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# Where's the value added? China's WTO entry, trade and value chains\*

Rahel Aichele $^{\dagger \ddagger}$  and Inga Heiland $^{\dagger}$ 

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#### Abstract

In the 2000s, China's WTO entry constituted a major trade shock. In this paper, we analyze its effects on trade and value chains. The fragmentation of the global value chain makes it hard to disentangle who produces for whom. Value added trade contains this information. We build a multi-sector gravity model of the Eaton and Kortum (2002) type with inter-sectoral linkages that gives rise to a gravity equation for value added trade flows. As in Koopman et al. (forthcoming), exports can be decomposed into value added exports, exports of foreign value added and double counting. We construct a panel database of value added trade for 40 countries and the years 1995-2009 from the World Input-Output database. With WIOD and tariff data, we estimate the gravity model's key parameters. The simulation then hypothetically sets tariffs w.r.t. China back to their pre-accession levels. We find that China's WTO entry strengthend the Asian production network. Chinese value added in exports reduced and increasingly foreign value added – most prominently from Japan and Korea – is assembled and exported.

JEL Classification: F13, F14, F17

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## 1 Introduction

The global value chain is increasingly fragmented into production stages across countries. Input trade—or vertical trade—is surging. Intermediate goods are "double-counted" as they cross borders several times embodied in upstream goods. This implies that gross export flows do not accurately measure the value added a country transfers to a trade partner. In a case study, Xing and Detert (2010) document that only about 4% of the value of an iPhone assembled in China and exported to the US is Chinese value added. Linden et al. (2009) come to similar results for the iPod. With macro data, Johnson and Noguera (2012a) estimate that the bilateral trade deficit of the US with China is by about 30-40% smaller when measured in value added. China assembles goods—especially in the electronics industry—with US knowledge/patents and intermediate inputs from Japan and Korea and often adds little value on its own. On the world level, the ratio of exports measured in gross terms to value added terms has dramatically declined.

The fragmentation of the global value chain makes it increasingly hard to track who produces for whom. This in turn makes it difficult to disentangle the effects of trade liberalization on the global value chain. In this paper, we want to address the question how trade liberalization has shaped the global value chain.

To do so, we look at a major trade shock in the 2000s: China's WTO entry. Value added trade contains information to evaluate effects of trade liberalization along the value chain. Therefore, we use a gravity model that features multiple sectors and input-output linkages to formulate an expression for value added trade. As in Koopman et al. (forthcoming), exports can be decomposed into value added exports, exports of foreign value added and double counting. Therefore, we can evaluate changes in the production fragmentation due to the trade shock. We use the model's structure to predict how trade and value added trade would have looked like if the tariff level with respect to China would have stayed at its pre-accession level. We find that China's WTO entry increased the level of production fragmentation at the world level. It also strengthend the Asian production network. Chinese value added in exports reduced and increasingly foreign value added – most prominently from Japan and Korea – is assembled and exported.

The trade literature offer theories on the formation of global value chains. Costinot et al. (2013) develop a model where the production process constitutes of sequentiel stages. A country's likelihood to make mistakes determines its position in the global value chain: the lower the probability of mistakes the more downstream are the production stages it performs. Antràs and Chor (forthcoming) develop a model with final goods producers and suppliers and sequential production and investigate how incomplete contractual relationships influence the organization of the global value chain. They also develop measures for an industry's position in the value chain.

An increasing body of literature documents value added trade flows (see e.g. Johnson and Noguera, 2012a; Baldwin and Lopez-Gonzalez, 2013). (Hummels et al., 2001; Daudin et al., 2011; Johnson and Noguera, 2012a) develop measures of the degree of vertical specialization. Data on the value added of trade between countries also provides a new perspective on revealed comparative advantage (Koopman et al., forthcoming), exchange rates (Bems and Johnson, 2012), business cycle comovements (Giovanni and Levchenko, 2010), the elasticity of trade with respect to tariff cuts (Yi, 2003) or the home bias in trade (Yi, 2010). It also provides an explanation why—during the financial crisis of 2008 and 2009—trade collapsed relatively stronger than GDP (Bems et al., 2011; Bénassy-Quéré et al., 2009).

Johnson and Noguera (2012b) and Johnson and Noguera (2012c) provide first empirical evidence on how the global value chain reacts to changes in trade costs. They study the effects of distance and FTA formation on trade in value added with a gravity equation. However, due to third country effects these estimates have to be interpreted with care. As we show with our model, value added of one country reaches the final consumer in another country via all other countries. Trade liberalization may lead to trade diversion and shock the whole global value chain. Consequently, it requires structural estimation and simulation to evaluate how trade liberalization affects who produces for whom.

Our paper is related to structural gravity applications. To take into account general equilibrium effects of trade liberalization, this strand of literature resorts to counterfactual policy experiments, typically evolving around effects of trade cost changes on (gross) trade patterns and welfare in general equilibrium. Several studies investigate the effects of abolishing the Canada-US border (see, for example Anderson and van Wincoop, 2003; Bergstrand et al., 2013). Other studies simulate the gains from trade of trade liberalization (see for example Eaton and Kortum, 2002) or free trade agreement (FTA) formation (Egger et al., 2011; Egger and Larch, 2011) or deal with the role of trade imbalances for welfare (Dekle et al., 2007). However, only Caliendo and Parro (2012) introduce input-output linkages in a multi-sector Eaton and Kortum (2002)-type gravity model. They provide a new method to identify the main model parameter – the dispersion of productivities within sectors – and simulate the welfare effects of tariff cuts in the wake of the North American free trade agreement (NAFTA) formation. Yet, they do not provide an explicit formulation of value added trade. Costinot and Rodríguez-Clare (forthcoming) evaluate the welfare implications of trade liberalization in different formulations of the gravity model (one vs. multi-sector, input-output linkages, homogenous vs. heterogeneous firms etc.). We contribute to the literature by explicitly investigating value added trade and the global value chain.

The paper procedes as follows. Chapter 2 uses the Caliendo and Parro (2012) gravity model with input-output linkages to derive an expression for value added trade. We show how trade liberalization affects gross exports and value added trade differently. While the trade elasticity is governed by a sector's productivity dispersion, the effect on bilateral value added trade depends on changes along the entirity of the global value chain. Exports are also decomposed into different value added parts as well as double counting. Chapter 3 explains how we identify the models key parameters, namely value added and input-output coefficients as well as a sectoral measure of productivity dispersion. Chapter 4 describes features of our data on bilateral (sectoral) value added trade for 40 countries over the period 1995-2009 and discusses the estimated model parameters. In Chapter 5 we present results from a simulation of China's WTO entry.

## 2 Trade in value added: a gravity model

In this chapter, we use the Caliendo and Parro (2012) multi-sector gravity model with input-output linkages to develop a formulation for bilateral value added trade flows.

#### 2.1 Consumption and production

There are N countries indexed by i, n and J sectors indexed by j, k. The representative consumer's utility over final goods consumption  $C_n^j$  follows Cobb-Douglas preferences, with  $\alpha_n^j$  denoting sectoral expenditure shares

$$u(C_n) = \prod_{j=1}^J C_n^{j \alpha_n^j}.$$
(1)

Household income  $I_n$  comprises wage income and lump-sum tariff rebates. The labor force  $L_n$  of a country is mobile across sectors, i.e.  $L_n = \sum_{j=1}^J L_n^j$ , but not between countries.

