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Dedication

To my dearest mom, a women with a strong mind and a soft heart. Thank you for standing by my side through all my ups and downs, and making me realize that a girl who values her self worth should never stop chasing her dreams.

Abstract

This dissertation consists of three chapters.The first chapter studies the heterogeneous impact of the US-China trade war in the presence of global value chains. By building a two-stage, multi-country, multi-sector general equilibrium model, this chapter discusses how tariffs on imports affect domestic producers through linkages within and across industries. The model shows that tariffs on imports of Chinese upstream intermediate goods negatively affect US downstream exports, output and employment. The effects are strong in US industries that rely heavily on targeted Chinese intermediate goods. In addition, this paper quantifies 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 contributes to US CPI by 0.09% in the first round and 0.22% in the second round. Finally, this chapter studies the welfare effects of the trade war, and estimates that in terms of aggregate real income, the trade war costs China $35.2 billion, or 0.29% of GDP, and costs the United States $15.6 billion, or 0.08% of GDP. The second chapter develops a two-country general equilibrium model to study the significant trade collapse in the US during the Great Recession. Compared with previous downturns, the trade reduction in 2008-2009 is exceptional in terms of its magnitude and rapidness. The recession in 2008-2009 is companied by a drastic credit crunch due to the global financial crisis. This paper aims to explain the uniqueness of 2008-2009 trade collapse by investigating the effect of a joint increasing financial friction in both the U.S. and its trading partners. The paper uses an International Real Business Cycle model with financial friction, where home and foreign countries trade intermediate inputs between each other. By simultaneously increasing the financial friction in both country, the model captures a negative correlation between financial friction and trade-to-GDP ratio. The third chapter introduces a literature review on the structural modeling of global value chains (GVCs). To understand how the production process is fragmented across the world, international economists explore different approaches to model global value chains. This chapter broadly divides the literature on the structural modeling of GVCs into two strands: the one that adopts the country-level approach and the one that adopts the firm-level approach. This chapter also discusses the advantage and drawback of each approach depending on the research questions and available data.

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Chapter 1

The US-China Trade War and Global Value Chains

1.1 Introduction

Globalization enables countries to specialize in producing different stages of a final good. For example, an iPhone is designed in the United States, 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 trade in intermediate goods, which inevitably amplifies the impact of international trade policies. Consider a final good whose upstream and downstream production takes place in two different countries. When both countries increase tariffs on upstream and downstream outputs against each other, the downstream producers not only confront impediments to export but bear expensive upstream intermediate inputs imported from the other country.

This paper studies the impacts of the US-China trade war in the presence of 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 increased from 0.86% to 1.75%, and the share of China's value added in US exports in the manufacturing sector increased 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. Given the linkage between the United States and China, especially in the manufacturing sector, it is essential to take global value chains into account when analyzing the impact of the US-China trade war.

The US-China trade war is the biggest trade war in US history after the Smoot-Hawley Tariff Act in 1930,. From January 2018 to January 2020, US weighted average tariffs on Chinese exports increased from 3.1% to 19.3%, and China's weighted average tariffs on US exports 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 1.1 summarizes the timeline of the US-China trade war (data from Bown, PIIE 2020). In February 2018, as a warm-up, the United States imposed safeguard tariffs on washing machines of which China accounted for 80% of the imports into the United States. In

July 2018, the trade war started. According to the US 301 tariff actions, the United States 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. According to 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 hardest. As retaliation China imposed 25% tariffs on $50 billion of goods imported from the United States, mainly transportation vehicles and agricultural products. In June 2019, the trade war escalated when the United States imposed 25% tariffs on $200 billion of goods imported from China. Compared with the initial round, more consumption goods got targeted in this, which included textiles, food and agricultural products. On the other hand, China imposed 10%-25% tariffs on $60 billion of goods imported from the United States. In September 2019, the trade war continued as the United States imposed 15% tariffs on another $112 billion of Chinese goods, mainly apparel and footwear. Finally, in January 2020, the two countries suspended the ongoing economic conflict by signing the Phase One trade deal.

The increase in tariffs on imports from China can be divided into two rounds, with the first round mainly targeting intermediate goods and the second round targeting more consumption goods. This paper builds a two-stage Eaton-Kortum model (2002) to quantify 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

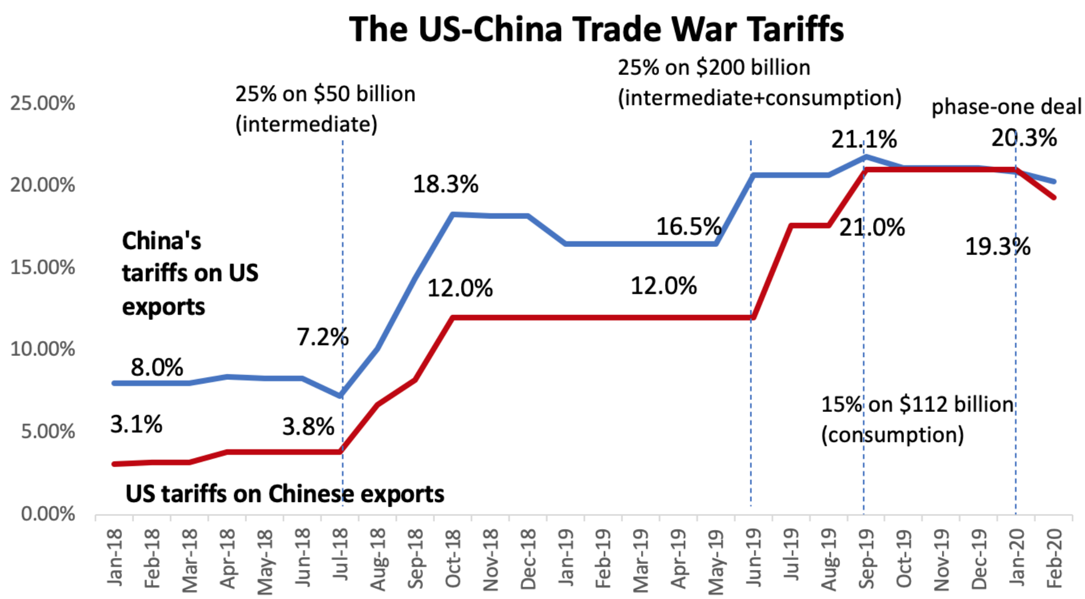

Figure 1.1: Weighted Average Tariffs (source: Chad Bown, PIIE)

goods from China negatively affected the output, employment and exports of US downstream industries. These impacts are especially strong in the US downstream industries that rely on China for those targeted intermediate inputs. In addition, while the first round negatively impacted US downstream producers, the second round had a stronger effect on US consumers, since the second round directly raises the price of imported consumption goods and generates a bigger increase in the consumer price index compared with the first round.

Finally, this paper does welfare analysis to study trade war's welfare effects on the United States, China, and third countries. By calibrating an economy with the United States, China and Vietnam, this paper estimates that, in terms of aggregate real income, the trade war costs China $35.2 billion, or 0.29% of GDP, costs US

$15.6 billion, or 0.08% of GDP, and benefits Vietnam by $402.8 million, or 0.18% of GDP. In the study of the impacts of the US-China trade war, this paper introduces a multi-country general equilibrium model. Previous research in this field mainly uses reduced-form or partial equilirbium models. Empirically, Handley and Kamal (2020) show that upstream imports tariffs has negative effects on downstream exports, and Bown et al. (2020) find upstream import tariffs have negative impacts on downtream sales and employment. Theoretically, Amiti, Redding and Weinstein (2019) apply a partial equilibrium framework to estimate the effects of the trade war on the price and welfare in the United States. Fajgelbaum et al. (2019) build a one-country general equilibrium model to study the trade war's impacts on the United States. Because Fajgelbaum et al. (2019) only model US 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: a linkage within each industry and a linkage across different industries. The most related paper is Antras and de Gortari (2020). They apply a one-sector, multi-stage Eaton Kortum (2002) model to demonstrate that the downstream stage of production is more sensitive to transportation costs. Compared with Antras and de Gortari (2020), this paper makes two modifications: 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 mechanism 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 evidence since the Inter-Country Input-Output Table does not present a significant difference between the share of imports in intermediate goods and final goods. In this paper productivity differs depending on 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 to the upstream sub-industries and the ones belonging to 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 has flourished. Lee and Yi (2018) explain how the reduction in trade costs affects labor market through global value chains. Caliendo and Parro (2015) apply a one-stage Ricardian model to estimate the welfare effects of change in NAFTA tariffs. Flaaen et al. (2020)

discuss the production relocation of washing machines after the United States imposed anti-dumping duties against South Korea and China. Other papers in this literature focus on firms' decisions regarding multinational production. Atkeson and Burstein (2010) study how the reduction in international trade costs affects firms' decisions. Antras and Yeaple (2003) explore the behaviors of multinational firms in international trade. Antras et al. (2017) and Antras and Helpman (2006) relate firms' sourcing decisions to their productivity and the features of source markets. Ramondo and Rodriguez-Clare (2012) evaluate the gains from multinational production. Ekholm et al. (2003) analyze the export-platfrom foriegn direct investment. Helpman et al. (2003) discuss heterogeneous firms' decision in exports and foriegn direct investment. Lind and Ramondo (2019) investigate 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 charaterizes its general equilibirum. 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.

1.2 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 similiar features but the one-sector model has a much simpler notation.

1.2.1 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:

$$\max_{\{c_i(z)\}} U_i = (\int_0^1 (c_i(z))^{(\sigma-1)/\sigma} dz)^{\sigma/(\sigma-1)} \tag{1.1}$$

where $c_i(z)$ is the consumption on the final-good variety z, and σ represents the elasticity of substitution. Because labor supply is perfectly 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:

$$y_i^1(z) = \frac{1}{a_i^1(z)} L_i^1(z)^{\gamma_i} I_i^1(z)^{1-\gamma_i} \tag{1.2}$$

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. Like 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:

$$y_i^2(z) = [\frac{1}{a_i^2(z)} L_i^2(z)^{\gamma_i} I_i^2(z)^{1-\gamma_i}]^{\alpha} [x_i^1(z)]^{1-\alpha} \tag{1.3}$$

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:

$$I_i(z) = (\int_0^1 (x_i^2(z'))^{(\sigma-1)/\sigma} dz')^{\sigma/(\sigma-1)} \tag{1.4}$$

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. Beisdes 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:

$$\tau_{ij} = d_{ij}(1 + t_{ij}) \tag{1.5}$$

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.

