ABSTRACT

Title of Dissertation:	ESSAYS ON GLOBAL SUPPLY CHAINS AND TRADE POLICIES
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The structure of international trade has become increasingly complex in recent decades. Advances in productivity, transportation, and information and communications technology (ICT) have significantly changed the nature of cross-border activities between countries, and global supply chains have become a substantial component of the world economy. Despite the importance of global supply chains, most existing studies take them as fixed and generally overlooked their endogenous responses to trade policies and economic shocks. This dissertation examines the role of global supply chains in shaping trade and welfare consequences of modern trade agreements, such as preferential trade agreements (PTAs).

The first chapter of this dissertation studies the trade effect of supply chain reallocations, with a focus on producers' endogenous input sourcing decisions. I first introduce a global sourcing framework where producers optimally choose their input sourcing locations based on trade-offs between variable input prices and fixed sourcing costs. As one of the major characterizations of the global supply chain structure, the distribution of producers' sourcing locations will en-

dogenously respond to economic and trade conditions, amplifying the corresponding impact on input trade flows. Based on the model-implied relationship between individual import values and the number of imported intermediate products for any given sourcing location, I find supporting evidence of this transmission channel using US product-level import data. The estimation results indicate that an increase in expected import values or a reduction in fixed sourcing costs equivalent to a 10% annual average import value would induce around a 1% increase in the number of US producers sourcing from a given location.

To capture the cross-country and cross-sector transmission and spillovers generated by global supply chains, the second chapter extends the global sourcing framework introduced in Chapter 1 to a general equilibrium (GE) structure and further studies the welfare consequences of several trade policy events. In addition to their input sourcing decisions, producers also make market entry decisions, which determine the size of domestic supply chains. These two decisions jointly characterize the supply chain structure in the model. I then calibrate the model to the World Input-Output Database (WIOD) and use it to quantify the trade and welfare consequences of two hypothetical trade policy changes, namely a US-China tariff war and the elimination of all preferential trade agreements. The quantitative analysis reveals two novel angles through which global supply chains transmit shocks. First, allowing endogenous supply chain reallocations amplifies the trade and welfare consequences of shocks to variable trade costs. Second, changes in fixed sourcing costs are essential in welfare evaluation and could generate a larger impact than similar changes in variable trade costs. These results suggest an important role of supply chain reallocations and fixed sourcing costs in shaping the macroeconomic impact of trade shocks.

In the third chapter, I examine dynamic features of global supply chains by investigating the interaction between global supply chains and preferential trade agreements during the Great

Trade Collapse (GTC) and the subsequent recovery. Using time-series data from WIOD, I first empirically test the relationship between bilateral trade flows and PTA status using a gravity specification. The estimated results indicate that a bilateral PTA relation can generate additional effects for supply chain-related (intermediate) trade during post-GTC recovery. I then introduce a novel method to decompose the impact of PTAs into a *direct border price channel* and an *indirect behind-border channel*. With the data structure of WIOT and some additional assumptions, I find that: (i) the structure of global supply chains changed significantly after the GTC, and behaved differently across countries; (ii) the border price channel was dominant before the GTC, the behind-border channel contributed considerably to the recovery of GVC-related trade and accounted for 26% of the aggregate impact. These results suggest an important role of PTAs in securing GVC growth after the GTC.

Essays on Global Supply Chains and Trade Policies

by

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Dedication

To my parents, my love,

and all the abandoned research ideas

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List of Abbreviations

BEC	Broad Economic Categories
CES	Constant elasticity of substitution
CRS	Constant return to scale
EHA	Exact hat algebra
FE	Free entry
GDP	Gross Domestic Product
GE	General equilibrium
GTC	Great Trade Collapse
GVC	Global value chain
HS	Harmonized System
HTS	Harmonized Tariff Schedule
ICT	Information and communication technology
ISIC	The International Standard Industrial Classification
IV	Instrumental variable
NAFTA	The North American Free Trade Agreement
NTB	Non-tariff barrier
OLS	Ordinary Least Square
PTA	Preferential trade agreement
ROW	The rest of the world
SCT	Supply chain transmission
SEA	Socio Economic Accounts
SNA	System of National Accounts (SNA)
WIOD	World Input-Output Database
WIOT	World Input-Output Table
WTO	World Trade Organization
WITS	World Integrated Trade Solution

Chapter 1: Global Supply Chains and Endogenous Input Sourcing

1.1 Introduction

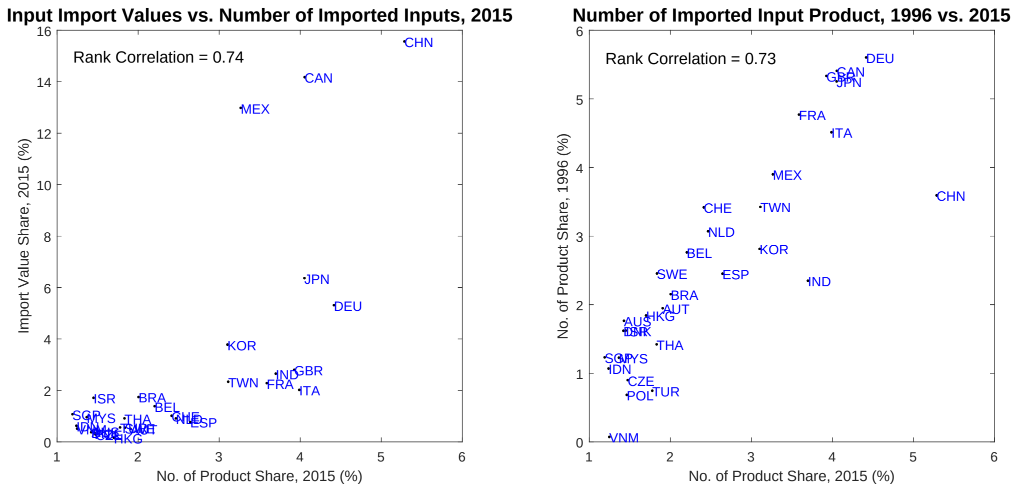
The structure of international trade has become increasingly complex in recent decades. On the one hand, advances in productivity, transportation, and information and communication technology (ICT) have significantly reduced production and shipping costs across country borders and made multinational production more appealing. On the other hand, the rapid pace of global integration, as represented by the foundation of the World Trade Organization (WTO) and the proliferation of preferential trade agreements (PTAs), has provided investors and producers with a stable environment to expand their businesses to foreign markets. As an important linkage of production across countries, global supply chains have become a substantial component of the world economy. Nowadays, trade in intermediate inputs consists of around 60% of international trade, and more than 20% of intermediate inputs used in manufacturing industries are produced in foreign countries[1].

Table 1.1: Rank Correlation: Number of Imported Manufacturing Inputs, US top 30 Suppliers. Source: US Census Bureau and author's calculation.

	2000	2005	2010	2015
Rank Corr. w. 1996	0.99	0.91	0.85	0.73

[1] Author's calculation for the year 2014 based on the World Input-Output Database.

Figure 1.1: Correlation Between Import Values and No. of Imported Products: Top 30 Foreign Suppliers of US Manufacturing Inputs



Source: US Census Bureau and author's calculation. A product is defined at the HTS 10 digit level. Intermediate inputs are classified based on the BEC Rev.3.

Meanwhile, the structure of global supply chains, mainly represented by the distribution of input sourcing locations, has changed considerably over time and evolved disproportionally with input trade flows. First, large input suppliers in terms of values do not coincide with those in terms of the number of products. The left panel of Figure 1.1 plots the number of imported products against the total import values of US producers from their top 30 manufacturing input suppliers in 2015. Although positively correlated, these two measures show an evident discrepancy, with a rank correlation of around 0.74. Some countries such as Italy export a wide range of manufacturing inputs to US producers, while some others like South Korea export more intensively. Second, large input suppliers today are not necessarily large input suppliers twenty years earlier. The right panel shows a rank correlation of 0.73 between the US top 30 input suppliers in 1996 and in 2015, which indicates clear changes in the US input sourcing structure. Table 1.1 also shows that adjustments in supply chain structure are gradual, as this rank correlation is decreasing over time.

The emergence and growth of global supply chains have complicated the transmission of trade and economic shocks across countries, especially when the structure of global supply chains also responds endogenously. First, in addition to some variable trade frictions such as import tariffs and transportation costs, organizers of global supply chains face fixed investments to accommodate customized production lines and establish relationships between upstream suppliers and downstream buyers. The existence of fixed investments is consistent with the findings documented in the left panel of Figure 1.1, since a high fixed cost can explain large but concentrated input suppliers observed in the data. Given that these investments typically happen before the actual production process, supply chain relationships typically adjust to trade and economic condition changes sluggishly, especially for partners in different countries.

Second, unlike export decisions where export revenues are generally independent across destinations, producers' import decisions regarding intermediate inputs are likely to be interrelated and directly impact their production costs. Each producer tends to source her intermediate input from the origin that gives her the lowest overall production cost. Hence, the input sourcing problem is a joint determination of input costs from all potential sourcing locations. The distribution of producers' input sourcing decisions, endogenously responds to input price changes. This kind of supply chain reallocation serves as a cost-sharing mechanism for domestic production with more significant fluctuations in international trade flows.

Finally, as countries start to participate in global supply chains, they are also tied with each other in terms of international trade and production. That means disruptions between two countries also influence other countries through input-output linkages and cross-country spillovers. Moreover, this supply chain transmission is amplified with producers' endogenous input sourcing decisions through stronger trade diversion and demand shifting.

All of these features are important for studying the behavior of global supply chains and their roles in transmitting economic and trade shocks, such as trade policy changes. These features also generate difficulties in modeling supply chain reallocations. In this chapter, I target the first two challenges, i.e., producers' input sourcing behaviors with the tradeoff between variable and fixed trade frictions.

I first introduce a global sourcing framework that features producers' endogenous input sourcing decisions. These decisions are characterized as discrete choice problems across multiple origins with agents' tradeoffs between variable input prices and fixed sourcing costs in my context. Each producer chooses the sourcing location that gives her the largest production revenue net of factor payments and fixed costs. When economic or trade conditions change, producers not only adjust how much to spend on their intermediate inputs but also where to purchase their inputs from. With standard assumptions of discrete choice models, this framework can generate a tractable prediction on the distribution of producers' input sourcing locations, which I call the aggregate input sourcing pattern, as a joint determination of individual import values and fixed sourcing costs. To my best knowledge, my work is the first application of discrete choice frameworks on import decisions [2].

Endogenous responses of the aggregate input sourcing pattern have two predictions on input trade. First, the strength of supply chain transmission that measures how individual import values affect the number of producers sourcing from the corresponding location, is mainly captured by a single parameter which I denote as the inverse origin-switching elasticity. This elas-

[2] Independently, Caliendo and Parro (2020) used a similar framework to study firms' production location choices, but not consider firms' input import decisions.

ticity can be empirically estimated using a model-implied specification with product-level import data. Second, the framework generates an augmented gravity representation. This representation shows an explicit role of supply chain reallocation and indicates a size-dependent partial trade elasticity for input trade flows, which is increasing in individual import values. Intuitively speaking, a higher import value indicates a lower marginal production cost faced by producers. Thus, the same reduction in trade costs is likely to increase the corresponding gross return more, which attracts more producers and amplifies the aggregate response in trade flows.

Using detailed US product-level import data, I find empirical support for this global sourcing framework. First, a model-implied empirical specification suggests a positive transmission between the intensive and extensive margins for any sourcing location. With the instrumental variable (IV) approach to reduce unobserved heterogeneity, the estimation results indicate that a 10% unit increase in expected import values from a certain country would induce around a 1% increase in the number of US-based producers who choose this country as their input sourcing location. Moreover, the strength of this supply chain transmission is not constant over time. The empirical evidence suggests that this transmission is weaker during the recovery period after the 2008-2009 Great Trade Collapse when global uncertainty was elevated.

Another advantage of this framework is its ability to address trade policies that affect fixed sourcing costs. Unlike conventional import tariffs, modern trade agreements such as preferential trade agreements (PTAs) typically cover policy areas such as investment facilitation and local market regulation, which are likely to reduce the fixed sourcing cost faced by foreign producers. With a proper characterization of the fixed sourcing cost, I empirically justify the above statement, as I find that foreign input suppliers who have PTAs in force with the United States tend to have lower fixed sourcing costs, with the average magnitude around 47% of annual average import value across products, than other input suppliers who do not have such PTAs.

1.2 Related Literature

This chapter is related to a group of studies on the effects of intermediate input sourcing with heterogeneous firms (Antràs et al., 2017; Blaum et al., 2018; Halpern et al., 2015; Handley et al., 2020b). Within this literature, the most relevant paper is Antràs et al. (2017) (AFT henceforth), which studies firms' global sourcing decisions on intermediate input across multiple origins with tradeoffs between variable and fixed costs. My work in this chapter differs from theirs in two aspects. First, AFT studies within-firm sourcing behaviors over a range of differentiated intermediate varieties from multiple origins. While in my framework, variety producers source homogenous intermediate inputs from only one country. Second, instead of using heterogeneous productivity across firms, variety producers in my model face heterogeneous fixed sourcing frictions, which generate their sourcing decisions. Although my model abstracts from the option firms have to lower their unit costs by sourcing from more origins, it generates a more tractable sourcing prediction than AFT, which is more convenient to conduct empirical and quantitative analyses. Furthermore, my framework has tractable predictions on the relationship between input sourcing patterns and individual import values, which can be estimated conveniently.

Alternatively, there is another group of studies looks at the risk-sharing motive of supply chain reallocation (Gervais, 2021; Kopytov et al., 2021; Tintelnot et al., 2018). In their frameworks, producers diversify their input sourcing locations to reduce fluctuations in their profits. Thus the aggregate input sourcing pattern will endogenously respond due to variation in origin-specific risks. However, this type of model relies heavily on the risk-averse assumption imposed on firms and producers. The aggregate input sourcing pattern generated by my framework is based on producers' trade-offs between variable and fixed sourcing costs, which do not depend on such an assumption.

This chapter is also related to the literature that uses discrete choice frameworks to characterize and explain the endogenous location choices of workers and producers. Artuç et al. (2010) used a dynamic labor adjustment framework with rational expectations to study the welfare effect of trade shocks while taking the endogenous cross-sectoral movement of workers into account. This framework is widely used in other studies on labor mobility and welfare evaluation. For example, Artuç et al. (2015) applied a new estimation method to this framework and estimate labor mobility costs in developing countries; Artuc et al. (2021) extended this framework to incorporate producers' endogenous occupation choices and study the trade impact on the Brazilian labor market. Caliendo et al. (2019) utilized the tractability of this framework and embedded it into a multi-country, multi-sector general equilibrium model to evaluate the welfare effect of the China shock on the US economy. While sharing the similar spirit of these papers, the framework I introduced in this chapter focuses specifically on producers' input sourcing decisions.

Finally, this chapter shares several common interests with the literature on the economic impacts of trade policies. First, recent studies have shown that the effects of import tariffs on trade flows are nonlinear (Limão, 2016; Yi, 2003) and time-varying (Boehm et al., 2020). Reductions in import tariffs increase the sensitivity of imports and trade flows, and these effects are realized gradually over time. Consistent with these findings, my theoretical framework with variable and fixed trade frictions generates a size-dependent trade elasticity for input trade which increases import values. Second, trade economists also investigate the economic effects of deep PTAs beyond tariff reductions. However, most have estimated non-tariff barriers (NTBs) as an *ad* *valorem* equivalence (Chen and Mattoo, 2008; Hayakawa and Kimura, 2015; Looi Kee et al., 2009; Novy, 2013). Many other empirical studies focus on the overall long-run effect of PTAs on trade, investment, and welfare (Baier and Bergstrand, 2007; Egger et al., 2011; Laget et al., 2020; Limão, 2016; Osnago et al., 2016; Ruta, 2017), and most studies identify strong influences of PTAs that might be far larger than those only accounted import tariffs. The current chapter contributes to this strand of literature by adding two components to the evaluation process. First, I augment the gravity framework with the extensive margin variation in the number of importers, which endogenously responds to trade shocks. Second, I explicitly explore the impact of PTAs on the fixed sourcing costs faced by intermediate input importers and empirically estimate the corresponding trade effect.