In each sector j, a continuum of goods  $\omega^j$  is produced with labor  $l_n^j(\omega^j)$  and a composite intermediate input  $m_n^{k,j}(\omega^j)$  of each source sector k according to the following production function:

$$q_n^j(\omega^j) = x_n^j(\omega^j)^{-\theta^j} \left[ l_n^j(\omega^j) \right]^{\beta_n^j} \left[ \prod_{k=1}^J m_n^{k,j}(\omega^j)^{\gamma_n^{k,j}} \right]^{(1-\beta_n^j)}, \tag{2}$$

where  $\beta_n^j \ge 0$  is the value added share in sector j in country n and  $\gamma_n^{k,j}$  denotes the cost share of source sector k in sector j's intermediate costs, with  $\sum_{k=1}^{J} \gamma_n^{k,j} = 1$ . It implies sectors are interrelated because sector j uses sector k's output as intermediate input, and vice versa.  $x_n^j(\omega^j)$  is the inverse efficiency of good  $\omega^j$  in sector j and country n.  $\theta^j$  describes the dispersion of efficiencies in a sector j. A higher  $\theta^j$  implies higher dispersion of productivities across goods  $\omega^j$ . The dual cost  $c_n^j$  of an input bundle depends on a country's wage rate  $w_n$  and the price of the composite intermediate goods k country n has to pay

$$c_n^j = \Upsilon_n^j w_n^{\beta_n^j} \left[ \prod_{k=1}^J p_n^{k \gamma_n^{k,j}} \right]^{(1-\beta_n^j)}, \qquad (3)$$

where  $\Upsilon_n^j$  is a constant. Note that sectoral goods  $\omega^j$  only differ in their efficiency  $x_n^j(\omega^j)$ . Consequently, we re-label goods with  $x_n^j$ .

Let  $\kappa_{in}^{j}$  denote trade costs of delivering good j from country i to country n. They 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 unit costs

$$p_{in}^j(x_i^j) = \kappa_{in}^j \left[ x_i^j \right]^{\theta^j} c_i^j.$$

$$\tag{4}$$

Label a particular intermediate good with the vector of efficiencies  $x^j = (x_1^j, \ldots, x_N^j)$ . Country *n* searches across all countries for the supplier with the lowest costs. Consequently, the price *n* pays for good  $x^j$  is

$$p_n^j(x^j) = \min_i \left\{ p_{in}^j(x_i^j); i = 1, \dots, N \right\}.$$
 (5)

Comparative advantage is introduced by assuming that countries differ in their productivity across sectors. The set of goods a country produces follows an exponential cumulative distribution function. The distribution of productivities is assumed to be independent across countries, sectors, and goods. The joint density of  $x^{j}$  is

$$\phi^{j}(x^{j}) = \left(\prod_{n=1}^{N} \lambda_{n}^{j}\right) \exp\left\{-\sum_{n=1}^{N} \lambda_{n}^{j} x_{n}^{j}\right\},\tag{6}$$

where  $\lambda_n^j$  shifts the location of the distribution, and thus, measures absolute advantage.

The composite intermediate good  $q_n^j$  in each sector j is produced with a Dixit-Stiglitz CES technology. Let  $\eta^j$  denote the elasticity of substitution and  $r_n^j(x^j)$  the demand for intermediate good  $x^j$ . The sum of costs for all intermediate goods  $x^j$  are minimized subject to

$$\left[\int r_n^j(x^j)^{\frac{\eta^j-1}{\eta^j}}\phi^j(x^j)dx^j\right]^{\frac{\eta^j}{\eta^j-1}} \ge q_n^j.$$

$$\tag{7}$$

As usual, demand for  $x^j$  depends on the variety's price relative to the sectoral price index  $p_n^j = \left[\int p_n^j (x^j)^{(1-\eta^j)} \phi^j (x^j) dx^j\right]^{\frac{1}{1-\eta^j}}:$ 

$$r_n^j(x^j) = \left(\frac{p_n^j(x^j)}{p_n^j}\right)^{-\eta^j} q_n^j.$$
(8)

Note that  $r_n^j(x^j)$  is the demand for intermediates of n from the respective lowest cost supplier of  $x^j$ . The composite intermediate good  $q_n^j$  is either used to produce intermediate input of each sector k or to produce the final consumption good.

#### 2.2 Gross exports

Solving for the distribution of prices and integrating over the sets of goods where each country i is the lowest cost supplier to country n, we get the price of the composite intermediate good

$$p_n^j = A^j \left( \sum_{i=1}^N \lambda_i^j \left( c_i^j \kappa_{in}^j \right)^{\frac{-1}{\theta^j}} \right)^{-\theta^j}, \qquad (9)$$

where  $A^j = \Gamma \left[1 + \theta(1 - \eta_j)\right]^{\frac{1}{1 - \eta_j}}$  is a constant. Prices are correlated across all sectors (via  $c_i^j$ ). The strength of the correlation depends on the coefficients of the input-output table  $\gamma_n^{k,j}$ .

Similarly, a country n's expenditure share  $\pi_{in}^{j}$  for source country i's goods in sector j is

$$\pi_{in}^{j} = \frac{\lambda_{i}^{j} \left[c_{i}^{j} \kappa_{in}^{j}\right]^{\frac{-1}{\theta^{j}}}}{\sum_{i=1}^{N} \lambda_{i}^{j} \left[c_{i}^{j} \kappa_{in}^{j}\right]^{\frac{-1}{\theta^{j}}}}.$$
(10)

These shares apply to gross exports. Hence, gross exports follow the usual gravity equation. In the following, we provide an expression for value added trade.

#### 2.3 Value added trade

As in Johnson and Noguera (2012a), we need information on bilateral final goods exports, the world input-output table and labor requirements in all countries and sectors to compute value added trade flows between *i* and *n*. Final consumption in sector *j* is  $C_n^j = \frac{\alpha_n^j I_n}{p_n^j}$ . As established above, a fraction  $\pi_{hn}^j$  of this consumption is imported from country *h*. So the FOB value of bilateral final goods imports of *n* stemming from *h* are

$$C_{hn}^{j} = \frac{\pi_{hn}^{j}}{(1+\tau_{hn}^{j})} p_{n}^{j} C_{n}^{j} = \frac{\lambda_{h}^{j} \left[ c_{h}^{j} \kappa_{hn}^{j} \right]^{\frac{-1}{\theta^{j}}}}{(1+\tau_{hn}^{j}) \sum_{h=1}^{N} \lambda_{h}^{j} \left[ c_{h}^{j} \kappa_{hn}^{j} \right]^{\frac{-1}{\theta^{j}}}} \alpha_{n}^{j} I_{n}.$$
 (11)