1.2.2 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 $p^1_{ji}(z)$ 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:

$$p^1_i(z) = \min_{j \in \mathcal{J}} \{p^1_{ji}(z)\} \tag{1.6}$$

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:

$$p_i(z) = \min_{j \in \mathcal{J}} \{p_{ji}(z)\} \tag{1.7}$$

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,

$$p^1_{ji}(z) = a^1_j(z) v_j(z) \tau_{ji} \tag{1.8}$$

$$p_{ji}(z) = (a^2_j(z) v_j(z))^{\alpha} {p^1_j(z)}^{1-\alpha} \tau_{ji} \tag{1.9}$$

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 the 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:

$$l_i^* = arg \min_{l_i \in \mathcal{J}^2} p_i(l_i) = (a^2_{l_i^2} v_{l_i^2})^{\alpha} (a^1_{l_i^1} v_{l_i^1} \tau_{l_i^1 l_i^2})^{1-\alpha} \tau_{l_i^2 i} \tag{1.10}$$

1.2.3 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:

$$Pr(a_i \geq a) = exp\{-a^{\theta} T_i\} \tag{1.11}$$

where T_i captures the absolute advantage in country i. When T_i is big it is more likely to take a 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 distributions 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:

$$Pr[(a^1_{l^1_i})^{1-\alpha}(a^2_{l^2_i})^{\alpha} \geq a] = exp\{-a^{\theta}(T^1_{l^1_i})^{1-\alpha}(T^2_{l^2_i})^{\alpha}\} \tag{1.12}$$

where T^n_i captures the absolute advantage of stage-n production in country i. Notice that one of this paper's contributions 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:

$$Pr[p(l_i) \leq p] = 1 - exp\{-p^{\theta}(T^1_{l^1_i}((v_{l^1_i})\tau_{l^1_i l^2_i})^{-\theta})^{1-\alpha} \times (T^2_{l^2_i})^{\alpha}((v_{l^2_i})^{\alpha}\tau_{l^2_i i})^{-\theta}\} \tag{1.13}$$

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:

$$Pr(p_i \leq p) = 1 - \prod_{l_i \in \mathcal{J}^2}[1 - Pr(p(l_i) \leq p)] = 1 - exp\{-p^{\theta}\Theta_i\} \tag{1.14}$$

where

$$\Theta_i = \sum_{l_i \in \mathcal{J}^2}((T^1_{l^1_i})((v_{l^1_i})\tau_{l^1_i l^2_i})^{-\theta})^{1-\alpha} \times (T^2_{l^2_i})^{\alpha}((v_{l^2_i})^{\alpha}\tau_{l^2_i i})^{-\theta} \tag{1.15}$$

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

$$P_i = \kappa(\Theta_i)^{-1/\theta} \tag{1.16}$$

where

$$\kappa = [\Gamma(\frac{\theta + 1 - \sigma}{\theta})]^{1/(1-\sigma)} \tag{1.17}$$

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

$$\pi_{l_i^*} = \frac{((T^1_{l_i^{*1}})((v_{l_i^{*1}})\tau_{l_i^{*1}l_i^{*2}})^{-\theta})^{1-\alpha} \times (T^2_{l_i^{*2}})^{\alpha}((v_{l_i^{*2}})^{\alpha}\tau_{l_i^{*2}i})^{-\theta}}{\Theta_i} \tag{1.18}$$

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^*.

1.2.4 General Equilibrium

Compared with Antras and de Gortari (2020) where iceberg transpotation 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 $i \in \mathcal{J}$:

$$Tr_i = Tr_i^f + Tr_i^{round} + Tr_i^{snake} \tag{1.19}$$

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 contraint:

$$P_i U_i = w_i L_i + Tr_i \tag{1.20}$$

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:

$$Tr_i^f = \sum_{j \in \mathcal{J}} (w_i L_i + Tr_i) Pr(\Lambda_{ji}^2) \frac{t_{ji}}{1 + t_{ji}} \tag{1.21}$$

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

$$Tr_i^{round} = \sum_{j \in \mathcal{J}} (\frac{1-\gamma_i}{\gamma_i} w_i L_i) Pr(\Lambda_{ji}^2) \frac{t_{ji}}{1+t_{ji}} \tag{1.22}$$

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 expenditures 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:

$$Tr_i^{snake} = \sum_{j \in \mathcal{J}} \sum_{h \in \mathcal{J}} (w_j L_j + Tr_j + \frac{1-\gamma_j}{\gamma_j} w_j L_j) Pr(\Lambda_{hij}^{12}) \frac{1}{1+t_{ij}} (1-\alpha) \frac{t_{hi}}{1+t_{hi}} \tag{1.23}$$

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 conditions for both stages are: $\forall z \in [0,1]$

$$\sum_{i \in \mathcal{J}} y_i^1(z) = \sum_{i \in \mathcal{J}} x_i^1(z) \tag{1.24}$$

$$\sum_{i \in \mathcal{J}} y_i^2(z) = \sum_{i \in \mathcal{J}} [c_i(z) + x_i^2(z)] \tag{1.25}$$

Labor is constant within each country and is not mobile across countries. The wage income of each country equals its value added for producing at both stages. Recall that country j spends $w_jL_j + Tr_j + \frac{1+\gamma_j}{\gamma_j}w_jL_j$ 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:

$$w_iL_i^2 = \gamma_i\alpha\sum_{j\in\mathcal{J}}(w_jL_j + Tr_j + \frac{1+\gamma_j}{\gamma_j}w_jL_j)Pr(\Lambda_{ij}^2)\frac{1}{1+t_{ij}} \tag{1.26}$$

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:

$$w_iL_i^1 = \gamma_i(1-\alpha)\sum_{j\in\mathcal{J}}\sum_{h\in\mathcal{J}}(w_jL_j + Tr_j + \frac{1-\gamma_j}{\gamma_j}w_iL_i)Pr(\Lambda_{ihj}^{12})\frac{1}{(1+t_{ih})(1+t_{hj})} \tag{1.27}$$

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

$$w_iL_i = [\gamma_i\alpha\sum_{j\in\mathcal{J}}(Tr_j + \frac{1}{\gamma_j}w_jL_j)\frac{Pr(\Lambda_{ij}^2)}{1+t_{ij}}] + [\gamma_i(1-\alpha)\sum_{j\in\mathcal{J}}\sum_{h\in\mathcal{J}}(Tr_j + \frac{1}{\gamma_j}w_iL_i)\frac{Pr(\Lambda_{ihj}^{12})}{(1+t_{ih})(1+t_{hj})}] \tag{1.28}$$

and the equilibrium wage vector $\mathbf{w} = (w_1, w_2, ...w_J)$ is pinned down to solve the system of labor market clear conditions. Recall that the price index vector $\mathbf{P} = (P_1, P_2, ...P_j)$ 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)[1], we can solve for the general equilibrium.

[1]The model is solved in levels instead of differences, because the hat algebra approach does not work in the two-stage production structure.

1.3 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. At the end, this section does a numerical exercise to compare the two-stage production structure in this paper with the one-stage production structure in Caliendo and Parro (2015).

1.3.1 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:

$$\max_{C_{is}} U_i = \prod_{s=1}^{S} (C_{is})^{b_s} \tag{1.29}$$

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:

$$C_{is} = (\int_0^1 c_{is}(z)^{(\sigma-1)/\sigma} dz)^{\sigma/(\sigma-1)} \qquad \forall s \in \mathcal{S} \tag{1.30}$$

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:

$$y_{is}^1(z) = \frac{1}{a_{is}^1(z)} L_{is}^1(z)^{\gamma_{is}} I_{is}^1(z)^{1-\gamma_{is}} \tag{1.31}$$

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

$$y_{is}^2(z) = [\frac{1}{a_{is}^2(z)} L_{is}^2(z)^{\gamma_{is}} I_{is}^2(z)^{1-\gamma_{is}}]^{\alpha_s} [x_{is}^1(z)]^{1-\alpha_s} \tag{1.32}$$

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 1.2 depicts the production structure in the multi-sector model. In each sector, the light blue dot is stage-1 output, and the dark 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.

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

$$Pr[(a_{is}^1)^{(1-\alpha_s)} (a_{js}^2)^{\alpha_s} \geq a] = exp\{-a^{\theta} (T_{is}^1)^{(1-\alpha_s)} (T_{js}^2)^{\alpha_s}\} \qquad \forall s \in \mathcal{S} \tag{1.33}$$

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

$$\tau_{ijs}^n = d_{ij}(1 + t_{ijs}^n) \tag{1.34}$$

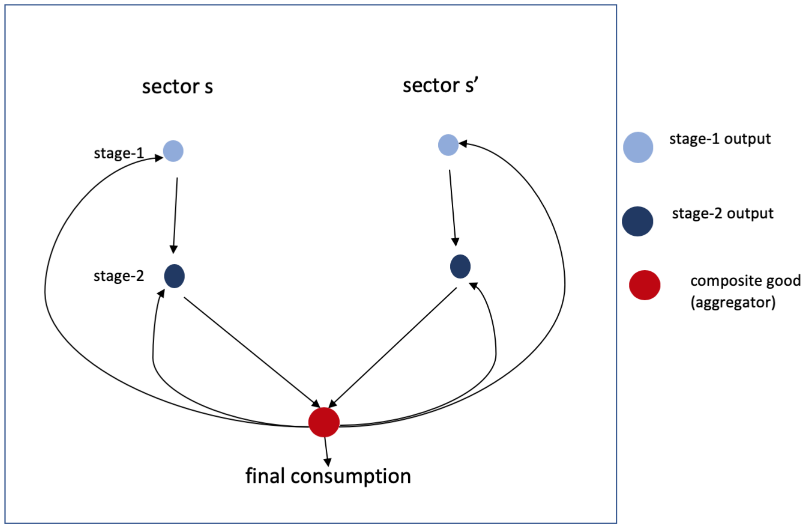

Figure 1.2: Production Structure in Multi-Sector Model

By definition t^n_{ijs} means the ad valorem tariff imposed by country j on stage-n, sector s goods imported from country i. Table 1.1 summarizes the parameters and exogenous variables in the multi-sector model.

Like the one-sector model, goods from both stages are imported from wherever offers 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 1.1: Parameters and Exogenous Variables in the Multi-Sector Model

1.3.2 General Equilibrium

This section characterizes the general equilibirum 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 1.3 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 intermediates 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 represent the value added and the gross output by each sector in each country.

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

	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_ijs's	X_ijs'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_jjs's	X_jjs'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 1.3: Inter-Country Input-Output Table

local consumers, equals 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,

$$Tr_i = Tr_i^f + \sum_{s \in \mathcal{S}} Tr_{is}^{round} + \sum_{s \in \mathcal{S}} Tr_{is}^{snake} \tag{1.35}$$

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:

$$Tr_i^f = \sum_{s \in \mathcal{S}} \sum_{j \in \mathcal{J}} b_s (w_i L_i + Tr_i) Pr(\Lambda_{jis}^2) \frac{t_{jis}^2}{1 + t_{jis}^2} \tag{1.36}$$

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:

$$Tr_{is}^{round} = \sum_{s' \in \mathcal{S}} \sum_{j \in \mathcal{J}} b_{s'}^s (\frac{1 - \gamma_{is}}{\gamma_{is}} w_i L_{is}) Pr(\Lambda_{jis'}^2) \frac{t_{jis'}^2}{1 + t_{jis'}^2} \tag{1.37}$$

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

$$Tr_{is}^{snake} = \sum_{j\in\mathcal{J}}\sum_{h\in\mathcal{J}}[b_s(w_jL_j+Tr_j)+\sum_{s'\in\mathcal{S}} b_s^{s'}\frac{1-\gamma_{js'}}{\gamma_{js'}}w_jL_{js'}]\frac{1}{1+t_{ijs}^2}(1-\alpha_s)Pr(\Lambda_{hijs}^{12})\frac{t_{his}^1}{1+t_{his}^1} \tag{1.38}$$

where Λ_{hijs}^{12} is the set of production paths in sector s that serve country j and 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:

$$L_i = \sum_{s\in\mathcal{S}}\sum_{n=1}^{2} L_{is}^n \tag{1.39}$$

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 flow in final consumption follows:

$$F_{ijs} = b_s(w_j L_j + Tr_j) Pr(\Lambda^2_{ijs}) \frac{1}{1 + t^2_{ijs}} \tag{1.40}$$

and trade flow 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:

$$X_{ijss} = X^{round}_{ijss} + X^{snake}_{ijs} \tag{1.41}$$

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 the same sector:

$$X_{ijss'} = X^{round}_{ijss'} \tag{1.42}$$

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

1.3.3 Model Comparison

Previous research which builds general equilibrium models to study the impacts of trade policies, e.g., Caliendo and Parro (2015), Fajgelbaum et al. (2019), mainly adopts the one-stage production structure, where final output is produced in one stage and the only type of intermediate goods is roundabout intermediates. This subsection does a numerical exercise to compare the one-stage production with the two-stage production introduced in this paper. The one-stage production is a special case of the two-stage production when α equals 1. That is the structure where stage one accounts for 0% and stage two accounts for 100% of the production of final output. To see how the impacts of trade policy depend on production structure, refer to tariff elasticty of trade volume in equation (18). In the one-stage production with $\alpha = 1$, tariff elasticity of trade volume is θ. In the two-stage production with $\alpha \in [0, 1)$, tariff elasticity of trade volume is $\theta(2-\alpha)$ which is greater than θ. In other words, trade volume is more elastic to tariff change under the two-stage production structure because trade in stage-2 products is not only affected by tariffs on stage-2 products but also affected by tariffs on stage-1 products. To compare the two-stage production in this paper with the one-stage production in Caliendo and Parro (2015), this subsection runs a numerical experiment on a symmetric three-country, two-sector economy. Figure 1.4 displays the simulation results of two production structures with scale of tariff on the horizontal axis and country's gross imports on the vertical axis. Both production structures share the same equipped labor share $\gamma = 0.5$ (i.e. same roundabout intermediates share) with $\alpha = 1$ in one-stage production and $\alpha = 0.5$ in two-stage production. Starting at autarky, tarde volume in two-stage production is more elastic to tariff reduction than the one in one-stage production. The results are inconsistent with the observation by Yi (2003) that tariff decline since World War II generates a disproportionate growth in world trade, and rationalize the multi-stage production structure.

