trade liberalization than the rest of China (see e.g. Kee and Tang, 2016, on domestic content levels).

As regards the magnitude of our predicted welfare effects, we find them to be comparable to the extant literature on trade with China that uses similar methodology. di Giovanni et al. (2014), for example, use a model similar to ours to quantify the overall gains from trading with China. Starting from a baseline equilibrium depicting the world in the 2000s, they find that changing China's status to autarky would entail a welfare loss of 3.7 percent for China. Our counterfactual welfare gain of .56 percent for China due to the tariff cuts associated with its WTO entry thus accounts 15 percent of China's gains from trade with the world. Hsieh and Ossa (2016) analyze the welfare gains due to productivity growth in China. They estimate that between 1995 and 2007, China's median industry experienced annual growth in productivity of 3.5 percent, which was associated with a real income increase by about 10 percent. Hence, compared to the effect of productivity growth, our predicted welfare gains for China entailed by the tariff reductions are rather small. As regards welfare effects for other countries, our qualitative findings align well with the results of di Giovanni et al. (2014) and Hsieh and Ossa (2016). Countries nearby appear to have gained from China's productivity growth and trade integration, while the effects on the U.S. and other industrialized countries are rather small.

6 Conclusion

In this paper, we analyze the effects of trade liberalization on production fragmentation and value added trade. To that end, we derive structural expressions for value added trade flows and production networks from a multi-sector multi-country model of the Eaton and Kortum (2002)-type. This permits to analyze how the global pattern of value added trade is affected by moving to a counterfactual equilibrium with liberalized trade. Our results strongly suggest that counterfactual analysis in a structural model rather than reduced form gravity-type estimations should be used to assess the impact of trade cost, trade policy, and other variables typically appearing in standard gravity equations on value added trade.

We apply our methodology to the case of China's entry into the WTO which constituted a major shock to global trade in 2001. We estimate the model's structural parameters, calibrate it to the year 2000 using the World Input-Output Database, and then simulate China's WTO entry by changing its inward and outward tariffs to the post entry level of 2007.

We find that the tariff changes associated with China's WTO entry spurred production fragmentation, explaining about 7 percent of the decline in the world value added export to gross export ratio observed between 2000 and 2007. Moreover, we find that China's WTO accession was the driving force behind the strengthening of supply and demand networks with its neighbors and also significantly shaped its value added trade relationship with the United States. China gained in importance as a location for processing value added into final goods for almost all countries and particularly so for the nearby Asian economies, which could, at the same time, foster their positions as major sources of foreign value added in China's final goods production. China and its neighboring countries experienced significant welfare gains, notwithstanding the substantial decrease in tariff income. We find no evidence for negative welfare consequences for the United States; in fact, only a few countries, primarily European, appear to have been marginally adversely affected.

References

Aichele, Rahel and Inga Heiland, "Gravity and Value Added Trade," Technical Report, mimeo 2016.

Alvarez, Fernando and Robert Jr. Lucas, "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade," *Journal of Monetary Economics*, 2007, *54* (6), 1726–1768.

Anderson, James E. and Eric van Wincoop, "Gravity with Gravitas: A Solution to the Border Puzzle," *American Economic Review*, 2003, *93* (1), 170–192.

Antrás, Pol and Davin Chor, "Organizing the Global Value Chain," *Econometrica*, 2013, *81* (6), 2127–2204.

Autor, David H., David Dorn, and Gordon H. Hanson, "The China Syndrome: Local Labor Market Effects of Import Competition in the United States," *American Economic Review*, 2013, *103* (6), 2121–68.

Baldwin, Richard and Anthony J. Venables, "Spiders and Snakes: Offshoring and Agglomeration in the Global Economy," *Journal of International Economics*, 2013, *90* (2), 245–254.

_ and Javier Lopez-Gonzalez, "Supply-chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses," *The World Economy*, 2015, *38* (11), 1682–1721.

Bems, Rudolfs and Robert C. Johnson, "Value-Added Exchange Rates," NBER Working Paper No. 18498, National Bureau of Economic Research 2012.

_ , _ , and Kei-Mu Yi, "Vertical Linkages and the Collapse of Global Trade," *American Economic Review, Papers & Proceedings*, 2011, *101* (3), 308–312.

Bénassy-Quéré, Agnès, Yvan Decreux, Lionel Fontagné, and David Khoudour-Casteras, "Economic Crisis and Global Supply Chains," CEPII Working Paper No. 2009-15, Centre d'Etudes Prospectives et d'Informations Internationales 2009.

Bergstrand, Jeffrey H., Peter Egger, and Mario Larch, "Gravity Redux: Estimation of Gravity-Equation Coefficients, Elasticities of Substitution, and General Equilibrium Comparative Statics under Asymmetric Bilateral Trade Costs," *Journal of International Economics*, 2013, *89* (1), 110–121.

