

The US-China Trade War and Global Value Chains*

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Abstract

This paper studies the heterogeneous impacts of the US-China trade war through linkages in global value chains. By building a two-stage, multi-country, multi-sector general equilibrium model, this paper discusses how imports tariffs effect domestic producers through internal linkage within industry and external linkage across industries. The model validates that imports tariffs on Chinese upstream intermediate goods negatively affects US downstream exports, outputs and employment. Effects are strong in the US industries that rely much on targeted Chinese intermediate goods. In addition, this paper differentiates the impacts of the two rounds of the trade war by comparing tariffs on intermediate goods and consumption goods. This paper estimates that the trade war increases US CPI by 0.09% in the first round and 0.22% in the second round. Finally, this paper studies the welfare effects of the trade war. This paper estimates that the trade war costs China \$35.2 billion, or 0.29% GDP, costs US \$15.6 billion, or 0.08% GDP, and benefits Vietnam by \$402.8 million, or 0.18% GDP.

JEL Codes: F00, F1, F6

Keywords: Trade War, Global Value Chain, Vertical specialization, Tariff, Trade Policy

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1 Introduction

Globalization enables countries to specialize in producing at different stages of a final good. For example, an iPhone is designed in the U.S., with its parts made in Japan and finally assembled in China. This fragmentation across national borders is called the global value chain. While global value chains strengthen the connection between countries, they involve massive trade in intermediate goods, which inevitably amplifies the impacts of international trade policies. Consider a final good whose upstream and downstream productions take place in two different countries, when both countries increase tariffs on upstream and downstream outputs against each other, the downstream producers not only confronts impediments to exports but bear expensive upstream intermediate inputs imported from the other country. This paper studies the impacts of the US-China trade war through the linkage in global value chains. According to Hummels et al.(2001), trade in value added indicates how countries are connected through the linkage in global value chains. From 2005 to 2015, the share of China's value added in US exports in all sectors had raised from 0.86% to 1.75%, and the share of China's value added in US exports in manufacturing sector had raised from 1.42% to 2.72%. This trend does not change much when scrutinizing the share of China's value added in US final demand. [Figure 12](#) and [Figure 13](#) in Appendix B display the time series of the share of China's value added in US exports and final demand. Under this tightening linkage between the U.S. and China, especially in manufacturing sector, it is essential to take global value chains into account when analyzing the impacts of the US-China trade war.

Since the Smoot-Hawley Tariff Act in 1930, the US-China trade war has become the biggest trade war in US history. From January 2018 to January 2020, US weighted average tariffs on Chinese exports had increased from 3.1% to 19.3%, and China's weighted average tariffs on US exports had increased from 8.0% to 20.3%. So far, the trade war has affected \$550 billion of Chinese products and \$185 billion of US products. [Figure 1](#) summarizes the timeline of the US-China trade war (Bown, PIIE 2020). In February 2018, as a warm up, the U.S. imposed safeguard tariffs on washing machines of which China accounted for 80% of the imports into the U.S.. In July 2018, the trade war started. According to the US 301

tariff actions, the U.S. imposed 25% tariffs on \$50 billion goods imported from China, with phase one (\$34 billion) implemented on July 6, 2018 and phase two (\$16 billion) implemented on August 23, 2018. By Bown and Kolb (2020), 95% of the goods targeted at this round are intermediate goods, with machinery, electrical machinery and metal being the industries hit the most. As retaliation China imposed 25% tariffs on \$50 billion goods imported from the U.S., mainly including transportation vehicles and agricultural products. In June 2019, the trade war escalated when the U.S. imposed 25% tariffs on \$200 billion goods imported from China. Compared with the initial round, more consumption goods got targeted in this round, which included textiles, food, agricultural products, etc. On the other hand, China imposed 10% – 25% tariffs on \$60 billion goods imported from the U.S.. In September 2019, the trade war continued as the U.S. imposed 15% tariffs on another \$112 billion of Chinese goods, mainly included apparel and footwear. Finally, in January 2020, the two countries suspended the ongoing economic conflict by signing the Phase One trade deal.

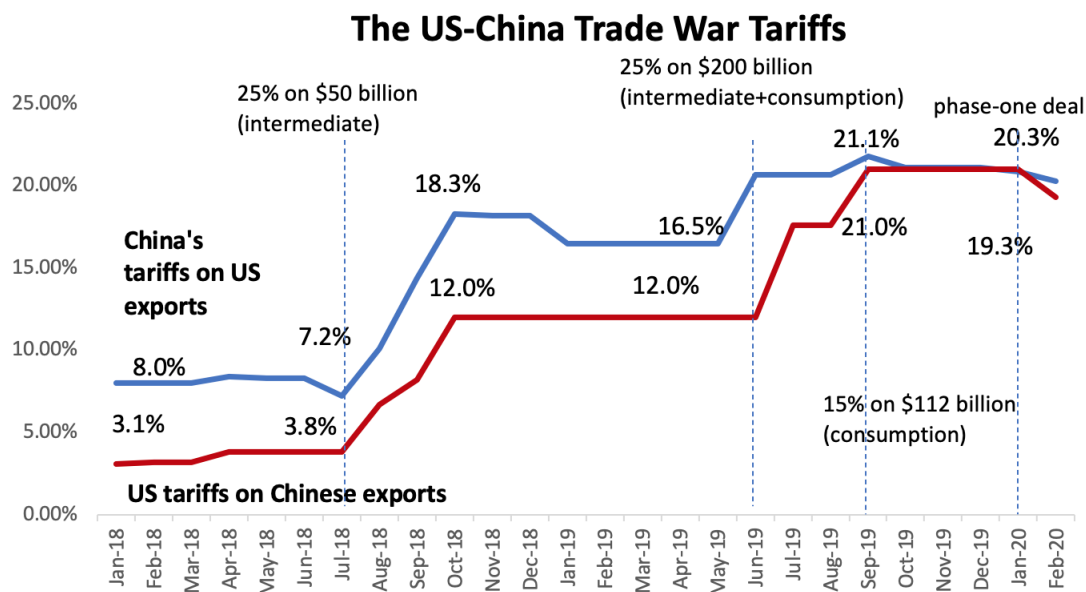


Figure 1: Weighted Average Tariffs (source: Chad Bown, PIIE)

When the U.S. increased tariffs on imports from China, the entire process can be divided into two rounds, with the first round mainly targeting intermediate goods and the second round including more consumption goods. This paper builds a two-stage Eaton-

Kortum model (2002) to differentiate the impacts of the two rounds. By structuring the linkage in global value chains, this paper finds that, in the first round, raising tariffs on intermediate goods from China negatively affects the outputs, employment and exports in US downstream industries. These impacts are especially strong in the US downstream industries that rely much on China for those targeted intermediate inputs. In addition, while the first round negatively impacts US downstream producers, the second round has a stronger effect on US consumers, since the second round directly raises the price of imported consumption goods and generates a bigger increase in consumer price index compared with the first round. Finally, this paper discusses the trade war’s welfare effects on the U.S., China, and the third countries. By calibrating an economy with the U.S., China and Vietnam, this paper estimates that the trade war costs China \$35.2 billion, or 0.29% GDP, costs US \$15.6 billion, or 0.08% GDP, and benefits Vietnam by \$402.8 million, or 0.18% GDP. In the study of the impacts of the US-China trade war, this paper makes a contribution by introducing a multi-country general equilibrium model. Previous research in this field mainly uses reduced-form or partial equilibrium model. Empirically, Handley and Kamal (2020) shows upstream imports tariffs has negative impacts on downstream exports, and Bown et al.(2020) finds upstream imports tariffs has negative impacts on downstream sales and employment. Theoretically, Amiti, Redding and Weinstein (2019) applies a partial equilibrium framework to estimate the impacts of the trade war on the price and welfare in the U.S.. Fajgelbaum et al.(2019) builds a one-country general equilibrium model to study the trade war’s impacts on the U.S.. Because Fajgelbaum et al.(2019) only models the U.S. economy and takes international demand as exogenously given, their framework is unable to measure the trade war’s impacts on other countries. However, this can be done by the multi-country model introduced in this paper.

The model in this paper extends the one-stage production structure in Eaton and Kortum (2002) into a two-stage production structure. The two-stage structure models two types of linkages in global value chains: the internal linkage within each industry and the external linkage across different industries. The most related literature is Antras and de Gortari (2020). They apply a one-sector, multi-stage Eaton Kortum (2002) model to demonstrate

that downstream stage of production is more sensitive to transportation costs. Compared with Antras and de Gortari (2020) this paper makes major contribution in two aspects: i) Adding tariffs. Besides iceberg transportation costs (Antras and de Gortari 2020) which vanish in transit this paper adds tariffs as another source of trade costs. Tariff revenues collected by the government are transferred to the local consumers who then spend on final consumption. Such circulation captures the essence of tariffs and is crucial in evaluating the impacts of the trade war. Simply replacing tariffs by iceberg costs ignores the tariff revenues and overestimates the negative impacts of the trade war. ii) Parameterizing productivity as stage-specific. In Antras and de Gortari (2020) productivity differs depends whether the outputs are used as intermediate goods or final consumption. This parameterization lacks numerical evidence since the Inter-Country Input-Output Table does not present a significant difference between imports share in intermediate and final goods. In this paper productivity differs depending whether the outputs are from the first or the second production stage. Following Antras et al. (2012), this paper divides commodities in each industry into the ones belonging the upstream sub-industries and the ones belonging the downstream sub-industries. The significant difference in the trade flows in upstream and downstream sub-industries provides evidence for differentiating productivity by production stages.

Over the last few years, research in global value chains and trade policy burgeons. Lee and Yi (2018) explains the impacts of reduction in trade costs on labor market through global value chains. Caliendo and Parro (2015) applies a one-stage Ricardian model to estimate the welfare effects of the change in NAFTA tariffs. Flaaen et al. (2020) discusses the production relocation of washing machines after the U.S. imposed antidumping duties against South Korea and China. Other literature in this field focus on firms' decisions about multinational production. Atkeson and Burstein (2010) explains the impacts of reduction in international trade costs on firms' decisions. Antras and Yeaple (2003) explores the behaviors of multinational firms in international trade. Antras et al. (2017) and Antras and Helpman (2006) relate firms' sourcing decisions to firms' productivity and the features of source markets. Ramondo and Rodriguez-Clare (2012) evaluates the gains from multinational production. Ekholm et al.(2003) analyzes the export-platform foreign direct investment, Helpman et al.

(2003) discusses heterogeneous firms' decision in exports and foreign direct investment. Lind and Ramondo (2019) investigates the correlation between countries' productivity and their gains from international trade.

The rest of this paper is structured as follows: Section 2 starts with a one-sector model to introduce the essential features and mechanisms of the two-stage production structure. Section 3 extends the one-sector model to a multi-sector model and characterizes its general equilibrium. This section also explains the one-to-one mapping between the observations from the Inter-Country Input-Output Table and the solutions to the multi-sector model. Section 4 describes the calibration of the multi-sector model and provides numerical evidence for the reasoning of parameterization. Section 5 describes the estimated results of the multi-sector model. Section 6 explores directions for further improvements. Appendix A covers detailed equations that characterize the general equilibrium of the multi-sector model. Appendix B records the estimated parameters of the multi-sector model.