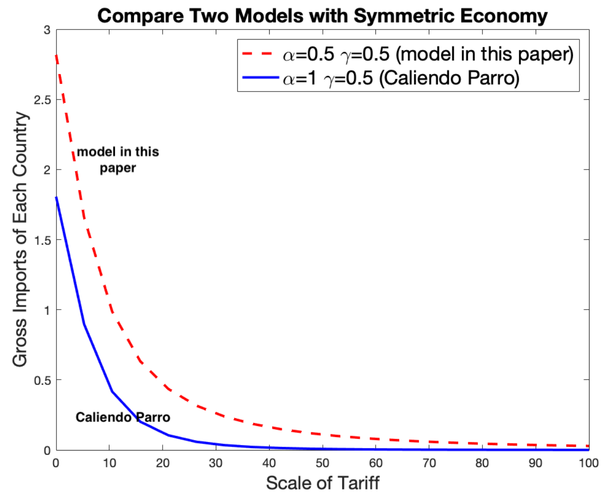

Figure 1.4: Model Comparison

1.4 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 United States, China, and the rest of the world, and eighteen industries composed of an aggregate agriculture sector, an aggregate service sector and sixteen manufacturing industries. The eighteen industries are regrouped from the thirty-six industries in the original ICIO Table. Table 1.2 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 1.2: Codes and Names of the 18 Industries

The value of θ and the calibration of L inherit the ones in Antras and de Gortari (2020). θ, the heterogeneity of productivity within each industry, is set to 5. L_j, the country-specific equipped labor, equals $(population_j)^{2/3}(capital_j)^{1/3}$, in which population and capital are obtained from the Penn World Tables. 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 $\frac{\sum_{i\in\mathcal{J}}\sum_{j\in\mathcal{J}}F_{ijs}}{\sum_{s'\in\mathcal{S}}\sum_{i\in\mathcal{J}}\sum_{j\in\mathcal{J}}Fijs'}$, and $b^s_{s'}$ the expenditure share of composite intermediate good I is measured by $\frac{\sum_{i\in\mathcal{J}}\sum_{j\in\mathcal{J}}X_{ijs's}}{\sum_{s''\in\mathcal{S}}\sum_{i\in\mathcal{J}}\sum_{j\in\mathcal{J}}Xijs''s}$. In Appendix B, Table B.1 displays the values of b_s in the economy with three countries and eighteen industries, and Table B.2 displays the values of $b_s^{s'}$.

The key parameters in this two-stage model are T, α and γ, with T dominating countries' comparative advantage, and α, γ depicting production structure. In this paper, the country, industry and stage-specific productivity T^n_{js} is calibrated to target trade flows. The industry-specific α_s, representing the stage share of final-output production, is measured by the share of downstream output in gross output. Finally, conditional on α_s the country and industry-specific labor share γ_{js} is calibrated to target the ratio of value added to gross output.

One of this paper's major contributions is the calibration of T, the parameter that captures the magnitude of productivity. By equation (18) a foreign country's share of a domestic country's gross imports is positively correlated to the foreign country's productivity level T. Therefore, it is reasonable to target imports share when calibrating T. Antras and de Gortari (2020) calibrate T using the trade flows in the World Input-Output table. Since the World Input-Output table is constructed using national make-use tables, it involves significant imputation and is not the best source for bilateral trade flows. Besides, the parameterization of T in Antras and de Gortari (2020) lacks persuasive evidence. In Antras and de Gortari (2020) T varies depending whether the output is used as intermediate inputs or final consumption. Using the ICIO table, Figure 1.5 plots China's share of US imports in the eighteen industries in Table 1.2. With each industry represented by one dot, the horizontal coordinate is China's share of US imports used as intermediate inputs and the vertical coordinate is China's share of US imports used as final consumption. Taking industry s as an example, its horizontal coordinate, according to Figure 1.3, is $\frac{\sum_{s' \in \mathcal{S}} X_{ch,us,s,s'}}{\sum_{s' \in \mathcal{S}} \sum_{j \in \mathcal{J}} X_{j,us,s,s'}}$, and its vertical coordinate is $\frac{F_{ch,us,s}}{\sum_{j \in \mathcal{J}} F_{j,us,s}}$. Most industries, except the industry of basic metal (D24), do not deviate much from the 45-degree line, indicating no significant difference between the share of imports in intermediate inputs and final consumption, which contradicts the parameterization of T in Antras and de Gortari (2020).

Instead, this paper varies T depending on source country, industry and production stage, and calibrates T using disaggregate trade flows from the US International Trade in Goods and Services Reports, a more reliable source for trade data. Such parameterization is validated by US trade flows in commodities from different industries. To calibrate T this paper derives US imports from China and the world in 1046 4-digit HS commodities. Since the 1046 4-digit HS commodities can be regrouped

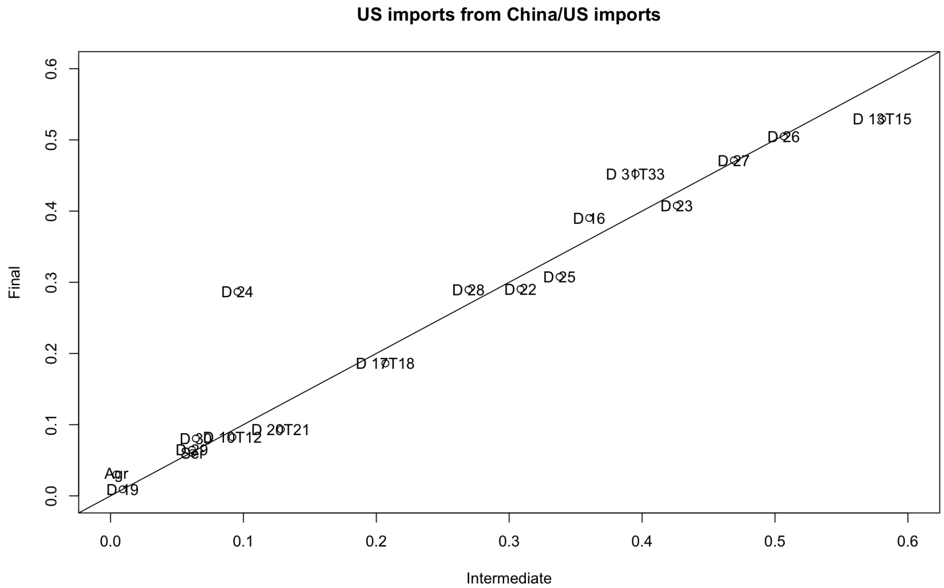

Figure 1.5: Parameterization of T, Year 2014

into the eighteen industries, the data is good enough for calibrating the country and industry-specific T in the three-country, eighteen-industry economy. However, T is also stage-specifc. To fit the 2-stage production structure we need a systematic methodology that divides commodities in each industry into the ones belonging to the upstream sub-industry and the ones belonging to the downstream sub-industry. This paper applies the algorithm introduced in Antras et al. (2012) to measures the upstreamness of 426 6-digit Input-Output industries (279 manufacturing industries) from the Input-Output Account Data by U.S. Bureau of Economic Analysis. The algorithm sets upstreamness indices to the 6-digit Input-Output industry. Following the concordance between the 6-digit Input-Output industry code and the 4-digit HS code, this paper sets upstreamness indicies to the 1046 4-digit HS commodities. The upstreamness index measures a commodity's weighted average distance from final use. For example, suppose in a one-country one-industry economy, \$100 of output is produced of which all is used as final consumption. According to Antras et al. (2012) the upstreamness index is $1 \times \frac{100}{100}$ which equals 1. Now suppose among the \$100 output, \$50 is used as final consumption and \$50 is used as intermediate inputs. Also, \$0.5 of intermediate inputs are needed to produce \$1 of final goods. Then the upstreamness index is $1 \times \frac{50}{100} + 2 \times \frac{\frac{1}{2}50}{100} + 3 \times \frac{\frac{1}{2}^2 50}{100}...$ which equals 2. Therefore, the bigger the upstreamness index is the further the commodity is away from final use. Finally, under the concordance between the 4-digit HS code and the ISIC Rev. 4 code, the 1046 4-digit HS commodities are divided into the eighteen industries. Table 1.3 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 index, com-

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 1.3: Upstreamness

modities in each of the eighteen industries are divided into the ones belonging to the upstream sub-industry and the ones belonging to the downstream sub-industry. 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 that maximizes the number of industries with commodities in both upstream and downstream sub-industries. In other words, a cut-off higher than 1.9 leaves one more industry with all its commodities in the downstream sub-industry and no commodities in the upstream sub-industry; a cut-off lower than 1.9 leaves one more industry with all its commodities in the upstream sub-industry and no commodities in the downstream sub-industry. Given the cut-off, in each industry aggregate US imports of commodities belonging to the upstream and the downstream sub-industry. Figure 1.6 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 1.5, the observations in Figure 1.6 deviate more away from the 45-degree line, which justifies parameterizing T as stage-specific. Besides, Figure 1.6 displays the structure of US imports from China. For example, in the motor vehicles industry (D29), the United States relies heavily 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 United States relies much on China for the commodities from both the upstream sub-industry and the downstream sub-industry. Let 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. T^n_{js} is calibrated to

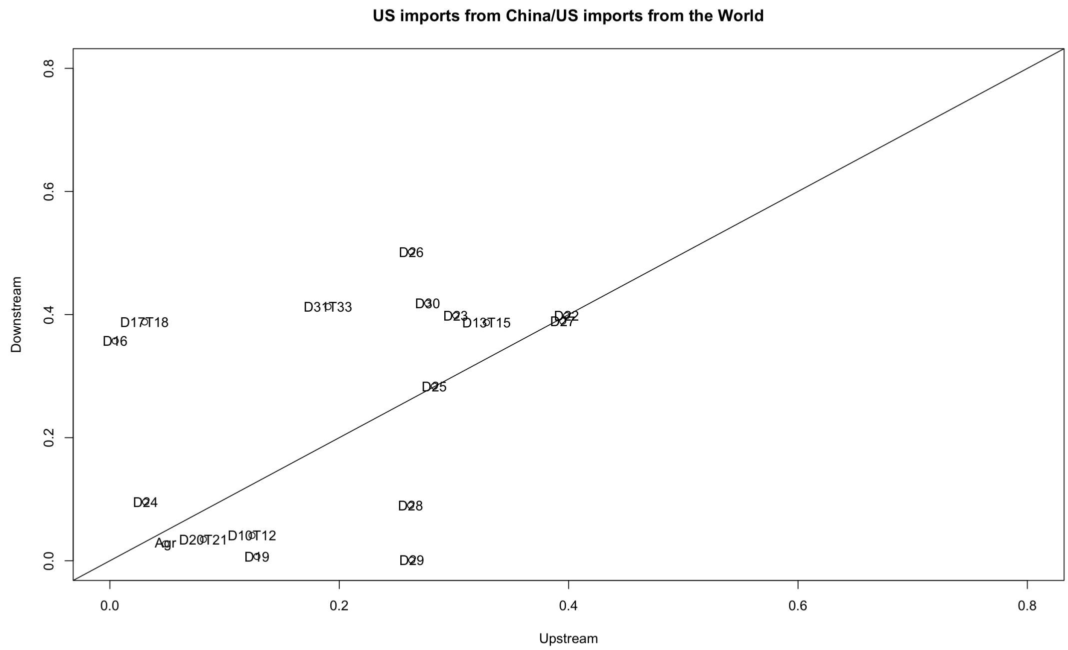

Figure 1.6: Parameterization of T, Year 2014

target country j's share in US imports in stage-n outputs from indutry s, that is

$$\frac{Imports^n_{j,us,s}}{\sum_{j\in\mathcal{J}} Imports^n_{j,us,s}} \tag{1.43}$$