The value added coefficient  $V_i^j(x_i^j) = \frac{l_i^j(x_i^j)w_i}{(x_i^j)^{\theta^j}c_i^j}$  in the production of good  $x^j$  in country i follows from Shepard's lemma

$$V_i^j(x_i^j) = \left(x_i^j\right)^{\theta^j} \frac{\partial c_i^j}{\partial w_i} \frac{w_i}{\left(x_i^j\right)^{\theta^j} c_i^j} = \beta_i^j = V_i^j.$$
(12)

and is independent of inefficiency. Similarly, we can derive input-output coefficients, i.e. the cost share of sector j in country i for the composite intermediate k

$$a_i^{k,j} = \frac{\partial c_i^j}{\partial p_i^k} \frac{p_i^k}{c_i^j} = (1 - \beta_i^j) \gamma_i^{k,j}.$$
(13)

This expression does not yet take into account that the composite k is produced from varieties of each country h. Using the proportionality assumption, we can derive bilateral

input-output coefficients  $a_{hi}^{k,j}$  (in FOB values)<sup>4</sup> as

$$a_{hi}^{k,j} = \frac{\pi_{hi}^k}{(1+\tau_{hi}^k)} a_i^{k,j} = \frac{(1-\beta_i^j)\gamma_i^{k,j}\lambda_h^k \left[c_h^k \kappa_{hi}^k\right]^{\frac{-1}{\theta^k}}}{(1+\tau_{hi}^j)\sum_{h=1}^N \lambda_h^k \left[c_h^k \kappa_{hi}^k\right]^{\frac{-1}{\theta^k}}}.$$
(14)

We can collect all bilateral input-output coefficients in a  $NJ \times NJ$  world input-output table **A**. Input coefficients are arranged in  $N \times N$  submatrices of dimension  $J \times J$ , each of which comprises the cross-sectoral relationships of a country pair, i.e. we write

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

Note that within each submatrix the row index k of  $a_{in}^{k,j}$  corresponds to the supply sector and the column index j denotes the demanding sector, while the indices i and n of the submatrix denote the source country and destination country, respectively.

Elements  $b_{hi}^{k,j}$  of the Leontief inverse of this matrix, i.e.  $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$ , inform about the fraction sector j in country i requires of inputs produced in country h in sector k in order to produce one dollar of output. **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  $i = 1, \ldots, N$ 

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

 $\mathbf{B} \cdot \mathbf{C_n}$  gives 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  $\sum_{h=1}^{N} \sum_{j=1}^{J} b_{ih}^{j,k} C_{hn}^{j}$ . It

<sup>&</sup>lt;sup>4</sup>Input-output tables are typically given in producer prices. Therefore, we have to adjust from CIF to FOB values by dividing with  $(1 + \tau_{hi}^k)$ .

takes into account that the produced good k can reach n embodied in final goods exports of all countries h in all sectors j.<sup>5</sup> Consequently, the value added generated in a sector kthat flows to country n from country i is

$$VA_{in}^{k} = va_{i}^{k} \sum_{j=1}^{J} \sum_{h=1}^{N} b_{ih}^{k,j} C_{hn}^{j} = \beta_{i}^{k} I_{n} \sum_{j=1}^{J} \alpha_{n}^{j} \sum_{h=1}^{N} b_{ih}^{k,j} \pi_{hn}^{j}$$
(15)  
$$= \beta_{i}^{k} I_{n} \sum_{j=1}^{J} \alpha_{n}^{j} \frac{\sum_{h=1}^{N} b_{ih}^{k,j} \lambda_{h}^{j} \left[ c_{h}^{j} \kappa_{hn}^{j} \right]^{\frac{-1}{\theta_{j}}}}{\sum_{h=1}^{N} \lambda_{h}^{j} \left[ c_{h}^{j} \kappa_{hn}^{j} \right]^{\frac{-1}{\theta_{j}}}}$$
$$= \beta_{i}^{k} I_{n} \sum_{j=1}^{J} \alpha_{n}^{j} \tilde{\phi}_{in}^{k,j},$$
(16)

where  $\tilde{\phi}_{in}^{k,j}$  is the fraction of embodied goods value of source k, i in destination j, n's price index. Let us further distinguish by the sector of final exports j

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

#### 2.4 General equilibrium

Let  $Y_n^j$  denote the value of gross production of varieties in sector j. For each county nand sector j,  $Y_n^j$  has to equal the value of demand for sectoral varieties from all countries

<sup>&</sup>lt;sup>5</sup>Note that it is not possible to find a closed form solution for  $b_{ih}^{j,k}$ .

 $i = 1, \ldots, N.^6$  So, the goods market clearing conditions are given by

$$Y_{n}^{j} = \sum_{i=1}^{N} \sum_{k=1}^{J} \frac{\pi_{ni}^{j}}{(1+\tau_{ni}^{j})} \gamma_{i}^{j,k} (1-\beta_{i}^{k}) Y_{i}^{k} + \sum_{i=1}^{N} \frac{\pi_{ni}^{j}}{(1+\tau_{ni}^{j})} \alpha_{i}^{j} I_{i}$$

$$= \sum_{i=1}^{N} \frac{\pi_{ni}^{j}}{(1+\tau_{ni}^{j})} \left( \sum_{k=1}^{J} \gamma_{i}^{j,k} (1-\beta_{i}^{k}) Y_{i}^{k} + \alpha_{i}^{j} I_{i} \right), \qquad (18)$$

$$= \sum_{i=1}^{N} \frac{\pi_{ni}^{j}}{(1+\tau_{ni}^{j})} X_{i}^{j},$$

where national income consists of labor income, tariff rebates  $R_i$  and the (exogenous) trade surplus  $S_i$ , i.e.  $I_i = w_i L_i + R_i - S_i$  and  $X_i^j$  is country *i*'s expenditure on sector *j* goods. The first term on the right hand side gives demand of sectors *k* in all countries *i* for intermediate usage of sector *j* varieties produced in *n*, the second term final demand. Both intermediate and final demand are divided by  $(1 + \tau_{ni}^j)$  to convert them from CIF to FOB values. 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 that takes into account trade imbalances for each country n. The value of total imports plus the trade surplus has to equal the value of total exports, which is equivalent to GDP  $Y_n$ :

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

$$\sum_{j=1}^{J} X_n^j \sum_{i=1}^{N} \frac{\pi_{in}^j}{(1+\tau_{in}^j)} + S_n = Y_n$$
(19)

<sup>&</sup>lt;sup>6</sup>Our exposition differs from Caliendo and Parro (2012) in that they use total expenditure on composite goods instead of total production of varieties as endogenous variable. So in Caliendo and Parro (2012) the value of gross production comprises all foreign varieties that are bundled into the composite good without generation of value added. The value of production of sectoral varieties seems a more natural choice.

#### 2.5 Value added trade and trade cost changes

In this section, we investigate how changes in trade costs affect value added trade. This motivates our structural approach. For ease of comparison, we can first derive the partial effect of a change in trade cost on bilateral trade shares

$$\frac{\partial X_{in}^{k,j}}{\partial \kappa_{in}^k} = (1 - \beta_n^j) \gamma_n^{k,j} \alpha_n^j I_n \frac{\partial \pi_{in}^k}{\partial \kappa_{in}^k}.$$
(20)

Note that the trade share  $\pi_{in}^k$  depends on  $\kappa_{in}^k$  directly and indirectly through  $c_i^k$  and  $c_h^k \forall h = 1, ..., N$ .