2 One-Sector Economy

To introduce the mechanism of the two-stage production structure, this section presents a one-sector model and characterizes its general equilibrium. The one-sector model helps to understand the multi-sector model in Section 3. Both models share similar features but the one-sector model has a much simpler notation.

2.1 Model

Consider a world with J countries, where population is constant in each country and immigration is not allowed. Each country has one aggregate sector which consists of a unit continuum of final-good varieties indexed by $z \in [0, 1]$. Let \mathcal{J} be the country set. For all $i \in \mathcal{J}$, consumers in country i derive utility from the continuum of final-good varieties, following a CES preference:

$$\max_{\{c_i(z)\}} U_i = \left(\int_0^1 (c_i(z))^{\frac{\sigma-1}{\sigma}} dz \right)^{\sigma/(\sigma-1)} \quad (1)$$

where $c_i(z)$ is the consumption on the final-good variety z , and σ represents the elasticity of substitution. Because labor supply is perfect inelastic, employment equals to population in each country.

Final goods from each variety z are produced through two stages. All the countries are capable of producing at both stages and markets are perfect competitive. In the first stage, goods are produced using labor and composite intermediate goods. That says, when the first stage of z is produced in country i it follows the production function:

$$y_i^1(z) = \frac{1}{a_i^1(z)} L_i^1(z)^{\gamma_i} I_i^1(z)^{1-\gamma_i} \quad (2)$$

where $y_i^1(z)$ is the stage-1 output, $L_i^1(z)$ is the stage-1 labor input and $I_i^1(z)$ is the composite intermediate good used for stage-1 production. Same as the utility function, $I_i^1(z)$ is a CES aggregator of all the final-good varieties. The parameter $a_i^1(z)$ and γ_i represent the unit factor requirement and labor share for the production in the first stage.

In the second stage, goods are produced using labor, composite intermediate goods, and the outputs from the first stage, so when the second stage of z is produced in country i it follows:

$$y_i^2(z) = \left[\frac{1}{a_i^2(z)} L_i^2(z)^{\gamma_i} I_i^2(z)^{1-\gamma_i} \right]^\alpha [x_i^1(z)]^{1-\alpha} \quad (3)$$

where $y_i^2(z)$ is the stage-2 output, $L_i^2(z)$ is the stage-2 labor input, and $I_i^2(z)$ is the composite intermediates used for stage-2 production. Now besides the composite intermediates $I_i^2(z)$, production in this stage also relies on another type of intermediate goods $x_i^1(z)$ which is the output from stage 1. As for the parameters, $a_i^2(z)$ is the unit factor requirement in the second stage, and $\alpha \in [0, 1]$ captures the intensity of the upstream-downstream linkage between stage 1 and stage 2. When α is small it implies stage-2 production relies much on the outputs from stage 1.

This two-stage production keeps the "roundabout" structure in Eaton and Kortum (2002) through the composite intermediate goods I . Notice that for both stages the composite intermediate good follows:

$$I_i(z) = \left(\int_0^1 (x_i^2(z'))^{(\sigma-1)/\sigma} dz' \right)^{\sigma/(\sigma-1)} \quad (4)$$

where $x^2(z)$ is the same type of good as $c(z)$ since they are both the outputs from stage 2. In other words, the stage-2 output from variety z is absorbed in two ways: the consumption $c(z)$ embedded in the utility function U , and the intermediates $x^2(z)$ embedded in the composite intermediate goods I . In the literature $x^2(z)$ is called the "roundabout" intermediate good. Besides the "roundabout" structure this two-stage production also captures the upstream-downstream linkage through another type of intermediate good: $x^1(z)$, the stage-1 output from variety z . In the literature $x^1(z)$ is called the "snake" intermediate good. Notice that $x^2(z)$ can be used in the production of all the varieties, while $x^1(z)$ can only be used in the production of the same variety.

Outputs from both stages are tradable across countries. The bilateral trading between country i and country j involves a trade cost τ_{ij} which consists of an iceberg transportation cost d_{ij} and an ad valorem tariff t_{ij} following:

$$\tau_{ij} = d_{ij}(1 + t_{ij}) \quad (5)$$

where $d_{ij} \geq 1$ is the units of goods shipped from i to deliver 1 unit of good to j , and $t_{ij} \in [0, 1]$ is the ad valorem tariff implemented by j on imports from i .

2.2 Pricing

Although all countries have the technology to produce at both stages, consumers and producers only import from the place offering the lowest price. Let $p_{ji}^1(z)$ be the price of the stage-1 output of z charged by country j in country i . Then the stage-2 producers in country i choose the optimal location to import $x^1(z)$ such that the price of $x^1(z)$ in country i follows:

$$p_i^1(z) = \min_{j \in \mathcal{J}} \{p_{ji}^1(z)\} \quad (6)$$

Similarly, let $p_{ji}(z)$ be the price of the final/stage-2 output z charged by country j in country i . The consumers and producers in country i choose the optimal location to import the final goods $c(z)$ and $x^2(z)$ such that the price of $c(z)$ and $x^2(z)$ in country i follows:

$$p_i(z) = \min_{j \in \mathcal{J}} \{p_{ji}(z)\} \quad (7)$$

Because all the markets are perfect competitive, price charged by country j in country i equals to the costs to produce and deliver 1 unit of goods from country j to country i . Let P_i be the price index of the CES aggregator in country i , and w_i be the wage in country i . The costs v_i of the Cobb-Douglas aggregator $L_i^{\gamma_i} I_i^{1-\gamma_i}$ then becomes $\gamma_i^{-\gamma_i} (1 - \gamma_i)^{\gamma_i-1} w_i^{\gamma_i} P_i^{1-\gamma_i}$. Therefore,

$$p_{ji}^1(z) = a_j^1(z) v_j(z) \tau_{ji} \quad (8)$$

$$p_{ji}(z) = (a_j^2(z) v_j(z))^\alpha p_j^1(z)^{1-\alpha} \tau_{ji} \quad (9)$$

Under this pricing scheme the price of final output z in country i , whether consumed as final consumption or used as roundabout intermediates, embodies the solutions to a series of stage-level cost minimization problems. According to Antras and de Gortari 2020, the solutions to the series stage-level cost minimization problems is equivalent to the solution to one cost minimization problem where the optimal production path is chosen from the possible \mathcal{J}^2 paths to serve final output z in country i . In other words, $p_i(z)$ is a function of production path. Let $l_i(z)$ be a production path to serve z in country i , and $l_i^n(z)$ be the location to produce stage n of z under path $l_i(z)$. For simplicity, z will be omitted in the following notations. The one cost minimization problem of choosing the optimal production path l_i^* then becomes:

$$l_i^* = \arg \min_{l_i \in \mathcal{J}^2} p_i(l_i) = (a_{l_i^2}^2 v_{l_i^2})^\alpha (a_{l_i^1}^1 v_{l_i^1} \tau_{l_i^1 l_i^2})^{1-\alpha} \tau_{l_i^2 i} \quad (10)$$

2.3 Technology

In Eaton and Kortum (2002), where final goods are produced in one-stage roundabout structure, the unit factor requirement a_i in country i follows a Frechet distribution:

$$Pr(a_i \geq a) = \exp\{-a^\theta T_i\} \quad (11)$$

where T_i captures the absolute advantage in country i . When T_i is big it is more likely to take high productivity draw; and θ captures the heterogeneity of productivity within a sector, with lower θ implying stronger heterogeneity and comparative advantage has a stronger force for trade. Because the product of two Frechet distribution is not Frechet, this paper

cannot simply assume that the productivity at each stage follows a Frechet distribution. To overcome this issue, this paper imposes an assumption introduced in Antras and de Gortari (2020): the productivity over a production path follows a Frechet distribution. In the two-stage model, any production path l_i satisfies:

$$Pr[(a_{l_i}^1)^{1-\alpha}(a_{l_i}^2)^\alpha \geq a] = exp\{-a^\theta(T_{l_i}^1)^{1-\alpha}(T_{l_i}^2)^\alpha\} \quad (12)$$

where T_i^n captures the absolute advantage of stage- n production in country i . Notice that one of this paper's contribution is parameterizing T as stage-specific. Section 4 provides numerical evidence for this parameterization. The distribution of the price of the final goods produced under l_i and served in i follows:

$$Pr[p(l_i) \leq p] = 1 - exp\{-p^\theta(T_{l_i}^1((v_{l_i}^1)\tau_{l_i^1 l_i^2})^{-\theta})^{1-\alpha} \times (T_{l_i}^2)^\alpha((v_{l_i}^2)^\alpha \tau_{l_i^2 i})^{-\theta}\} \quad (13)$$

Let p_i be the actual price of final good in country i . Since p_i is the price generated by the lowest-cost production path, p_i is less than or equal to a given price level p unless the price generated by every production path is higher than p . Therefore, p_i follows the distribution:

$$Pr(p_i \leq p) = 1 - \prod_{l_i \in \mathcal{J}^2} [1 - Pr(p(l_i) \leq p)] = 1 - exp\{-p^\theta \Theta_i\} \quad (14)$$

where

$$\Theta_i = \sum_{l_i \in \mathcal{J}^2} ((T_{l_i}^1)((v_{l_i}^1)\tau_{l_i^1 l_i^2})^{-\theta})^{1-\alpha} \times (T_{l_i}^2)^\alpha((v_{l_i}^2)^\alpha \tau_{l_i^2 i})^{-\theta} \quad (15)$$

Under this distribution, the price index of the CES aggregator of final-good varieties in country i satisfies:

$$P_i = \kappa(\Theta_i)^{-1/\theta} \quad (16)$$

where

$$\kappa = [\Gamma(\frac{\theta + 1 - \sigma}{\theta})]^{1/(1-\sigma)} \quad (17)$$

and the probability that production path l_i^* generates the lowest cost to serve final good in country i is derived as:

$$\pi_{l_i^*} = \frac{((T_{l_i^*}^1)((v_{l_i^*}^1)\tau_{l_i^{*1} l_i^{*2}})^{-\theta})^{1-\alpha} \times (T_{l_i^*}^2)^\alpha((v_{l_i^*}^2)^\alpha \tau_{l_i^{*2} i})^{-\theta}}{\Theta_i} \quad (18)$$

which is a function of wages, price indices and trade costs along the production path. Since there is a unit continuum of final-good varieties, $\pi_{l_i^*}$ is also the fraction of final goods purchased by country i that is produced under path l_i^* . Because the price index P_i is independent from the chosen production path, $\pi_{l_i^*}$ can also be interpreted as the share of country i 's final goods expenditure on goods that are produced under path l_i^* .