A problem arises when it comes to the United States imports from itself. Since the US International Trade in Goods and Services Reports only includes US trade flows with its trading partners, $Imports_{us,us}$ cannot be directly read off from the data. As estimation, $\forall n \in \{1, 2\}$

$$Imports^n_{us,us,s} = \frac{X_{us,us,s} + F_{us,us,s}}{\sum_{j\in\mathcal{J},j\neq us}(X_{j,us,s} + F_{j,us,s})} \times Imports^n_{world,us,s} \tag{1.44}$$

where $X_{j,us,s}$, $F_{j,us,s}$ are derived from the ICIO Table, and $Imports^n_{world,us,s}$ is derived from the US International Trade in Goods and Services Reports. Normalize $T^n_{us,s}$ to

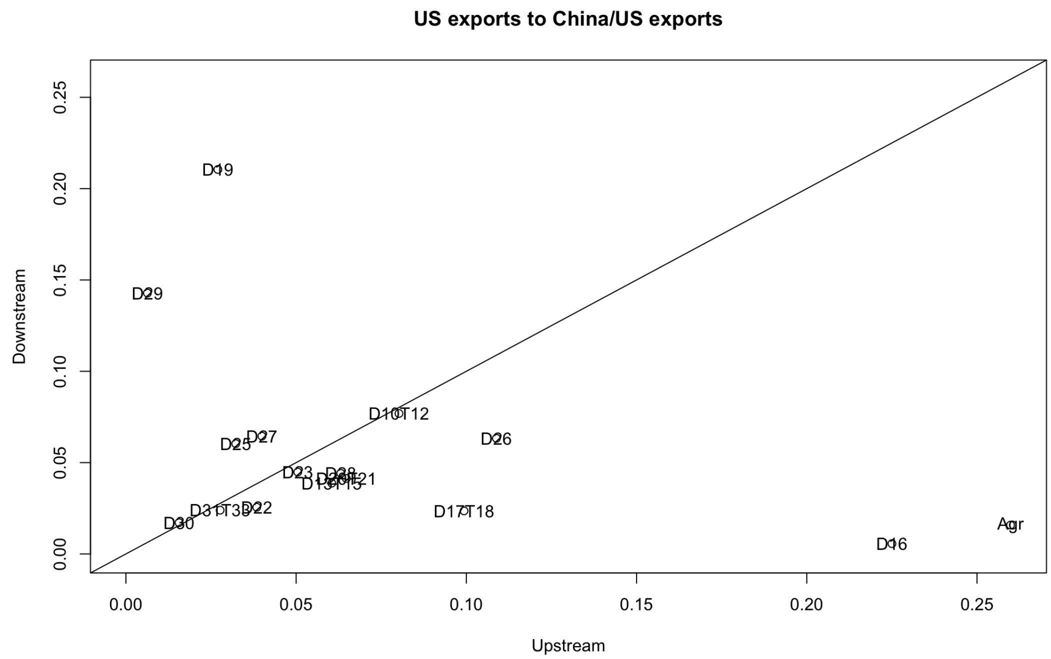

Figure 1.7: Parameterization of T, Year 2014

be 50 for $n \in \{1, 2\}$ and $s \in \mathcal{S}$. Table B.3 in Appendix B displays the value of T in the economy with three countries, and eighteen industries.

Next, α_s is estimated by the ratio of the stage-2 outputs in industry s to the gross outputs of industry s in the United States. Let the ratio be R_s

$$R_s = \frac{Output^2_{us,s}}{(Output^1_{us,s} + Output^2_{us,s})} \tag{1.45}$$

where

$$Output^n_s = \sum_{j \in \mathcal{J}} Exports^n_{us,j,s} \tag{1.46}$$

with $Exports^n_{us,j,s}$ read off from the US International Trade in Goods and Services Reports, and $Exports^n_{us,us,s}$ is same as $Imports^n_{us,us,s}$ 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 1 and α_s^2 equals 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 0.5 and α_s^2 equals 0, implying stage-2 production accounts for 0% of stage-2 outputs. To understand why R_s equals 0.5 when α_s^2 is 0, consider that stage-2 production contributes zero to stage-2 outputs the value of stage-2 outputs is the same as the value of stage-1 outputs, so the gross outputs in this industry are twice the value of stage-2 outputs. Table B.1 in Appendix B diplays the value of α in the three-country, eighteen-industry economy, and Figure B.3 presents the calibration performance of α.

Given the value of α, the country and industry-specific labor share γ_{js} is calibrated under the method of moments to target $\frac{VA_{js}}{GO_{js}}$, where the value added VA_{js}, and gross output GO_{js} can be found in the last two rows of the ICIO Table. Table B.1 displays the values of γ_{js}.

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

$$\tau_{ijs} = (\frac{\pi^F_{ijs}\pi^F_{jis}}{\pi^F_{iis}\pi^F_{jjs}})^{-\frac{1}{2\theta}} \tag{1.47}$$

where

$$\pi_{ijs}^{F} = \frac{F_{ijs}}{\sum\limits_{k \in \mathcal{J}} F_{kjs}} \tag{1.48}$$

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 the bilateral ad valorem tariffs of the 4-digit HS commodities from industry s. Finally iceberg transportation cost d_{ijs} is estimated 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.

1.5 Results

This section describes the estimated results of the multi-sector model. Subsection 5.1 discusses the heterogeneous impacts of the trade war through linkages within industry and 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 United States, China and the third countries.

1.5.1 The Heterogeneous Impacts of The US-China Trade War

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

This subsection calibrates an economy with the United States, China and the rest of the world, and the eighteen industries introduced in Section 4. According to the U.S. section 301 tariff actions on China, the first round of the trade war mainly targeted intermediate goods and increased the prices of those intermediate goods imported from China. To see the impacts of import tariffs through linkage within industry, this subsection scales up import tariffs on products in the upstream sub-industries and checks the exports, output and employment in the domestic downstream sub-industries. For example, Figure B.4 in Appendix B displays the simulated results that, given other tariffs are unchanged, import tariffs on Chinese upstream products in the automotive industry (D29) negatively effect US export, output and employment in downstream automotive industry. When US tariffs on Chinese upstream products in the automotive industry increase from 0.9% to 4.5%, in US downstream automotive industry export decreases by 0.4%, output decreases by 0.2% and employment decreases by 0.2%. The negative relationships stay the same when checking other industries. Figure B.5 in Appendix B scales up tariffs on upstream imports from China in all the eighteen industries. With each dot representing one simulation, aggregate downstream outputs, downstream exports, and downstream employment in the United States. decrease as tariffs on upstream imports from China increase. Table B.4, Table B.5 and Table B.6 in Appendix B summarize the regressions of downstream outputs, downstream exports and downstream employment on upstream imports tariffs. Through linkages in global value chains, an increase in upstream

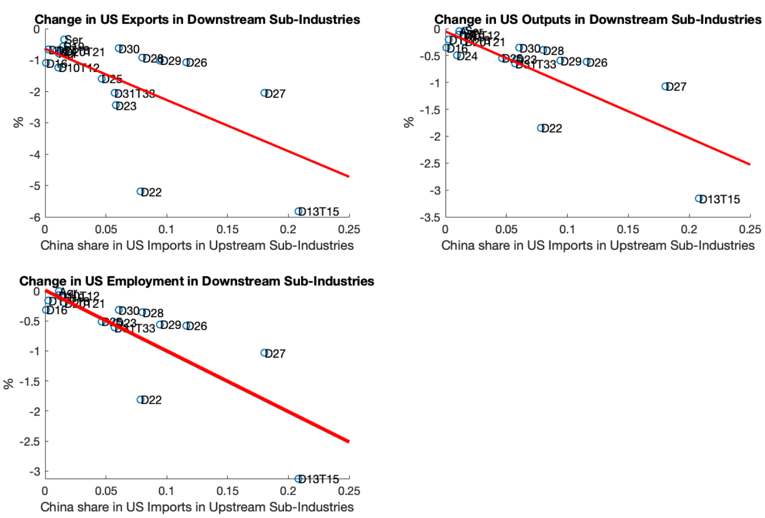

Figure 1.8: Tariff Increase in Upstream Sub-Industries

imports tariffs raises the price and decreases the demand of the downstream outputs produced in the United States. The results are consistent with the observations in Handley and Kamal (2020) that import tariffs on upstream industries have negative effects on downstream exports through the linkage in supply chains, and the observations in Bown et al. (2020) that import tariffs on upstream industries have negative effects on downstream employment. To visualize the heterogeneous impacts on different industries, Figure 1.8 displays the estimated results when the United States increases tariffs on upstream commodities from China in all eighteen industries by six times. Figure 1.8 plots the correlation between China's share in US upstream imports and the percentage change in US downstream outputs, exports, and employment. While upstream tariffs negatively affect downstream outputs, exports and employment in all industries, it especially hits those industries that rely much on China for upstream intermediate goods. Table B.7 and Table B.8 in Appendix B summarize the regression of percentage change in US downstream outputs and employment on China's share in US upstream imports. To see the impacts through

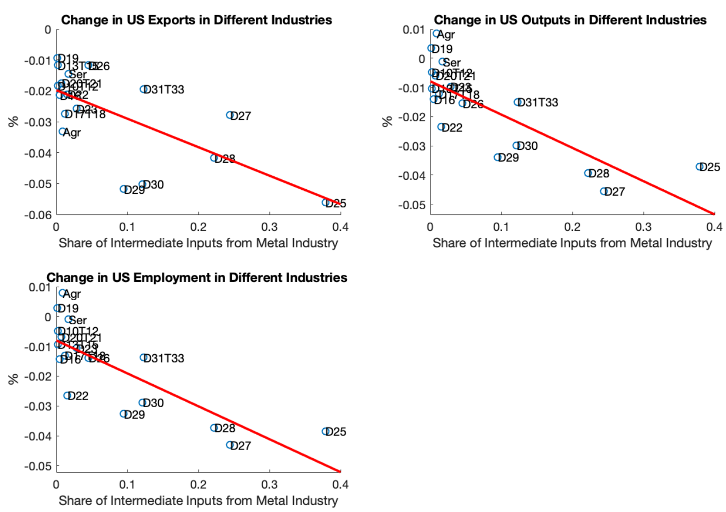

Figure 1.9: Tariff Increase in Metal Industry

cross-industry linkages, this subsection evaluates how imports tariffs on one industry affect other industries. For example, Figure 1.9 displays the results when the tariff on Chinese metal increases by six times, from 2% to 12%. This action especially hits the US industries that rely much on metal, such as fabricated metal products (D25), with output decreasing by 0.037%, electrical equipment (D27), with output decreasing by 0.046%, machinery (D28), with output decreasing by 0.039%, motor vehicles (D29), with output decreasing by 0.034%; and other transport equipment (D30), with output decreasing by 0.030%.