1.3 An Endogenous Global Sourcing Framework

A crucial component of global supply chains is trade in intermediate inputs, which connects production across countries. Thus, deciding where to source inputs is key in shaping the supply chain structure. This section describes producers' global sourcing problem on intermediate inputs.

1.3.1 Environment

The world economy consists of N countries, indexed by $i = 1, 2, ..., N$. Each country has S sectors, indexed by $s = 1, 2, ..., S$. Time is discrete and labeled as $t = 0, 1, 2, ...$ Within country i and sector s, there is a certain mass $\Omega^s_{i,t}$ of variety producers, who choose the optimal input sourcing locations in the current period t and make optimal production decisions in the second period $t+1$. I denote each variety producer by the corresponding variety ω she produces.

The demand side of the economy is characterized by a downstream demand shifter $D_{i,t}^{s}$ on the composite variety bundle $X_{i,t}^{s}$:

$$D_{i,t}^{s}=X_{i,t}^{s}=\left(\int_{\Omega_{i,t}^{s}} x_{i,t}^{s}\left(\omega\right)^{\frac{\sigma-1}{\sigma}}d\omega\right)^{\frac{\sigma}{\sigma-1}} \tag{1.1}$$

where $x_{i,t}^{s}$ is the downstream usage of variety ω, and $\sigma>1$ is the elasticity of substitution. The market of variety goods is perfect competitive. Let $p_{i,t}^{s}\left(\omega\right)$ as the output price faced by producer ω. The demand for variety ω can be expressed as:

$$x_{i,t}^{s}\left(\omega\right)=p_{i,t}^{s}\left(\omega\right)^{-\sigma}\frac{D_{i,t}^{s}}{\left(P_{i,t}^{s}\right)^{1-\sigma}} \tag{1.2}$$

where $P_{i,t}^{s}=\left(\int_{\Omega_{i,t}^{s}}p_{i,t}^{s}\left(\omega\right)^{1-\sigma}d\omega\right)^{\frac{1}{1-\omega}}$ is the demand price index aggregated over $p_{i,t}^{s}\left(\omega\right)$.

1.3.2 Producer Problems: Period t

As mentioned earlier, problems faced by variety producers take two periods, labeled as t and $t+1$. In period t, producers in country i and sector s enter the domestic market with capital $k_{i,t}^{s}$ [3] and optimally choose one of the N sourcing countries (including the domestic country) that gives them the highest net return in period $t+1$:

$$v_{i,t}^{s}\left(\omega\right)=\max_{n}\left\{\beta E_{t}\left[\pi_{ni,t+1}^{s}\left(\omega\right)\right]-f_{ni,t}^{s}+\nu\varepsilon_{n,t}^{s',s}\left(\omega\right)\right\} \tag{1.3}$$

[3] The production capital $k_{i,t}^{s}$ is assumed to be homogenous for all producers in country i and sector s. This can be relaxed later.

where n denotes one of the potential sourcing locations, and β is the one-period discount factor. There are three components that affect producers' optimal input sourcing decisions. First, the expected gross returns $E_t\left[\pi_{ni,t+1}^s\right]$, which vary across sourcing countries based on the material input import prices $p_{ni,t+1}^{s,M} = \tau_{ni,t+1}^s P_{ni,t+1}^s$; second, a fixed sourcing cost $f_{ni,t}^s$ that should be paid in advance of production in period t; and lastly a sourcing disturbance $\nu\varepsilon_{ni,t}^s(\omega)$ that is destination and producer specific, independent and identically drawn from a certain distribution $F(\varepsilon)$ at the beginning of period t. Both the expected gross return $E_t\left[\pi_{ni,t+1}^s\right]$ and the fixed sourcing cost $f_{ni,t}^s$ are systematic and homogenous to all producers in country i and sector s, where the sourcing disturbance is idiosyncratic to each producer.

The fixed sourcing cost $f_{ni,t}^s$ captures all tangible and intangible entry barriers or fixed investment that a variety producer would encounter if she decides to source her material inputs from country n. These costs include multiple types of distortions not captured by import tariffs, such as contracting frictions to establish a long-run partnership, concerns about intellectual property rights safety, or costs to set up a customized production line. In my model, I abstract from these detailed structures and use a country and sector-specific fixed sourcing cost to represent all of these potential distortions. I set the domestic fixed sourcing cost $f_{ii,t}^s = 0$ for all sectors as a normalization.

On the other hand, the sourcing disturbance $\nu\varepsilon_{ni,t}^s(\omega)$ mainly captures all idiosyncratic reasons that may affect variety producers' sourcing decisions individually, whose example involves random searching frictions for a compatible material input supplier, entrepreneurs' preferences for sourcing locations, and forecast errors about the macro and trade conditions in the next period. Generally, this term could be either positive or negative. This type of additive idiosyncratic assumption is extremely common in discrete choice models, but the models with heterogeneous productivities can be isomorphic and transformed into this setup[4].

Following standard settings of discrete choice models, I assume that $\varepsilon^s_{ni,t}(\omega)$ follows a Type-I extreme value distribution with zero mean and unit dispersion, as the following cumulative distribution function:

$$F(\varepsilon) = \exp\left\{-e^{-\varepsilon-\overline{\gamma}}\right\} \tag{1.4}$$

where $\overline{\gamma} = \int_{-\infty}^{\infty} x \exp(-x - \exp(-x))\, dx$ is Euler's constant. This distributional assumption leads to the following expression of expected value functions before the realization of sourcing disturbances:

$$E_\omega\left[v^s_{i,t}(\omega)\right] = \nu \log\left(\sum_n \exp\left(\frac{\beta E_t\left[\pi^s_{ni,t+1}\right] - f^s_{ni,t}}{\nu}\right)\right) \tag{1.5}$$

Notice that given $f^s_{ii,t} = 0$, the expected value above is always positive[5].

This distributional assumption also indicates a closed-form expression for the sourcing probability $\alpha^s_{ni,t+1}$, which is the fraction of variety producers in country i that source from country n in period $t+1$ as

$$\alpha^s_{ni,t+1} = \frac{\exp\left(\frac{\beta E_t\left[\pi^s_{ni,t+1}\right] - f^s_{ni,t}}{\nu}\right)}{\sum_k \exp\left(\frac{\beta E_t\left[\pi^s_{ki,t+1}\right] - f^s_{ki,t}}{\nu}\right)} \tag{1.6}$$

This expression indicates a clear relationship between the sourcing probability $\alpha^s_{ni,t+1}$ and

[4]Caliendo and Parro (2020) independently uses a similar framework to model the dynamic location choices of production for establishments. To the best of my knowledge, this is the closest paper to my work in terms of modeling techniques.

[5]It is easy to show that
$\nu \log\left(\sum_n \exp\left(\frac{\beta E_t\left[\pi^s_{ni,t+1}\right] - f^s_{ni,t}}{\nu}\right)\right) \geq \nu \log\left(\exp\left(\frac{E_t\left[\pi^s_{ii,t+1}\right]}{\nu}\right)\right) = E_t\left[\pi^s_{ii,t+1}\right]$.

the three components. First, if intermediate inputs from country n are cheaper, either because of lower labor/material costs or tariff/transportation costs, then more producers in country i will choose to source their inputs from country n due to higher gross returns. Second, a higher fixed sourcing cost $f^{s}_{ni,t}$ will effectively reduce producers' incentives to source their inputs from country n, leading to a smaller sourcing share. Finally, the role of idiosyncratic sourcing disturbances is governed by the structural parameter ν. Recall that this parameter measures the relative volatility of producers' idiosyncratic component compared to the systematic component. A larger value of ν means a more significant consideration of $\varepsilon^{s}_{ni,t}(\omega)$ when producers make their sourcing decisions and pay less attention to the systematic component. I denote ν as the inverse origin-switching elasticity since its inverse represents the partial elasticity of sourcing probability $\alpha^{s}_{ni,t+1}$ (the extensive margin) with respect to the systematic component $\beta E_t\left[\pi^{s}_{ni,t+1}\right] - f^{s}_{ni,t}$ (the intensive margin and the fixed sourcing cost).

1.3.3 Producer Problems: Period $t+1$

In period $t+1$, each producer produces a differentiated variety $x^{s}_{i,t+1}(\omega)$ with the production capital she possessed $k^{s}_{i,t}$, the labor input $l^{s}_{i,t+1}(\omega)$ she hires domestically, and the intermediate input $m^{s}_{i,t+1}(\omega)$ based on her sourcing location choice in period t. The production technology is as follow:

$$x^{s}_{i,t+1}(\omega) = z^{s}_{i,t+1}\left[\left(k^{s}_{i,t}\right)^{\delta^{s}_{i}}\left(l^{s}_{i,t+1}(\omega)\right)^{1-\delta^{s}_{i}}\right]^{\eta^{s}_{i}}\left(m^{s}_{i,t+1}(\omega)\right)^{1-\eta^{s}_{i}} \tag{1.7}$$

where $z^{s}_{i,t+1}$ is the productivity of differentiated variety production that is homogeneous for all variety producers within country i and sector s. η^{s}_{i} is the value-added share in intermediate production, and δ_i^s is the corresponding capital share that governs producers' gross returns.

Since the variety good markets are perfect competitive, variety producers take the purchasing price $p_{i,t+1}^s(\omega)$ as given. Their return maximization problems lead to the following allocation of revenue:

$$
\begin{aligned}
w_{i,t+1} l_{i,t+1}^s(\omega) &= (1-\delta_i^s)\,\eta_i^s p_{i,t+1}^s(\omega)\, x_{i,t+1}^s(\omega) &(1.8)\\
p_{i,t+1}^{s',M}(\omega)\, m_{i,t+1}^s(\omega) &= (1-\eta_i^s)\, p_{i,t+1}^s(\omega)\, x_{i,t+1}^s(\omega) &(1.9)\\
\pi_{i,t+1}^s(\omega) &= \delta_i^s \eta_i^s p_{i,1}^s(\omega)\, x_{i,t+1}^s(\omega) &(1.10)
\end{aligned}
$$

where $w_{i,t+1}$ is the nationwide wage rate in period $t+1$ and $p_{i,t+1}^{s,M}(\omega)$ is the unit cost of material inputs, which depends on producers' sourcing location choice $n(\omega)$ in the previous period.

These equilibrium conditions indicate that gross returns are proportional to intermediate input import values:

$$
\pi_{ni,t+1}^s = \frac{\delta_i^s \eta_i^s}{1-\eta_i^s} p_{ni,t+1}^{s',M} m_{ni,t+1}^s \equiv \frac{\delta_i^s \eta_i^s}{1-\eta_i^s} im_{ni,t+1}^s \tag{1.11}
$$

Combining the production and demand sides, the gross return can be expressed as a function of productivity $z_{i,t+1}^s$, capital inputs $k_{i,t}^s$, factor and input prices $w_{i,t+1}$, $p_{ni,t+1}^{s,M}$, $P_{i,t+1}^s$, and the downstream demand shifter $D_{i,t+1}^s$:

$$\pi^s_{ni,t+1} = \delta^s_i \eta^s_i \left(\frac{\Lambda^s_i}{z^s_{i,t+1}} \left(\frac{1}{k^s_{i,t}} \right)^{\delta^s_i \eta^s_i} \right)^{\frac{1-\sigma}{1-\delta^s_i \eta^s_i (1-\sigma)}} \left(w_{i,t+1} \right)^{\frac{(1-\delta^s_i)\eta^s_i(1-\sigma)}{1-\delta^s_i \eta^s_i (1-\sigma)}}$$
$$\times \left(p^{s,M}_{ni,t+1} \right)^{\frac{(1-\eta^s_i)(1-\sigma)}{1-\delta^s_i \eta^s_i (1-\sigma)}} \left(\left(P^s_{i,t+1} \right)^{\sigma-1} D^s_{i,t+1} \right)^{\frac{1}{1-\delta^s_i \eta^s_i (1-\sigma)}} \tag{1.12}$$

where Λ^s_i is a function of time-invariant structural parameters. Without any heterogeneity in productivity, production capital, and sourcing frictions, this gross return is homogeneous to all producers in country i and sector s who choose their sourcing location as country n.

1.4 Predictions on Global Supply Chains

In this section, I discuss several theoretical predictions of this global sourcing framework on trade and global supply chains. With endogenous input sourcing decisions, responses of intermediate trade flows are characterized by changes in both the intensive (individual import flows) and extensive (number of producers) sourcing margins. More specifically, the model implies a closed-form relationship related to how these two margins interact, which further leads to an extended gravity specification where the partial trade elasticity of intermediate inputs is increasing in individual import values.

1.4.1 Endogenous Supply Chain Reallocations

Based on condition (1.6) and given the normalization $f^s_{ii,t} = 0$, we can derive the following relationship between the ratio of foreign-to-domestic sourcing probability $\frac{\alpha^s_{ni,t+1}}{\alpha^s_{ii,t+1}}$ and the corresponding difference in expected net returns $E_t \left[\pi^s_{ni,t+1} \right] - E_t \left[\pi^s_{ii,t+1} \right]$:

$$\log\left(\frac{\alpha^s_{ni,t+1}}{\alpha^s_{ii,t+1}}\right) = \frac{\beta\left(E_t\left[\pi^s_{ni,t+1}\right] - E_t\left[\pi^s_{ii,t+1}\right]\right) - f^s_{ni,t}}{\nu} \tag{1.13}$$

Thus, holding domestic sourcing conditions constant, the strength of how the expected return $E_t\left[\pi^s_{ni,t+1}\right]$, i.e., the intensive margin, could influence the corresponding sourcing probability $\alpha^s_{ni,t+1}$, i.e., the extensive margin, is governed by the semi-elasticity of supply chain transmission SCT defined as follows:

$$SCT = \frac{\partial \ln \alpha^s_{ni,t+1}}{\partial \pi^s_{ni,t+1}} = \frac{\beta}{\nu} \tag{1.14}$$

Equation (1.14) shows that this elasticity is positively related to the intertemporal discount factor β and negatively related to the inverse origin-switching elasticity ν. It measures how level changes in the realized gross return $\pi^s_{ni,t+1}$ in period $t+1$ will affect producers' input sourcing decision from location n in period t, as measured by the sourcing probability $\alpha^s_{ni,t+1}$. Holding β constant, a larger value of SCT (or a smaller value of ν) indicates a stronger transmission from the intensive margin to the extensive margin and hence a larger response in aggregate input trade flows. Moreover, a producer who sources intermediate inputs from country n would be more likely to switch her sourcing location when input prices in other countries change.