2.4 General Equilibrium

Compared with Antras and de Gortari (2020) where iceberg transportation cost is the only source of trade cost, this paper makes a major improvement by adding tariffs. Let Tr_i be the total tariff revenue collected by the government in country i . Following the one-sector model, for all $i \in \mathcal{J}$:

$$Tr_i = Tr_i^f + Tr_i^{round} + Tr_i^{snake} \quad (19)$$

where Tr_i^f is the tariff revenue collected from importing final consumption c , Tr_i^{round} is the tariff revenue collected from importing roundabout intermediates x^2 , and Tr_i^{snake} is the tariff revenue collected from importing snake intermediates x^1 . Eventually, Tr_i is transferred to consumers in country i , who maximize the utility under the budget constraint:

$$P_i U_i = w_i L_i + Tr_i \quad (20)$$

Next, let's explain the derivation of the three components of Tr_i . When country i imports a final good from country j , its stage-2 production has to take place in country j . Referring to the notation in Antras and de Gortari (2020), let Λ_{ji}^2 be the set of production paths that serve country i and go through country j at stage 2, that is $\Lambda_{ji}^2 = \{l_i \in \mathcal{J}^2 \mid l_i^2 = j\}$, then the share of country i 's final goods expenditure on goods imported from country j is denoted by $Pr(\Lambda_{ji}^2)$ with $Pr(\Lambda_{ji}^2) = \sum_{l_i \in \Lambda_{ji}^2} \pi_{l_i}$. Since consumers in country i spend $w_i L_i + Tr_i$ on final consumption, the tariff revenue of country i collected from importing final consumption from all over the world becomes:

$$Tr_i^f = \sum_{j \in \mathcal{J}} (w_i L_i + Tr_i) Pr(\Lambda_{ji}^2) \frac{t_{ji}}{1 + t_{ji}} \quad (21)$$

Producers in country i spend $\frac{1-\gamma_i}{\gamma_i}w_iL_i$ on roundabout intermediate goods, so the tariff revenue of country i collected from importing roundabout intermediates from all over the world becomes:

$$Tr_i^{round} = \sum_{j \in \mathcal{J}} \left(\frac{1-\gamma_i}{\gamma_i} w_i L_i \right) Pr(\Lambda_{ji}^2) \frac{t_{ji}}{1+t_{ji}} \quad (22)$$

Let Λ_{hij}^{12} be the set of production paths that serve country j , go through country h at stage 1 and go through country i at stage 2, that is $\Lambda_{hij}^{12} = \{l_j \in \mathcal{J}^2 \mid l_j^1 = h, l_j^2 = i\}$, then the share of country j 's final goods expenditure on goods produced under $l_i \in \Lambda_{hij}^{12}$, denoted by $Pr(\Lambda_{hij}^{12})$, now follows $Pr(\Lambda_{hij}^{12}) = \sum_{l_j \in \Lambda_{hij}^{12}} \pi_{l_j}$. Consumers and producers in country j spend $w_j L_j + Tr_j + \frac{1-\gamma_j}{\gamma_j} w_j L_j$ on final consumption and roundabout intermediates. Of those expenditure a fraction $Pr(\Lambda_{hij}^{12}) \frac{1}{1+t_{ij}} (1-\alpha)$ is paid by country i on importing stage-1 product from country h , so the tariff revenue of country i collected from importing snake intermediates becomes:

$$Tr_i^{snake} = \sum_{j \in \mathcal{J}} \sum_{h \in \mathcal{J}} \left(w_j L_j + Tr_j + \frac{1-\gamma_j}{\gamma_j} w_j L_j \right) Pr(\Lambda_{hij}^{12}) \frac{1}{1+t_{ij}} (1-\alpha) \frac{t_{hi}}{1+t_{hi}} \quad (23)$$

Now let's clarify market clear conditions to close the model. As previously discussed outputs from both stages are tradable across countries, with stage-1 outputs absorbed by snake intermediates, and stage-2/final outputs absorbed by final consumption and roundabout intermediates, so the goods market clear condition for both stages are: $\forall z \in [0, 1]$

$$\sum_{i \in \mathcal{J}} y_i^1(z) = \sum_{i \in \mathcal{J}} x_i^1(z) \quad (24)$$

$$\sum_{i \in \mathcal{J}} y_i^2(z) = \sum_{i \in \mathcal{J}} [c_i(z) + x_i^2(z)] \quad (25)$$

Labor is constant within each country and is not mobile across countries. The wage income of each country equals to its value added for producing at both stages. Recall that country j spends $w_j L_j + Tr_j + \frac{1+\gamma_j}{\gamma_j} w_j L_j$ on final outputs. When country i produces at stage 2 of the final outputs purchased by country j , the share of country i 's value added is $\gamma_i \alpha$. Therefore, excluding tariffs, the wage income actually received by country i for producing at stage 2 of the final outputs purchased by the world is:

$$w_i L_i^2 = \gamma_i \alpha \sum_{j \in \mathcal{J}} \left(w_j L_j + Tr_j + \frac{1+\gamma_j}{\gamma_j} w_j L_j \right) Pr(\Lambda_{ij}^2) \frac{1}{1+t_{ij}} \quad (26)$$

When country i produces at stage 1 of the final outputs purchased by country j , the share of country i 's value added is $\gamma_i(1 - \alpha)$. Excluding tariffs the wage income received by country i for producing at stage 1 of the final outputs purchased by the world follows:

$$w_i L_i^1 = \gamma_i(1 - \alpha) \sum_{j \in \mathcal{J}} \sum_{h \in \mathcal{J}} (w_j L_j + Tr_j + \frac{1 - \gamma_j}{\gamma_j} w_i L_i) Pr(\Lambda_{ihj}^{12}) \frac{1}{(1 + t_{ih})(1 + t_{hj})} \quad (27)$$

The sum of (25) and (26) establishes the labor market condition $\forall i \in \mathcal{J}$:

$$w_i L_i = [\gamma_i \alpha \sum_{j \in \mathcal{J}} (Tr_j + \frac{1}{\gamma_j} w_j L_j) \frac{Pr(\Lambda_{ij}^2)}{1 + t_{ij}}] + [\gamma_i(1 - \alpha) \sum_{j \in \mathcal{J}} \sum_{h \in \mathcal{J}} (Tr_j + \frac{1}{\gamma_j} w_i L_i) \frac{Pr(\Lambda_{ihj}^{12})}{(1 + t_{ih})(1 + t_{hj})}] \quad (28)$$

and the equilibrium wage vector $\mathbf{w} = (w_1, w_2, \dots, w_J)$ is pinned down to solve the system of labor market clear conditions. Recall that the price index vector $\mathbf{P} = (P_1, P_2, \dots, P_J)$ is a function of \mathbf{w} , and the expenditure share π is a closed-form expression of \mathbf{P} and \mathbf{w} . Adopting the algorithm introduced in Alvarez and Lucas (2007), we can solve the general equilibrium.

3 Multi-Sector Economy

This section extends the one-sector model to a multi-sector version, and describes the one-to-one mapping between the model solutions and the observations from the Inter-Country Input Output Table.

3.1 Model

Imagine a world with J countries and S sectors. Immigration is not allowed, but within in each country labor is mobile across sectors. Let \mathcal{S} be the sector set. Each sector consists of a unit continuum of final-good varieties. Consumers in country $i \in \mathcal{J}$ derive utility from final consumption of all sectors, following a Cobb-Douglas preference:

$$\max_{C_{is}} U_i = \prod_{s=1}^S (C_{is})^{b_s} \quad (29)$$

where b_s is the share of final goods expenditure on sector s , and C_{is} is the final consumption of sector s , which is a CES aggregator of the unit continuum of final-good varieties within

this sector:

$$C_{is} = \left(\int_0^1 c_{is}(z)^{(\sigma-1)/\sigma} dz \right)^{\sigma/(\sigma-1)} \quad \forall s \in \mathcal{S} \quad (30)$$

In each sector the production process is similar to that in the one-sector model. When the first stage of final good z in sector s is produced in country i the production follows:

$$y_{is}^1(z) = \frac{1}{a_{is}^1(z)} L_{is}^1(z)^{\gamma_{is}} I_{is}^1(z)^{1-\gamma_{is}} \quad (31)$$

When the second stage of final good z in sector s is produced in country i the production follows:

$$y_{is}^2(z) = \left[\frac{1}{a_{is}^2(z)} L_{is}^2(z)^{\gamma_{is}} I_{is}^2(z)^{1-\gamma_{is}} \right]^{\alpha_s} [x_{is}^1(z)]^{1-\alpha_s} \quad (32)$$

The composite good I_s in both stages is a CES aggregator like the utility function, but the sector expenditure share in I_s is different from the one in the utility function. Let $b_{s'}^s$ be the share of intermediate goods from sector s' that is used to produce intermediate good in sector s . **Figure 2** depicts the production structure in the multi-sector model. In each sector, the shallow blue dot is stage-1 output, and the deep blue dot is stage-2 output. Eventually, stage-2 outputs from all the sectors compose the aggregator, which is the utility function U and the composite intermediate good I .

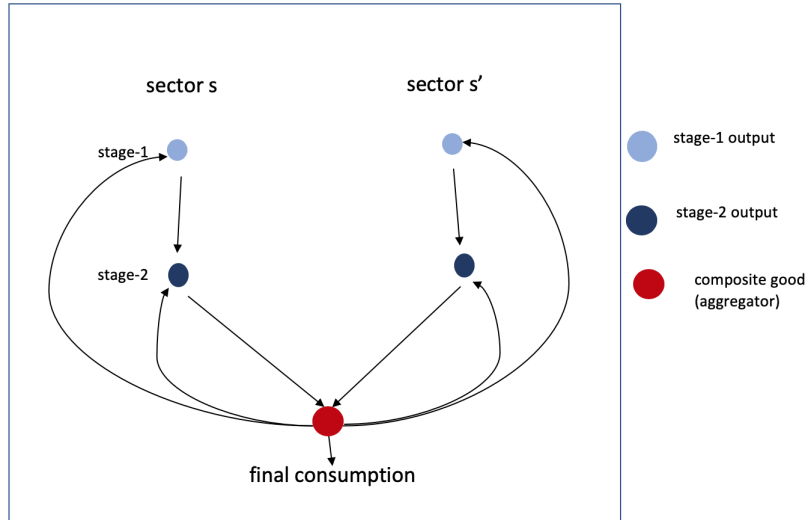


Figure 2: Production Structure in Multi-Sector Model

The productivity of each production path still follows a Frechet distribution which is now on a sector-specific level:

$$Pr[(a_{is}^1)^{(1-\alpha_s)}(a_{js}^2)^{\alpha_s} \geq a] = \exp\{-a^\theta (T_{is}^1)^{(1-\alpha_s)}(T_{js}^2)^{\alpha_s}\} \quad \forall s \in \mathcal{S} \quad (33)$$

Trade cost incorporates iceberg cost and tariff with the tariff being sector and stage-specific:

$$\tau_{ijs}^n = d_{ij}(1 + t_{ijs}^n) \quad (34)$$

By definition t_{ijs}^n means the ad valorem tariff imposed by country j on stage- n , sector s good imported from country i . [Table 1](#) summarizes the parameters and exogenous variables in the multi-sector model.

Like the one-sector model, goods from both stages are imported from wherever offering the lowest price. Following the pricing scheme in Appendix A.2, we derive a closed-form expression for $\pi_{l_{is}^*}$, the sector-specific expenditure share on final goods produced under each production path. That is, of country i 's expenditure on final goods in sector s , $\pi_{l_{is}^*}$ is the share spent on those produced under path l_{is}^* . The explicit expression of $\pi_{l_{is}^*}$ can be found in Appendix A.1.