1.5.2 The Two Rounds of the US-China Trade War

When the United States increased tariffs on Chinese exports, the first round of the 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 of the trade war by scaling up tariffs on upstream commodities (stage-1 outputs), and mimics the second round by scaling up tariffs on downstream commodities (stage-2 outputs). Although this exercise does not replicate 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"

% 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 1.4: Compare the two rounds trade war

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 the counterfactual exercise tairffs on intermediate goods particularly means tariffs on the "snake" intermediate goods. Based on the calibration of the eighteen-industry economy, Table 1.4 compares the estimated results when the United States multiplies tariffs on all upstream imports from China by three times (1^{st} round trade war), and when the United States multiplies tariffs on all downstream imports from China by three times (2^{nd} round trade war). Although this exercise is not same as the real trade war, it is effective to assess the impacts of the two rounds of the trade war on the upstream producers, the downstream producers and the consumers in the United States. In Table 1.4, 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, causing US consumers to be more negatively affected through a bigger increase in price level. As for the producers in the United States, the first round trade war benefits the upstream industries and hurts the downstream industries in terms of outputs and employment. This is because the first round protects the domestic competitors which are the upstream industries in the United States, but raises the production costs of the downstream industries in the United States. 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 domestic competitors which are the downstream industries in the United States, but raise the production costs of the upstream industries in the United States since in the model stage-2 outputs are used as "roundabout" intermediates in the production of upstream goods. After checking model validity, this subsection quantitatively simulates the two rounds of the trade war by plugging in the tariff change in HS products. Table B.9 in Appendix B summarizes the mainly targeted products in each round of the trade war. Table 1.5 displays the top hit and benefited US industries in each round. For example, in the first round the United States 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 changes 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%. In summary, during the trade war between January 2018 and December 2019, the top hit industries are the agricultural and automotive industries. The model estimates that, taking global-value-chain reshaping into account, output in the agricultural sector drops by 1.2% and the output in automotive industry drops by 3.9%.

Round	Top Hit		Top Benefited	
1^{st}	Automotive	-3.40%	Electrical Machinery	4.32%
1^{st}	Agriculture	-0.72%	Machinery	0.58%
2^{nd}	Chemical	-0.82%	Textile	0.98%
2^{nd}	Agriculture	-0.51%	Rubber and Plastic	0.05%

Table 1.5: Two Rounds % Change in US Output

1.5.3 The Welfare Impacts of the US-China Trade War

As the trade tension between the United States and China escalates, countries such as Vietnam benefit from shifts in global value chains. Figure 1.10 plots the time series of US goods imports from China and Vietnam. From year 2018 to year 2019, US goods imports from China plunged $87.5 billion, while US goods imports from Vietnam surged $17.5 billion. To rationalize the observation this subsection calibrates an economy of four countries, which are the United States, China, Vietnam, and the rest of the world, and two sectors, goods and service. Appendix B covers the calibrated prameters. For simplicity, in this four-country, two-sector economy, producitivty T is country and sector-specific but not stage-specific. The model estmiates that from

January 2018 to December 2019 the United States 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.

VNM	0.18
CHN	−0.32
USA	−0.08
ROW	0.03

Table 1.6: % Change in Real Income

The welfare effect of the trade war is estimated by the percentage change in aggregate real income. In the multi-sector model aggregate income in country i is the sum of wage income and tax income in country i, and the aggregate real income in country i is measured as

$$\frac{w_i L_i + Tr_i}{P_i} \tag{1.49}$$

Table 1.6 summarizes the estimated welfare effect of the trade war. The model estimates that, from January 2018 to December 2019, in terms of aggregate real income, the trade war costs China \$35.2 billion, or 0.29% of GDP in 2017, costs the United States \$15.6 billion, or 0.08% of GDP in 2017, and benefits Vietnam by \$402.8 million, or 0.18% of GDP in 2017.

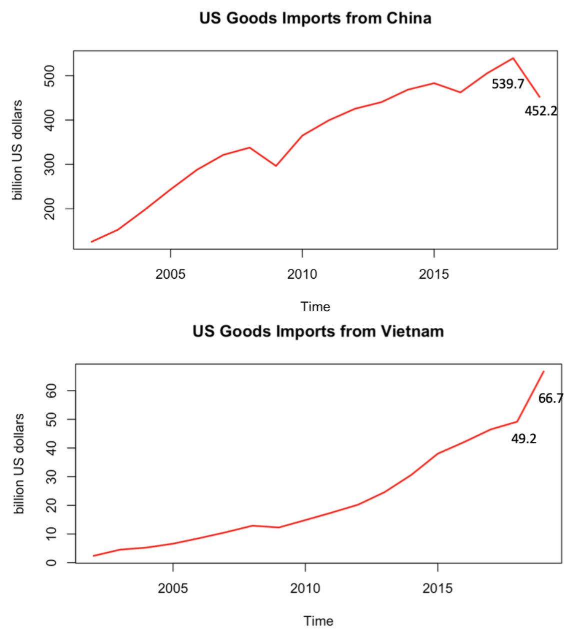

Figure 1.10: US goods imports from China and Vietnam

1.6 Conclusion

This paper studies the heterogeneous impact of the US-China trade war in the presence of global value chains. By building a two-stage Eaton-Kortum model this paper finds that increasing tariffs on intermediate goods from China especially hits US industries that rely heavily on the targeted Chinese intermediate goods. The model justifies the obervations in Handley and Kamal (2020), and Bown et al. (2020) that upstream import tariffs have negative efffects on downstream exports, output and employments. This paper also quantifies the impacts of the two rounds of the trade war by comparing the tariff increase in intermediate goods and consumption goods. This paper finds that a tariff increase in intermediate goods benefits the domestic industries that produce the targeted intermediate goods but hits the domestic industries that rely on the targeted intermediate goods. In addition, compared with a tariff increase in intermediate goods, a tariff increase in consumption goods causes a bigger rise in the domestic consumer price index. Finally, this paper estimates the welfare effects of the trade war by calibrating an economy with the United States, China and Vietnam. The model estimates that the trade war hurts China and the United States, while benefitting 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.

Chapter 2

The Collapse of International Trade during the Financial Crisis

2.1 Introduction

During the recession of 2008-2009, the U.S. experienced a significant collapse in international trade. From the beginning to the end of the recession, imports-to-GDP ratio declines by 15.7% and exports-to-GDP ratio declines by 10%. Figure 1. plots the import and export adjusted by GDP since 1970s with recession periods shaded in grey bars, and Table 1. summarizes the statistics of those historical data. Both the graph and table show that the reduction in trade-to-GDP ratio in the recession of 2008-2009 appears deeper than most declines in the past years, and only the recession in 2001 is relatively comparable. Besides the magnitude, the 2008-2009 collapse of trade is also notable in terms of its rapidness. Both imports and exports plummet to trough within one year, and bounce back to trend in the following 12 to 13 months. Compared with GDP which declines in 18 months and recovered in 30 months, the contraction and recovery in trade volume occurs in a shorter period of time. So what

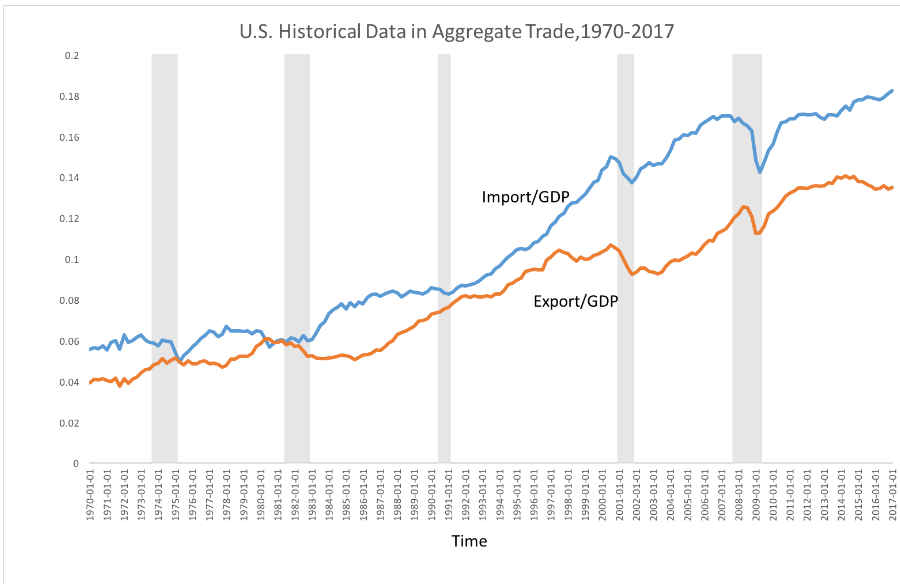

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Figure 2.1: U.S. Historical Data in Aggregate Trade, 2012 U.S. dollar

causes the the uniqueness of the 2008-2009 trade collapse? Due to the financial crisis the recession of 2008-2009 is companied with a dramatic increase in financial friction. As it is shown in Figure 2., the spread between corporate bonds and and 10-year treasury kept climbing since early 2007, and reached its unprecedented maximum by the end of 2008. Furthermore, Table 2.1 and Table 2.2 shows that the length of expansion and recovery of financial friction is consistent with the length of contraction and recovery of trade volume. Motivated by those facts, this paper aims to explain

Table 1. Percentage Changes in Exports/GDP and Imports/GDP

	2008	
	Recession	From Peak
Exports/GDP	-10.00%	-10.40%
Imports/GDP	-15.70%	-16.40%
	2001	
	Recession	From Peak
Exports/GDP	-7.80%	-10.00%
Imports/GDP	-6.70%	-8.60%
	Avergae 1970s-1990s	
	Recession	
Exports/GDP	0.20%	
Imports/GDP	-3.00%	

the influence of increasing financial friction on the collapse of international trade. According to Chor and Manova 2012, exporters and importers face prepaid expense occuring in international trade, and need to take out loans to cover those expense. Therefore, a rise in financial friction impedes international trade by increasing the difficulty of borrowing. This paper inherits the intuition from Chor and Manova, and improves on their research by investigating the global impact of financial crisis. The recession of 2008-2009 is a global recession with financial crisis spreaded around the world. Both U.S. and its trading partners are affected. Therefore, could the exceptional trade collapse be arrtibuted to the joint financial shocks in the U.S. and its trading partner. Could the results be different if the U.S. is the only country hit by the financial crisis?

To answer those questions, this paper uses an two-country International RBC model, where households from home and foreign countries consume and invest a final

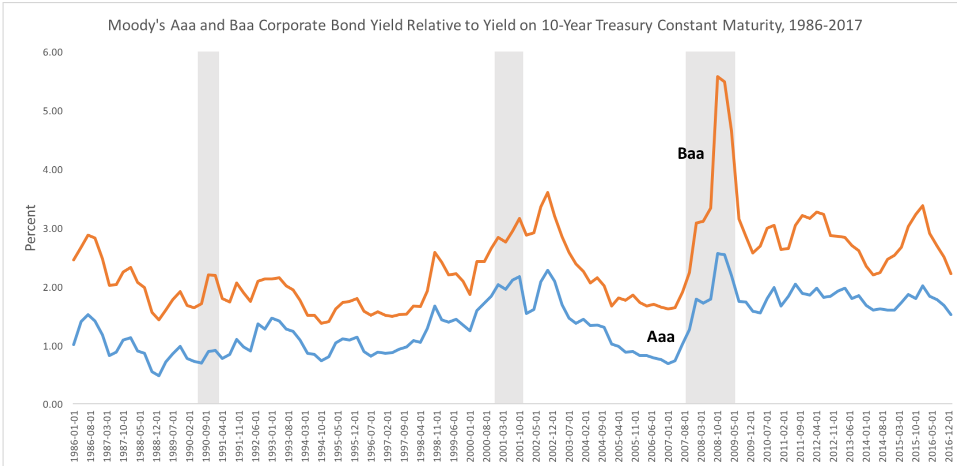

Figure 2.2: Spread between Aaa/Baa Corporate Bond and 10-year Treasury

Table2.1 Rates of Contraction and Recovery ,recession of 2008-2009

	No. months (peak to trough)	No. months (trough back to trend)
GDP	18	30
Imports	12	12
Expoorts	7	13

Table2.2 Rates of Change in Spreads, recession of 2008-2009

	No.months(to peak)	No. months (peak back to trend)
Aaa-10year	10	12
Baa-10year	10	12

good. The final good is produced with intermediate inputs from home and foreign countries. In both countries, final-good firm accumulates capital and takes out a loan to cover its prepaid expense on intermediate inputs, with the size of the loan capped by the value of capital stock. In this model, trade volume between home and foreign countries depends on the joint effect of financial friction in both countries. This mechanism captures the fact that the financial crisis hit both the U.S. and its trading partners, and attributes the trade collapse to the bilateral financial shocks in import and export countries. The model implies that the global impact of financial crisis plays key role in explaining the U.S. trade collapse of 2008-2009.