More importantly, this expression guides an empirical specification that can be used to estimate the value of ν. Assume that the realized gross profit in period $t+1$ is an imperfect measure of its period t's expectation with some mean-zero disturbances or measurement errors. Then equation (1.14) can be written in the following form:

$$\log\left(\frac{\alpha^s_{ni,t+1}}{\alpha^s_{ii,t+1}}\right) = \frac{\beta}{\nu}\left(\pi^s_{ni,t+1} - \pi^s_{ii,t+1}\right) - \frac{1}{\nu} f^s_{ni,t} + \epsilon^s_{ni,t+1} \tag{1.15}$$

where $\epsilon^s_{ni,t+1}$ is a random disturbance term that realized at time $t+1$ and satisfies $E_t \epsilon^s_{t+1} = 0$. $\epsilon^s_{ni,t+1}$ generally captures the idiosyncratic errors that are not systematically different across sourcing locations, such as unexpected transportation cost variations and capital utilization frictions.

Ideally, the estimation of equation (1.15) requires information on the number of producers that source inputs from a certain location (including domestic sourcing) and the corresponding average import values across these producers. However, in the real world, producers are likely to differ from each other in productivity and many other aspects, and hence their import values often show significant variations within a single sourcing location. These unobserved heterogeneities might severely affect the identification of the supply chain transmission channels. In the next section, I introduce an instrumental variable approach to address this issue.

1.4.2 Supply-Chain Augmented Gravity Equation

So far this chapter has established a framework that features producers' endogenous input location choices and hence the endogenous supply chain reallocation. This subsection takes a further look at the implication on aggregate intermediate input import flows.

Similar to many quantitative trade frameworks, my global sourcing framework generates closed-form representations for final goods and intermediate input import shares, which can be used to derive gravity equations. Combining the demand function (1.1) with the definition of sourcing probability, we can derive the following condition for the input import share $a^s_{ni,t+1}$:

$$\frac{M^s_{ni,t+1}}{\sum_k M^s_{ki,t+1}} \equiv a^s_{ni,t+1} = \frac{\alpha^s_{ni,t+1}\left(p^s_{ni,t+1}\right)^{1-\sigma}}{\sum_k \alpha^s_{ki,t+1}\left(p^s_{ki,t+1}\right)^{1-\sigma}} = \frac{\alpha^s_{ni,t+1}\left(P^s_{n,t+1}\tau^s_{ni,t+1}\right)^{1-\varepsilon^s_i}}{\sum_k \alpha^s_{ki,t+1}\left(P^s_{k,t+1}\tau^s_{ki,t+1}\right)^{1-\varepsilon^s_i}} \tag{1.16}$$

where $1-\varepsilon^s_i = \frac{\left(1-\eta^s_i\right)(1-\sigma)}{1-\delta^s_i\eta^s_i(1-\sigma)}$ and the sourcing probability $\alpha^s_{ni,t+1}$ is characterized by (1.6).

Taking log on both sides and replace the sourcing probability with the expression (1.6), we have

$$\log\left(a^s_{ni,t+1}\right) = \frac{\beta}{\nu}\pi^s_{ni,t+1} - \frac{1}{\nu}f^s_{ni,t} + (1-\varepsilon^s_i)\log\left(\tau^s_{ni,t+1}\right) + \psi^s_{i,t+1} + \psi^s_{n,t+1} + v^s_{ni,t+1} \tag{1.17}$$

where $1-\varepsilon^s_i$ becomes the conditional partial trade elasticity of intermediate inputs. $\psi^s_{i,1}$ is the fixed effect that represents factors that affect all sourcing locations, such as the sector-specific downstream demand in the importing country; and $\psi^s_{n,1}$ is the fixed effect that captures variations only from the specific sourcing location, such as the price level of sectoral goods in country n, $P^s_{n,t+1}$ before shipping to country i.

Compared to the conventional gravity expression for trade flows, the supply-chain augmented representation (1.17) differs in two aspects. In addition to the trade effect from changes in variable trade costs $(1-\varepsilon^s_i)\log\left(\tau^s_{ni,t+1}\right)$, this representation also features endogenous supply chain reallocations through adjustments in the sourcing probability $\alpha^s_{ni,t+1}$, which, based on equation (1.13), can be further decomposed into two components: (i) changes in the fixed sourcing costs $f^s_{ni,t}$; and (ii) responses induced by changes in realized gross returns $\frac{\beta}{\nu}\pi^s_{ni,t+1}$. Based on the linear relationship between gross returns and input import values 1.11, this component also indicates a channel on how input trade flows endogenously reflect producers' sourcing decisions. Intuitively, this extended gravity representation generates an endogenous partial trade elasticity for input trade:

Proposition 1 *The endogenous global sourcing structure indicates a **size-dependent** trade elasticity for intermediate imports:*

$$\frac{\partial \log\left(a^s_{ni,t+1}\right)}{\partial \log\left(\tau^s_{ni,t+1}\right)} = \left(\underbrace{1}_{\textit{Intensive Margin}} + \underbrace{\frac{\beta \pi^s_{ni,t+1}}{\nu}}_{\textit{Extensive Margin}}\right)\left(1 - \varepsilon^s_i\right) \tag{1.18}$$

The proof of Proposition 1 can be found in Appendix A.

Proposition 1 has several important implications for trade liberalization and the transmission of trade shocks. First, a size-dependent trade elasticity that is increasing in individual gross returns (import values) implies a stronger impact of trade cost reductions on larger trade partners. When import tariffs decline, both bilateral import flows and the responsiveness of imports increase, leading to a more significant effect of trade liberalization. This result is consistent with the theoretical and empirical work in Yi (2003) and Limão (2016), where they find a non-linear trade elasticity which is decreasing in variable trade costs. Thus, Proposition 1 serves as a theoretical background for this strand of literature.

Second, equation (1.18) also indicates that the transmission of trade shocks could be time-variant. For the same magnitude of variable trade shock $\Delta \log\left(\tau^s_{ni,1}\right)$, its impact on input trade is larger when economic conditions are better (i.e., stronger global demand). Also, the value of β is smaller when the time gap between two periods is longer. This means trade flows are less responsive to future shocks.

1.5 Empirical Analysis: Strength of Supply Chain Transmission

I use product-level import data to empirically test and estimate condition (1.15). Moreover, I also utilize one advantage of the empirical specification, which is its ability to address trade policy changes through fixed sourcing costs, to investigate the effect of preferential trade agreements (PTAs) on input trade that is beyond the scope of conventional import tariffs. This feature is especially useful for analyzing modern trade policies, given that more and more provisions, such as investment facilitation and local market regulations, are included in these agreements. That means the overall impact of PTAs might be significantly mismeasured if we ignore these provisions in our analysis.

1.5.1 Empirical Strategy

Three measures of data moments are required to estimate equation (1.15). First, the sourcing probability $\alpha^s_{ni,t+1}$ or the number of producers who choose to source inputs from a certain origin n; second, the average gross return producers receive from a specific origin n, $\pi^s_{ni,t+1}$ as well as the domestic gross returns $\pi^s_{ii,t+1}$; and finally, a characterization of fixed sourcing costs $f^s_{ni,t}$.

The sourcing probability α captures the extensive margin of intermediate imports, or equivalently, the number of products that source from a particular country $N^s_{ni,t}$ that is normalized by the total number of products across all origins $\sum_n N^s_{ni,t}$. Ideally, this variable should be measured by counting the number of imported products at a sufficient disaggregate level:

$$\frac{\alpha^s_{ni,t+1}}{\alpha^s_{ii,t+1}} = \frac{N^s_{ni,t+1}}{N^s_{ii,t+1}} \tag{1.19}$$

where $N^s_{ii,t+1}$ is the number of intermediate products that are sourced domestically.

The gross return $\pi^s_{ni,t+1}$ is typically not directly observable from the data. However, based on condition (1.11), we can use the average import values across products within a certain sector for a specific origin-destination pair:

$$\overline{\pi}^s_{ni,t+1} = \frac{\delta^s_i \eta^s_i}{1-\eta^s_i} \overline{im}^s_{ni,t+1}$$

There are three sources of variation in this expression of gross returns: the share of capital in value-added δ^s_i, the intensity of intermediate inputs in production $1-\eta^s_i$, and the average imports values $\overline{im}^s_{ni,t+1}$. The first two variations are homogeneous within-country i and a sector s. If we normalize the gross return (or similarly the import value) variable with the corresponding cross-product average within each country-sector pair (i, s), the first two sources of variation can be absorbed:

$$\overline{\pi}^{s,N}_{ni,t+1} = \frac{\overline{\pi}^s_{ni,t+1}}{\frac{1}{N}\sum_{k=1}^N \overline{\pi}^s_{ki,t+1}} = \frac{\frac{\delta^s_i \eta^s_i}{1-\eta^s_i}\overline{im}^s_{ni,t+1}}{\frac{1}{N}\frac{\delta^s_i \eta^s_i}{1-\eta^s_i}\sum_{k=1}^N \overline{im}^s_{ki,t+1}} = \frac{\overline{im}^s_{ni,t+1}}{\frac{1}{N}\sum_{k=1}^N \overline{im}^s_{ki,t+1}} = \overline{im}^{s,N}_{ni,t+1}$$

where $\overline{\pi}^{s,N}_{ni,t+1}$ and $\overline{im}^{s,N}_{ni,t+1}$ is the normalized value of $\overline{\pi}^s_{ni,t+1}$ and $\overline{im}^s_{ni,t+1}$, respectively. The last source of variation provides the key identification of the inverse origin-switching elasticity ν[6].

[6]The interpretation of ν naturally depends on this normalization. For example, Artuç et al. (2010) uses the annual average wage to normalize sectoral wage differences. Hence their interpretation of this cross-sectoral worker mobility elasticity is in the unit of this annual average wage.

The fixed sourcing cost $f_{ni,t}^{s}$ is also an unobservable variable that could be affected by various countries, sectors, and bilateral determinants. Similar to AFT, I introduce the following reduced-form characterization for this fixed cost $f_{ni,t}^{s}$:

$$f_{ni,t}^{s} = \lambda_1 PTA_{ni,t} + \psi_{it}^{s} + \psi_{ni} + u_{ni,t}^{s}$$

Where $PTA_{ni,t}$ is a bilateral measure of preferential trade agreement relationship, and the set of ψ are various fixed effects that capture other unobservable variations. For example, ψ_{it}^{s} may include the license fee for all producers in country i and sector t who want to import intermediate inputs from abroad; ψ_{ni} may capture some pre-existing bilateral investment treaties between country i and n that facilitate producers to enter the foreign market easier. The remaining term $u_{ni,t}^{s}$ is an i.i.d. residual with zero mean and independent with other disturbances (such as $\epsilon_{ni,t+1}^{s}$) and across time.

Combining all the three measures, the empirical specification becomes

$$\begin{aligned}\log\left(\frac{N_{ni,t+1}^{s}}{N_{ii,t+1}^{s}}\right) &= \frac{\beta}{\nu}\frac{\delta_i^s\eta_i^s}{1-\eta_i^s}\left[\overline{im}_{ni,t+1}^{s} - \overline{im}_{ii,t+1}^{s}\right] - \frac{\lambda_1}{\nu} PTA_{ni,t} \\ &\quad + \widetilde{\psi}_{it}^{s} + \widetilde{\psi}_{ni} + \widetilde{\epsilon}_{ni,t+1}^{s} \qquad (1.20)\end{aligned}$$

where $\widetilde{\psi} = -\psi/\nu$ and $\widetilde{\epsilon}_{ni,t+1}^{s} = \epsilon_{ni,t+1}^{s} - u_{ni,t}^{s}/\nu$. Given the values of β, δ_i^s and η_i^s, an empirical estimation that regresses the relative sourcing probability $\log\left(\frac{\alpha_{ni,t+1}^{s}}{\alpha_{ii,t+1}^{s}}\right)$ on the absolute difference between foreign and domestic average input purchasing values $\frac{\delta_i^s\eta_i^s}{1-\eta_i^s}\left[\overline{im}_{ni,t+1}^{s} - \overline{im}_{ii,t+1}^{s}\right]$ and a measure of preferential trade agreements $PTA_{ni,t}$, will provide the identification of ν and

λ_1.

An advantage of this specification is that it does not require a value of trade elasticity σ and measures of variable trade costs $\tau^s_{ni,t+1}$ in the estimation. Typically, the value of trade elasticity varies significantly across sectors, and a considerable component of variable trade costs is either unobserved or hard to measure. Getting rid of these two measures greatly reduces the dimension of the required variables in my empirical analysis.

Qualitatively speaking, the value of ν is expected to be greater than zero, indicating a positive supply chain transmission from the intensive to extensive margins. The sign of λ_1 determines the impact of PTAs on the corresponding fixed sourcing cost. Since many provisions included in PTAs are likely to reduce the fixed sourcing cost faced by foreign producers, the value of λ_1 is expected to be negative, so that the estimated coefficient of $PTA_{ni,t}$ $(-\frac{\lambda_1}{\nu})$ is positive.

1.5.2 Data Description

I use the HTS-10 digit product-level import data from the United States Census Bureau to conduct this empirical estimation. This dataset has the advantage of very disaggregated product-level import information, which is ideal for me to get the appropriate measures of both sourcing probability and the individual import values.

Following Schott (2008), I denote each ”product” defined in my framework as a country-HS10 pair, i.e. a steering wheel manufactured in Japan is a different product compared to a steering wheel manufactured in Germany. I classify into three mutually exclusive categories, namely capital goods, intermediate goods, and consumption goods, based on the Broad Economic Categories (BEC) under the framework of the System of National Accounts (SNA)[7]. Sectors

[7]If an HTS-10 digit product does not satisfy any of the categories, it is put in another separate category called

are defined as the 2-digit Harmonized System (HS) level. It is possible to have multiple or all categories within a single sector. The focus of this study is on the second category, which is the intermediate good.

This dataset also has several limitations. First, since the United States is the only importer, there is no variation on the importer side. That means several fixed effects in (1.20) must be modified to satisfy the data, which reduces the dimension of unobservable variations I can control in this analysis. Second, this dataset does not contain the information on the total number of varieties $\Omega^s_{i,t+1}$ or domestic absorption $\alpha^s_{ii,t+1}$ and $\overline{im}^s_{ii,t+1}$. Given that the specification has the sector-year fixed effect $\widetilde{\psi}^{s'}_t$ that can address these domestic absorption terms, this data limit is not a significant concern. Finally, the HTS classification has several versions which are not consistently defined across time, and misspecification of products might generate structural breaks in the data. I utilize product concordances between different revisions to deal with this issue.

Sourcing Probability. The sourcing probability $\alpha^s_{ni,t+1}$ is defined as the share of producers who source their inputs from country n in all variety producers. Based on (1.19), I rely on the count of intermediate goods that US importers in sector s source from country n, $N^s_{n,t+1}$, to approximate the sourcing probability. The number of domestic-sourcing producers is absorbed by the sector-year fixed effect $\widetilde{\psi}^{s'}_t$.

Average Import Value. Within each sector, the average import value from a certain origin is simply measured as the mean of all corresponding individual product's import values $\overline{im}^s_{n,t+1}$. I normalize this mean import value by the overall product-level average on an annual basis. That means the interpretation of the inverse origin-switching elasticity should also be in the unit of the annual average import value at the product level in this sector. With this normalization, variations

”Not Classified”, which I ignore from this analysis at this moment.

of δ_i^s and η_i^s are cancelled out within each sector.

PTA Measures. Information on the preferential trade agreements comes from the World Bank Content of Deep Trade Agreement Database. This dataset covers 279 agreements signed by 189 countries from 1958 to 2015. Policy areas covered by these agreements are classified into 52 categories based on different purposes. I delegate a detailed description of this database in Chapter 3. In this chapter, I rely on two measures of PTA relationship that are widely used in the literature (Osnago et al., 2016), (Laget et al., 2020). The first measure is a dummy variable that takes 1 if two countries have a PTA that contains at least one legally enforceable provision, and 0 elsewhere; the second one is a depth measure based on the number of legally enforceable provisions within a PTA.