Parameter	Definition	Specific by
T_{js}^n	productivity	country,sector,stage
γ_{js}	equipped labor share	country,sector
α_s	share of stage2 production in final output	sector
b_s	sector expenditure share of consumption (U)	sector
$b_{s'}^s$	sector expenditure share of intermediate (I)	sector
θ	heterogeneity within sectors	none
Exogenous Variable		
L_i	Population	country
t_{ijs}^n	ad valorem tariff	country,sector,stage

Table 1: Parameters and Exogenous Variables in the Multi-Sector Model

3.2 General Equilibrium

This section characterizes the general equilibrium of the multi-sector model and describes the one-to-one mapping between the solutions to the model and the observations from the Inter-Country Input-Output Table, which is also the main database used for calibration. The Inter-Country Input-Output (ICIO) Table, developed by OECD, captures the industry-level bilateral trade flows. **Figure 3** presents a schematic ICIO Table. The blue and green areas represent the trade flows in intermediate and final goods, with each row corresponding to a source and each column corresponding to a destination. For example, $X_{ijss'}$ is the value of intermediate goods in sector s that are sold by country i and bought by sector s' in country j ; F_{ijs} is the value of final goods in sector s that are sold by country i and bought by country j . Notice that all the trade flows are recorded at basic price which is the price received by the sellers. The purple area represents the tax revenue collected from purchasing intermediate or final goods. For example, Tr_{is} is the tax revenue generated from the purchasing of intermediate goods by sector s in country i ; Tr_i^f is the tax revenue generated from the purchasing of final goods by country i . The red area and the grey area respectively represents the value added and the gross output by each sector in each country.

	Country_i , Sector_s	Country_i , Sector_s'	Country_j , Sector_s	Country_j , Sector_s'	Country_i	Country_j	Gross_Output
Country_i , Sector_s	X_iiss	X_iiss'	X_ijss	X_ijss'	F_iis	F_ijs	Y_is
Country_i , Sector_s'	X_iis's	X_iis's'	X_ij's's	X_ij's's'	F_iis'	F_ijs'	Y_is'
Country_j , Sector_s	X_jiss	X_jiss'	X_jjss	X_jjss'	F_jis	F_jjs	Y_js
Country_j , Sector_s'	X_jis's	X_jis's'	X_jj's's	X_jj's's'	F_jis'	F_jjs'	Y_js'
Tax_Revenue	Tr_is	Tr_is'	Tr_js	Tr_js'	Tr ^f _i	Tr ^f _j	
Value_Added	VA_is	VA_is'	VA_js	VA_js'			
Gross_Output	Y_is	Y_is'	Y_js	Y_js'			

Figure 3: Inter-Country Input-Output Table

The characterization of the general equilibrium is similar to that of the one-sector model. Recall that in each country the tariff revenue Tr_i , eventually transferred to local consumers, equals to the sum of the tariff revenue collected from importing final consumption, roundabout intermediate goods and snake intermediate goods. In the multi-sector model, let Tr_i^f be the tariff revenue generated from country i 's purchasing of final consumption,

Tr_{is}^{round} be the tariff revenue generated from sector s in country i 's purchasing of roundabout intermediate goods, and Tr_{is}^{snake} be sector s in country i 's purchasing of snake intermediate goods. Hence,

$$Tr_i = Tr_i^f + \sum_{s \in \mathcal{S}} Tr_{is}^{round} + \sum_{s \in \mathcal{S}} Tr_{is}^{snake} \quad (35)$$

with each component of the equation explained as follows. Notice that of country i 's expenditure on final consumption $(w_i L_i + Tr_i)$, b_s is the share spent on sector s . Let Λ_{jis}^2 be the set of production paths in sector s that serve country i and pass through country j at stage 2. Then Tr_i^f follows:

$$Tr_i^f = \sum_{s \in \mathcal{S}} \sum_{j \in \mathcal{J}} b_s (w_i L_i + Tr_i) Pr(\Lambda_{jis}^2) \frac{t_{jis}^2}{1 + t_{jis}^2} \quad (36)$$

Of sector s in country i 's expenditure on the roundabout intermediate goods $(\frac{1-\gamma_{is}}{\gamma_{is}} w_i L_{is})$, $b_{s'}^s$ is spent on sector s' , so Tr_{is}^{round} is derived as:

$$Tr_{is}^{round} = \sum_{s' \in \mathcal{S}} \sum_{j \in \mathcal{J}} b_{s'}^s \left(\frac{1-\gamma_{is}}{\gamma_{is}} w_i L_{is} \right) Pr(\Lambda_{jis'}^2) \frac{t_{jis'}^2}{1 + t_{jis'}^2} \quad (37)$$

The expression of Tr_{is}^{snake} is more complicated. When country j spends $w_j L_j + Tr_j$ on final consumption, b_s of the expenditure is on sector s . In addition, country j spends $\sum_{s' \in \mathcal{S}} b_s^{s'} \frac{1-\gamma_{js'}}{\gamma_{js'}} w_j L_{js'}$ on roundabout intermediate goods from sector s . Similar to the derivation of Tr_i^{snake} in the one-sector model, Tr_{is}^{snake} follows:

$$Tr_{is}^{snake} = \sum_{j \in \mathcal{J}} \sum_{h \in \mathcal{J}} [b_s (w_j L_j + Tr_j) + \sum_{s' \in \mathcal{S}} b_s^{s'} \frac{1-\gamma_{js'}}{\gamma_{js'}} w_j L_{js'}] \frac{1}{1 + t_{ijs}^2} (1 - \alpha_s) Pr(\Lambda_{hjs}^{12}) \frac{t_{his}^1}{1 + t_{his}^1} \quad (38)$$

where Λ_{hjs}^{12} is the set of production paths in sector s that serve country j pass through country i at stage 2 and through country h at stage 1. So far all the endogenous variables can be expressed as functions of the exogenous variables and the wage vector. Recall that labor is fixed within a country but mobile across sectors, so the wage vector is adjusted to clear the labor market:

$$L_i = \sum_{s \in \mathcal{S}} \sum_{n=1}^2 L_{is}^n \quad (39)$$

where L_i is the population in country i , and L_{is}^n is country i 's labor demand for producing stage n of final output in sector s . L_{is}^n is pinned down through the value-added equation. Refer to Appendix A.3 for the explicit format of L_{is}^n .

Next let's move on to the mapping between the solutions to the model and the observations from the ICIO Table. In the ICIO Table, Tr_i^f is backed up by the Tr_i^f from the model, Tr_{is} is backed up by the sum of Tr_{is}^{round} and Tr_{is}^{snake} from the model. and VA_{is} is backed up by the product of w_i and L_{is} from the model. As for the bilateral trade flows at basic price, trade flows in final consumption follows:

$$F_{ijs} = b_s(w_j L_j + Tr_j) Pr(\Lambda_{ijs}^2) \frac{1}{1 + t_{ijs}^2} \quad (40)$$

and trade flows in intermediate goods depends on the source and destination sectors. In the case where source and destination sectors are the same, trade in intermediate goods consists of roundabout and snake intermediates:

$$X_{ijss} = X_{ijss}^{round} + X_{ijss}^{snake} \quad (41)$$

In the case where source and destination sectors are different, trade in intermediates goods only includes roundabout intermediates since snake intermediates can only be used in production of same sector:

$$X_{ijss'} = X_{ijss'}^{round} \quad (42)$$

Refer to Appendix A.4 for the explicit expressions of X_{ijss}^{round} and X_{ijss}^{snake} .

4 Calibration

This section describes the calibration of the multi-sector model. The main database used for calibration is the Inter-Country Input-Output (ICIO) Table developed by OECD and the U.S. International Trade in Goods and Services Reports from the United States Census Bureau. This section calibrates an economy in year 2014 with three countries including the U.S., China, and the rest of the world, and eighteen industries composed of an aggregate agriculture sector, an aggregate service sector and sixteen manufacturing industries. These

eighteen industries are regrouped from the thirty-six industries in the original ICIO Table. **Table 2** summarizes the names and the ICIO codes of the eighteen industries. Notice that the ICIO Table codes each industry according to its covered sub-industries' ISIC Rev.4 codes. For example, D10T12 in the ICIO Table includes 10, 11, and 12 in ISIC Rev.4.

Code	Industry
D01T09	Agriculture, forestry, fishing, mining
D10T12	Food products, beverages and tobacco
D13T15	Textiles, wearing apparel, leather and related products
D16	Wood and products of wood and cork
D17T18	Paper products and printing
D19	Coke and refined petroleum products
D20T21	Chemicals and pharmaceutical products
D22	Rubber and plastic products
D23	Other non-metallic mineral products
D24	Basic metals
D25	Fabricated metal products
D26	Computer, electronic and optical products
D27	Electrical equipment
D28	Machinery and equipment
D29	Motor vehicles, trailers and semi-trailers
D30	Other transport equipment
D31T33	Other manufacturing; repair and installation of machinery and equipment
D35T98	Service

Table 2: Codes and Names of the 18 Industries

The value of θ and the calibration of L and γ inherit the ones in Antras and de Gortari (2020). θ , the heterogeneity of productivity within each industry, is set to be 5. L_j , the country-specific equipped labor, equals to $(population_j)^{2/3}(capital_j)^{1/3}$, in which population and capital are obtained from the Penn World Tables. γ_{js} , the country and industry-specific

labor share is calibrated under the method of moments to target $\frac{VA_{js}}{GO_{js}}$, where the value added VA , and gross output GO can be found in the last two rows of the ICIO Table. As for b_s the expenditure share of final consumption is measured by each industry's share of the world's final consumption in the ICIO Table, that is $\frac{\sum_{i \in \mathcal{J}} \sum_{j \in \mathcal{J}} F_{ijs}}{\sum_{s' \in \mathcal{S}} \sum_{i \in \mathcal{J}} \sum_{j \in \mathcal{J}} F_{ijs'}}$, and $b_s^{s'}$ the expenditure share of composite intermediate good I is measured by $\frac{\sum_{i \in \mathcal{J}} \sum_{j \in \mathcal{J}} X_{ijs's}}{\sum_{s'' \in \mathcal{S}} \sum_{i \in \mathcal{J}} \sum_{j \in \mathcal{J}} X_{ijs''s}}$. In Appendix B, [Table 7](#) displays the values of γ_{js} and b_s in the economy with three countries and eighteen industries, and [Table 8](#) displays the values of $b_s^{s'}$.