Related literature (Chor and Manova 2012) provided numerical evidence of a negative correlation between the a country's credit market tightness and its exports. The most related literature to this topic is established by Manova and Chor (2008) and Manova (2012). In these paper, they build a static partial equilibrium model where exporters get external finance to cover fixed cost and working capital. They indicate that countries with higher financial friction exported less to the U.S during the peak of financial crisis. This paper differs from theirs in the following aspects: First, Manova et. al. focus on the peak of financial crisis and compare the exports of different countries within that period, while this paper compares the U.S. trade collapse of 2008-2009 with trade downturns in previous recession periods. Second, Manova et. al. use a static model and demonstrate the impact of financial friction on exports with comparative statics. This paper improves on their work by using a dynamic model which can do comparative statics at steady state, as well as track the transition of trade and GDP following a credit shock. The transition process explains why trade volume contracted and recovered much faster than GDP. Third, when explaining the trade collapse Manova et. al. highlight the effect of financial friction in export countries, while this paper emphasizes the joint effect of the financial friction in both import and export countries.

Besides the impact of financial friction, literatures in this field mainly explain the trade collapse from two other perspectives: vertical specialization and compositional effects. Giovanni and Levchenko (2009) find that cross-border vertical linkage plays a key role in transmitting shocks, which causes the collapse in international trade. Hummels, Ishii and Yi (2001) and Yi (2003) provided evidence of a significant increase in vertical trade in recent decades. Bems, Johnson and Yi (2011) use empirical evidence to indicate that vertical specialization is essential in explaining the trade collapse during the Great Recession. Another kind of explanation focuses on compositional effect. Proponents of this explanation point out that international trade happens in sectors that collapse the most. Engel and Wang (2011) show that international trade in durable goods is more sensitive to shocks than trade in nondurable goods. Bem, Johnson, and Yi (2013) emphasize the asymmetries in expenditure changes across sectors. They show that trade dropped more than GDP during the recession because changes in expenditure were largest in the most traded sectors. Eaton, Kortum, Neiman and Romalis (2016) demonstrates that during the Great Recession, declines in durable investment efficiency shift the final spending away from tradable sectors.

The paper is structured as follows. Section 2 presents the two-country IRBC model with financial friction, and the parameterized results derived from the model. Section 3 explores the direction for further improvements.

2.2 Model

2.2.1 Households

This paper uses a two-country IRBC model. In this model, households from country i where $i \in \{H, F\}$ maximize their expected life-time utility $E_0 \sum_{t=0}^{\infty} \beta^t U_t(C_t^i, N_t^i)$, where

$$U_t(C_t^i, N_t^i) = lnC_t^i - \theta \frac{{N_t^i}^{1+\chi}}{1+\chi} \tag{2.1}$$

C_t^i in the consumption of final goods in country i, N_t^i is labor supplied by households in country i, and β is the discount factor. Households receive wage income at wage w_t^i, dividend distribution Π_t^i from the firm, and hold a risk-free bond B_t^i which can be traded cross-border at interest rate r_t, so the households face the budget constraint:

$$C_t^i + B_{t+1}^i \leq w_t^i N_t^i + \Pi_t^i + (1 + r_t) B_t^i \tag{2.2}$$

The first order conditions with respect to C_t^i, N_t^i and B_t^i generate:

$$\theta {N_t^i}^{\chi} = \frac{1}{C_t^i} w_t^i \tag{2.3}$$

$$\frac{1}{C_t^i} = \beta E_t \frac{1}{C_{t+1}^i}(1 + r_{t+1}) \tag{2.4}$$

2.2.2 Firms

The production of final good contains two stages. In the first stage, intermediate-sector firm from each country produces a country-specific intermediate good, and the intermediate good is produced linear in labor, with the production function

$$m_i = z_i N_i \tag{2.5}$$

where m_i is the quantity of intermediate goods produced in country i and z_i is the labor productivity in country i. Let q_i be the price of intermediate good in country i, the frim's problem in intermediate sector in country i where $i \in \{h, f\}$ becomes

$$\max_{N_i} q_i z_i N_i - w_i N_i \tag{2.6}$$

In the second stage, final-sector firm uses capital and a CES composition of country-specific intermediate goods to produce the final good. The production function is Cobb-Douglas:

$$Y_i = A_i K_i^{\alpha} M_i^{1-\alpha} \tag{2.7}$$

where Y_i is production of final goods in country i, K_i is the capital used to produce final goods in country i, A_i is the productivity of final goods in country i, and M_i is the composite intermediate inputs used in country i and

$$M_i = (m_{ii}^{1-\frac{1}{\epsilon}} + m_{ij}^{1-\frac{1}{\epsilon}})^{\frac{1}{1-\frac{1}{\epsilon}}} \tag{2.8}$$

where m_{ij} is the intermediate goods consumed in country i and produced in country j. ϵ is the elasticity of substitution between country specific intermediate goods. In other words, intermediate goods are tradable, while final goods are nontradable and can only be consumed and invested domestically.

Besides, the final-sector firms accumulate capital with the investment financed out of its dividends, and for simplicity assume firms issue no interemporal bonds. So far the firms in final sector face the problem:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t^i}{\lambda_0^i} (A_t^i K_t^{i\alpha} M_t^{i1-\alpha} - Q_t^i M_t^i - I_t^i) \tag{2.9}$$

$$I_t^i = K_{t+1}^i - (1-\delta) K_t^i \tag{2.10}$$

where λ_t^i is the lagrangian multiplier of households' budget constraint, and Q_t^i is the price index of the composite intermediate good M_t^i. To add financial friction, it is assumed that the composite intermediate inputs has to be paid in advance. The final-sector firm takes out an intraperiod loan to cover this pre-paid expense, and the size of the loan is bounded above by the value of its capital stock. Suppose at the time of contracting the loan the value of capital is uncertain, with probability ζ_t^i the lender can recover full value of K_t^i, and with probability $1 - \zeta_t^i$ the value of capital drops to zero. So the final-sector firm also faces a collateral constraint:

$$Q_t^i M_t^i \leq \zeta_t^i K_t^i \tag{2.11}$$

Let μ_t^i be the lagrangian multiplier of the collateral constraint. The first order condition with respect to M_t^i and K_t^i are

$$(1-\alpha) A_t^i K_t^{i\alpha} M_t^{i-\alpha} = (1+\mu_t^i) Q_t^i \tag{2.12}$$

$$\lambda_t^i = E_t \beta \lambda_{t+1}^i (\alpha A_{t+1}^i K_{t+1}^{i\,\alpha-1} M_{t+1}^{i\,1-\alpha} + (1-\delta) + \mu_{t+1}^i \zeta_{t+1}^i) \tag{2.13}$$

By equation (13) capital-to-composite intermediate good ratio at non-stochastic steady state can be derived as

$$\frac{K^i}{M^i} = (\frac{A^i\alpha}{\frac{1}{\beta} - (1-\delta) - \mu^i\zeta^i})^{\frac{1}{1-\alpha}} \tag{2.14}$$

If collateral constraint binds at steady state,

$$Q^i = \zeta^i \frac{K^i}{M^i} \tag{2.15}$$

Also by equation (12) at steady state

$$Q^i = \frac{1-\alpha}{1+\mu^i} A^i K^{i\alpha} M^{i-\alpha} \tag{2.16}$$

combine (14), (15) and (16) when collateral constraint binds at steady state

$$\mu^i = \frac{1-\alpha}{\zeta^i}(\frac{1}{\beta} - (1-\delta)) - \alpha \tag{2.17}$$

Since μ^i represents the tightness of collateral constraint, by equation (17) the contraint get tighter when ζ^i decreases.

For simplicity we starts with the model where two countries are symmertic, so $z^h = z^f = z$,$A^h = A^f = A$, and $\zeta^h = \zeta^f = \zeta$. Also, let $\tau \in (0, 1)$ be the iceberg cost. Because the intermediate goods is produced linearly in labor, the price of domestic intermediate good $p_h = \frac{w}{z}$, the price of foreign intermediate good $p_f = \frac{w(1+\tau)}{z}$, and the price index of composite intermediate goods becomes:

$$Q = \{(\frac{w}{z})^{1-\epsilon} + (\frac{w(1+\tau)}{z})^{1-\epsilon}\}^{\frac{1}{1-\epsilon}} \tag{2.18}$$

and

$$w = z(\frac{Q^{1-\epsilon}}{1+(1+\tau)^{1-\epsilon}})^{\frac{1}{1-\epsilon}} \tag{2.19}$$

Let m_h be the intermediate goods produced and consumed in home country, m_f be the intermediate goods produced in home country and consumed in foreign country.Therefore

$$N_h = \frac{m_h}{z} + \frac{m_f(1+\tau)}{z} \tag{2.20}$$

By equation (3) and (20)

$$[\frac{m_h}{z} + \frac{m_f(1+\tau)}{z}]^{\chi} M = \frac{1}{\theta}\frac{M}{C} w \tag{2.21}$$

Using feasible constraint at steady state,

$$C + K - (1-\delta)K = AK^{\alpha}M^{1-\alpha} \tag{2.22}$$

and

$$\frac{C}{M} = A(\frac{K}{M})^{-\alpha} - \delta\frac{K}{M} \tag{2.23}$$

Since $\frac{K}{M}$ is a function of parameters by equation (14) , $\frac{C}{M}$ is a function of parameters. Also w is a function of parameter by equation (16) and (19), w is a function of parameters. So the LHS of equation (21) is in parameters, and the RHS is in m_h and m_f By CES composition

$$\frac{m_f}{m_h} = (\frac{q_f}{q_h})^{-\epsilon} = (1+\tau)^{-\epsilon} \tag{2.24}$$

with (21) and (24), m_f can be pinned down and the imports-to-GDP ratio is measured by $\frac{q_f m_f}{Y}$ at the steady state. With the following parameter values: $\beta = 0.99$, $\alpha = 0.33$, $\delta = 0.02$, $\theta = 7.71$, $\chi = 1$, $\epsilon = 6.8$,$\tau = 0.1$, $A = 1$ and $z = 1$, Figure 3. plots the change in imports-to-GDP ratio at steady state with ζ decreases from 0.1 to 0.01. At the beginning, ζ is high enough so that the collateral constrait does not bind and imports-to-GDP ratio does not change in ζ. As ζ keeps decreases, collateral constrait starts to bind and imports-to-GDP ratio declines. Since two countries are symmetric

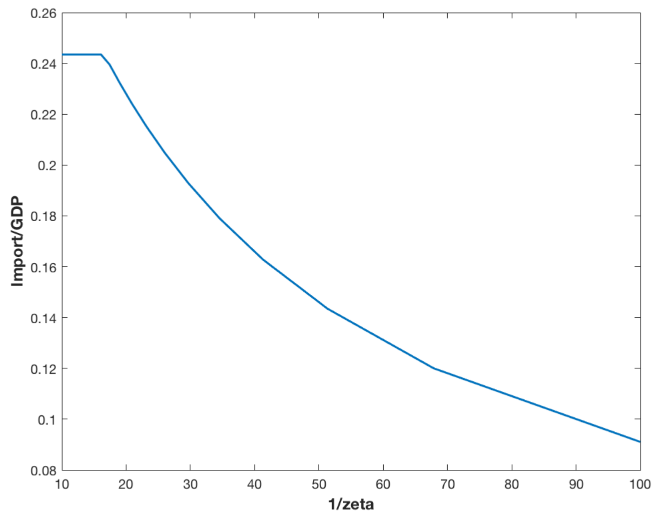

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Figure 2.3: Imports/GDP at steady state with change in zeta

in this case, there is no cross-border borrowing $B_t = 0$, and imports-to-GDP ratio is same as exports-to-GDP ratio.