The finally compiled dataset used for this empirical analysis covers a sample period from 1996 to 2015, with more than 200 sourcing locations. The adjusted empirical specification for estimating ν is

$$\ln\left(N_{n,t+1}^s\right) = \frac{\beta}{\nu}\overline{im}_{n,t+1}^s - \frac{\lambda_1}{\nu}PTA_{n,t} + \widehat{\psi}_t^s + \widetilde{\psi}_n + \widetilde{\epsilon}_{n,t+1}^s \tag{1.21}$$

where n denotes the exporter. Notice that $\widehat{\psi}_t^s = \widetilde{\psi}_t^s + \ln\left(N_{i,t+1}^s\right) - \frac{\beta}{\nu}\overline{im}_{i,t+1}^s$ now captures two terms of unobserved domestic absorption.

1.5.3 Baseline Results

Table 1.2 summarizes the baseline estimation results of specification 1.21. In this table, $PTA_{n,t}$ is the dummy variable indicating that two countries have a legally enforceable PTA. Results using the PTA depth measure are similar and relegated to section 1.5.6.

Table 1.2: Estimation of the (Inverse) Origin Switching Elasticity and PTA Effect: Baseline

	(1) OLS-Baseline	(2) IV-Past Value	(3) IV-Past Value
$\overline{im}^{s}_{n,t+1}$	0.0290***	0.0341***	0.0355***
	(0.00447)	(0.00457)	(0.00455)
$PTA_{n,t}$	0.0526***	0.0442**	
	(0.0176)	(0.0189)	
Observations	126,158	108,219	107,949
HS2-Year F.E.	Yes	Yes	Yes
Exporter F.E.	Yes	Yes	No
Exporter-Year F.E.	No	No	Yes
Implied ν (w. $\beta = 0.96$)	33.1	28.2	27.0
Implied λ_1	-1.74	-1.25	N.A.

Standard errors in parentheses and clustered at HS2-year level.

Column (1) shows the baseline estimation with standard OLS specification. First of all, both regression coefficients of $\overline{im}^{s}_{n,t+1}$ and $PTA_{n,t}$ are positive and significant. These results are consistent with the intuition of a positive supply chain transmission and a negative effect of PTAs on fixed sourcing costs. However, the magnitude of estimated ν is very large, with a value of more than 30. As mentioned earlier, this estimate suggests a significant role of idiosyncratic sourcing disturbances in determining producers' sourcing decisions, and potential unaddressed issues in the analysis.

One potential problem is the endogeneity issue. As documented in Artuç et al. (2010) and Caliendo et al. (2019), the disturbance term $\widetilde{\epsilon}^{s}_{n,t+1}$ will be potentially correlated with current import values. For instance, any new information in period $t+1$ but is not anticipated in period t will affect the average import values in period $t+1$. Conventionally, existing studies use one-period lag values as the instrument to deal with this issue. Column (2) adopts this approach and uses the lagged value of average imports as the instrumental variable for the current import values. We can see that the regression coefficient of $\overline{im}^{s}_{n,t+1}$ increases from 0.029 to 0.034, and a considerable reduction on the estimated value of ν. The endogeneity issue is only partially addressed, as the magnitude of ν is still high.

Finally, Column (3) controls for the country-year fixed effect instead of the PTA measure to capture a larger scope of unobservable variations. Doing so further helps reduce the magnitude of the estimated value of ν to 27.

The baseline empirical results are generally consistent with the model intuition and verify the transmission channel featured by the endogenous global sourcing framework. However, a high value of ν might still be problematic because it suggests the weak role of systematic components in determining producers' input sourcing behaviors. For example, $\nu = 27$ means a standard error of $\pi\nu/\sqrt{6} \approx 34.6$ for the effect idiosyncratic sourcing disturbance $\nu\varepsilon_{n,t}^{s',s}(\omega)$. Given that this number is in terms of the average annual import value across products, it suggests significant heterogeneity across producers that might be not observed. Alternatively, the estimated values for similar parameters in the literature are 0.5 to 2 for worker mobility and 14.1 for firms' production location choice[8]. Compared to these values in the literature, the baseline estimates for ν are relatively high.

1.5.4 Addressing Unobserved Heterogeneity: IV Approach

Some unaddressed variations across variety producers could be a source of bias. For example, given the most disaggregated level of data I have is at the HTS-10 digit, a large import value of a specific HTS-10 product may result from many importing firms rather than a single importer. Moreover, suppose the number of importers within an HTS-10 product is highly correlated with the number of HTS-10 products in the corresponding HS-2 sector. In that case, $\widetilde{\epsilon}_{n,t+1}^{s}$

[8] Artuc et al. (2021) uses Brazilian labor market information and has an estimate of worker mobility elasticity around 0.5; Caliendo et al. (2019) uses US labor market data and results in an estimate of worker mobility elasticity around 2, and Caliendo and Parro (2020) uses US establishment-level information and has an estimate for the elasticity of firms' location choice around 14.1.

is potentially correlated with the measure of average import values and hence causes the endogeneity problem. Finally, even with the assumption that only one importer imports each HS-10 product from a certain origin, there are still possible variations across input importers in their productivities, actual trade costs, etc.

This subsection addresses this issue formally by utilizing a two-step IV approach. The idea of this approach is similar to AFT, where the first step uses a product level regression to isolate the so-called ”sourcing potential”, and the second step uses this ”sourcing potential” as the instrument for the current average import values.

Recall the expression of gross return (1.12). Assume that instead of having homogenous production capital $k^s_{i,t}$, productivity $z^s_{i,t+1}$, and trade friction $\tau^s_{ni,t}$, producers face uncertainty in these variables after making their sourcing decisions:

$$
\begin{aligned}
k^s_{i,t}(\omega) &= \bar{k}^s_{i,t} \times k(\omega) \\
z^s_{i,t+1}(\omega) &= \bar{z}^s_{i,t+1} \times z(\omega) \\
\tau^s_{ni,t+1}(\omega) &= \bar{\tau}^s_{ni,t+1} \times \tau(\omega)
\end{aligned}
$$

where $\bar{k}^s_{i,t}$, $\bar{z}^s_{i,t+1}$, and $\bar{\tau}^s_{ni,t+1}$ are homogenous to all producers and $k(\omega)$, $z(\omega)$, and $\tau(\omega)$ are idiosyncratic shocks, whose log terms follow mean zero distributions. Then the condition (1.12) at the product level can be expressed as

$$\begin{aligned}\pi^{s}_{ni,t+1}\left(\omega\right) &= \delta^{s}_{i}\eta^{s}_{i}\left(\frac{\Lambda^{s}_{i}}{\bar{z}^{s}_{i,t+1}z\left(\omega\right)}\left(\frac{1}{\bar{k}^{s}_{i,t}k\left(\omega\right)}\right)^{\delta^{s}_{i}\eta^{s}_{i}}\right)^{\frac{1-\sigma}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}} \\ &\times\left(w^{s}_{i,t+1}\right)^{\frac{\left(1-\delta^{s}_{i}\right)\eta^{s}_{i}(1-\sigma)}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}}\left(p^{s,M}_{ni,t+1}\bar{\tau}^{s}_{ni,t+1}\tau\left(\omega\right)\right)^{\frac{\left(1-\eta^{s}_{i}\right)(1-\sigma)}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}} \\ &\times\left(\left(P^{s}_{i,t+1}\right)^{\sigma-1}D^{s}_{i,t+1}\right)^{\frac{1}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}}\end{aligned}$$

Taking log on both sides of this expression gives:

$$\begin{aligned}\log\left(\pi^{s}_{ni,t+1}\left(\omega\right)\right) &= \log\bar{\pi}^{s}_{ni,t+1}-\frac{1-\sigma}{1-\delta^{s}_{i}\eta^{s}_{i}\left(1-\sigma\right)}\log\left(z\left(\omega\right)\right) \\ &-\frac{\delta^{s}_{i}\eta^{s}_{i}\left(1-\sigma\right)}{1-\delta^{s}_{i}\eta^{s}_{i}\left(1-\sigma\right)}\log\left(k\left(\omega\right)\right) \\ &+\frac{\left(1-\eta^{s}_{i}\right)\left(1-\sigma\right)}{1-\delta^{s}_{i}\eta^{s}_{i}\left(1-\sigma\right)}\log\left(\tau\left(\omega\right)\right)\end{aligned}$$

where $\bar{\pi}^{s}_{ni,t+1}$ is the systematic component of gross return that is the same for all producers in country i and sector s whose input sourcing location is n.

All these error terms can be combined into a single one $\log\left(\upsilon^{s}\left(\omega\right)\right)$. The linearity between gross returns and input import flows indicates the following decomposition of individual import values:

$$\log\left(im^{s}_{n,t+1}\left(\omega\right)\right)=\log\widetilde{\zeta}^{s}_{n,t+1}+\log\vartheta_{n}\left(\omega\right)+\log\vartheta_{t+1}\left(\omega\right)+\log\upsilon^{s}_{n,t+1}\left(\omega\right) \tag{1.22}$$

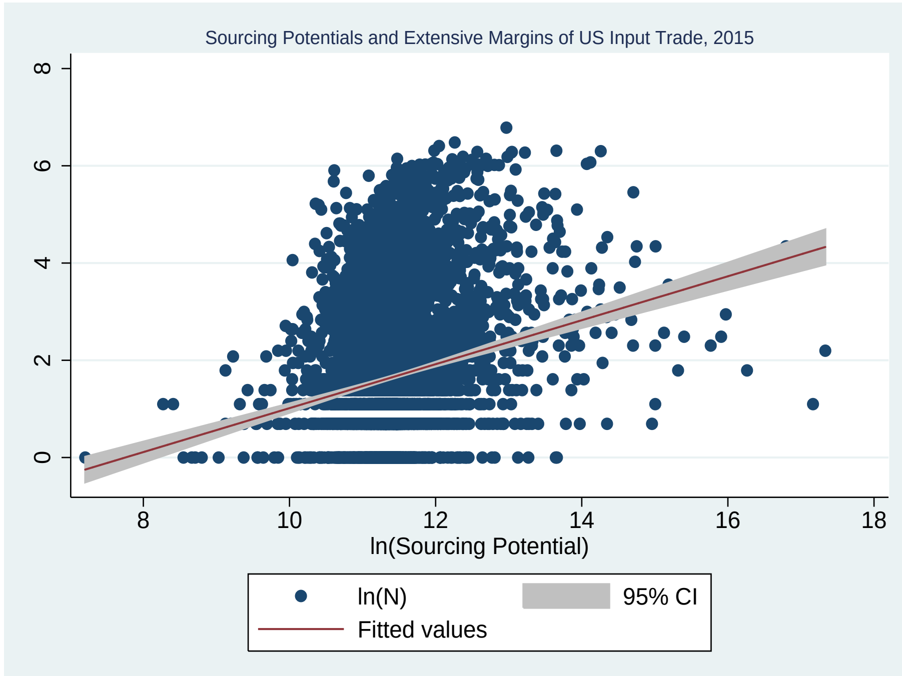
where $\vartheta_{n}\left(\omega\right)$ captures heterogeneities across HS-10 products and origin countries, such as different numbers of importing firms within the HS-10 digit level that are systematically different across sourcing countries; $\vartheta_{t+1}(\omega)$ captures time-varying features that are potentially different across HS-10 products, such as product-specific productivities and shipping costs. The variable in interest is $\widetilde{\zeta}^s_{n,t+1}$, which is the exporter-time-sector (HS-2 digit level) fixed effect, and analogous to AFT, I denote it as the "sourcing potential" of sector s of exporting country n in year $t+1$.

Conceptually, without the other two sets of fixed effects, the estimated $\widetilde{\zeta}^s_{n,t+1}$ is simply the geometric average of HS-10 digit level imports within sector s and exporter n. Compared to the simple average measure that I use in the baseline specification, this "sourcing potential" measure has two main advantages: first, it takes care of extreme values. An unusually large observation of import values may increase the simple average measure significantly and generate biases in the estimation. Second, the inclusion of the other two sets of fixed effects could greatly reduce unobservable heterogeneities across HS-10 products and increase the reliability of the estimation[9].

Figure 1.5.4 plots the relationship between the extracted sourcing potential $\widetilde{\zeta}^s_{n,t+1}$ with all fixed effects and the extensive margin of input trade $N^s_{n,t+1}$ in 2015. Both variables are demonstrated in log terms. A clear and upward-sloping fitted line between these two variables indicates that origins with higher sourcing potentials generally export a larger number of intermediate products to US producers.

In the second step, I use the estimated "sourcing potentials" $\widetilde{\zeta}^s_{n,t+1}$ as instruments for average import values in the empirical specification. This instrumental strategy takes advantage of reduced unobservable heterogeneity from "sourcing potentials" and keeps essential normalization

[9] These two sets of controlling fixed effects are manipulated to have zero means



for average import values.

Table 1.3 shows the regression results with the two-step IV approach. In addition to the OLS specification in Column (1), Column (2) to (4) illustrates the regression results where the ”sourcing potential” $\widetilde{\zeta}^{s}_{ni,t+1}$ generated in the first step is implemented as the instrument variable. In Column (2), the first step regression only involves $\widetilde{\zeta}^{s}_{ni,t+1}$ (exporter-year-HS2 fixed effect) and hence represents the geometric average feature of the instruments; I then add the exporter-HS10 and HS10-year fixed effects sequentially to Column (3) and (4) to control for other sources of heterogeneity.

After addressing several unobservable variations, the estimated values of ν drop significantly with this two-step IV approach, from 33.1 (column (1)) to 9.7 (column (4)). A higher value of ν implies a larger role of idiosyncratic disturbances in determining sourcing decisions of intermediate goods producers. In this sense, having a smaller estimate with ”sourcing potentials” as instruments are consistent with the idea of reduced heterogeneity across producers.

Table 1.3: Estimation of the (Inverse) Origin Switching Elasticity and PTA Effect: Two-Step IV

	(1) OLS-Baseline	(2) IV-Two Steps	(3) IV-Two Steps	(4) IV-Two Steps
$\overline{im}^{s}_{n,t+1}$	0.0290***	0.0961***	0.0911***	0.0988***
	(0.00447)	(0.00910)	(0.00918)	(0.00922)
$PTA_{n,t}$	0.0526***	0.0484***	0.0487***	0.0483***
	(0.0176)	(0.0175)	(0.0175)	(0.0175)
Observations	126,158	126,158	126,158	126,158
HS2-Year F.E.	Yes	Yes	Yes	Yes
Exporter F.E.	Yes	Yes	Yes	Yes
Implied ν (w. $\beta = 0.96$)	33.1	10.0	10.5	9.7
Implied λ_1	-1.74	-0.48	-0.51	-0.47
F.E. in 1st step				
HS2-Exporter-Year	N.A.	Yes	Yes	Yes
HS10-Exporter	N.A.	No	Yes	Yes
HS10-Year	N.A.	No	No	Yes

Standard errors in parentheses and clustered at HS2-year level.

1.5.5 Supply Chain Transmission and Impact of PTAs

Based on my preferred empirical specification and the appropriate IV strategy for controlling endogeneity issues, the regression results in Table 1.3 are ready to explain the strength of supply chain transmission and the additional impact of PTAs through fixed sourcing costs. I mainly rely on Column (4) for these interpretations, with $\nu = 9.7$ and $\lambda_1 = -0.47$.

Recall the definition of the elasticity of supply chain transmission (SCT) (1.14), the estimated value of ν indicates a transmission strength of around 10%. That means, holding everything else constant, when the intensive margin, as represented by import value or fixed sourcing cost from origin n, increases with a magnitude equivalent to 10% of the average annual import value across all sourcing origins, there would be 1% more producers choosing to source from country n. In terms of aggregate trade flows, there will be a 10% amplification due to this additional adjustment on the extensive margin.