One of this paper's major contributions is the calibration of T which captures the magnitude of productivity and is positively correlated with imports share. In Antras and de Gortari 2020, T varies depending whether the output is used as an intermediate good or final consumption. This parameterization lacks numerical evidence. [Figure 4](#) plots the correlation between China's share of US imports in intermediate goods and final consumptions, with each dot corresponding to an industry. Most industries, except the industry of basic metal (D24), do not deviate much from the 45-degree line, which implies no significant difference between the T of intermediate goods and the T of final consumptions. As an improvement,

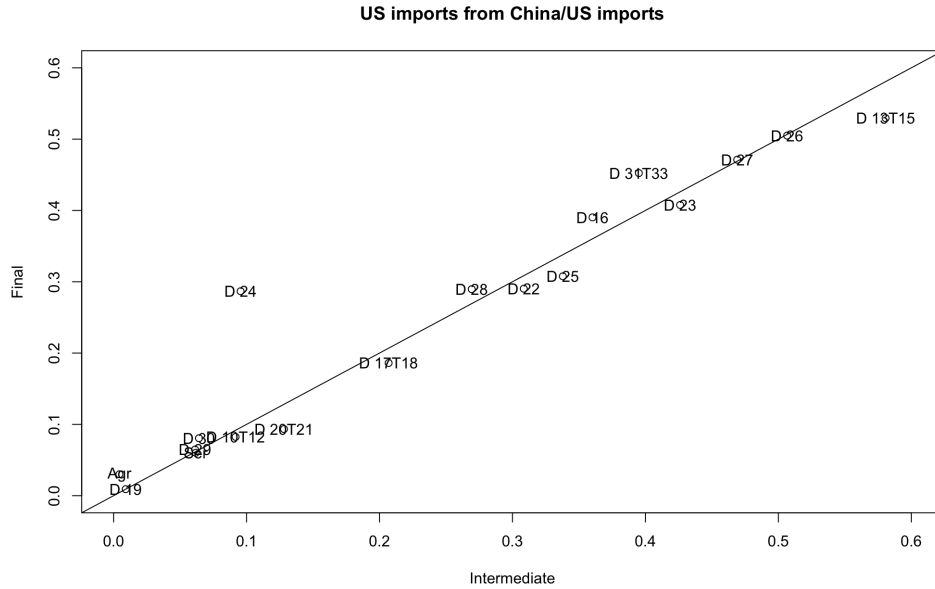


Figure 4: Parameterization of T , Year 2014

this paper parameterizes T as stage-specific and validates the parameterization using the U.S. trade flows in commodities at different production positions of a value chain. To fit the 2-stage production structure in our model, we need a systematic methodology dividing each of the eighteen industries into the upstream and the downstream sub-industries. This paper derives the U.S. trade flows with China and the world in 1046 4-digit HS commodities from the U.S. Census Bureau. Applying the algorithm in Antras et.al 2012, which measures the upstreamness of 426 6-digit Input-Output industries (279 manufacturing industries), this paper sets the upstreamness index to the 1046 4-digit HS commodities depends on the 6-digit Input-Output industry they belong to. Finally, following the concordance between the HS code and the ISIC Rev. 4 code, the 1046 4-digit HS commodities are divided into our eighteen industries. [Table 3](#) gives a glimpse of the 1046 commodities with their codes and upstreamness indices. Notice that bigger upstreamness index implies the commodity is further away from final consumption and is more upstream. By choosing a cut-off upstreamness

Commodity	HS 4-digit	18-industry code	Upstreamness
Meat and Edible Offal Nesoi	0208	D01T09	1.500601
Barley	1003	D01T09	4.230754
Motor Vehicles For Transporting Persons	8703	D29	1.000336
...

Table 3: Upstreamness

index, within each of the eighteen industry commodities are divided into two sub-industries: the upstream and the downstream. Commodities with upstreamness higher than the cut-off are grouped into the upstream sub-industries, and commodities with upstreamness lower than the cut-off are grouped into the downstream sub-industries. This paper chooses the cut-off upstreamness index to be 1.9, considering it is the cut-off maximizing the number of industries that have commodities in both upstream and downstream sub-industries. In other words, a cut-off higher than 1.9 leaves one more industry with all commodities in downstream sub-industry and no commodities in upstream sub-industry; a cut-off lower than 1.9 leaves one more industry with all commodities in upstream sub-industry and no commodi-

ties in downstream sub-industry. **Figure 5** plots the correlation between China's share of US imports in the upstream and the downstream sub-industries of the eighteen industries. Compared with **Figure 4**, the observations in **Figure 5** deviate more away from the 45-degree line, which justifies parameterizing T as stage-specific. Besides, **Figure 5** displays the struc-

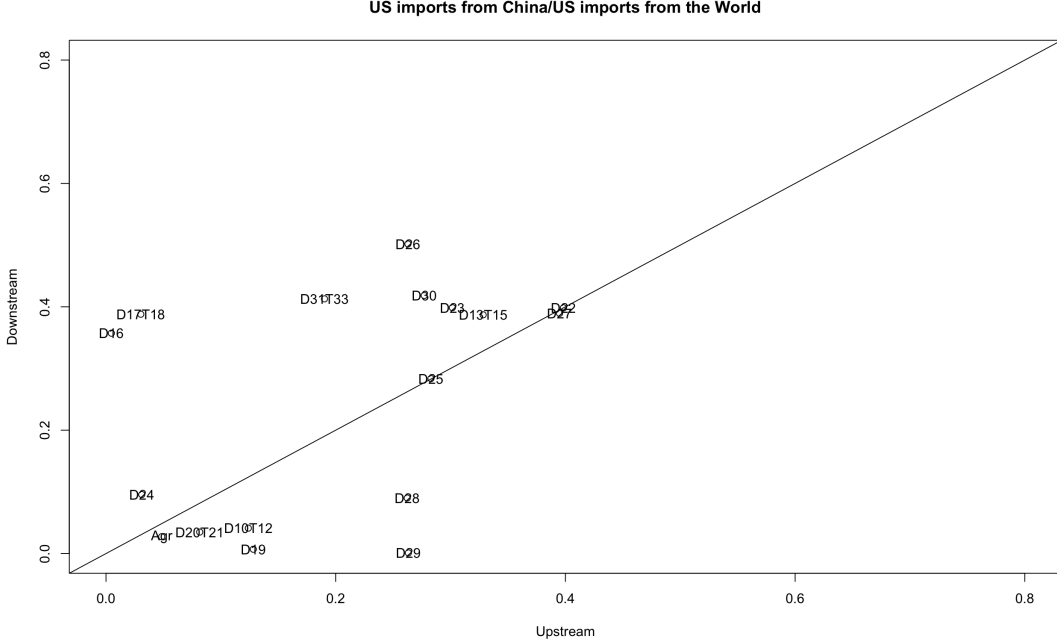


Figure 5: Parameterization of T , Year 2014

ture of US imports from China. For example, in the motor vehicles industry (D29), the U.S. relies much on China for the commodities from the upstream sub-industry but little for the commodities from the downstream sub-industry. In the electrical equipment (D27) industry, the U.S. relies much on China for the commodities from both the upstream sub-industry and the downstream sub-industry. The calibration of T applies the method of moments to target imports share in both stages. Stage-1 outputs in the model correspond to commodities in the upstream sub-industries and stage-2 outputs in the model correspond to the commodities in the downstream sub-industries. To be specific, T_{js}^n is calibrated to target country j 's share in US imports in stage- n outputs of industry s , that is

$$\frac{Imports_{j,us,s}^n}{\sum_{j \in \mathcal{J}} Imports_{j,us,s}^n} \quad (43)$$

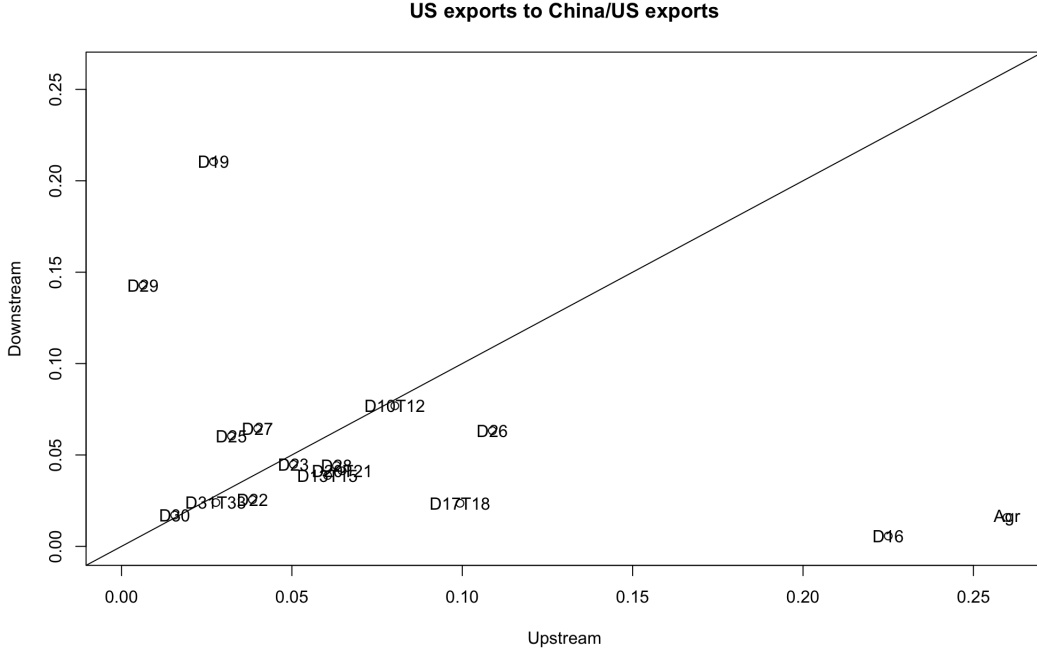


Figure 6: Parameterization of T , Year 2014

A problem arises when it comes to the U.S. imports from itself. Since the U.S. Census Bureau reports the U.S. trade flows with its trading partners, $Imports_{us,us}$ cannot be directly read off from the database. As estimation, $\forall n \in \{1, 2\}$

$$Imports_{us,us,s}^n = \frac{X_{us,us,s} + F_{us,us,s}}{\sum_{j \in \mathcal{J}, j \neq us} (X_{j,us,s} + F_{j,us,s})} \times Imports_{world,us,s}^n \quad (44)$$

where $X_{j,us,s}$, $F_{j,us,s}$ are derived from the ICIO Table, and $Imports_{world,us,s}^n$ is derived from the U.S. Census Bureau. Normalize $T_{us,s}^n$ to be 50 for $n \in \{1, 2\}$ and $s \in \mathcal{S}$. Table 9 in Appendix B displays the value of T in the economy with three countries, and eighteen industries.

Next, α_s is calibrated under the method of moments to target the ratio between the stage-1 outputs in industry s and gross outputs industry s in the U.S.. Let the ratio be R_s

$$R_s = \frac{Output_{us,s}^2}{\sum_{j \in \mathcal{J}} (Output_{us,s}^1 + Output_{us,s}^2)} \quad (45)$$

where

$$Output_s^n = \sum_{j \in \mathcal{J}} Exports_{us,j,s}^n \quad (46)$$

with $Exports_{us,j,s}^n$ read off from the U.S. Census Bureau, and $Exports_{us,us,s}^n$ is same as $Imports_{us,us,s}^n$ in equation (44). Notice that in an industry where all commodities belong to the downstream sub-industry, the value of stage-1 outputs $Output^1$ is zero, so R_s equals to 1 and α_s^2 equals to 1 implying stage-2 production accounts for 100% of stage-2 outputs. On the other hand, in an industry where all commodities belong to the upstream sub-industry, R_s equals to 0.5 and α_s^2 equals to 0 implying stage-2 production accounts for 0% of stage-2 outputs. To understand why R_s equals to 0.5 when α_s^2 is 0, consider when stage-2 production contributes zero to stage-2 outputs the value of stage-2 outputs is same as the value of stage-1 outputs, so the gross outputs in this industry is twice the value of stage-2 outputs. [Table 7](#) in Appendix B displays the value of α in the three-country, eighteen-industry economy, and [Figure 14](#) presents the calibration performance of α .