Brandt, Loren, Johannes van Biesebrock, Luhang Wang, and Yifan Zhang, "WTO Accession and Performance of Chinese Manufacturing Firms," 2015. unpublished manuscript.

Caliendo, Lorenzo and Fernando Parro, "Estimates of the Trade and Welfare Effects of NAFTA," *The Review of Economic Studies*, 2015, *82* (1), 1–44.

Costinot, Arnaud and Andres Rodriguez-Clare, "Trade Theory with Numbers: Quantifying the Consequences of Globalization," in Gita Gopinath, Elhanan Helpman, and Kenneth Rogoff, eds., *Handbook of International Economics*, Vol. 4 2014, chapter 4, pp. 197–261.

_ , Jonathan Vogel, and Su Wang, "An Elementary Theory of Global Supply Chains," *The Review of Economic Studies*, 2013, *80* (1), 109–144.

Daudin, Guillaume, Christine Rifflart, and Danielle Schweisguth, "Who Produces for Whom in the World Economy?," *Canadian Journal of Economics*, 2011, *44* (4), 1403–1437.

Dean, Judith M., Mary E. Lovely, and Jesse Mora, "Decomposing China-Japan-U.S. Trade: Vertical Specialization, Ownership, and Organizational Form," *Journal of Asian Economics*, 2009, *20* (6), 596 – 610. China, Japan, and the United States: Deeper Economic Integration.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum, "Unbalanced Trade," *The American Economic Review*, 2007, *97* (2), 351–355.

_ , _ , and _ , "Global Rebalancing with Gravity: Measuring the Burden of Adjustment," *IMF Staff Papers*, 2008, *55* (3), 511–540.

di Giovanni, Julian and Andrei A. Levchenko, "Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement," *American Economic Journal: Macroeconomics*, 2010, *2* (2), 95–124.

_ , _ , and Jing Zhang, "The Global Welfare Impact of China: Trade Integration and Technological Change," *American Economic Journal: Macroeconomics*, 2014, *6* (3), 153–83.

Eaton, Jonathan and Samuel Kortum, "Technology, Geography, and Trade," *Econometrica*, 2002, *70* (5), 1741–1779.

Egger, Peter and Mario Larch, "An Assessment of the Europe Agreements' Effects on Bilateral Trade, GDP, and Welfare," *European Economic Review*, 2011, *55* (2), 263–279.

_ , _ , and Kevin E Staub, "Trade Preferences and Bilateral Trade in Goods and Services: A Structural Approach," CEPR Discussion Papers 9051, CEPR 2012.

—, —, Kevin E. Staub, and Rainer Winkelmann, "The Trade Effects of Endogenous Preferential Trade Agreements," *American Economic Journal: Economic Policy*, 2011, *3* (3), 113–43.

Ghosh, Madanmohan and Someshwar Rao, "Chinese Accession to the WTO: Economic Implications for China, Other Asian and North American Economies," *Journal of Policy Modeling*, 2010, *32* (3), 389–398.

Greaney, Theresa M. and Yao Li, "Assessing foreign direct investment relationships between China, Japan, and the United States," *Journal of Asian Economics*, 2009, *20* (6), 611 – 625. China, Japan, and the United States: Deeper Economic Integration.

Grossman, Gene M. and Esteban Rossi-Hansberg, "Trading Tasks: A Simple Theory of Offshoring," *American Economic Review*, 2008, *98* (5), 1978–97.

Helpman, Elhanan, "Trade, FDI, and the Organization of Firms," *Journal of Economic Literature*, September 2006, *44* (3), 589–630.

Hsieh, Chang-Tai and Ralph Ossa, "A Global View of Productivity Growth in China," *Journal of International Economics*, 2016, *Forthcoming.*

Hummels, David, Jun Ishii, and Kei-Mu Yi, "The Nature and Growth of Vertical Specialization in World Trade," *Journal of International Economics*, 2001, *54* (1), 75–96.

Johnson, Robert C. and Guillermo Noguera, "Accounting for Intermediates: Production Sharing and Trade in value Added," *Journal of International Economics*, 2012, *86* (2), 224–236.

— and —, "Proximity and Production Fragmentation," *American Economic Review*, May 2012, *102* (3), 407–411.

— and —, "Fragmentation and Trade in Value Added over Four Decades," mimeo 2016.

Kee, Hiau Looi and Heiwai Tang, "Domestic Value Added in Exports: Theory and Firm Evidence from China," *American Economic Review*, June 2016, *106* (6), 1402–36.

Keller, Wolfgang and Stephen Ross Yeaple, "The Gravity of Knowledge," *American Economic Review*, 2013, *103* (4), 1414–44.

Koopman, Robert, Zhi Wang, and Shang-Jin Wei, "Estimating domestic content in exports when processing trade is pervasive," *Journal of Development Economics*, 2012, *99* (1), 178 – 189.

— , — , and — , "Tracing Value-Added and Double Counting in Gross Exports," *American Economic Review*, 2014, *104* (2), 459–94.