Alternatively, $\lambda_1 = -0.47$ means that having a PTA could effectively lower the fixed sourcing cost faced by foreign producers with the amount equivalent to 47% of the average annual import value. This is an economically significant impact, which is further translated into a nearly 5% increase in the number of producers sourcing from this country and hence the aggregate input trade flows.

1.5.6 Robustness 1: Alternative Measure of PTAs

As the first robustness check, Table 1.4 shows regression results for the same empirical specifications in Table 1.3 but uses the PTA depth measure. This measure captures another source of variation between sourcing countries in terms of the number of legally enforceable provisions, as input suppliers that are deeply integrated with the United States (such as NAFTA countries) tend to face lower fixed sourcing costs than others.

Table 1.4: Robustness 1: PTA depth

	(1) OLS-Baseline	(2) IV-Two Steps	(3) IV-Two Steps	(4) IV-Two Steps
$\overline{m}^s_{n,t+1}$	0.0290***	0.0961***	0.0911***	0.0988***
	(0.00447)	(0.00910)	(0.00918)	(0.00922)
PTA Depth, t	0.0528**	0.0472**	0.0476**	0.0470**
	(0.0200)	(0.0198)	(0.0199)	(0.0199)
Observations	126,158	126,158	126,158	126,158
HS2-Year F.E.	Yes	Yes	Yes	Yes
Exporter F.E.	Yes	Yes	Yes	Yes
Implied ν (w. $\beta = 0.96$)	33.1	10.0	10.5	9.7
Implied λ_1	-1.75	-0.47	-0.50	-0.46
F.E. in 1st step				
HS2-Exporter-Year	N.A.	Yes	Yes	Yes
HS10-Exporter	N.A.	No	Yes	Yes
HS10-Year	N.A.	No	No	Yes

Standard errors in parentheses and clustered at HS2-year level.

The estimated values of ν and λ_1 are broadly the same, with slightly lower magnitudes for the PTA depth measure in most specifications.

1.5.7 Robustness 2: Alternative Sector Classification

As the second robustness check, Table 1.5 demonstrates the regression results using the same empirical specifications but a different sector classification. Instead of defining sectors at the HS2 digit level, I define sectors at the broader 21-section level. On the one hand, a larger sector is helpful to address potential issues caused by singleton groups (i.e., groups with only one observation), which reduces biases and increases the reliability of empirical results. On the other hand, failure in capturing unobserved heterogeneity across narrowly defined sectors might also generate difficulties in the identification of key regression coefficients.

Table 1.5: Robustness 2: Broader Sector Classification

	(1) OLS-Baseline	(2) IV-Two Steps	(3) IV-Two Steps	(4) IV-Two Steps
$\overline{im}^s_{n,t+1}$	0.0664***	0.226***	0.215***	0.226***
	(0.00642)	(0.0355)	(0.0313)	(0.0324)
PTA Dummy, t	0.0769**	0.0608*	0.0619*	0.0607*
	(0.0328)	(0.0317)	(0.0317)	(0.0317)
Observations	48,359	48,359	48,359	48,359
Sector-Year F.E.	Yes	Yes	Yes	Yes
Exporter F.E.	Yes	Yes	Yes	Yes
Implied ν (w. $\beta = 0.96$)	14.5	4.2	4.5	4.2
Implied λ_1	-1.12	-0.26	-0.28	-0.26
F.E. in 1st step				
Sector-Exporter-Year	N.A.	Yes	Yes	Yes
HS10-Exporter	N.A.	No	Yes	Yes
HS10-Year	N.A.	No	No	Yes

Standard errors in parentheses and clustered at sector-year level.

In this case, both regression coefficients are still positive and significant, and their magnitudes are generally higher compared to baseline results. These results indicate a smaller value of ν and λ_1, with a stronger supply chain transmission and weaker impact of PTAs on fixed sourcing costs. The trade effect of PTAs on the extensive margin of sourcing, however, is still higher as represented by a more significant coefficient of $PTA_{n,t}$.

1.5.8 Robustness 3: Time-Varying Inverse Origin-Switching Elasticity

The inverse origin-switching elasticity ν governs the role of sourcing uncertainty $\varepsilon^s_{n,t}$ and hence the transmission of intensive to extensive margins in input trade. However, this structural parameter is likely to change over time. As a third robustness check, I explore the time-varying feature of ν by examining US producers' sourcing behaviors during the 2008-2009 Great Trade Collapse. As I will discuss later in Chapter 3, the Great Trade Collapse, especially the recovery period after it, is associated with a sharp decline in global demand and rising economic uncertainty. Conceptually, it might suggest a higher value of ν during the recovery period.

More specifically, I use the following modified specification:

$$\ln\left(N^s_{n,t+1}\right) = \frac{\beta}{\nu}\overline{im}^s_{n,t+1} + \gamma postGTC_t \times \overline{im}^s_{n,t+1} - \frac{\lambda_1}{\nu} PTA_{n,t} + \widehat{\psi}^s_t + \widetilde{\psi}_n + \widetilde{\epsilon}^s_{n,t+1} \quad (1.23)$$

where $postGTC_t = 1$ when $t > 2009$ and 0 elsewhere. This additional interaction term would capture the difference in the estimated ν before and after the Great Trade Collapse.

Table 1.6 demonstrates the estimation results based on (1.23). The first two columns conduct this estimation using baseline OLS and the two-step IV approach, respectively. No matter in which case, I find a larger estimated value for the inverse origin-switching elasticity ν. This

Table 1.6: Estimation of the (Inverse) Origin Switching Elasticity and PTA Effect: Two-Step IV

	(1) OLS-Baseline	(2) IV-Two Steps	(3) Exclude GTC	(4) Sector-Year F.E.
$\overline{im}^{s}_{n,t+1}$	0.0446***	0.114***	0.122***	0.111***
	(0.00666)	(0.0128)	(0.0146)	(0.0113)
postGTC$\times\overline{im}^{s}_{n,t+1}$	-0.0266***	-0.0327**	-0.0413**	-0.0257
	(0.00781)	(0.0164)	(0.0179)	(0.0166)
$PTA_{n,t}$	0.0522***	0.0480***	0.0546***	
	(0.0176)	(0.0174)	(0.0183)	
Observations	126,158	126,158	112,839	132,038
HS2-Year F.E.	Yes	Yes	Yes	Yes
Exporter F.E.	Yes	Yes	Yes	No
Exporter-Year F.E.	No	No	No	Yes
Implied ν before GTC (w. $\beta = 0.96$)	21.5	8.4	7.9	8.6
Implied ν after GTC (w. $\beta = 0.96$)	53.3	11.8	11.9	11.3
F.E. in 1st step				
HS2-Exporter-Year	N.A.	Yes	Yes	Yes
HS10-Exporter	N.A.	Yes	Yes	Yes
HS10-Year	N.A.	Yes	Yes	Yes

Standard errors in parentheses and clustered at HS2-year level.

amplification in ν during the post-GTC era stays when I exclude the crisis period (2008 and 2009) from the regression sample (Column (3)), and when I use the exporter-year fixed effect instead of $PTA_{n,t}$ to capture more unobserved variations (Column (4), although not significant).

These findings are consistent with the insight that sourcing uncertainty, as governed by the value of ν, could be time-varying and likely to be higher after the global economy suffered from the Great Trade Collapse and faced rising economic uncertainty.

1.6 Concluding Remarks

This chapter introduces a global sourcing framework to study the endogenous adjustments of global supply chains, with a focus on producers' input sourcing decisions. In this framework, each producer optimally chooses one location to buy their intermediate inputs based on tradeoffs between variable input prices and fixed sourcing costs across locations. When economic and trade conditions change, producers not only adjust how much intermediate inputs to purchase from a certain country but may also switch their sourcing locations as a result. Incorporating the response from the extensive margin leads to a supply chain augmented gravity specification for input trade flows and a size-dependent partial trade elasticity for intermediate good imports.

The global sourcing framework also implies a novel testable relationship between producers' import values and the number of importers within a specific sourcing location, which can be empirically applied to estimate the strength of supply chain transmission. Using detailed US product data on tariffs and import values, I show a positive transmission between the intensive and extensive margins for any sourcing location. The instrumental variable results indicate that an increase in expected import values from a certain country with a magnitude equivalent to 10% annual average import value across products is associated with around a 1% increase in the corresponding number of intermediate products.

I also find that trade partners who have PTAs in force tend to have lower fixed sourcing costs than other input suppliers who do not have PTAs, with the average magnitude around 47% of annual average import value across products. This impact further results in a trade effect on the extensive margin of sourcing around 4.8%, which is not captured by conventional import tariffs.

There are several aspects of this empirical analysis that are interesting to explore further. First, the identification problem might not be fully resolved with this IV approach. For example, individual import values of intermediate goods are likely to depend on past and current PTA status. This correlation could affect the identification of key regression coefficients and hence the inverse origin-switching elasticity and the impact of PTAs through fixed sourcing costs. A meaningful classification of PTA provisions into variable versus fixed cost channels is useful to improve the estimated results in this direction. Second, a considerable fraction of observations in the sample has only one imported product. These observations are not informative in the IV approach and may be influenced more due to unobservable variations. Instead of having a broader classification of sectors, applying the multinomial logistic (MNL) regression model to the product level import data could be another approach to estimate this model and avoid the concerns above.

Chapter 2: Quantitative Effects of Trade Shocks Under Global Supply Chains

2.1 Introduction

In Chapter 1, I construct a global sourcing framework to study the trade effect of endogenous supply chain reallocations and the impact of preferential trade agreements through fixed sourcing costs. However, this partial equilibrium setup is not able to address an important feature of global supply chains, which is the cross-country, cross-sector transmission through market and factor prices. This general equilibrium (GE) effect can be significant once we take the endogenous responses of supply chains into account.

This chapter further extends this framework to a GE structure to study the quantitative consequence of trade shocks with supply chain reallocations. To do so, I construct a quantitative trade model that embeds the global sourcing framework I introduced in Chapter 1, with cross-country, cross-sector, and input-output linkages. In addition to their input sourcing decisions, producers also make market entry decisions, which determine the size of domestic supply chains. These two decisions jointly characterize the supply chain structure in the model. More specifically, producers face two types of trade frictions in the foreign input market: variable trade costs, such as iceberg transportation costs and import tariffs; and fixed sourcing costs, involving the costs of setting up customized production lines, the protection of intellectual property rights, contracting frictions, etc. In response to trade shocks, these producers adjust import values (intensive margin) and sourcing locations (extensive margin) of their intermediate inputs to maximize production returns. Moreover, changes in trade conditions also affect producers' expected gains from production when they make market entry decisions, leading to further adjustments to the mass of domestic producers and hence production. These supply chain adjustments greatly enrich the transmission mechanism of the model and bring new insights into the corresponding trade and welfare outcomes.

The model has several advantages in analyzing the trade and welfare consequences of trade shocks compared to existing trade frameworks. First, this framework features adjustments through both the intensive (import value of individual products) and extensive (number of imported products) margins of sourcing, where their interactions are governed by the inverse origin-switching elasticity (defined in chapter 1). Second, the model provides a decomposition of the trade effect into intensive and extensive margins, which is convenient for studying the relative importance of these two channels in shaping global supply chains.

Another advantage of this endogenous global sourcing framework is its tractability for analyzing trade shocks through the fixed sourcing cost margin. This feature is relevant especially for evaluations of modern trade policies such as preferential trade agreements (PTAs), as more trade policy areas beyond import tariffs have been included in recent trade negotiations. Removal of non-tariff barriers is likely to affect the fixed sourcing costs faced by importers for input trade, which requires investment in customized inputs. Moreover, unlike variable trade costs, changes in fixed sourcing costs do not directly influence import prices. Thus their trade effects mainly go through the extensive margin of sourcing and affect the entry of domestic producers. This mechanism indicates that the impact of fixed sourcing cost shocks is likely to weigh more on domestic markets compared to similar shocks from variable trade costs.

The parsimonious expressions for production and trade enable the model to be disciplined with data and allow for counterfactual exercises. I do so using the World Input-Output Database (WIOD) and the corresponding Socio-Economic Accounts (SEA), and use the year 2014 to calibrate the baseline economy[1]. I then use this framework to study the trade and welfare consequences of two issues: a 25% bilateral import tariff increase on inputs between the US and China and the role of PTAs in global integration.

In the first counterfactual, rising import tariffs increase production costs faced by US producers, reduce both individual import values and the number of producers sourcing from China, and hence bilateral trade flows. US producers have more flexibility in adjusting their production plans due to endogenous input sourcing decisions. These supply chain reallocations induce a sharp decline in foreign input demand faced by Chinese producers, which translates into lower profitability, and fewer active producers in the Chinese market and ultimately harm Chinese production. This channel is more critical when higher import tariffs are targeted at intermediate inputs, as in the recent US-China trade war. The quantitative analysis shows that endogenous responses of global supply chains amplify the decline in US input imports from China by around 25%. Even if the import tariffs do not directly target final goods, the model predicts a moderate reduction of US final good imports from China and a trade diversion towards other US trade partners. Compared to a model without supply chain reallocations, these more drastic shifts in intermediate and final goods demand lead to a sharper contraction in Chinese real income (-0.75% compared to -0.04%), less welfare loss for the United States, and positive spillovers to third countries.

In the second exercise, I evaluate the impact of PTAs by looking at a counterfactual scenario

[1] 2014 is the latest year available for conducting counterfactuals using recent trade policy events.

where all existing PTA relationships are removed, causing higher tariffs and fixed sourcing costs between PTA partners. Incorporating trade policy information from the World Bank Content of Deep Trade Agreement Database and the World Integrated Trade Solution (WITS), my quantitative model shows a more significant real income effect of PTAs through reductions in fixed sourcing costs than that through lower import tariffs. Fixed cost increase accounts for around two-thirds of the overall welfare effect in most countries in the sample. Moreover, the endogenous adjustments of supply chains and production also play an essential role in amplifying these welfare effects. Thus, the role of deep trade agreements might be significantly underestimated if we only evaluate their impacts through import tariffs and do not take the corresponding supply chain reallocations into account.

The organization of this chapter is as follows. In Section 2, I review related literature and state the position and contribution of my work. In Section 3, I characterize the endogenous global sourcing framework in a GE environment. Then in Section 4, I calibrate my quantitative framework to match trade and production data and demonstrate several quantitative exercises on the welfare implications of trade shocks. Lastly, in Section 5, I make concluding remarks on the results, together with possible future extensions.

2.2 Related Literature

The quantitative trade model with endogenous supply chain reallocations discussed in this chapter mainly bridges two strands of literature. First, as described in Chapter 1, this global sourcing framework shares several common features with the group of studies on the effect of intermediate input sourcing in quantitative models with heterogeneous firms (Antràs et al., 2017;

Blaum et al., 2018; Halpern et al., 2015; Handley et al., 2020b). Most of them use a partial equilibrium framework that does not capture the general equilibrium feedback on factor prices and other types of trade flows[2]. My model has the advantage to generate a tractable input sourcing pattern that matches the aggregate data well and is capable of conducting welfare analysis in a more comprehensive GE environment. The GE environment is essential if the shocks under study are global and have substantial spillover effects across countries. In addition, my model also features another margin of supply chain adjustments: producers' market entry decisions, which is important in generating welfare implications of trade shocks.