Now let's keep the symmetric framework, and track the transition of equilibrium followed by a shock in ζ. The social planner faces the problem:

$$\max_{K^{i'}} V^i(K^i) = lnC^i - \theta \frac{N^{i^{1+\chi}}}{1+\chi} + \beta V^i(K^{i'}) \tag{2.25}$$

s.t.

$$C^i + K^{i'} - (1-\delta)K^i \leq A^i K^{i^{\alpha}} M^{i^{1-\alpha}} \tag{2.26}$$

$$Q^i M^i \leq \zeta^i K^i \tag{2.27}$$

Suppose collateral constraint binds and the social planner problem can be written in terms of C, K, K', N only:

$$\max_{K'} V(K) = lnC - \theta \frac{N^{1+\chi}}{1+\chi} + \beta V(K') \tag{2.28}$$

$$C + K' - (1-\delta)K \leq AK^{\alpha}[zN(1 + (1+\tau)^{1-\epsilon})^{\frac{1}{\epsilon-1}}]^{1-\alpha} \tag{2.29}$$

$$\theta N^{\chi} = \frac{1}{c} \frac{Qz}{((1 + (1+\tau)^{1-\epsilon})^{\frac{1}{1-\epsilon}}} = \frac{\zeta K}{cN} \tag{2.30}$$

Figure 4. plots the impulsive response of imports-to-GDP ratio to shocks in ζ at

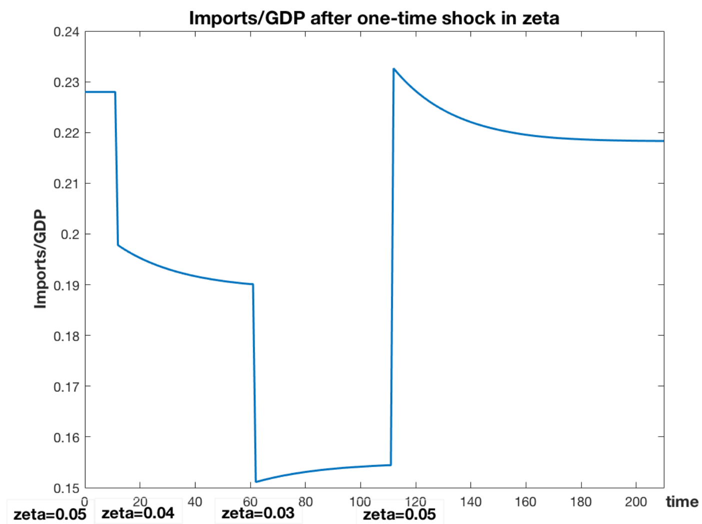

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Figure 2.4: Imports/GDP after one-time shock in zeta

different time. As it can be seen, when the financial friction in both countries gets stronger simultaneously, imports-to-GDP ratio decreases at the steady state.

2.3 Further Improvements

So far two countries are symmetric and receive the same shock at the same time. To better evaluate the whether global financial crisis exacerbates the trade collapse, we could compare the two-symmetric-country model with the model where only the home country is hit by a shock in ζ, while the foreign country faces a constant ζ, and explore how this change affects the trade-to-GDP ratio differently, and whether the domestic financial shock will be transmitted to the foreign country.

Chapter 3

Modeling Global Value Chains

3.1 Introduction

This chapter introduces a literature review on the structural modeling of global value chains (GVCs). As international fragmentation and global sourcing become increasingly popular, research in global value chains has been burgeoning in the past few decades. To understand how the production process is established across the world, international economists explore different approaches to model global value chains. In this chapter, we broadly divide the literature on the structural modeling of GVCs into two strands: the one that adopts the country-level approach and the one that adopts the firm-level approach. Depending on the research questions and data available, each approach has its advantage and drawback, which will be discussed in details in the following sections.

3.2 The Country-Level Approach

Facilitated by globalization, countries are able to specialize in different production stages of final goods from different industries. Given that, multi-country general equilibrium models are commonly used to study the formation of global value chains. In this type of model, technology in each country is captured by a representative firm production function, and countries differ in features that determine their specialization. In a more disaggregate setting, production features are not only country-specific but industry-specific. Since firms in each country or industry behave exactly the same, it is a country/industry instead of an individual firm that determines its specialization. We call this type of approach the country/industry-level approach. Results generated by models following this approach can be mapped into the observations from the World Input-Output Table, an open data source commonly used in the study of GVCs. Given the accessibility of data, models in this strand are less challenging to calibrate.

A classic example of the country-level approach is the model introduced in Eaton and Kortum (2002). In Eaton and Kortum (2002), trade is motivated by comparative advantage. Firms in each country share the same production function with their total factor productivity following a Frechet distribution characterized by parameters dominating comparative advantage. Since market is perfectly competitive, under the strategy that goods are only imported from the place offering the lowest price, each country ends up producing goods it has comparative advantage in. Similarly, Caliendo and Parro (2015) incoporates the sectoral linkage in the Eaton and Kortum (2002) model. By depicting the across-sector GVC linkage, Caliend and Parro (2005) estimates the welfare effect of tariff change in NAFTA. In Caliendo and Parro (2005) final goods produced in one stage are also used as intermediate inputs, known as the roundabout intermediate goods. To better differentiate the stages in real production process, Antras and de Gortari (2020) builds a multi-country model where final goods are produced through multiple stages. This structure allows countries to specialize in different stages, which inevitably involves intermediate goods crossing borders multiple times. Given the repetitive tariff accumulated through frequent boarder crossing, trade in downtream industries is more elastic to tariff changes and downstream industries are more likely to located at certralized places. Also motivated by comparative advantage, Baldwin and Venables (2013) builds a two-country model to study how the offshoring process depends on the production structure. Besides comparative advantage, factor endowments as claimed in Heckscher-Ohlin Model also determine the establishment of global value chains. Using the US make-use table, Antras et al.(2012) finds that upstream manufacturing industries are more capital and skilled-labor intensive than downstream industries, which suggests capital and skilled-labor abundant countries are more likely to specialize in upstream industries. Lee and Yi (2018) develops a multi-country model that takes both comparative advatange and Heckscher-Ohlin framework into account. The model is built on Antras and de Gortari (2020). By setting production at different stage using factors with different intensities, Lee and Yi (2018) allows heterogenous workers to endogenously choose occupation and the industry they would like to work in. Sposi et al.(2020) inherits the features in Lee and Yi (2018) but develops to a dynamic environment. In Sposi et al. (2020), two countries differ in initial stock of production factors: capital and labor, both immobile between countries. Final goods are produced through multiple stages, with production technology at each stage involving different intensity of capital and labor. By letting each country accumulate domestic capital, they find that as GVC accelerates capital accumulation, capital accumulation on the other hand reinforces the pattern of GVC, driving capital-abundant country to specialize in capital-intensive production stage. Limited by the framework of the country/industry-level approach, most literature in this strand adopts static environment. Sposi et al. (2020) makes a contribution by introducing the dynamic mechanism. However, to make the model solvable, they adopt a two-country environment and do not allow domestic household to invest on foreign capital, which is a major obstacle to unveiling the relationship between FDI and GVC participation. As can be seen, the country/industry-level approach is successful in capturing some essential determinants (productivity, the endowment of production factors) of the GVC participation of a country or an industry, but this approach is not ideal when exploring questions involving certain topics such as the uncertainty of shocks, firm behaviors, FDI, etc. For example, how does the uncertainty of trade policy impact GVC; what is the firm dynamic under the environment of GVC. Some of these questions can be answered using the firm-level approach, which will be discussed in the following section.

3.3 The Firm-Level Approach

In contrast to the country/industry-level approach where firms in the same country/industry share the same technology and behave exactly the same, the firm-level approach allows each individual firm to be distinguished by different features and make individual decisions based on its own features. Eventually, it is the aggregation of individual firm's behavior that determines the GVC participation at macro level.

Melitz (2003) plays a significant role in the study of firms' behaviors in international trade. Using a dynamic model with heterogeneous firms, Melitz (2003) finds that the exposure to trade leads more productive firms to export and the least productive firms to leave the market, which promotes the aggregate productivity of an industry. In Melitz (2003), firms produce differentiated products in a monopolistic competitive market, following the technology of increaseing returns to scale (IRS). The operating profits genetrated under IRS technology are used to cover the fixed costs of entering domestic and foreign markets, determining firms' decisions to produce and export. Builds on the framework of Melitz (2003), Helpman et al. (2003) studies firm's decision making in a multi-country environment with the options of trade and FDI. To serve foreign consumers firm chooses between direct exporting or selling through its invested foreign subsidiary, a trade-off between low-fixed-high-operating cost and low-operating-high-fixed cost. This framework is inspirational in studying GVC establishment in the presence of FDI, which helps to understand the impact of trade cost and FDI regulation on the shaping of GVCs. However, in Melitz (2003) and Helpman et al.(2003), tradable final goods are produced through one stage with labor input being the only factor of production. The lack of intermediate goods fails to capture the input-output linkage among countries, which is also the essence of GVCs. To overcome this drawback, recent literature in firm-level approach introduces trade in intermediate goods. For example, to evaluate the impact of trade policy uncertainty, Steinberg (2019) builds a dynamic general equilibrium model with heterogeneous firms and stochastic trade costs, where differentiated goods produced by domestic firms are traded across countries and then aggregated into non-tradable final goods in the use of consumption, investment and intermediate inputs. Antras and Helpman (2004) develops a two-country model where heterogeneous final-good producers choose between buying intermediate goods domestically or outsourcing from the foreign land. Similarly, Antras et al. (2017) and Gopitath and Neiman (2014) establish a multi-country model where heterogeneous final-good producers,differing in productivity, decide whether and where to import intermediate goods. Besides, Tintelnot (2017) develops a multi-country model which allows heterogeneous firms to choose production locations and invest on foreign countries for the purpose of establishing export platform. Compared with the country-level approach, models adopting the firm-level approach behave more efficient in depicting the reality, since in real life it is the firm rather than the country or industry that makes sourcing, producing and exporting decisions, and determines the dynamic of GVCs. However, restricted by the availability of firm-level data, unlike the country-level-approach models whose results can be mapped in to the cells in the World Input-Output Table, models in the this strand are more challenging to calibrate.