Now, differentiate  $VA_{in}^{k,j}$  with respect to  $\kappa_{in}^{j}$ 

$$\frac{\partial V A_{in}^{k,j}}{\partial \kappa_{in}^k} = \beta_i^k \alpha_n^j I_n \sum_{h=1}^N \frac{\partial (b_{ih}^{k,j} \pi_{hn}^j)}{\partial \kappa_{ni}^k}.$$
(21)

In contrast to bilateral trade flows, value added flows are also affected by the reorganization of the entire global value chain. This finding implies that empirical estimates on the value added trade elasticity depend on which country pairs' trade costs are reduced. However, we can use the structural model as outlined above to predict changes in value added trade from counterfactual trade liberalization scenarios – taking into account changes along the entirity of the global value chain.

#### 2.6 Comparative statics

In this paper, we are interested in the effects of trade liberalization on exports, value added flows and welfare. In particular, our policy experiments will simulate what the world would look like without China's WTO accession. To simulate this trade policy experiments, we change the tariff structure from the currently prevailing level  $\tau$  to a counterfactual level  $\tau'$ . As suggested by Dekle et al. (2008), instead of solving for the new equilibrium one can also solve for the equilibrium changes. This approach has the advantage that we do not need information on, e.g. the level of technological know-how  $\lambda_i^j$ .

Denote with  $\hat{x} \equiv x'/x$  the relative change in a variable x. The equilibrium change in input costs is given by

$$\hat{c}_{n}^{j} = \hat{w}_{n}^{\beta_{n}^{j}} \left( \prod_{k=1}^{J} \left[ \hat{p}_{n}^{k} \right]^{\gamma_{n}^{k,j}} \right)^{1-\beta_{n}^{j}}.$$
(22)

The change in the price index is

$$\hat{p}_{n}^{j} = \left(\sum_{i=1}^{N} \pi_{in}^{j} \left[\hat{\kappa}_{in}^{j} \hat{c}_{i}^{j}\right]^{-1/\theta^{j}}\right)^{-\theta^{j}}.$$
(23)

The change in the bilateral trade shares

$$\hat{\pi}_{in}^j = \left(\frac{\hat{c}_i^j}{\hat{p}_n^j}\kappa_{in}^j\right)^{-1/\theta^j}.$$
(24)

The trade balance is

$$\sum_{j=1}^{J} F_n^{j\prime} X_n^{j\prime} + S_n = \sum_{j=1}^{J} \sum_{i=1}^{N} \frac{\pi_{ni}^{j\prime}}{1 + \tau_{ni}^{j\prime}} X_i^{j\prime},$$
(25)

and the counterfactual expenditure in each country and each sector

$$X_n^{j\prime} = \sum_{k=1}^J \gamma_n^{j,k} (1 - \beta_n^k) \left( \sum_{i=1}^N \frac{\pi_{ni}^{k\,\prime}}{1 + \tau_{ni}^{k\,\prime}} X_i^{k\prime} \right) + \alpha_n^j I_n^{\prime}, \tag{26}$$

where  $F_n^j \equiv \sum_{i=1}^N \frac{\pi_{in}^j}{(1+\tau_{in}^j)}$  and  $I'_n = \hat{w}_n w_n L_n + \sum_{j=1}^J X_n^{j\prime} (1-F_n^{j\prime}) - S_n$ .

This system of equations of equilibrium changes can be solved with a searching algorithm proposed by Alvarez and Lucas (2007) which assumes a seed for the wage change, computes price and trade share changes and the new expenditure levels based on this wage change, then evaluates the trade balance condition to finally update the wage change with a projection until the equilibrium is found.<sup>7</sup>

<sup>&</sup>lt;sup>7</sup>This algorithm is also used by Dekle et al. (2008) and in a multi-sector input-output version by

Once the equilibrium trade share changes are determined, we can compute the counterfactual Leontief inverse, and thus counterfactual bilateral value added flows. The counterfactual input-output coefficients are determined as

$$a_{hi}^{k,j\prime} = \frac{\hat{\pi}_{hi}^k}{\hat{\kappa}_{hi}^k} a_{hi}^{k,j}.$$
 (27)

These can be collected in the counterfactual input-output table  $\mathbf{A}'$ . The counterfactual Leontief inverse is then just  $\mathbf{B}' = (\mathbf{I} - \mathbf{A}')^{-1}$ . Final goods trade in the counterfactual experiment is

$$C_{hn}^{j}{}' = \frac{\hat{\pi}_{hn}^{j} \pi_{hn}^{j}}{(1 + \tau_{hn}^{j}{}')} \alpha_{n}^{j} I_{n}'.$$
(28)

The counterfactual value added flow results as

$$VA_{in}^{k}{}' = \beta_i^k I_n' \sum_{j=1}^J \alpha_n^j \sum_{h=1}^N b_{ih}^{k,j'} \hat{\pi}_{hn}^j \pi_{hn}^j.$$
(29)

This allows us to investigate how trade liberalization affects bilateral value added flows, i.e. the sourcing choice of consumers. In a similar vein, we can also investigate the sourcing choice of producers. Instead of the value added flows behind final consumption, we can also look at the production vector  $Y_n$ . In other words, we can determine how trade liberalization affects to global value chain.

#### 2.7 Decomposition

To get at the effects a trade liberalization has on global value chains, we can decompose the total effect as in Koopman et al. (forthcoming). A country's exports are partly value added exports, partly exports of value added generated in other countries and partly double-counted value added because embodied intermediate goods cross borders several times.

Caliendo and Parro (2012).

$$1 \cdot EX_{i} = \underbrace{V_{i} \sum_{n \neq i}^{N} B_{ii}C_{in} + V_{i} \sum_{n \neq i}^{N} B_{in}C_{nn} + V_{i} \sum_{n \neq i}^{N} \sum_{m \neq i,n}^{N} B_{in}C_{nm}}_{i's \text{ VA consumed in } n \neq i \text{ or passed on to } m \neq i,n}$$

$$+ \underbrace{V_{i} \sum_{n \neq i}^{N} B_{in}C_{ni} + V_{i} \sum_{n \neq i}^{N} B_{in}A_{ni}(I - A_{ii})^{-1}C_{ii}}_{i's \text{ VA returning home}}$$

$$+ \underbrace{\sum_{n \neq i}^{N} \sum_{m \neq i}^{N} V_{m}B_{mi}C_{in} + \sum_{n \neq i}^{N} \sum_{m \neq i}^{N} V_{m}B_{mi}A_{in}(I - A_{nn})^{-1}C_{nn}}_{\text{Foreign VA in } i's \text{ exports}}$$

$$+ \underbrace{V_{i} \sum_{n \neq i}^{N} B_{in}A_{ni}(I - A_{ii})^{-1}EX_{i} + \sum_{m \neq i}^{N} V_{m}B_{mi}A_{in} \sum_{n \neq i}^{N}(I - A_{nn})^{-1}EX_{n},}_{\text{Pure double counting}}$$

where **1** is a unity vector and  $EX_i$  a vector that collects *i*'s sectoral total exports.