Another related strand of literature is quantitative trade frameworks that analyze trade and welfare implications of economic and trade shocks in a GE setup (Caliendo and Parro, 2015; Caliendo et al., 2019; Eaton and Kortum, 2002; Huo et al., 2020). This chapter contributes to this group of papers by introducing an extra layer of adjustment through the reallocation of supply chains. Another value-added of this model is its capacity to address multiple trade frictions, including variable and fixed trade costs. This property is relevant for the analysis of modern international trade due to the complexity of global supply chains. The standard Armington trade structure introduced by Armington (1969) uses representative agents in all trade and production decisions; thus, all adjustments go through the intensive margin. On the other side, the Eaton and Kortum (2002) model assumes that each product's import decision is based on the location of the lowest import price; thus, most adjustments go through the extensive margin. The endogenous global sourcing structure used in this paper is a combination of these two types of models. Additionally, as in Antràs et al. (2017), the existence of both variable and trade frictions justifies the

[2]For example, Halpern et al. (2015) focus on Hungarian importers, AFT look at US firms, and Blaum et al. (2018) studies French firms.

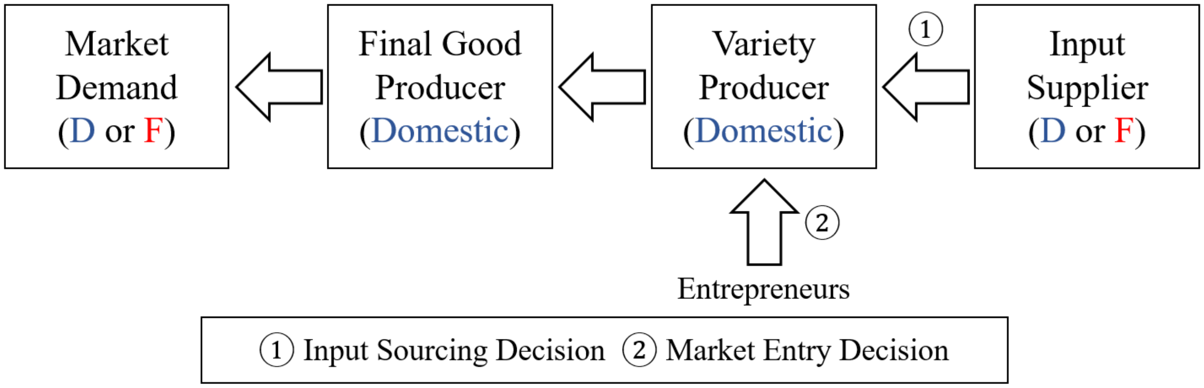
non-monotonic input sourcing pattern between import values and numbers of imported products that are observed in the real world (see Figure 1.1 in Chapter 1), which cannot be explained by either type of models.

Finally, there is a growing literature that studies the relative contribution of different margins in the growth of trade flows. Most of these studies find a crucial role of the extensive margin in explaining trade flow fluctuations, especially in the long run. More specifically, the extensive margin is estimated to contribute around 30% (Baier et al., 2014) to 70% (Bernard et al., 2009) of trade growth, depending on the lengths of horizons understudy and measurements. Between input trade and final good trade, Türkcan (2014) investigated the role of various trade margins on Turkey's export growth during 1998-2011 and found a stronger extensive margin growth in intermediate inputs. My work provides a theoretical decomposition of input trade into intensive and extensive margins and can be applied to further quantitative evaluations.

2.3 Endogenous Sourcing: A General Equilibrium Approach

In this section, I introduce a two-period general equilibrium framework that features three advantages over the standard gravity structural estimation. First, like other standard quantitative trade frameworks (Caliendo and Parro, 2015; Costinot and Rodríguez-Clare, 2014; Eaton et al., 2011), the model features supply chain linkages across countries and sectors in a general equilibrium environment. Second, the model allows for endogenous adjustments of global supply chains through both the extensive margin, e.g. the number of imported products, and intensive margin, e.g. individual import values. Finally, the model captures both the variable trade cost and the fixed sourcing cost faced by producers when making their input sourcing decisions.

Figure 2.1: Illustration of the Supply Chain Structure



The input-output structure of a particular supply chain in the model is characterized in Figure 2.1. The world economy consists of N countries indexed by i (home), n (foreign), and k (third country), and within each country there are S sectors indexed by s and s'. Except for country and sector-specific characteristics like labor endowment, productivity, and trade costs, countries are identical in terms of market structures and sectors are symmetric in terms of production structures. Hence in Figure 2.1 I only show the case for a single-sector country and summarize all other countries in foreign markets. Time is discrete and all decisions are made in two periods, denoting them by $t = 0, 1$.

2.3.1 Households

There is a representative household in each country i. She supplies fixed labor endowment $L_{i,1}$ inelastically to domestic variety producers and receives a wage $w_{i,1}$ per unit of labor in period 1. Assume the household in country i has the following nested-CES (constant elasticity of substitution) utility function:

$$U_{i,1} = \prod_{s \in S} \left(\sum_{n \in N} \left(D_{ni}^s\right)^{\frac{1}{\sigma}} \left(C_{ni,1}^s\right)^{\frac{\sigma}{\sigma-1}} \right)^{\frac{\sigma-1}{\sigma}\xi_i^s} \tag{2.1}$$

where $C_{ni,1}^s$ is the consumption of final goods from country n and sector s, D_{ni}^s is the exogeneous demand shifter which is country pair and sector specific, and ξ_i^s is the Cobb-Douglas coefficient which satisfies $\sum_s \xi_i^s = 1$ for every i. $\sigma > 1$ is the elasticity of substitution between sectoral final goods from different countries. The domestic aggregate price index is then defined as

$$P_{i,1} = \prod_s \left(\frac{P_{i,1}^{s,F}}{\xi_i^s} \right)^{\xi_i^s}$$

where $P_{i,1}^{s,F} = \left(\sum_k D_{ki,1}^s \left(P_{k,1}^s \tau_{ki,1}^s\right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$ is the price index for sectoral consumption goods and $P_{n,1}^s$ represents the price of final goods produced by sector s in country n. $\tau_{ki,1}^s$ is the bilateral iceberg trade cost, including transportation costs, import tariffs, etc.

Denote $F_{ni,1}^s$ as the total imports of country i from country n and sector s. We can derive the following final demand system from the household's utility function:

$$\frac{F_{ni,1}^s}{\sum_k F_{ki,1}^s} \equiv \phi_{ni,1}^s = \frac{D_{ni,1}^s \left(P_{n,1}^s \tau_{ni,1}^s\right)^{1-\sigma}}{\sum_k D_{ki,1}^s \left(P_{k,1}^s \tau_{ki,1}^s\right)^{1-\sigma}} \tag{2.2}$$

2.3.2 Production

The domestic production structure consists of two types of producers in each country and each sector, namely the final good producers and the variety producers. The final good producers collect all domestic differentiated varieties and combine them into the sectoral composite final goods, which can be either consumed directly or used as intermediate inputs for further production. On the other hand, the variety producers combine labor from the household, capital purchased upon entry, and intermediate inputs to produce differentiated varieties and supply them to the corresponding downstream final good producers. This input-output linkage captures the roundabout production structure widely used in the literature (Caliendo and Parro, 2015).

2.3.2.1 Final Good Producers

In each country and sector, a representative final goods producer produces a final sectoral composite good with the following nested-CES production technology in period 1:

$$Y_{i,1}^{s} = A_{i,1}^{s} \prod_{s' \in S} \left(X_{i,1}^{s',s} \right)^{\gamma_i^{s',s}} \tag{2.3}$$

where i is the production location and s is the production sector. We have $\sum_{s'} \gamma_i^{s',s} = 1$ for all i and s so that the production technology is constant return-to-scale (CRS). $A_{i,1}^{s}$ is the total factor productivity of the final goods production; $X_{i,1}^{s',s}$ is the material input from sector s'. More specifically, $X_{i,1}^{s',s}$ is a composite of domestic differentiated varieties:

$$X_{i,1}^{s',s} = \left(\int_0^{\Omega_{i,1}^{s',s}} \left(x_{i,1}^{s',s}(\omega) \right)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}, \omega \in \left[0, \Omega_{i,1}^{s',s} \right] \tag{2.4}$$

where $\Omega_{i,1}^{s',s}$ is the mass of domestic differentiated varieties that captures the size of sectoral production.

The final goods market is perfectly competitive and all final good producers are price takers both in input and product markets. This production technology generates the following demand function for each variety, given the corresponding variety price $p_{i,1}^{s',s}(\omega)$:

$$
\begin{aligned}
x_{i,1}^{s',s}(\omega) &= p_{i,1}^{s',s}(\omega)^{-\sigma}\left(P_{i,1}^{s',s}\right)^{\sigma-1}\gamma_i^{s',s}R_{i,1}^{s} \\
&\equiv p_{i,1}^{s',s}(\omega)^{-\sigma}\,\widetilde{D}_{i,1}^{s',s} \qquad (2.5)
\end{aligned}
$$

Where $R_{i,1}^{s}$ is the total revenue of the downstream final good producer, $P_{i,1}^{s',s}$ and $\widetilde{D}_{i,1}^{s',s}$ are location and supply-chain specific price indices and demand shifter for the intermediate suppliers, with

$$
P_{i,1}^{s',s} = \left(\int_0^{\Omega_{i,1}^{s',s}}\left(p_{i,1}^{s',s}(\omega)\right)^{1-\sigma}d\omega\right)^{\frac{1}{1-\sigma}} \qquad (2.6)
$$

The sectoral composite final good can be consumed by households or used as material inputs to produce differentiated varieties all over the world. I keep the production and export decisions for final good producers to be standard as in the literature for model tractability and focus on the sourcing problem of variety producers.

2.3.2.2 Differentiated Variety Producers

The optimization problem of differentiated variety producers is the main building block of my theoretical framework. It can be separated into three sub-problems and solved sequentially. At the beginning of period 0, entrepreneurs (or potential variety producers) make entry decisions regarding whether to become an active intermediate goods producer in a certain sector. After entry, they choose the optimal sourcing locations based on a trade-off between material import prices and the fixed cost of sourcing. Finally, in period 1, given the realization of macro and trade conditions, each intermediate producer decides the quantity of material imports, contingent on their sourcing decisions made in period 0, and finishes production. I assume that all variety producers exit the market after production for the sake of model tractability.

Entry Decision There is an infinite number of entrepreneurs in country i who are ex-ante homogeneous and have zero outside option values. In period 0, they make decisions to become variety producers and participate into a certain production chain (i, s', s). This decision can be characterized by the following production contract. To become a variety producer, each entrepreneur has the option to make a production-chain-specific fixed investment $\kappa_i^{s',s}$ in period 0. This fixed investment includes (i) the cost of one unit of production capital $k_{i,0}^{s',s} = 1$ that is required for variety production; and (ii) the additional production-chain specific cost of installation. In addition, the contract requires the entrepreneur to commit her production in period 1 and provide a variety ω to the corresponding downstream final good producer in (i, s). After all obligations and payments to labor and intermediate inputs are fullfilled, the entrepreneur is eligible to claim the residual revenue of production in period 1, which is the gross return to the unit of production capital.

After entry, entrepreneurs face idiosyncratic sourcing shocks that affect their later input sourcing decisions. Denote $E\left[v_i^{s',s}\right]$ as the expected value of becoming a variety producer over these sourcing shocks in period 0. The free-entry (FE) condition is characterized by

$$\kappa_{i,0}^{s',s} = E\left[v_i^{s',s}\right] \tag{2.7}$$

This FE condition determines the mass of variety producers (hence the mass of differentiated varieties) $\Omega_{i,1}^{s',s}$ which will be active for production in period 1.

Global Sourcing Decision Upon entry, each variety producer decides from where to source their material inputs in period 0 to maximize expected returns in the next period. Denote ω as the differentiated variety produced by each variety producer. Material inputs used in a specific production chain (i, s', s) are viewed as homogeneous and perfectly substitutable across all sourcing origins n, thus each variety producer will only pick one sourcing location. This assumption abstracts from the channel through which importers can lower their unit costs by sourcing from more origins, but makes the model more tractable in terms of model predictions on sourcing patterns.

There are three components that affect variety producers' sourcing decisions. Denote n as the sourcing country. The three components are: the expected gross returns $E_0\left[\pi_{ni,1}^{s',s}\right]$, which vary across sourcing countries based on the material input import prices $p_{ni,1}^{s',M} = \tau_{ni,1}^{s'} P_{ni,1}^{s'}$; a fixed sourcing cost $f_{ni,0}^{s',s}$ that should be paid before production in period 0; and lastly an idiosyncratic sourcing shock $\nu\varepsilon_{ni,0}^{s',s}(\omega)$ that is drawn after entry in period 0. In sum, the global sourcing decision can be charaterized by the following value function:

$$v_{i,0}^{s',s}(\omega) = \max_{n} \left\{\beta E_0\left[\pi_{ni,1}^{s',s}(\omega)\right] - f_{ni,0}^{s',s} + \nu\varepsilon_{n,0}^{s',s}(\omega)\right\} \tag{2.8}$$

where E_0 is the expectation over unanticipated shocks in period 1 and β is the discount factor across two periods.

The fixed cost component $f_{ni,0}^{s',s}$ captures all tangible and intangible entry barriers that a variety producer would encounter if she decides to source her material inputs from country n. These costs include multiple types of distortions not captured by import tariffs, such as contracting frictions to form a long run partnership, concerns of intellectual property right safety, or costs to set up a customized production line. In my model I abstract from these detailed structures and use a country and supply-chain specific fixed sourcing cost to represent all of these potential distortions. I set the domestic fixed sourcing cost $f_{ii,0}^{s',s} = 0$ for all supply chains as a normalization[3].

On the other hand, the sourcing shock $\nu\varepsilon_{ni,0}^{s',s}(\omega)$ mainly captures all idiosyncratic disruptions that may affect variety producers' sourcing decisions individually, whose example involves random searching frictions for a compatible material input supplier, entrepreneurs' own preferences for sourcing locations, and forecast errors about the macro and trade conditions in the next period. Generally this term could be either positive or negative[4]. This type of additive idiosyncratic assumption is extremely common in discrete choice models, but the models with heterogeneous productivities can be isomorphic and transformed into this setup[5].

Following those discrete choice models, I assume that all $\varepsilon_{ni,0}^{s',s}(\omega)$ are independent and identically distributed and drawn from a Type-I extreme value distribution with zero mean and unit dispersion, with the following cumulative distribution function:

$$F(\varepsilon) = \exp\left\{-e^{-\varepsilon-\overline{\gamma}}\right\}$$

where $\overline{\gamma} = \int_{-\infty}^{\infty} x \exp(-x - \exp(-x))\, dx$ is Euler's constant. This distributional assumption leads to the following expression of (expected) value functions:

[3]This normalization can be applied to cases where domestic sourcing costs are nonzero. However, the whole system would be equivalent with the following transformation: if $f_{ii,0}^{s',s} > 0$, denote $\widetilde{\kappa}_{i,0}^{s',s} = \kappa_{i,0}^{s',s}$ and $\widetilde{f}_{ni,0}^{s',s} = f_{ni,0}^{s',s} - f_{ii,0}^{s',s}$. In the transformed system, we can still have $\widetilde{f}_{ii,0}^{s',s} = 0$

[4]One concern is the possibility that a variety producer could make bad draws on all $\varepsilon_{ni,0}^{s',s}(\omega)$ and end up exiting the market without any production. The probability of making all negative draws in my later quantitative example is smaller than $1e-13$. This tiny fraction of producers will not affect the aggregate implications of my model.