Finally, iceberg transportation cost d and tariff t are derived from the ICIO Table and the UNCTAD Trade Analysis Information System (TRAINS). According to Head and Ries 2001, bilateral trade costs τ can be pinned down following the gravity equation, and

$$\tau_{ijs} = \left(\frac{\pi_{ijs}^F \pi_{jis}^F}{\pi_{iis}^F \pi_{jjs}^F} \right)^{-\frac{1}{2\theta}} \quad (47)$$

where

$$\pi_{ijs}^F = \frac{F_{ijs}}{\sum_{k \in \mathcal{J}} F_{kjs}} \quad (48)$$

with F_{ijs} read off from the ICIO Table. Recall that trade costs incorporate iceberg transportation costs and tariffs following $\tau_{ijs} = d_{ijs}(1 + t_{ijs})$. t_{ijs} is measured as the simple average of bilateral ad valorem tariffs of the 4-digit HS commodities that belong in industry s . Finally iceberg transportation cost d_{ijs} is backed out by $\frac{\tau_{ijs}}{(1+t_{ijs})}$. To differentiate the impacts of tariff increase in intermediate goods and final goods, this paper models tariff to be stage-specific. For stage $n \in \{1, 2\}$, t_{ijs}^n is measured following the cut-off upstreamness index 1.9.

5 Results

This section describes the estimated results of the multi-sector model. Subsection 5.1 discusses the heterogeneous impacts of the trade war through internal linkages within

industry and external linkages across industries. Subsection 5.2 differentiates the impacts of the two rounds of the trade war on US consumers and producers. Subsection 5.3 explores the welfare effects of the trade war on the U.S., China and the third countries.

5.1 The Heterogeneous Impacts of The US-China Trade War

This subsection discusses the heterogeneous impacts of imports tariffs through two types of linkages in global value chains: internal linkages within industry and external linkage across industries. In the multi-sector model, the "snake" intermediate goods capture the internal linkage by connecting the two production stages within each industry, and the "roundabout" intermediate goods capture the external linkage by connecting the production across different industries.

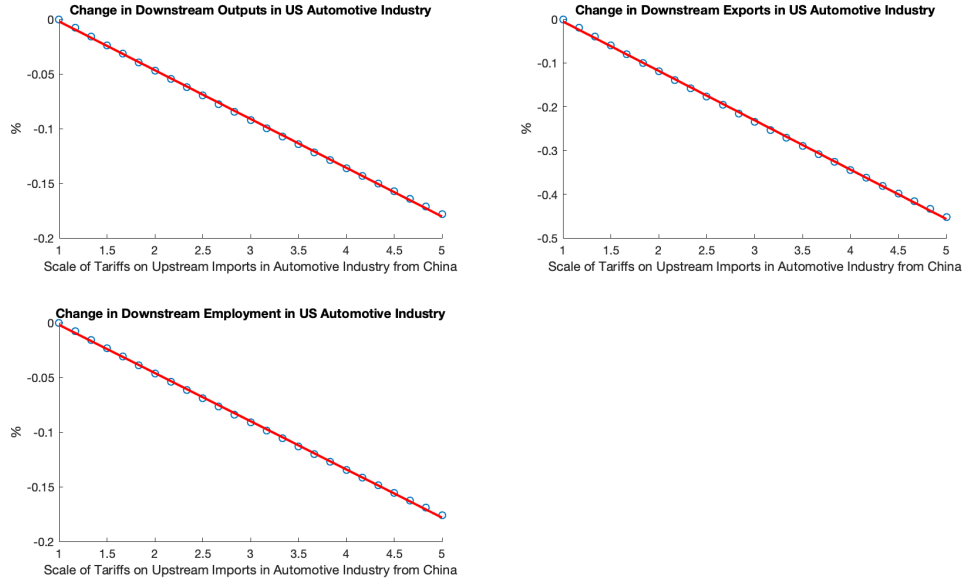


Figure 7: Increase Tariffs on Upstream Imports in Automotive Industry from China

This subsection calibrates an economy with the U.S., China and the rest of the world, and the eighteen industries introduced in Section 4. According to the U.S. section 301 tariffs actions on China, the first round of the trade war mainly targeted intermediate goods and increases the prices of those intermediate goods imported from China. To see the impacts of

imports tariffs through internal linkages, this subsection scales up imports tariffs on products in upstream sub-industries and check the exports, outputs and employment in domestic downstream sub-industries. For example, [Figure 7](#) displays the simulated results that given other tariffs unchanged imports tariffs on Chinese upstream products in automotive industry (D29) negatively effect US exports, outputs and employment in downstream automotive industry. The negative relationships keep the same when checking other industries. In aggregate level [Figure 8](#) scales up tariffs on upstream imports from China in all the eighteen industries. With each dot representing one simulation, both aggregate downstream outputs, downstream exports, and downstream employment in the U.S. decrease as tariffs on upstream imports from China increase. [Table 10](#), [Table 11](#) and [Table 12](#) in Appendix B summarize

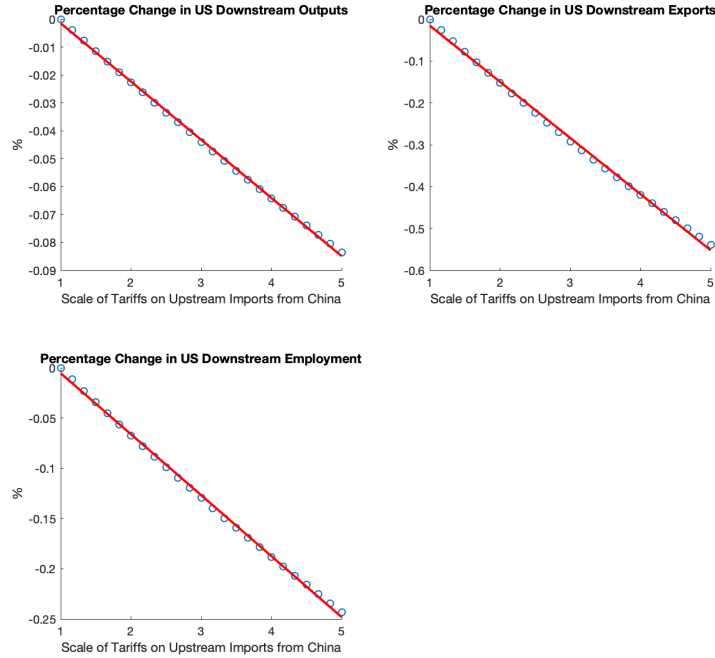


Figure 8: Increase Tariffs on Upstream Imports from China

the regressions of downstream outputs, downstream exports and downstream employment on upstream imports tariffs. Through linkages in global value chains increase in upstream imports tariffs raises up the price and decreases the demand of the downstream outputs produced in the U.S.. The results are in consistent with the observations in Handley and

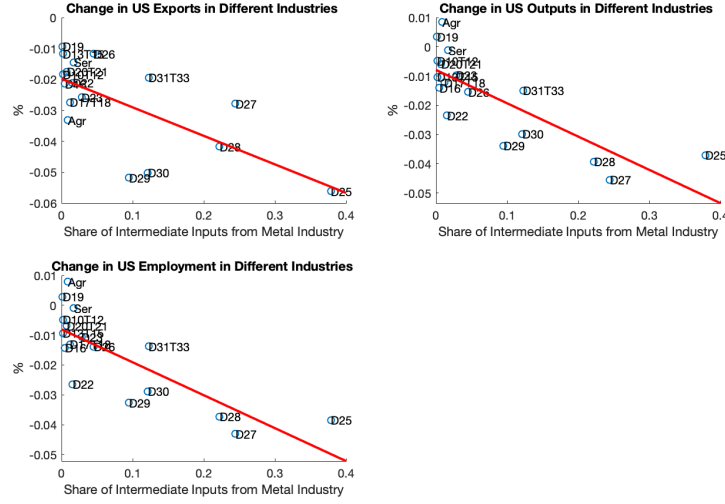


Figure 10: Tariff Increase in Upstream Sub-Industries

5.2 The Two Rounds of the US-China Trade War

When US increases tariffs on Chinese exports, the first round trade war mainly targeted intermediate goods, while the second round added more consumption goods into the list. In order to differentiate the two rounds of the trade war, this subsection first does an counterfactual exercise to study the qualitative results and then simulates the trade war to see the quantitative results. The counterfactual exercise simply mimics the first round trade war by scaling up tariffs on upstream commodities (stage-1 outputs), and mimics the second round trade war by scaling up tariffs on downstream commodities (stage-2 outputs). Although this exercise does not represent the real trade war, it validates the model through its qualitative results. Notice that the two-stage production structure has two types of intermediate goods: the "snake" intermediate goods, which are the stage-1 outputs, and the "roundabout" intermediate goods, which are the stage-2 outputs. Since the "roundabout" intermediate goods and consumption goods are all stage-2 outputs, to better distinguish the two rounds of the trade war, in counterfactual exercise tariffs on intermediate goods particularly means tariffs on the "snake" intermediate goods. Based on the calibration of the eighteen-industry economy, [Table 4](#) compares the estimated results when the U.S. multiplies tariffs on all upstream imports from China by three times (1st round trade war), and when

% change in US	1 st round	2 nd round
price index	0.03%	0.10%
upstream employment	0.01%	−0.04%
upstream outputs	0.01%	−0.08%
downstream employment	−0.13%	0.64%
downstream outputs	−0.04%	0.09%

Table 4: Compare the two rounds trade war

the U.S. multiplies tariffs on all downstream imports from China by three times (2nd round trade war). Although this exercise is not same as the reality, it is effective to assess the impacts of the two rounds trade war on the upstream producers, the downstream producers and the consumers in the U.S.. In [Table 4](#), both rounds raise the consumer price index of the utility aggregator, with the increase in the second round bigger than the increase in the first round. This is because more consumption goods are covered in the second round which got the U.S. consumers more negatively effected through a bigger increment in price level. As for the producers in the U.S., the first round trade war benefits the upstream industries and hurts the downstream industries in terms of outputs and employment. This because, the first round protects the upstream industries in the U.S., but raise the production costs of the downstream industries in the U.S.. On the contrary, the second round trade war benefits the downstream industries and hurts the upstream industries. This is because the second round protects the downstream industries in the U.S., but raise the production costs of the upstream industries in the U.S. since in the model stage-2 outputs are used as "round-about" intermediates in the production of upstream goods. After checking model validity, this subsection quantitatively simulates the two rounds of the trade war by plugging tariff change in HS products. [Table 15](#) in Appendix B summarizes the mainly targeted products in each round the trade war. [Table 5](#) displays the top hit and benefited US industries in each round. For example, in the first round US increased tariffs on Chinese electrical machinery which protects and benefits US electrical machinery industry. One thing to notice is that in

the model labor is mobile across industries, which causes labor to be more elastic to tariff change and amplifies the industry-level impact of the trade war. In addition, the model finds the second round trade war has a greater impact on US consumer price index. The model estimates that the first round increases US CPI by 0.09% and the second round increases US CPI by 0.22%.