The first three terms are *i*'s value added exports to other countries, i.e., value added generated in *i* that is absorbed in other countries  $n \neq i$ . The second line represents value added generated in *i* that first leaves the country in the form of intermediate goods but is eventually re-imported (as final or intermediate good) and absorbed in *i*. These goods flows show up in *i*'s export statistic but they do not constitute value added exports. The third line shows the part of *i*'s exports that is made up of foreign value added in both final and intermediate goods exports. The last line shows value added (originating either in home or in foreign) that appears several times in *i*'s export statistic. It constitutes pure double-counting due to intermediate goods exports that cross *i*'s borders several times embodied in other goods.

This decomposition helps to categorize countries. For countries heavily involved in the global value chain, we expect double-counting to be important. A country's position in the global value chain is indicated by the importance of final in comparison to intermediate value added exports. The higher up a country is in the value chain, the more important should the first term be in comparison to terms 2 and 3. We will later use the decomposition to study the effects of tarif liberalization on production networks and the global value chain.

## **3** Parameter identification

In order to simulate the effects of changes in the tariff scheme, we need to identify the model parameters  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\theta$  and require data on bilateral trade shares, tariff levels as well as countries' total value added and trade surplus. In this section, we describe the identification strategy of these parameters. Due to the Cobb-Douglas utility and production function with constant returns to scale,  $\alpha$ ,  $\beta$  and  $\gamma$  can be computed as expenditure respectively cost shares. In other words, we can impute these parameters directly from the input-output tables.

The sectoral productivity dispersion can be directly identified from the gravity equation: the coefficient of tariffs in the gravity equation is  $1/\theta^j$ , see (10). While tariff data is directly observable, iceberg trade costs are not. In order to estimate (10), the gravity literature typically assumes a functional form of iceberg trade costs based on proxies such as bilateral distance and dummies for contiguity and for whether a country pair is in a free trade agreement (FTA). Therefore, we proceed 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 given in (10) and multiplying by  $X_n^j$ , allows us to formulate the following log-linearized estimable gravity equation for each sector j:

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

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

given by the coefficient on tariffs.

Alternatively, we can identify the sectoral productivity dispersion as suggested by Caliendo and Parro (2012). The idea is to divide a country pair's trade flow with trade flows of other trade partners such that importer, exporter and pair specific symmetric effects cancel each other out. The corresponding estimation equation is

$$\ln \frac{X_{in}^j X_{hi}^j X_{nh}^j}{X_{ni}^j X_{ih}^j X_{hn}^j} = -\frac{1}{\theta^j} \ln \left( \frac{\tau_{in}^j \tau_{hi}^j \tau_{nh}^j}{\tau_{ni}^j \tau_{ih}^j \tau_{hn}^j} \right) + \varepsilon_{inh}^j, \tag{31}$$

where  $\varepsilon_{inh}^{j}$  is an i.i.d. error term. We provide results for both the Caliendo and Parro (2012) estimation methodology and the gravity equation with importer and exporter fixed effects and bilateral trade cost controls.

### 4 The empirical evidence

#### 4.1 Data

We construct value added trade flows by applying (15). That is we need data on final goods trade flows, a world input-output table and value added coefficients. These data are, e.g., provided in the world input-output database (WIOD). It features data for 40 mainly OECD countries for the years 1995-2011 with a sectoral breakdown at the two digit ISIC level, i.e. 35 industries. It contains information on trade levels for all goods, including the services industries. Note that the WIOD does not have information on bilateral input-output coefficients. These are imputed from national input-output tables with the proportionality assumption. Accordingly, a sector's usage of a certain intermediate input is split between trade partners according to their respective import share of the intermediate. See Timmer (2012) for an in-depth description of methods and assumptions used to construct the WIOD. Also note that in the model there exists only one production factor. Consequently, value added is equivalent to labor input. In the WIOD database,

Variable	Observations	Mean	Std.Dev.	Min	Max
Exports (Mio US-\$)	22,230	3,892	13,876	0	428,893
of final goods	$22,\!230$	$1,\!547$	$6,\!175$	0	236,162
of intermediate goods	22,230	$2,\!345$	8,089	0	207, 139
Value added exports (Mio US-\$)	$22,\!230$	2,758	9,911	0.3	323,342
FTA dummy $(0,1)$	$22,\!230$	.528	.499	0	1
Distance (km)	22,230	4,971	$4,\!459$	60	$18,\!550$
Contiguity $(0,1)$	22,230	.061	.239	0	1

Table 1: Summary statistics

Note: The table provides summary statistics for dependent and independent variables averaged over the years 1995 to 2009.

the value added coefficient captures labor as well as capital services.<sup>8</sup>

Data on bilateral tariff levels for manufacturing sectors is taken from the UNCTAD's TRAINS database.<sup>9</sup> It provides effective applied tariffs at the 6 digit level of the Harmonized System goods classification. We aggregate this data to the WIOD sectoral level with import value weights. Information on tariff levels for service sectors is not available.

Bilateral distance and a dummy for contiguity are obtained from the CEPII distance database. The FTA dummy is constructed from the WTO homepage.

Table 1 provides summary statistics for all variables. The average bilateral export value amounts to about 4,000 US-\$. Intermediate goods trade constitutes about two thirds of trade flows. Bilateral value added exports are on average smaller than gross exports. In about 50% of all observations, trade partners are in a FTA. On average, trade partners are 5,000 km apart. 6% of the country pairs share a common border.



Figure 1: Heterogeneity in sectoral value added intensity 2007

Note: The figure shows boxplots of each sector's value added per dollar of output for the year 2011. For each sector, the vertical line within the box gives the median value of the countries' value added intensity, the box shows the range of 50% of the observations, the outer lines depict the 95% range and the dots show outliers.

## 4.2 Model parameters: value added intensity, input-output coefficients, productivity dispersion

Country- and sector-specific parameter values for  $\alpha, \beta$  and  $\gamma$  are taken from the inputoutput tables provided by the WIOD database. Parameter values for sectoral expenditure shares,  $\alpha_i^j$ , are computed as sectoral expenditure for final consumption (summed over all sourcing countries) divided by total expenditure for final consumption. Sectoral value added coefficients,  $\beta_i^j$ , are constructed as value added divided by output value. Figure 1

<sup>&</sup>lt;sup>8</sup>We also construct the high, medium and low skilled contents of trade.

<sup>&</sup>lt;sup>9</sup>The database can be accessed via the World Banks World Integrated Trade Solution (WITS) project, https://wits.worldbank.org/WITS/WITS/Restricted/Login.aspx?AspxAutoDetectCookieSupport=1.

shows boxplots of each sector's value added intensity. Within a given sector, there is heterogeneity in terms of countries' value added intensity. There is also substantial variation in the value added intensity across sectors. For example, the education sector relies little on intermediate inputs; its median value added intensity is around 80%. On the other end of the spectrum are sectors like "Coke, Refined Petroleum and Nuclear Fuel" or "Transportation equipment" where only around 15 respectively 25% of the output value are attributed to value added. The former sector relies heavily on materials from the mining and quarrying sector such as crude oil while the latter uses intermediate inputs from other manufacturing and service industries. Summarizing, service sectors have a high value added coefficient while manufacturing sectors are at the lower end of the spectrum. Since the bulk of trade is in manufacturing, this observation has important implications. Bilateral trade and value added flows may differ substantially and the value added perspective can contribute to our understanding of the global value chain. The model takes this heterogeneity across sectors and across countries into account by allowing for sector-and country-specific value added coefficients  $\beta_i^j$ .