[5]Caliendo and Parro (2020) independently uses a similar framework to model the dynamic location choices of production for establishments. To the best of my knowledge, this is the closest paper to my work in terms of modeling techniques.

$$E\left[v_i^{s',s}\right] = \nu \log\left(\sum_n \exp\left(\frac{\beta E_0\left[\pi_{ni,1}^{s',s}\right] - f_{ni,0}^{s',s}}{\nu}\right)\right) \tag{2.9}$$

Notice that given $f_{ii,0}^{s',s} = 0$, the expected value above is always positive[6]. Also, we can derive the sourcing probability $\alpha_{ni,1}^{s',s}$, which is the fraction of variety producers in country i that source from country n in period 1 as

$$\alpha_{ni,1}^{s',s} = \frac{\exp\left(\frac{\beta E_0\left[\pi_{ni,1}^{s',s}\right] - f_{ni,0}^{s',s}}{\nu}\right)}{\sum_k \exp\left(\frac{\beta E_0\left[\pi_{ki,1}^{s',s}\right] - f_{ki,0}^{s',s}}{\nu}\right)} \tag{2.10}$$

Production and Returns The production of a differentiated variety takes place in period 1. Each variety producer combines their single unit of production capital, labor, and material inputs to produce a specific variety ω, with the following production technology:

$$x_{i,1}^{s',s}(\omega) = z_{i,1}^{s',s}\left[\left(k_{i,0}^{s',s}\right)^{\delta_i^s}\left(l_{i,1}^{s',s}(\omega)\right)^{1-\delta_i^s}\right]^{\eta_i^s}\left(m_{i,1}^{s'}(\omega)\right)^{1-\eta_i^s} \tag{2.11}$$

where $z_{i,1}^{s',s}$ is the productivity of differentiated variety production that is homogeneous for all variety producers within the production chain (i, s', s), $l_{i,1}^{s',s}(\omega)$ is the corresponding local labor inputs and $m_{i,1}^{s'}(\omega)$ is the material input from the final product of sector s'. η_i^s captures the country-sector specific value-added shares in intermediate production, and δ_i^s is the corresponding capital shares and hence gross returns.

Assume that variety producers face perfectly competitive demand markets, i.e. each variety producer is small enough so that she cannot affect the purchasing price $p_{i,1}^{s',s}(\omega)$. This leads to the

[6] It is easy to show that
$\nu \log\left(\sum_n \exp\left(\frac{\beta E_0\left[\pi_{ni,1}^{s',s}\right] - f_{ni,0}^{s',s}}{\nu}\right)\right) \geq \nu \log\left(\exp\left(\frac{E_0\left[\pi_{ii,1}^{s',s}\right]}{\nu}\right)\right) = E_0\left[\pi_{ii,1}^{s',s}\right]$.

following allocation of revenue:

$$w_{i,1}l_{i,1}^{s',s}(\omega) = (1-\delta_i^s)\,\eta_i^s p_{i,1}^{s',s}(\omega)\,x_{i,1}^{s',s}(\omega) \tag{2.12}$$

$$p_{i,1}^{s',M}(\omega)\,m_{i,1}^{s'}(\omega) = (1-\eta_i^s)\,p_{i,1}^{s',s}(\omega)\,x_{i,1}^{s',s}(\omega) \tag{2.13}$$

$$\pi_{i,1}^{s',s}(\omega) = \delta_i^s\eta_i^s p_{i,1}^{s',s}(\omega)\,x_{i,1}^{s',s}(\omega) \tag{2.14}$$

where $w_{i,1}$ is the nationwide wage rate and $p_{i,1}^{s',M}(\omega)$ is the unit cost of material inputs, which is contingent on the sourcing decisions made by variety producers.

2.3.3 Aggregation and Market Clearing

Based on equation (2.10), the composite of intermediates in equation (2.4) can be expressed as

$$\begin{aligned} X_{i,1}^{s',s} &= \left(\int_0^{\Omega_{i,1}^{s',s}}\left(x_{i,1}^{s',s}(\omega)\right)^{\frac{\sigma-1}{\sigma}}d\omega\right)^{\frac{\sigma}{\sigma-1}} \\ &= \left(\Omega_{i,1}^{s',s}\right)^{\frac{\sigma}{\sigma-1}}\left(\sum_n \alpha_{ni,1}^{s',s}\left(x_{ni,1}^{s',s}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \end{aligned} \tag{2.15}$$

Denote $a_{ni,1}^{s',s}$ as the aggregate bilateral expenditure share of material inputs used by variety producers in supply chain (i,s',s) from country n. Then based on (2.15), we have the following expression of $a_{ni,1}^{s',s}$:

$$\frac{M_{ni,1}^{s',s}}{\sum_k M_{ki,1}^{s',s}} \equiv a_{ni,1}^{s',s} = \frac{\alpha_{ni,1}^{s',s}\left(p_{ni,1}^{s',s}\right)^{1-\sigma}}{\sum_k \alpha_{ki,1}^{s',s}\left(p_{ki,1}^{s',s}\right)^{1-\sigma}} = \frac{\alpha_{ni,1}^{s',s}\left(P_{n,1}^{s'}\tau_{ni,1}^{s'}\right)^{\frac{\left(1-\eta_i^s\right)(1-\sigma)}{1-\delta_i^s\eta_i^s(1-\sigma)}}}{\sum_k \alpha_{ki,1}^{s',s}\left(P_{k,1}^{s'}\tau_{ki,1}^{s'}\right)^{\frac{\left(1-\eta_i^s\right)(1-\sigma)}{1-\delta_i^s\eta_i^s(1-\sigma)}}} \tag{2.16}$$

where the sourcing probability $\alpha_{ni,1}^{s',s}$ is characterized by (2.10).

Notice that the partial trade elasticity of intermediate input trade flows with respect to variable trade costs $\tau_{ni,1}^{s'}$ is $\frac{\left(1-\eta_i^s\right)(1-\sigma)}{1-\delta_i^s\eta_i^s(1-\sigma)}$, smaller than that of final goods trade flows (which equals to $1-\sigma$) in absolute values. There are two reasons for the dilution of the impact of variable trade costs on intermediate demand. First, differentiated variety production involves both material inputs and domestic production factors. Domestic production factors are common to all entrepreneurs who operate in the same supply chain and whose prices are not directly affected by trade costs. This reduces the transmission of trade costs to production costs, as captured by $1-\eta_i^s$. Second, since production capital is pre-determined, the actual production technology entrepreneurs possess is decreasing return-to-scale (DRS). That means even though they are price takers, their quantity decisions matter for the unit costs of production and hence generate another channel for dampening the transmission of all factor and input prices, as captured by $1-\delta_i^s\eta_i^s(1-\sigma)$[7].

These parsimonious expressions of aggregate trade flows can be also applied to price indices on production:

[7]These statements are based on the fact that $\sigma > 1$, i.e. that differentiated varieties are substitutable rather than complementary with each other.

$$P_{i,1}^{s',s} = \left(\Omega_{i,1}^{s',s}\right)^{\frac{1}{1-\sigma}} \left(\sum_n \alpha_{ni,1}^{s',s} \left(p_{ni,1}^{s',s}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{2.17}$$

$$P_{i,1}^{s} = \frac{1}{A_{i,1}^{s}} \prod_{s'} \left(\frac{P_{i,1}^{s',s}}{\gamma_i^{s',s}}\right)^{\gamma_i^{s',s}} \tag{2.18}$$

Now let us focus on the entry problem of entrepreneurs. Combining equations (2.7) and (2.9) allows the derivation of a condition for the equilibrium mass of active variety producers $\Omega_{i,1}^{s',s}$:

$$\kappa_{i,0}^{s',s} = \nu \log \left(\sum_n \exp\left(\beta E_0 \left[\frac{\left(p_{ni,1}^{s',s}\right)^{1-\sigma}}{\sum_k \alpha_{ki,1}^{s',s}\left(p_{ki,1}^{s',s}\right)^{1-\sigma}} \frac{\delta_i^s \eta_i^s \gamma_i^{s',s} R_{i,1}^s}{\Omega_{i,1}^{s',s}}\right] - f_{ni,0}^{s',s}\right)^{1/\nu}\right) \tag{2.19}$$

Thus, as trade and macro conditions change, the mass of variety producers in each supply chain will adjust endogeneously to ensure the FE condition holds.

I close the economy with market clearing conditions. Each country's total income in period 1 is the summation of labor income and returns from intermediate input producers:

$$\begin{aligned} I_{i,1} &= \sum_s w_{i,1} L_{i,1}^s + \Omega_{i,1}^{s',s} \sum_{s,s',n} \alpha_{ni,1}^{s',s} \pi_{ni,1}^{s',s} + B_{i,1} \\ &= \sum_s \left(1-\delta_i^s\right) \eta_i^s R_{i,1}^s + \sum_s \delta_i^s \eta_i^s R_{i,1}^s + B_{i,1}, \end{aligned} \tag{2.20}$$

where $B_{i,1}$ is the country-specific external borrowing. I internalize trade imbalances following Caliendo et al. (2019) by assuming a global mutual fund which hires all variety producers in the world, and is funded by all countries with fixed investment shares λ_i. In period 1, this mutual fund collects all the gross returns $\Pi_1 = \sum_i \Omega_{i,1}^{s',s} \sum_{s,s',n} \alpha_{ni,1}^{s',s} \pi_{ni,1}^{s',s} = \sum_{i,s} \delta_i^s \eta_i^s R_{i,1}^s$ and then rebates them to each country according to its investment shares:

$$\begin{aligned} B_{i,1} &= \lambda_i \Pi_1 - \sum_s \delta_i^s \eta_i^s R_{i,1}^s \\ &= \lambda_i \sum_n \sum_s \delta_n^s \eta_n^s R_{n,1}^s - \sum_s \delta_i^s \eta_i^s R_{i,1}^s \end{aligned} \tag{2.21}$$

The market clearing condition for each sector's final goods can then be characterized by:

$$\begin{aligned} R_{i,1}^s &= \sum_n \phi_{in,1}^s \xi_n^s \left(\sum_{s'} \left(1 - \delta_n^{s'}\right) \eta_n^{s'} R_{n,1}^{s'} + \lambda_i \Pi_1 \right) \\ &\quad + \sum_{n,s'} a_{in,1}^{s,s'} \gamma_n^{s,s'} \left(1 - \eta_n^{s'}\right) R_{n,1}^{s'} \end{aligned} \tag{2.22}$$

where $R_{i,1}^s$ on the left-hand side of the equation represents the supply of sectoral final goods s in country i in period 1, which equals to the corresponding input and final good demand from other countries and other sectors on the right-hand side of the equation.

Finally, the labor market clearing condition in each country can be expressed as

$$\sum_s \left(1 - \delta_i^s\right) \eta_i^s R_{i,1}^s = w_{i,1} L_{i,1} \tag{2.23}$$

where $L_{i,1}$ is the exogeneous total amount of labor supplied by the representative household in country i.

2.3.4 Equilibrium

The main focus of this paper is to evaluate the trade and welfare consequences of trade shocks with endogenous supply chain reallocations. I define by $\Gamma = \left\{\tau^s_{ni,1}, f^{s',s}_{ni,0}\right\}^{N;S}_{n,i=1;s,s'=1}$ the set of trade shocks that can be influenced by trade policies[8].

The exogenous state of the economy can be charaterized by the set of fundamentals $\Xi = \left\{D^s_{ni}, A^s_{i,1}, z^{s',s}_{i,1}, L_{i,1}, \lambda_i, \kappa^{s',s}_{i,0}\right\}^{N;S}_{n,i=1;s',s=1}$ which I assume to be fixed.

The set of endogeneous state variables at period 1 involves the mass of active intermediate goods producers $\Omega_1 = \left\{\Omega^{s',s}_{i,1}\right\}^{N;S}_{i=1;s',s=1}$, and the distribution of sourcing $\alpha_1 = \left\{\alpha^{s',s}_{ni,1}\right\}^{N;S}_{n,i=1;s',s=1}$.

We can then define the competitive equilibrium of the model as follows:

Definition 1 *Given the realization of fundamentals Ξ and trade policies Γ, a **competitive equilibrium** of the model is a set of endogeneous variables*
$\left\{\Omega_1, \alpha_1, E\left[v^{s',s}_i\right], p^{s',s}_{ni,1}, P^s_{i,1}, P^{s',s}_{i,1}, P_{i,1}, P^{s,F}_{i,1}, w_{i,1}, R^s_{i,1}, \Pi_1\right\}$ *that solves the households' utility maximization problem (2.1), (2.2), the final and intermediate goods producers' problems (2.5), (2.9)-(2.19), and satisfies all the equilibrium market clearing conditions (2.20)-(2.23).*

2.3.5 Supply Chain Reallocation Under Trade Shocks

The global supply chains in my model are characterized by three variables, which can be further classified into two margins. The **intensive margin** involves the gross return $\pi^{s',s}_{ni,1}$,

[8] This implicitly assumes that the influence of fixed sourcing costs takes a one period lag to be effective, as the sourcing decisions are made prior to the production decisions.

which is negatively related to the input import price $P^{s'}_{ni,1}\tau^{s'}_{ni,1}$. The **extensive margin** includes the sourcing probability $\alpha^{s',s}_{ni,1}$ and the mass of variety producers $\Omega^{s',s}_{i,1}$. Accordingly, my model features two types of trade frictions that can induce supply chain reallocations: the variable trade cost $\tau^{s}_{ni,1}$ and the fixed sourcing cost $f^{s',s}_{ni,0}$. In this section, I discuss how global supply chains respond to changes in these two types of trade frictions and the corresponding trade and welfare implications.

Trade effect: Consider an increase in the variable trade cost $\tau^{s'}_{ni,1}$. This trade shock has a direct positive impact on the import price and hence reduces the gross return $\pi^{s',s}_{ni,1}$. Moving one period backwards, the lower gross return further reduces producers' incentives to source from country n when making their input sourcing decisions, leading to a smaller sourcing probability $\alpha^{s',s}_{ni,1}$. Given that the aggregate intermediate import flows are jointly determined by both the intensive (π) and extensive (α) margins of sourcing, the transmission described above indicates an amplification impact of variable trade cost changes on input trade.

Alternatively, an increase in the fixed sourcing cost $f^{s',s}_{ni,0}$ does not have a direct impact on the gross return, since it does not directly affect the marginal cost of production. However, this trade shock to the fixed cost margin effectively deters variety producers from choosing country n and the sourcing location in period 0. This result also suggests that the trade effect on intermediate imports generated by fixed sourcing cost changes mainly attributes to the extensive margin of sourcing. The difference in trade effect compositions could be a potential identification to separate these two types of trade frictions.

Welfare effect: The impacts on domestic real production and welfare are mainly through the upstream-to-downstream transmission. Deteriorations in both types of trade frictions faced by producers in country i and sector s tend to negatively affect the overall expected return to become a variety producer in this production chain (i, s', s). As a result, there are fewer entrepreneur entrants through the FE condition, leading to a smaller number of variety producers $\Omega_{i,1}^{s',s}$ in the domestic market. Due to the love-of-variety property in final good production, a lower number of domestic varieties will push up the production cost of final goods $P_{i,1}^{s}$ and generate a downward pressure on sectoral real output $Y_{i,1}^{s}$.

In contrast, the welfare impacts on the origin country n are much like the downstream-to-upstream transmission. Decline in the import demand $a_{ni,1}^{s',s}$ generates a downward pressure on the sectoral output $Y_{n,1}^{s'}$ in country n. The transmission typically ends here if there is no supply chain reallocation, but in my framework, this consequence further translates into lower downstream demand and hence fewer variety producers in country n and sector s' through the rebalancing of the FE condtions. Then the similar upstream-to-downstream transmission mechanism described above applies, further amplifying the foreign sectoral real output. These transmission channels are crucial for understanding the welfare implications of trade shocks in the model.