Round	Top Hit		Top Benefited	
1 st	Automotive	−2.81%	Electrical Machinery	4.32%
1 st	Agriculture	−0.65%	Machinery	0.58%
2 nd	Chemical	−1.31%	Textile	0.98%
2 nd	Agriculture	−0.32%	Rubber and Plastic	0.05%

Table 5: Two Rounds % Change in US Output

5.3 The Impacts of the US-China Trade War on the Third Countries

As the trade tension between the U.S. and China escalates, countries such as Vietnam benefits from shifts in global value chains. [Figure 11](#) plots the time series of the U.S. goods imports from China and Vietnam. From year 2018 to year 2019, the U.S. goods imports from China plunged \$87.5 billion, while the U.S. goods imports from Vietnam surged \$17.5 billion. To rationalize the observation this subsection calibrates an economy of four countries, which are the U.S., China, Vietnam, and the rest of the world, and two sectors which are goods sector and service sector. Appendix B covers the calibrated parameters. For simplicity, in this four-country, two-sector economy, productivity T is only country and sector specific but not stage-specific. The model estimates that from January 2018 to December 2019 U.S. reduces its goods imports from China by 16.8%, compared with 16.2% from the data, and increases its goods imports from Vietnam by 27.6%, compared with 35.5% from the data. [Table 6](#) summarizes the estimated welfare effect of the trade war. The model estimates that, from January 2018 to December 2019, the trade war costs China \$35.2 billion, or 0.29% GDP in

VNM	0.18
CHN	−0.32
USA	−0.08
ROW	0.03

Table 6: % Change in GDP

2017, costs US \$15.6 billion, or 0.08% GDP in 2017, and benefits Vietnam by \$402.8 million, or 0.18% GDP in 2017.

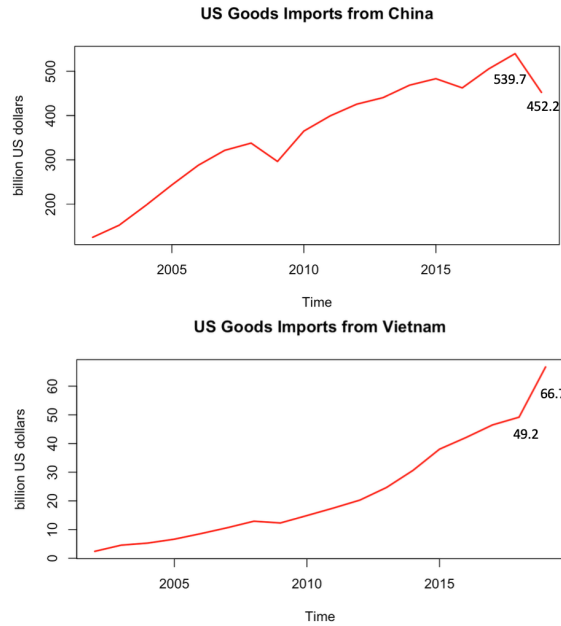


Figure 11: US goods imports from China and Vietnam

6 Conclusion

This paper studies the heterogeneous impacts of the US-China trade war through linkages in global value chains. By building a two-stage Eaton-Kortum model this paper finds that increasing tariffs on intermediate goods from China especially hits the US industries that rely much on the targeted Chinese intermediate goods. The model justifies the observations in Handley and Kamal (2020), and Bown et al. (2020) that upstream imports

tariffs have negative effects on downstream exports, outputs and employments. This paper also differentiates the impacts of the two rounds of the trade war by comparing tariff increase in intermediate goods and consumption goods. This paper finds tariff increase in intermediate goods benefits the domestic industries that produce the targeted intermediate goods but hit the domestic industries that rely on the targeted intermediate goods. In addition, compared with tariff increase in intermediate goods, tariff increase in consumption goods causes a bigger raise in domestic consumer price index. Finally, this paper estimates the welfare effects of the trade war by calibrating an economy with the U.S., China and Vietnam. The model estimates that the trade war hurts China and the U.S., while benefits Vietnam .

One possible extension of the model is making labor fixed within each industry, which better depicts the reality and can be effective in scrutinizing the impacts of trade policies on industry-level employment. Future research in global value chains may explore the factors that determine a country's position in global value chains, and how production position is related to its corresponding value added.

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A Appendix

A.1 Closed-Form Expression for $\pi_{l_{is}^*}$

let $l_{is}^{*1} = j$, $l_{is}^{*2} = k$

$$\pi_{l_{is}^*} = \frac{(T_{js}^1(v_{js}\tau_{jks}^1)^{-\theta})^{1-\alpha_s} \times (T_{ks}^2)^{\alpha_s}(v_{ks}^{\alpha_s}\tau_{kis}^2)^{-\theta}}{\Theta_{is}} \quad (49)$$

where

$$\Theta_{is} = \sum_{l'_{is} \in \mathcal{J}^2} (T_{j's}^1(v_{j's}\tau_{j'k's}^1)^{-\theta})^{1-\alpha_s} \times (T_{k's}^2)^{\alpha_s}(v_{k's}^{\alpha_s}\tau_{k'j's}^2)^{-\theta} \quad (50)$$

and

$$v_{is} = \gamma_{is}^{-\gamma_{is}}(1 - \gamma_{is})^{\gamma_{is}-1} w_i^{\gamma_{is}} P_{is}^{1-\gamma_{is}} \quad (51)$$

A.2 Pricing in Multi-Sector Model

The price of final good z in sector s in country i is a function of production path l_{is}^* :

$$p_{is}(z) = p_{is}(l_{is}^*) \quad (52)$$

l_{is}^* is chosen to solve the cost minimization problem:

$$l_{is}^* = \arg \min_{l_{is} \in \mathcal{J}^2} p_{is}(l_{is}) \quad (53)$$

Let Q_{is} be the price index of aggregator C_{is} :

$$Q_{is} = (\int_0^1 p_{is}(z)^{1-\sigma} dz)^{\frac{1}{1-\sigma}} \quad (54)$$

$$Q_{is} = \kappa(\Theta_{is})^{-1/\theta} \quad \text{where} \quad \kappa = [\Gamma(\frac{\theta+1-\sigma}{\theta})]^{1/(1-\sigma)} \quad (55)$$

Let P_i be the price index of aggregator U_i :

$$P_i = \prod_{s=1}^S (\frac{Q_{is}}{b_s})^{b_s} \quad (56)$$

Let P_{is} be the price index of aggregator I_{is} :

$$P_{is} = \prod_{s'=1}^S (\frac{Q_{is'}}{b_{s'}^s})^{b_{s'}^s} \quad (57)$$

A.3 Market Clear Conditions

Goods Market:

\forall stage $n \in \{1, 2\}$

$$I_{is}^n(z) = \prod_{s'=1}^S (M_{is'}^n(z))^{b_{s'}^s} \quad (58)$$

where

$$M_{is'}^n(z) = \left(\int_0^1 (x_{is'}^2(z'))^{(\sigma-1)/\sigma} dz' \right)^{\sigma/(\sigma-1)} \quad (59)$$

Like the one-sector economy, $\forall s \in \mathcal{S}$ and $\forall z \in [0, 1]$ stage-1 outputs are absorbed by snake intermediates:

$$\sum_{i \in \mathcal{I}} y_{is}^1(z) = \sum_{i \in \mathcal{I}} x_{is}^1(z) \quad (60)$$

and stage-2 outputs are absorbed by final consumption and roundabout intermediates:

$$\sum_{i \in \mathcal{I}} y_{is}^2(z) = \sum_{i \in \mathcal{I}} [c_{is}(z) + x_{is}^2(z)] \quad (61)$$

Notice that snake intermediates x^1 are inputs for producing final goods in the same sector, while roundabout intermediates x^2 are inputs for producing final goods in all the sectors.

Labor Market Clear:

\forall stage $n \in \{1, 2\}$, $\forall s \in \mathcal{S}$

$$L_i = \sum_{s \in \mathcal{S}} \sum_{n=1}^2 L_{is}^n \quad (62)$$

where

$$L_{is}^2 = \frac{\gamma_{is}}{w_i} \sum_{j \in \mathcal{J}} [b_s(w_j L_j + Tr_j) + \sum_{s' \in \mathcal{S}} b_s^{s'} \frac{1 - \gamma_{js'}}{\gamma_{js'}} w_j L_{js'}] \alpha_s Pr(\Lambda_{ijs}^2) \frac{1}{1 + t_{ijs}^2} \quad (63)$$

and

$$L_{is}^1 = \frac{\gamma_{is}}{w_i} \sum_{j \in \mathcal{J}} \sum_{h \in \mathcal{J}} [b_s(w_j L_j + Tr_j) + \sum_{s' \in \mathcal{S}} b_s^{s'} \frac{1 - \gamma_{js'}}{\gamma_{js'}} w_j L_{js'}] (1 - \alpha_s) Pr(\Lambda_{hij}^{12}) \frac{1}{(1 + t_{his}^1)(1 + t_{ijs}^2)} \quad (64)$$

A.4 Bilateral Trade Flows

$$F_{ijs} = b_s(w_j L_j + Tr_j) Pr(\Lambda_{ijs}^2) \frac{1}{1 + t_{ijs}^2} \quad (65)$$

$$X_{ijss} = X_{ijss}^{round} + X_{ijss}^{snake} \quad (66)$$

$$X_{ijss'} = X_{ijss'}^{round} \quad (67)$$

where

$$X_{ijss'}^{round} = b_s^{s'} \left(\frac{1 - \gamma_{js'}}{\gamma_{js'}} w_j L_{js'} \right) Pr(\Lambda_{ijs}^2) \frac{1}{1 + t_{ijs}^2} \quad (68)$$

$$X_{ijs}^{snake} = \sum_{k \in \mathcal{J}} [b_s(w_k L_k + Tr_k) + \sum_{s' \in \mathcal{S}} b_s^{s'} \frac{1 - \gamma_{ks'}}{\gamma_{ks'}} w_k L_{ks'}] (1 - \alpha_s) Pr(\Lambda_{ijks}^{12}) \frac{1}{(1 + t_{ijs}^1)(1 + t_{jks}^2)} \quad (69)$$