Input-output coefficients,  $\gamma_i^{kj}$ , are obtained by summing a sector j's usage of intermediate inputs from sector k over all countries, and then dividing by sector j's total costs of intermediates. Figure 2 (a) and (b) depict the US and Chinese input-output table for the year 2007, respectively. It shows contour plots of  $(1 - \beta_i^j)\gamma_i^{k,j}$  for all sourcing sectors k, listed on the vertical axis, and all demanding sectors j, listed on the horizontal axis. A darker shade in the contour plot indicates a stronger input-output relationship. Intermediate usage is highest along the diagonal, i.e. for products of the demanding sector's own sector k = j. But some off-diagonal entries also stand out. In the US, many service sectors rely on intermediates from the "Other business activities" sector. All transport sectors have a high usage of products from the "Coke, Refined Petroleum and Nuclear Fuel" sector or machinery and equipment sectors use basic metals as inputs, to give just a few examples. Countries differ in terms of their sourcing structure. The Chinese inputoutput table looks slightly different than the US table, which is most evident for the intermediate inputs of the "Other business activities" and also "Electrical and optical equipment" sectors.

Sectoral productivity dispersions,  $\theta^{j}$ , are identified with a log-linearized cross-sectional gravity equation as given in (31) or (30). Table 2 provides the results. 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 (2012) methodology; in column (2) we drop the 0.5% of observations with the highest tariffs from the sample. Column (3) applies a gravity equation where importer and exporter fixed effects take into account unobserved country-level heterogeneity. The log of distance and dummies for FTAs and contiguity proxy for unobservable bilateral trade costs. Sectors are sorted in descending order of the estimated coefficient on tariffs. The higher  $1/\theta^{j}$ , the smaller the productivity dispersion in the respective sector. The coefficients are fairly stable across the different estimation procedures. As one might expect, "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 rather homogeneous products, and thus have a high estimate of  $1/\theta^{j}$ . At the lower end of the table are sectors like "Transport equipment", and "Manufacturing nec" which provide rather heterogeneous goods. All in all, the sorting of the sectors seems plausible.<sup>10</sup> Also, the order of magnitude of the estimated coefficients seems plausible. In the gravity literature, the estimates typically lie between 2 and 10.

Data on bilateral tariffs is not available for service sectors. Therefore, we cannot apply our estimation strategy for sectors of ISIC chapters E through Q. Instead, we use an average  $1/\theta^j = 5.959$  for all service sectors taken from Egger et al. (2012).

<sup>&</sup>lt;sup>10</sup>The estimates indicate that the agricultural sector has a rather high productivity disperion. This is unexpected. However, given that this sector aggregates agriculture, hunting, forestry and fishing, this might be due to an aggregation bias.



Figure 2: The US and Chinese input-output table 2007

Note: The figure shows the contour plot of input-output coefficients,  $\gamma_i^{kj}$ , for (a) the USA and (b) China for the year 2007. The sourcing sectors k are listed on the vertical axis, while the demanding sectors j are listed on the horizontal axis. Input-output coefficients range from 0 to 0.8, where a darker shade indicates a stronger input-output relation.

		(1)	(2)	(3)		
ISIC Rev. 3	Sector	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)		
$\mathbf{C}$	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***		
	U	(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***		
	C C	(0.1579)	(0.1621)	(0.6876)		
# Observatio	ns	1 146 618	1 126 494	93 691		
# Exporters/	# Importers	212/120	212/120	212/120		
"- Exporters/	// importons	212/120	<u>414/140</u>	<u> </u>		

Table 2: Gravity estimates of sectoral dispersion parameter

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 (31), column (3) applies the gravity equation with importer and exporter fixed effects (FE) and controls for bilateral trade costs given in (30). Column (2) drops the 0.5% highest tariff outliers from the sample. Sectors are sorted in descending order of the estimated coefficient in column (2). Standard errors (in parantheses) are heteroskedasticity-robust. \*, \*\* and \*\*\* indicate statistical significance at the 10, 5 and 1% level, respectively.

# 5 China's WTO accession: Effects on the global value chain

#### 5.1 Counterfactual experiment

China's accession to the World Trade Organization (WTO) in 2001 constituted a major trade shock. It is widely thought that it lastingly changed the global sourcing structure. Most notably is the evolution of an Asian production network in which Japan and Korea and other Asian countries supply intermediates to China which then assembles those intermediate inputs to final goods and exports them, in particular to the USA but also to the EU. The upper panel of Figure 3 shows the US trade balance with China. During the whole period 1995 to 2009, the US was running a trade deficit with China. With China's accession to the WTO, the US trade deficit with China strongly increased. Starting at about 0.5% of US GDP in 2001, US net imports from China almost quadrupled to 2% of US GDP in the year 2007. However, the increase of value added transfers from China to the US was much less pronounced. In the same time period, they increased from around 0.5% of US GDP to 1.5% only. This implies that the US trade deficit with China is overstated considerably when measured in gross instead of in value added terms. In 2007, e.g., the bilateral trade deficit would have been around 20% smaller in value added terms. At the same time, Japan lost trade to the US but indirect exports to the US (in value added terms) have increased relativ to direct trade, see the lower panel in Figure 3. In value added terms, the US trade deficit is understated by around 35% in 2007.

These observations lead us to simulate a multilateral trade liberalization scenario: namely China's accession to the WTO. Can this policy experiment explain the observed divergence of the US-China trade deficit when measured with gross and value added exports. Is the evolution of the Asian production network an effect of China's WTO accession? Who actually produces for the US market after the trade liberalization?



Figure 3: US trade deficit with China and Japan: net exports vs. net value added flows (a) US-China

Note: The figure shows the evolution of US net exports (dark blue bars) and net value added exports (light blue bars) to China (upper panel) and Japan (lower panel) as a share of US GDP for the period 1995-2009. It also shows the adjustment of the US trade deficit with both countries when measured from a value added instead of gross trade perspective (orange line, right scale).

ISIC	Sector	$\hat{\tau} - 1$	Std.dev.
		(in %)	
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, 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
С	Mining and Quarrying	-0.8	1.1

Table 3: China's WTO accession: Scope of the policy change

To investigate these questions, we start with the equilibrium observed in 2000 prior to China's accession. We then simulate the effect of the change of China's tariff rates with respect to all other countries going from the level observed in 2000 to the observed level in 2007. Table 3 shows the magnitude of the tariff cuts. On average, there have been considerable tariff cuts, especially in the "Food, beverages and tobacco" and agricultural sector, but also for "Transport equipment", "Manufacturing, nec" and "Electrical and optical equipment". For these sectors, the magnitude of the tariff cuts also vary largely across trade partners. So we do not expect all countries to benefit equally from China's WTO entry. Some countries will gain while others might lose their shares of a bigger pie.

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

#### 5.2 Results: What changed due to China's WTO entry?

The multi-sector input-output gravity model predicts that overall trade increased by around 0.84% due to China's WTO entry, see Table 4. This small total effect masks large heterogeneity in the country-specific responses. Chinese exports increase by 37%, Australian and US exports by 26 and 8%, respectively. For Germany, India and Indonesia, for example, the model predicts a reduction in overall exports. relationships.