Linden, Greg, Kenneth L. Kraemer, and Jason Dedrick, "Who Captures Value in a Global Innovation Network?: The Case of Apple's iPod," *Communications of the ACM*, 2009, *52* (3), 140–144.

Mattoo, Aaditya, "China's Accession to the WTO: The Services Dimension," *Journal of International Economic Law*, 2003, *6* (2), 299–339.

Noguera, Guillermo, "Trade Costs and Gravity for Gross and Value Added Trade," manuscript, Columbia University 2012.

Timmer, Marcel P., "The World Input-Output Database (WIOD): Contents, Sources and Methods," WIOD working paper No. 10 2012.

Trefler, Daniel and Susan Chun Zhu, "The Structure of Factor Content Predictions," *Journal of International Economics*, 2010, *82* (2), 195–207.

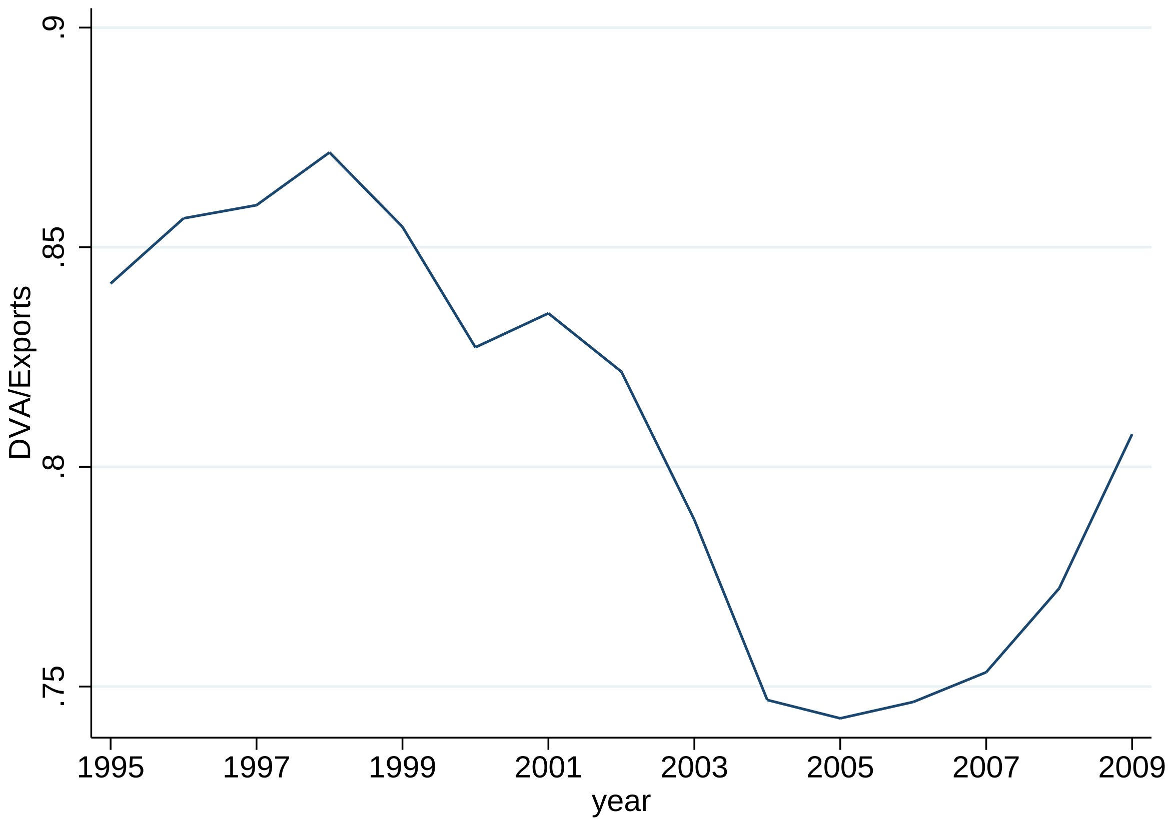
Wang, Zhi, Shang-Jin Wei, and Kunfu Zhu, "Quantifying International Production Sharing at the Bilateral and Sector Levels," Working Paper 19677, National Bureau of Economic Research November 2013.

Xing, Yuqing and Neal Detert, "How the iPhone Widens the United States Trade Deficit with the People's Republic of China," ADBI Working Papers No. 257, Asian Development Bank Institute 2010.

Yi, Kei-Mu, "Can Vertical Specialization Explain the Growth of World Trade?," *Journal of Political Economy*, 2003, *111* (1), 52–102.

— , "Can Multistage Production Explain the Home Bias in Trade?," *The American Economic Review*, 2010, *100* (1), 364–393.

Figure 13: Share of domestic value added in total exports (DVAR), China 1995-2009



Note: The figure plots changes in the domestic value added in total exports (DVAR), where DVAR includes returned and double counted domestic value added.