B Appendix

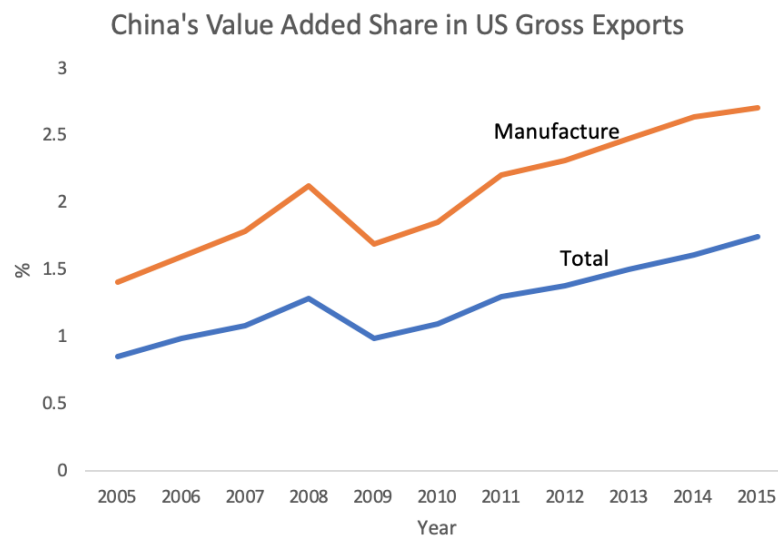


Figure 12: source: OECD

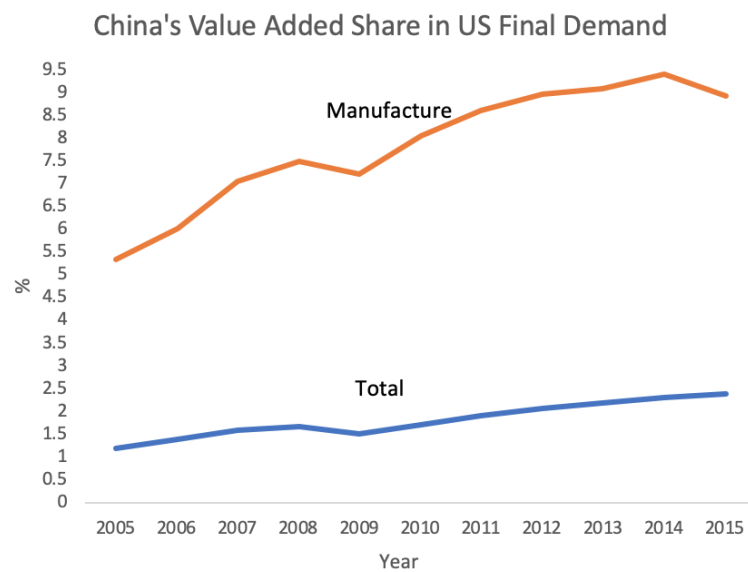


Figure 13: source: OECD

	CHN		USA	ROW	
	α	γ	γ	γ	b
Agriculture	0.24	0.96	0.99	0.99	0.037
D10T12	0.44	0.46	0.32	0.42	0.054
D13T15	0.72	0.31	0.39	0.46	0.015
D16	0.01	0.98	0.91	0.61	0.001
D17T18	0.01	0.68	0.80	0.55	0.003
D19	0.01	0.39	0.46	0.29	0.012
D20T21	0.13	0.46	0.87	0.58	0.020
D22	0.01	0.55	0.77	0.56	0.003
D23	0.28	0.53	0.78	0.61	0.002
D24	0	0.53	0.45	0.42	0.001
D25	0.47	0.34	0.61	0.62	0.006
D26	0.79	0.23	0.83	0.42	0.019
D27	0.83	0.23	0.48	0.38	0.011
D28	0.84	0.26	0.40	0.40	0.026
D29	0.95	0.18	0.24	0.26	0.031
D30	0.96	0.27	0.39	0.33	0.011
D31T33	0.77	0.38	0.56	0.49	0.014
Service	0.99	0.49	0.61	0.56	0.734

Table 7: α_s , γ_{js} and b_s

	Agr	D10T12	D13T15	D16	D17T18	D19	D20T21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31T33	Ser
Agr	0.418	0.410	0.059	0.249	0.055	0.669	0.093	0.027	0.127	0.239	0.015	0.002	0.009	0.008	0.004	0.005	0.023	0.035
D10T12	0.091	0.212	0.015	0.004	0.0.011	0.0.003	0.029	0.007	0.003	0.001	0.002	0.001	0.002	0.002	0.001	0.0.002	0.004	0.026
D13T15	0.006	0.002	0.480	0.010	0.0115	0.001	0.010	0.026	0.008	0.002	0.005	0.004	0.006	0.006	0.014	0.014	0.060	0.007
D16	0.003	0.001	0.002	0.268	0.016	0.000	0.002	0.004	0.007	0.001	0.005	0.002	0.003	0.003	0.004	0.006	0.089	0.008
D17T18	0.003	0.016	0.012	0.018	0.351	0.001	0.015	0.021	0.021	0.002	0.008	0.007	0.011	0.008	0.006	0.004	0.018	0.014
D19	0.057	0.009	0.013	0.017	0.020	0.106	0.088	0.023	0.057	0.038	0.011	0.006	0.011	0.010	0.006	0.015	0.015	0.042
D20T21	0.055	0.011	0.085	0.048	0.074	0.038	0.360	0.334	0.068	0.037	0.033	0.032	0.045	0.022	0.022	0.028	0.046	0.017
D22	0.009	0.017	0.018	0.016	0.024	0.003	0.022	0.170	0.024	0.008	0.021	0.029	0.048	0.038	0.057	0.034	0.044	0.013
D23	0.006	0.006	0.003	0.016	0.002	0.001	0.008	0.011	0.225	0.009	0.011	0.016	0.014	0.009	0.011	0.009	0.011	0.023
D24	0.009	0.002	0.002	0.005	0.012	0.002	0.007	0.016	0.028	0.319	0.379	0.045	0.244	0.222	0.095	0.121	0.122	0.017
D25	0.011	0.010	0.005	0.024	0.012	0.003	0.008	0.022	0.018	0.034	0.166	0.021	0.046	0.094	0.058	0.059	0.053	0.016
D26	0.002	0.001	0.002	0.004	0.009	0.001	0.004	0.008	0.005	0.003	0.011	0.467	0.073	0.036	0.024	0.023	0.021	0.014
D27	0.003	0.001	0.002	0.004	0.003	0.001	0.003	0.006	0.005	0.008	0.014	0.053	0.186	0.048	0.028	0.029	0.020	0.010
D28	0.021	0.004	0.006	0.010	0.014	0.002	0.006	0.014	0.015	0.017	0.028	0.023	0.031	0.177	0.053	0.068	0.032	0.010
D29	0.003	0.001	0.001	0.004	0.003	0.000	0.002	0.005	0.004	0.002	0.007	0.004	0.013	0.026	0.356	0.018	0.008	0.008
D30	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.002	0.001	0.002	0.006	0.003	0.240	0.002	0.004
D31T33	0.006	0.003	0.008	0.012	0.009	0.001	0.005	0.005	0.009	0.012	0.011	0.009	0.010	0.014	0.010	0.011	0.082	0.008
Ser	0.296	0.295	0.286	0.290	0.372	0.169	0.338	0.300	0.374	0.268	0.272	0.275	0.247	0.272	0.248	0.313	0.350	0.726

Table 8: $b_s^{s'}$

	CHN		USA		ROW	
	<i>stage 1</i>	<i>stage 2</i>	<i>stage 1</i>	<i>stage 2</i>	<i>stage 1</i>	<i>stage 2</i>
	<i>T</i>	<i>T</i>	<i>T</i>	<i>T</i>	<i>T</i>	<i>T</i>
Agriculture	0.60	1.11	50	50	0.02	0.12
D10T12	1.50	12.00	50	50	0.65	9.88
D13T15	6.00	25.00	50	50	7.89	10.21
D16	0.83	6.00	50	50	0.20	0.48
D17T18	0.85	3.50	50	50	0.22	0.08
D19	8.00	0.01	50	50	0.33	0.42
D20T21	1.80	4.60	50	50	0.22	0.25
D22	9.00	9.00	50	50	0.40	0.40
D23	2.81	5.12	50	50	0.20	1.10
D24	5.00	5.00	50	50	1.50	1.50
D25	0.82	10.00	50	50	0.03	0.61
D26	0.007	4.50	50	50	0.05	1.00
D27	0.10	28.00	50	50	0.02	3.00
D28	0.002	5.00	50	50	0.02	3.00
D29	6.00	0.15	50	50	5.00	3.00
D30	$1E - 5$	3.5	50	50	$1E - 5$	0.33
D31T33	0.008	8.20	50	50	0.015	2.00
Service	1.40	1.40	50	50	0.006	0.006

Table 9: T_{js}^n

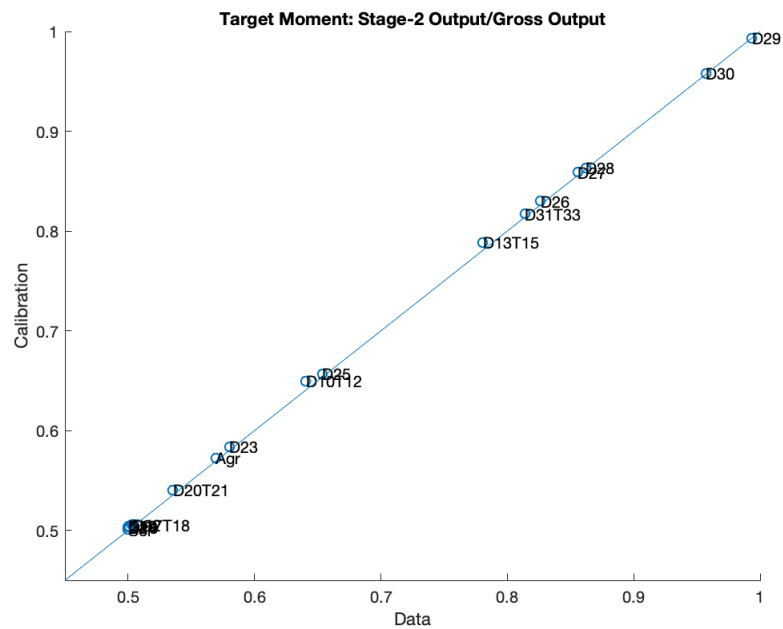


Figure 14: Calibration of α

	<i>Estimate</i>	<i>SE</i>	<i>p - value</i>
(Intercept)	0.02	0.0004	$1.5e - 24^{***}$
Scale of upstream imports tariffs	-0.02	0.0001	$5.7e - 37^{***}$
R-squared: 0.999			

Table 10: Dependent Variable: Percentage change in US downstream outputs

	<i>Estimate</i>	<i>SE</i>	<i>p - value</i>
(Intercept)	0.12	0.004	$9.9e - 20^{***}$
Scale of upstream imports tariffs	-0.13	0.001	$1.5e - 32^{***}$
R-squared: 0.998			

Table 11: Dependent Variable: Percentage change in US downstream exports

	<i>Estimate</i>	<i>SE</i>	<i>p - value</i>
(Intercept)	0.06	0.001	$2.7e - 22^{***}$
Scale of upstream imports tariffs	-0.06	0.0004	$6.9e - 35^{***}$
R-squared: 0.998			

Table 12: Dependent Variable: Percentage change in US downstream employment

	<i>Estimate</i>	<i>SE</i>	<i>p - value</i>
(Intercept)	-0.05	0.16	0.07
China's share in US upstream imports	-9.90	1.96	0.0001^{***}
R-squared: 0.616			

Table 13: Dependent Variable: Percentage change in US downstream outputs

	<i>Estimate</i>	<i>SE</i>	<i>p – value</i>
(Intercept)	0.01	0.19	0.96
China’s share in US upstream imports	−10.09	2.13	0.0003***
R-squared: 0.616			

Table 14: Dependent Variable: Percentage change in US downstream employments

Round	Tariffs on Goods from	Products
1 st	China	metal, electrical machinery, machinery
1 st	US	agricultural products, automotive vehicle
2 nd	China	textiles, clothing, food, electronic equipment
2 nd	US	agricultural products, chemicals

Table 15: Two Rounds of the Trade War

	<i>Goods</i>	<i>Service</i>
VNM	0.02	0.0009
CHN	0.82	0.009
USA	50	50
ROW	1.25	0.33

Table 16: T_{js}

	<i>Goods</i>	<i>Service</i>
VNM	0.38	0.48
CHN	0.39	0.49
USA	0.74	0.60
ROW	0.63	0.56

Table 17: γ_{js}

<i>Goods</i>	<i>Service</i>
0.35	0.98

Table 18: α_s