Exporter	Change in the share of in exports Ch					
	Value added	Value added	Foreign	Double	Exports	
		re-import	value added	counting		
		(in percentag	ge points)		(in %)	
Luxemburg	3.80	-0.01	0.21	-3.99	122.25	
Latvia	2.24	-0.01	-0.12	-2.12	49.11	
China	-2.09	0.28	0.50	1.31	37.01	
Russia	2.46	-0.03	-0.64	-1.79	34.59	
Australia	-1.30	0.15	0.14	1.01	26.09	
USA	2.12	-0.52	-0.45	-1.15	8.18	
Japan	0.76	-0.04	-0.15	-0.57	7.72	
Korea	0.47	0.02	0.18	-0.67	6.43	
Germany	-0.34	0.06	0.07	0.22	-1.61	
India	0.88	0.01	-0.23	-0.66	-6.01	
Indonesia	-0.27	0.03	0.08	0.16	-6.19	
Finland	-0.75	0.01	0.17	0.57	-6.37	
Irland	-2.49	0.01	0.60	1.89	-15.39	
Rest of World	-4.86	0.36	1.06	3.44	-21.23	
Total	-0.29	0.02	0.10	0.17	0.84	

Table 4: Decomposition of countries' exports

Note: The table shows for selective countries the change in export volumes (in %) and the change in the composition of exports due to China's WTO entry.

What is more, from the simulation, we learn that China's WTO entry led to an increase in the production fragmentation at the world level. The share of value added associated with exports drops by roughly 0.3 percentage points. This drop is most pronounced for China, which faces a reduction of the share of value added exports of 2.1 percentage points. This already indicates China's position as a place of assembly of intermediates from all over the world in the global production chain. This is supported by an increase in the share of foreign value added in Chinese exports of 0.5 percentage points, as well as an increase in double counting of about 1.3 percentage points. We observe the same pattern for many other countries, Germany, Indonesia, and Australia among them. For the US and Japan, the model predicts a different story. The US value added to export ratio actually increases by about 2 percentage points, the Japanese one by 0.8 percentage points. The foreign value added and double counting shares, on the other hand, decrease. To investigate the changes in the global production chain further, we turn to a decomposition of bilateral relationships.

Exporter	Importer	Change in	Change in the share of in exports				
		Exports	١	value added in		value added	Foreign
			final	inter-	re-	re-import	value added
			goods	mediates	exports		
		(in %)		(1	in percent	age points)	
China	USA	6.3	-5.0	-2.1	4.4	29.2	12.0
	World	37.0	-1.8	-3.8	-9.9	39.7	11.7
USA	China	37.1	17.4	-7.0	49.8	-2.9	-19.1
	Japan	5.1	-0.9	<b>3.0</b>	10.0	-1.0	-12.3
	Korea	7.8	-2.3	3.3	8.3	-2.4	-12.4
	World	8.2	0.9	4.9	5.5	-5.1	-11.9
Ianan	China	33.7	1.0	15	36 7	10.0	14.0
Japan		00.1	1.5	-4.0	50.1	10.5	-14.0
	USA	-2.0	0.0	0.6	7.4	5.3	-7.8
	World	7.7	-1.5	2.8	1.1	-2.5	-8.5
Korea	China	36.6	6.6	-5.2	38.3	32.6	-12.9
110100		3.0	0.0	0.5	60	5 5	1 9
	USA	-3.0	-0.4	0.0	0.9	5.5	-1.8
	World	6.4	-1.9	2.0	4.5	5.4	-2.6

Table 5: The Asian production network

Note: The table shows for selective country pairs the change in export volumes (in %) and the change in the composition of exports due to China's WTO entry.

At the bilateral level, the simulation reveals a strengthening of the Asian production network due to China's WTO entry, see Table 5. Japan and Korea export their value added through China and re-import their own value added from China. The same is true for the USA. The share of foreign value added in Chinese exports to the USA increases by 12 percentage points. Also, the Japanese and Korean value added that is absorbed in the USA increasingly stems from Japanese and Korean intermediate exports. This indicates that the intermediates of these countries are assembled in China and exported to the USA. A similar picture is predicted for US value added that is finally absorbed in Japan or Korea.

	Table 0. Onna=05 trade. a sectoral	anarysis	
ISIC	Sector description	Trade share	Value added
		change	share change
		(in %)	(in %)
19	Leather, Leather and Footwear	28.05	36.16
17 + 18	Textiles and Textile Products	16.00	-13.84
$\mathbf{C}$	Mining and Quarrying	10.09	11.92
20	Wood and Products of Wood and Cork	7.84	-27.93
34 + 35	Transport Equipment	6.76	-2.59
30-33	Electrical and Optical Equipment	6.75	-15.28
27 + 28	Basic Metals and Fabricated Metal	6.25	-15.64
A+B	Agriculture, Hunting, Forestry and Fishing	5.17	-2.02
36 + 37	Manufacturing, Nec; Recycling	4.80	-12.74
21 + 22	Pulp, Paper, Paper, Printing and Publishing	4.53	-13.94
29	Machinery, Nec	4.50	-16.40
24	Chemicals and Chemical Products	3.07	-13.09
15 + 16	Food, Beverages and Tobacco	2.24	-3.73
25	Rubber and Plastics	2.20	-19.66
23	Coke, Refined Petroleum and Nuclear Fuel	0.79	-8.42
26	Other Non-Metallic Mineral	-0.77	-30.19

Table 6: China–US trade: a sectoral analysis

Note: The table shows for selective country pairs the change in export volumes (in %) and the change in the composition of exports due to China's WTO entry.

Next, we put some more scrutiny on Chinese exports to the US. In terms of exports, the sectors "Leather and footwear" and "Textiles and textile products" have benefited most from the tariff cuts ensuing China's WTO entry. For these sectors, China could increase its share in US imports by 28 and 16%, respectively. China's share in US imports also picked up in the "Electrical and optical equipment" sector and all other sectors except "Other

non-metallic minerals". However, the picture looks entirely different for Chinese value added generated in a sector which is absorbed in the US. Even though Chinese exports to the US picked up in the "Electrical and optical equipment" sector, for example, the US absorbs relatively less Chinese value added that has been generated in this sector. China's share in US absorption of "Electrical and optical equipment" decreased by 15%. Combining this with the evidence on the bilateral level, it seems plausible that the value added is actually generated in Japan and Korea. Only in the "Leather and footwear" and the "Mining and quarrying" sectors could China increase its share in US value added absorption.

Summarizing, the model predicts an increase in the fragmentation of the global value chain due to China's WTO entry. The ratio of value added to gross exports declines. Maybe not surprisingly, the simulation also indicates that the strengthening of the Asian production network is due to China's WTO entry. Last, simple trade effects often mask underlying effects on the flows of value added. Especially at the sectoral level, we see that while some sectors pick up a lot in the export statistic of a country, the generated value added (and potentially jobs) may acrue to other countries entirely. The multi-sector input-output gravity model augmented with value added trade flows helps to disentangle these effects on global production.