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Appendix A

Appendix A

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

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

$$\pi_{l^*_{is}} = \frac{(T^1_{js}(v_{js}\tau^1_{jks})^{-\theta})^{1-\alpha_s} \times (T^2_{ks})^{\alpha_s}(v_{ks}{}^{\alpha_s}\tau^2_{kis})^{-\theta}}{\Theta_{is}} \tag{A.1}$$

where

$$\Theta_{is} = \sum_{l'_{is} \in \mathcal{J}^2} (T^1_{j's}(v_{j's}\tau^1_{j'k's})^{-\theta})^{1-\alpha_s} \times (T^2_{k's})^{\alpha_s}(v_{k's}{}^{\alpha_s}\tau^2_{k'js})^{-\theta} \tag{A.2}$$

and

$$v_{is} = \gamma_{is}^{-\gamma_{is}}(1-\gamma_{is})^{\gamma_{is}-1} w_i^{\gamma_{is}} P_{is}^{1-\gamma_{is}} \tag{A.3}$$

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}:

$$p_{is}(z) = p_{is}(l^*_{is}) \tag{A.4}$$

l^*_{is} is choosen to solve the cost minimization problem:

$$l^*_{is} = arg \min_{l_{is} \in \mathcal{J}^2} p_{is}(l_{is}) \tag{A.5}$$

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

$$Q_{is} = (\int_0^1 p_{is}(z)^{1-\sigma} dz)^{\frac{1}{1-\sigma}} \tag{A.6}$$

$$Q_{is} = \kappa(\Theta_{is})^{-1/\theta} \qquad where \qquad \kappa = [\Gamma(\frac{\theta + 1 - \sigma}{\theta})]^{1/(1-\sigma)} \tag{A.7}$$

Let P_i be the price index of aggregator U_i:

$$P_i = \prod_{s=1}^{S} (\frac{Q_{is}}{b_s})^{b_s} \tag{A.8}$$

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

$$P_{is} = \prod_{s'=1}^{S} (\frac{Q_{is'}}{b^s_{s'}})^{b^s_{s'}} \tag{A.9}$$

A.3 Market Clear Conditions

Goods Market:

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

$$I_{is}^{n}(z) = \prod_{s'=1}^{S} \left(M_{is'}^{n}(z)\right)^{b_{s'}^{s}} \tag{A.10}$$

where

$$M_{is'}^{n}(z) = (\int_{0}^{1} (x_{is'}^{2}(z'))^{(\sigma-1)/\sigma} dz')^{\sigma/(\sigma-1)} \tag{A.11}$$

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

$$\sum_{i \in \mathcal{J}} y_{is}^{1}(z) = \sum_{i \in \mathcal{J}} x_{is}^{1}(z) \tag{A.12}$$

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

$$\sum_{i \in \mathcal{J}} y_{is}^{2}(z) = \sum_{i \in \mathcal{J}} [c_{is}(z) + x_{is}^{2}(z)] \tag{A.13}$$

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

$$L_i = \sum_{s \in \mathcal{S}} \sum_{n=1}^{2} L_{is}^{n} \tag{A.14}$$

where

$$L_{is}^{2} = \frac{\gamma_{is}}{w_i} \sum_{j \in \mathcal{J}} [b_s(w_j L_j + Tr_j) + \sum_{s' \in \mathcal{S}} b_s^{s'} \frac{1 - \gamma_{js'}}{\gamma_{js'}} w_j L_{js'}] \alpha_s Pr(\Lambda_{ijs}^{2}) \frac{1}{1 + t_{ijs}^{2}} \tag{A.15}$$

and

$$L_{is}^1 = \frac{\gamma_{is}}{w_i} \sum_{j\in\mathcal{J}} \sum_{h\in\mathcal{J}} [b_s(w_j L_j + Tr_j) + \sum_{s'\in\mathcal{S}} b_s^{s'} \frac{1-\gamma_{js'}}{\gamma_{js'}} w_j L_{js'}](1-\alpha_s) Pr(\Lambda_{hijs}^{12}) \frac{1}{(1+t_{his}^1)(1+t_{ijs}^2)} \tag{A.16}$$

A.4 Bilateral Trade Flows

$$F_{ijs} = b_s(w_j L_j + Tr_j) Pr(\Lambda_{ijs}^2) \frac{1}{1+t_{ijs}^2} \tag{A.17}$$

$$X_{ijss} = X_{ijss}^{round} + X_{ijs}^{snake} \tag{A.18}$$

$$X_{ijss'} = X_{ijss'}^{round} \tag{A.19}$$

where

$$X_{ijss'}^{round} = b_s^{s'} (\frac{1-\gamma_{js'}}{\gamma_{js'}} w_j L_{js'}) Pr(\Lambda_{ijs}^2) \frac{1}{1+t_{ijs}^2} \tag{A.20}$$

$$X_{ijs}^{snake} = \sum_{k\in\mathcal{J}} [b_s(w_k L_k + Tr_k) + \sum_{s'\in\mathcal{S}} b_s^{s'} \frac{1-\gamma_{ks'}}{\gamma_{ks'}} w_k L_{ks'}](1-\alpha_s) Pr(\Lambda_{ijks}^{12}) \frac{1}{(1+t_{ijs}^1)(1+t_{jks}^2)} \tag{A.21}$$

Appendix B

Appendix B

Figure B.1: source: OECD

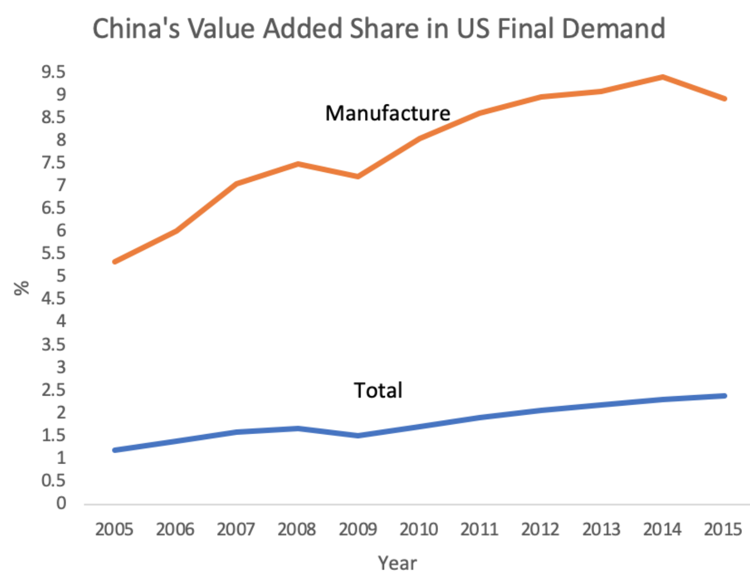

Figure B.2: source: OECD

		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 B.1: 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 B.2: $b_s^{s'}$

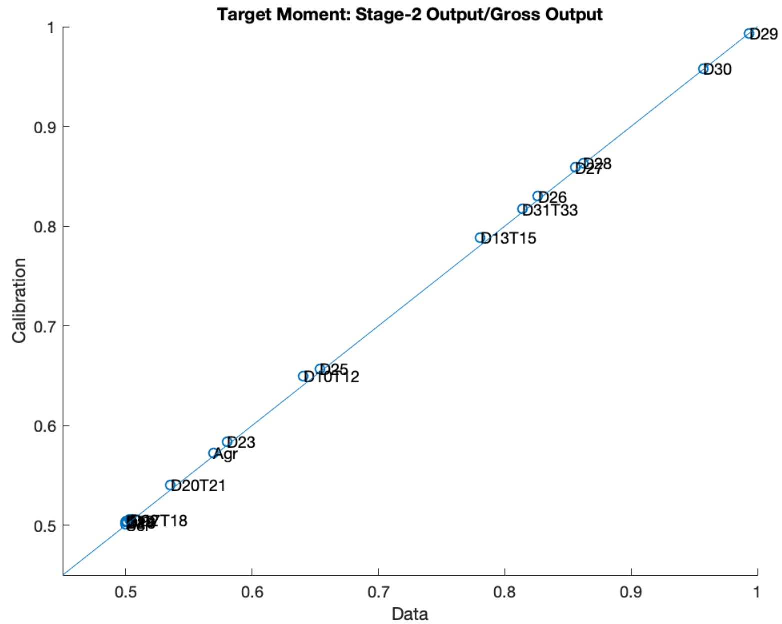

Figure B.3: Calibration of α

	CHN		USA		ROW	
	stage 1	*stage* 2	*stage* 1	*stage* 2	*stage* 1	*stage* 2
	T	T	T	T	T	T
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 B.3: T^n_{js}

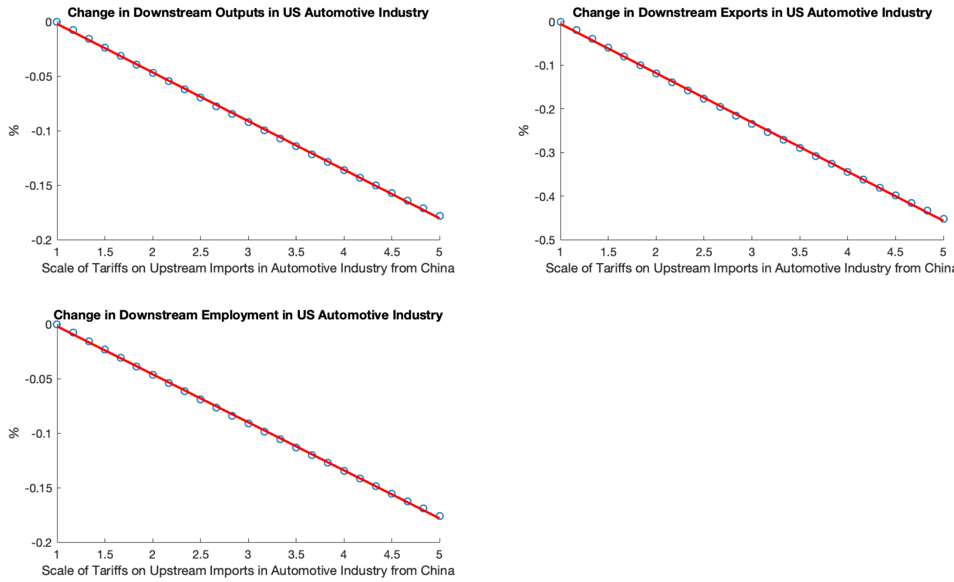

Figure B.4: Increase Tariffs on Upstream Imports in Automotive Industry from China

	$Estimate$	SE	$p-value$
(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 B.4: Dependent Variable: Percentage change in US downstream outputs

	$Estimate$	SE	$p - value$
(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 B.5: Dependent Variable: Percentage change in US downstream exports

	$Estimate$	SE	$p - value$
(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 B.6: Dependent Variable: Percentage change in US downstream employment

	$Estimate$	SE	$p - value$
(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 B.7: Dependent Variable: Percentage change in US downstream outputs

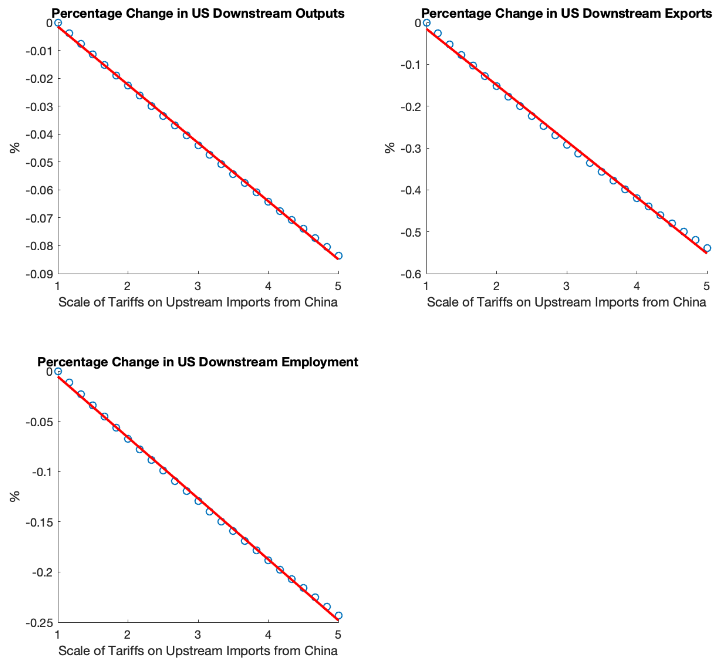

Figure B.5: Increase Tariffs on Upstream Imports from China

	Estimate	*SE*	$p-value$
(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 B.8: 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,aircraft,vessels
2^{nd}	China	textiles, clothing, food, electronic equipment, auto parts
2^{nd}	US	agricultural products, chemicals, metal products

Table B.9: Two Rounds of the Trade War

	Goods	*Service*
VNM	0.02	0.0009
CHN	0.82	0.009
USA	50	50
ROW	1.25	0.33

Table B.10: T_{js}

	Goods	*Service*
VNM	0.38	0.48
CHN	0.39	0.49
USA	0.74	0.60
ROW	0.63	0.56

Table B.11: γ_{js}

Goods	*Service*
0.35	0.98

Table B.12: α_s