## 6 Conclusion

China's WTO entry constituted a major trade shock. In this paper, we analyze its effects on trade and value chains. Since the fragmentation of the global value chain makes it hard to disentangle who produces for whom, a structural model and simulation will help trace effects along the global value chain. We build a multi-sector gravity model of the Eaton and Kortum (2002) type with inter-sectoral linkages that gives rise to a gravity equation for value added trade flows. As in Koopman et al. (forthcoming), exports can be decomposed into value added exports, exports of foreign value added and double counting. A reduction of the ratio of value added to gross exports indicates an increase in the level of production fragmentation. We construct a panel database of value added trade for 40 countries and the years 1995-2009 from the World Input-Output database. With WIOD and tariff data, we estimate the gravity model's key parameters. The simulation then hypothetically sets tariffs with respect to China back to their pre-accession levels. We find that China's WTO entry strengthend the Asian production network. Chinese value added in exports reduced and increasingly foreign value added – most prominently from Japan and Korea – is assembled and exported.

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## Approximation of Leontief inverse coefficients

Note that closed form expressions for the elements of the Leontief inverse do not exist. Yet, to obtain arbitrarily close approximations we can make use of the fact that it can be written as a geometric series in **A** (see also Trefler and Zhu, 2010). In view of  $\mathbf{B} =$  $(\mathbf{I} - \mathbf{A})^{-1} = \sum_{m=0}^{\infty} \mathbf{A}^m$  we denote by  $\mathbf{B}^{(M)}$  the matrix of approximate Leontief coefficients capturing all direct value flows as well as indirect value flows through third countries and sectors up to the  $M^{\text{th}}$  round. A typical element of  $\mathbf{B}^{(4)}$  denoting net inputs from sector kin country i in country n's output in sector j that has travelled through at most 3 transit countries and all sectors therein is then

$$b_{in}^{k,j} \stackrel{(4)}{=} \mathcal{I}[j = k \wedge n = i] + a_{in}^{k,j} + \sum_{\ell_1=1}^J \sum_{h_1=1}^N a_{ih_1}^{k,\ell_1} a_{h_1n}^{\ell_1,j} + \sum_{\ell_1=1}^J \sum_{h_1=1}^N \sum_{\ell_2=1}^J \sum_{h_2=1}^N a_{ih_2}^{k,\ell_2} a_{h_2h_1}^{\ell_2,\ell_1} a_{h_1n}^{\ell_1,j} + \sum_{\ell_1=1}^J \sum_{h_1=1}^J \sum_{\ell_2=1}^J \sum_{h_2=1}^J a_{ih_2}^{k,\ell_2} a_{h_2h_1}^{\ell_2,\ell_1} a_{h_1n}^{\ell_1,j} + \sum_{\ell_1=1}^J \sum_{h_1=1}^J \sum_{\ell_2=1}^J a_{ih_2}^{k,\ell_2} a_{ih_2}^{\ell_2,\ell_1} a_{h_1n}^{\ell_1,j} + \sum_{\ell_1=1}^J a_{ih_2}^{k,\ell_2} a_{ih_2}^{\ell_2,\ell_1} a_{ih_1n}^{\ell_1,j} + \sum_{\ell_1=1}^J a_{ih_2}^{k,\ell_2} a_{ih_2}^{\ell_2,\ell_1} a_{ih_2}^{\ell_2,\ell_2} a_{ih_2}^{\ell_2,\ell_1} a_{ih_1n}^{\ell_1,j} + \sum_{\ell_1=1}^J a_{ih_2}^{k,\ell_2} a_{ih_2}^{\ell_2,\ell_1} a_{ih_2}^{\ell_2,\ell_1} a_{ih_1n}^{\ell_2,\ell_2} a_{ih_2}^{\ell_2,\ell_1} a_{ih_1n}^{\ell_2,\ell_2} + \sum_{\ell_1=1}^J a_{ih_2}^{\ell_2,\ell_2} a$$

The first term is the direct output from sector k in country i in final consumption of goods in country n's sector k. Note that this term is zero unless the source sector and demanding sector and source country and destination country are identical, i.e. the indicator function takes on a value one only if  $j = k \wedge n = i$ , and zero otherwise. The second component captures the output value from k in i that is embodied in the intermediates consumed by j in n. The third component describes j's demand for composites from other sectors  $\ell_1 = 1, ..., J$  in any country  $h_1 = 1, ..., N$ ,  $a_{h_1,n}^{\ell_1,j}$  and the output from country i's sector k that is embodied, which is  $a_{ih_1^{k,\ell_1}}$ . The third and forth term capture output value from k in i that has travelled through a second, respectively third, transit country  $h_2$  and  $h_3$ and all sectors  $\ell_2, \ell_3$  therein.

Using a third round approximation to the Leontief coefficients we obtain an approxi-

mation for the effect of trade cost changes on bilateral value added flows

$$\frac{\partial V A_{in}^{k,j}}{\partial \kappa_{in}^{k}} \approx \beta_{i}^{k} \alpha_{n}^{j} I_{n} \sum_{h=1}^{N} \left( \mathcal{I}[j=k,h=i] \frac{\partial \pi_{hn}^{j}}{\partial \kappa_{in}^{k}} + (1-\beta_{n}^{j}) \gamma_{n}^{k,j} \frac{\partial (\pi_{ih}^{j} \pi_{hn}^{j})}{\partial \kappa_{in}^{k}} \right. \\
\left. + \sum_{\ell_{1}=1}^{J} \sum_{h_{1}=1}^{N} (1-\beta_{h_{1}}^{\ell_{1}}) \gamma_{h_{1}}^{k,\ell_{1}} (1-\beta_{h}^{j}) \gamma_{h}^{\ell_{1,j}} \frac{\partial (\pi_{ih_{1}}^{\ell_{1}} \pi_{h_{1}h}^{j} \pi_{hn}^{j})}{\partial \kappa_{in}^{k}} \\
\left. + \sum_{\ell_{1}=1}^{J} \sum_{h_{1}=1}^{N} \sum_{\ell_{2}=1}^{J} \sum_{h_{2}=1}^{N} (1-\beta_{h_{2}}^{\ell_{2}}) \gamma_{h_{2}}^{k,\ell_{2}} (1-\beta_{h_{1}}^{\ell_{1}}) \gamma_{h_{1}}^{\ell_{2,\ell_{1}}} (1-\beta_{h}^{j}) \gamma_{h}^{\ell_{1,j}} \frac{\partial (\pi_{ih_{2}}^{\ell_{2}} \pi_{h_{2,h_{1}}}^{\ell_{1}} \pi_{h_{1}h}^{j} \pi_{hn}^{j})}{\partial \kappa_{in}^{k}} \right)$$

$$(32)$$

Note that  $\sum_{h=1}^{N} \mathcal{I}[j=k, h=i] \frac{\partial \pi_{hn}^{j}}{\partial \kappa_{in}^{k}} = \frac{\partial \pi_{in}^{k}}{\partial \kappa_{in}^{k}}$ , hence the first term in parenthesis is equal to partial effect on bilateral trade flows as in (20). n contrast to bilateral trade flows, value added flows are also affected by the reorganization of the entire global value chain. This is reflected in the additional terms and depends on changes in all other bilateral sectoral trade shares. The sign of these terms is ambiguous. Some entries may be positive, but since we also expect some trade diversion we also expect negative entries.