Finally, since this model features a general equilibrium (GE) environment, it is also necessary to consider the GE effects of trade shocks through price and wage changes. Under my global sourcing framework, this GE channel is mainly summarized in changes in gross returns $\pi_{ni,t}^{s',s}$, including influences from both prices and wages, which are proportional to bilateral import values. The strength of this GE channel is determined mainly by two structural parameters in the model. First, as in many quantitative trade models, the magnitude of demand elasticity σ governs the flexibility of marginal production costs to changes in sourcing prices; thus a higher value of σ indicates larger adjustments to trade shocks on the variable cost margin and trade flows, but smaller impacts on real incomes. Second, the origin-switching elasticity $1/\nu$ governs how the extensive margin of sourcing responds to intensive margin changes. Larger values of ν (smaller

$1/\nu$) dampen this transmission channel and reduce the responses of $\alpha_{ni,1}^{s',s}$ and $\Omega_{i,1}^{s',s}$ to a given trade shock, hence restrain both trade and welfare consequences. An extreme case is when ν goes to infinity, and the model collapses to a standard Armington trade framework with an exogenous input-sourcing structure. In the later quantitative analysis, I will demonstrate various robustness checks with different values of this parameter to justify these predictions.

2.3.6 Discussion: Model Assumptions

Specification of Fixed Sourcing Costs In my model, variable trade costs are applied to both input and final goods trade, while fixed sourcing costs are specific to intermediate goods producers. This is a relatively restrictive statement, since importing final goods may also incur fixed costs. There are two approaches to justify this model assumption.

First, in my model the representative household makes import decisions about final goods based on a CES utility function. I assume the fixed cost of importing this sectoral final good is not high compared to the corresponding demand from household, so that the representative household will always import final goods from all countries and sectors. In this case, the existence of fixed costs would not change the final demand structure. This simplification on the final demand side enables me to focus on reallocations on supply chains, as well as provide a characterization of the complete world market.

Second, the fixed sourcing cost f in my model can be viewed as a summary of all **additional** fixed costs that are encountered by input sourcing, compared to final good sourcing. Imported final goods and intermediate inputs face common non-tariff trade barriers, such as import quotas, discrepancy in product standards, and searching costs. However, given that intermediate inputs are used for further production, additional investment, especially on input-specific production technologies, is often required prior to the actual production process. My model assumes that fixed sourcing costs are paid one period in advance, which is consistent with the nature of these fixed investments.

Variable trade costs and demand elasticity In the model structure, I assume trade in final goods $\phi_{ni,1}^{s'}$ and intermediate inputs $a_{ni,1}^{s',s}$ face the same variable trade costs $\tau_{ni,1}^{s'}$. This assumption may not be true in the real world, especially for import tariffs. However, these discrepancies in variable trade costs can be summarized in the bilateral final demand shifters $D_{ni}^{s'}$ and do not affect the main transmission mechanism of the model. One could partially address this issue by incorporating detailed tariff and transportation cost information for final good and input trade.

The framework also assumes the same demand elasticities σ between sectoral goods from different locations and between domestic varieties. One may argue that the demand elasticity between domestic varieties is generally larger. Again, the model is able to handle alternative values for the variety demand elasticity with proper additional calibration, but would not qualitatively change the main story of the model.

2.3.7 Decomposition: Extensive vs. Intensive Margins

This subsection introduces a model-based method to decompose respsonses in trade flows into extensive versus intensive margins. This decomposition takes general equilibrium feedback into account and is feasible for quantitative exercises.

Recall expression (2.16) for intermediate import shares $a_{ni,1}^{s',s}$. The log-linearized approximation of this import share is:

$$
\begin{aligned}
\log\left(a_{ni,1}^{s',s}\right) &\approx \log\left(\alpha_{ni,1}^{s',s}\right) + (1-\sigma)\log\left(p_{ni,1}^{s',s}\right) - \sum_k a_{ki,1}^{s',s}\left(\log\left(\alpha_{ki,1}^{s',s}\right) + (1-\sigma)\log\left(p_{ki,1}^{s',s}\right)\right) \\
&= \underbrace{\left(\log\left(\alpha_{ni,1}^{s',s}\right) - \sum_k a_{ki,1}^{s',s}\log\left(\alpha_{ki,1}^{s',s}\right)\right)}_{\text{Extensive Margin}} + \underbrace{(1-\sigma)\left(\log\left(p_{ni,1}^{s',s}\right) - \sum_k a_{ki,1}^{s',s}\log\left(p_{ki,1}^{s',s}\right)\right)}_{\text{Intensive Margin}}
\end{aligned}
\tag{2.24}
$$

This log-linear approximation provides an intuitive decomposition for variations in intermediate trade shares. The first term captures impacts through extensive margin changes, as measured by the direct effect ($\log\left(\alpha_{ni,1}^{s',s}\right)$) minus the indirect spillover from changes in other origins ($\sum_k a_{ki,1}^{s',s}\log\left(\alpha_{ki,1}^{s',s}\right)$). Similarly, the second term shows impacts through intensive margin changes, as measured by the net effect of changes in individual import values, which, based equilibrium conditions, are characterized by variety prices or production costs. As described later in the quantitative analysis, This decomposition is very useful for comparing the relative strengths of extensive and intensive sourcing margins in trade effects.

It is worth noting that this expression is similar but still different from the empirical decomposition approach in Hummels and Klenow (2005) (HK henceforth). In my model, the extensive margin of sourcing is computed as the count of products imported from a certain location over the total number of products imported, while HK uses product-level import values as weights in the calculation. Additionally, my framework takes domestic absorption into account, while HK and following researches (Baier et al., 2014; Türkcan, 2014) do not due to data limitations.

2.4 Quantitative Analysis

In this section, I take the model to data and quantitatively explore the trade and welfare implications of trade shocks. In my model, welfare is characterized by country-level real incomes, which is the summation of both real wage incomes and real transfers from the global mutual fund. Compared to other quantitative trade frameworks, my model has two advantages in evaluating the welfare consequence of trade shocks. First, it features endogenous responses of supply chains both through sourcing location choices and domestic production. Second, it incorporates both variable trade costs and fixed sourcing costs, providing an additional dimension to evaluate modern trade policies, such as preferential trade agreements.

Following Dekle et al. (2008), I use the exact hat algebra (henceforth EHA) to solve the model counterfactuals. This method aims to solve the new equilibrium in terms of relative changes to the baseline economy. Without knowing complete information on the baseline equilibrium, EHA enables me to solve the counterfactuals while only relying on moment conditions on the observable allocations of the baseline economy and some structural parameters. All exogenous unobservable fundamentals are kept constant at their reference year levels across two equilibria and will not affect the computation of the counterfactuals.

To illustrate the role of supply chain reallocations, I first conduct a counterfactual scenario of the US-China trade conflict, where the United States unilaterally applies 25% additional import tariffs against intermediate imports from China. In the second quantitative exercise, I evaluate the trade and welfare impacts of existing PTAs by investigating a counterfactual scenario where all of these trade agreements disintegrate. As opposed to the first exercise, this global disintegration works through both the variable and fixed cost margins, leading to a clear comparison between the relative strengths of these two types of trade shocks. This counterfactual exercise also provides a comprehensive evaluation of the welfare and trade implications of PTAs.

In this section, all quantitative results are based on four aggregate sectors: commodity (agricultural and mining), manufacturing, non-manufacturing industry (utility supply and construction), and services. This approach allows for cross-sector supply chain linkages and avoids inaccurate data at a more disaggregated sector level[9] and is enough to distinguish between sectors covered by import tariffs (such as commodity and manufacturing sectors) and those that are not (mostly service sectors)[10].

2.4.1 Solving Counterfactuals

Denote x' as the equilibrium outcome of variable x in the counterfactual equilibrium. Define $\widehat{x} = x'/x$ as the relative change of variable x between the counterfactual and initial equilibria, and $\Delta x = x' - x$ as the corresponding level change. I can now define the system of equations that characterize the equilibrium in changes. The detailed derivation and description of equilibrium conditions are in Appendix B. Here I only demonstrate those that are directly related to my counterfactual analysis.

Proposition 2 (Trade Effect) *Consider two types of exogenous trade shocks: the variable cost trade shock $\widehat{\tau}^{s}_{ni,1}$ and the fixed cost trade shock $\Delta f^{s',s}_{ni,0}$. The impacts of trade shocks on bilateral*

[9]Some of the sectoral level data in WIOD are imputed and not accurate. For example, the cross-sector import flows are imputed using domestic input-output tables.

[10]Extensions with more disaggregated sectors are straightforward based on the model structure.

import shares can be summarized by the following two equations:

$$\textbf{\textit{(Final Goods)}} \qquad \widehat{\phi}^{s}_{ni,1} = \frac{\left(\widehat{P}^{s}_{n,1}\widehat{\tau}^{s}_{ni,1}\right)^{1-\sigma}}{\sum_k \phi^{s}_{ki,1}\left(\widehat{P}^{s}_{k,1}\widehat{\tau}^{s}_{ki,1}\right)^{1-\sigma}} \tag{2.25}$$

$$\textbf{\textit{(Intermediate Goods)}} \qquad \widehat{a}^{s',s}_{ni,1} = \frac{\widehat{\alpha}^{s',s}_{ni,1}\left(\widehat{P}^{s'}_{n,1}\widehat{\tau}^{s'}_{ni,1}\right)^{1-\varepsilon^{s}_{i}}}{\sum_k a^{s',s}_{ni,1}\widehat{\alpha}^{s',s}_{ki,1}\left(\widehat{P}^{s'}_{k,1}\widehat{\tau}^{s'}_{ki,1}\right)^{1-\varepsilon^{s}_{i}}} \tag{2.26}$$

where changes in sourcing probabilities are characterized by

$$\widehat{\alpha}^{s',s}_{ni,1} = \frac{\exp\left(\beta\Delta\pi^{s',s}_{ni,1} - \Delta f^{s',s}_{ni,0}\right)^{1/\nu}}{\exp\sum_k \alpha^{s',s}_{ni,1}\left(\beta\Delta\pi^{s',s}_{ki,1} - \Delta f^{s',s}_{ki,0}\right)^{1/\nu}} \tag{2.27}$$

In these expressions, changes in sectoral final good prices $\widehat{P}^{s}_{n,1}$ *and producers' gross returns* $\Delta\pi^{s',s}_{ni,1}$ *are endogenous and determined through market clearing.*

The corresponding welfare implication in my framework is defined as follows:

Definition 2 (Welfare Effect) *The welfare effect on country* i *is defined as*

$$\widehat{W}_{i,1} = \widehat{E}_{i,1}/\widehat{P}_{i,1}$$

where $E_{i,1} = \sum_s \left(1-\delta^{s}_{n}\right)\eta^{s}_{n}R^{s}_{n,1} + \lambda_i\Pi_1$ *is the total nominal income received by the representative household in country* i.

Although the equilibrium changes of welfare need to be determined using market clearing conditions, there are some intuitions which can be inferred through price variations. Consider the bilateral imports of country B from country A. Reductions in bilateral variable trade costs

τ_{AB} lead to a direct decline in import prices and the production price in country A. Alternatively, reducing fixed sourcing costs f_{AB} attracts more entrepreneur entry in country A, which leads to a larger number of differentiated varieties. Both types of trade shocks generate a reduction in the price of sectoral final goods and benefit the representative household in country A.

In the model, other countries are also affected by variable trade cost reductions between country A and B. However, this third-country effect is still ambiguous. Consider a third country C who sources these sectoral final goods from country A. On the one hand, variety producers and the representative household benefit from both types of trade shocks by enjoying a lower import price. On the other hand, country C's export of these sectoral final goods becomes less competitive in the global market. This leads a downward pressure on country C's production and real income. The overall third-country effect depends on the relative strengths of these two driving forces in the equilibrium.

2.4.2 Calibration Strategy

I match the baseline economy of my quantitative model to a world economy characterized by the World Input-Output Database (WIOD), which covers $N = 44$ countries. Given the timing assumptions of the model, I set 2014 as the reference year for trade and production (denoted as period 1) and 2013 as the reference year for PTA status (denoted as period 0)[11].

The initial allocations of the world economy are characterized by the sectoral bilateral final goods trade flows $\phi^s_{ni,1}$ and inter-sectoral bilateral intermediate trade flows $a^{s',s}_{ni,1}$ across countries; gross revenues by sector and country $R^s_{i,1}$, payments to labor $w_{i,1}L^s_{i,1}$, and capital $VA^s_{i,1} - w_{i,1}L^s_{i,1}$.

[11] Import tariff changes are still based on 2014, but I only use partners which have a PTA relationship in 2013 to compute counterfactual changes.

I also construct the unobserved sourcing probability $\alpha_{ni,1}^{s',s}$ within each supply chain (i, s', s) by utilizing the model relationship between observed variables.

For constant and exogenous parameters, I need the value-added shares in gross output η_i^s, the capital shares in value-added δ_i^s, across sectors and countries; the sectoral expenditure share in final goods production $\gamma_i^{s',s}$ and final goods consumption ξ_i^s across countries; the production capital requirement upon entry $\kappa_{i,0}^{s',s}$ for participating each supply chain, and the ownership structure of the global mutual fund λ_i[12].

Some structural parameters need to be decided externally. Table 2.1 demonstrate the value and source of each parameter. "Model-based estimation" implies an estimation based on equation (1.15) which is described in detail in Chapter 1. More specifically, I choose $\nu = 10$ as the benchmark value.

Table 2.1: External Calibration and Assigned Parameters

Parameter	Description	Value	Source
σ	demand elasticity	5	Trade elasticity ≈ 4 (Simonovska and Waugh, 2014)
β	discount factor	0.96	Real interest rate = 4%
ν	(inverse) origin-switching elasticity	10	Model-based estimation

2.4.2.1 Trade and Production

The World Input-Output Database (WIOD) contains a complete set of information on country-sector level gross output and value-added, as well as a separation between final goods and input trade at the bilateral level, which fits perfectly with my quantitative framework. I calibrate the trade and production structure of my model $\phi_{ni,1}^s$, $a_{ni,1}^{s',s}$, $R_{i,1}^s$ and η_i^s directly to WIOD. The mappings are quite straight-forward, and the market clearing conditions hold given the self-balancing feature of the world input-output table. In terms of country coverage, this database

[12] I assume these fundamentals to be fixed at this moment.

covers 28 European Union members, 15 non-EU countries including the United States and China, and the Rest of the World (ROW). These 43 countries account for more than 80 percent of world GDP and around 70 percent of world trade. In terms of sector coverage, WIOD contains information on 4 commodity sectors, 18 manufacturing industry sectors, 5 non-manufacturing industry sectors, and 29 services sectors based on the ISIC rev. 4 classification. As noted previously, I consolidate all 56 sectors into four aggregate sectors.

I obtain capital share in value-added δ_i^s and nominal capital stock from the WIOD Socio Economic Accounts (SEA) at the country-sector level.

2.4.2.2 Sourcing Probability

The sourcing probability $\alpha_{ni,1}^{s',s}$ cannot be directly observed from the data. However, the model structure provides an identification strategy for these two sets of variables. Rearrange terms in condition (2.2) and define

$$\widetilde{\phi}_{ni,1}^{s} = \frac{\phi_{ni,1}^{s}/D_{ni}^{s}}{\sum_k \phi_{ki,1}^{s}/D_{ki}^{s}} = \frac{\left(P_{n,1}^{s}\tau_{ni,1}^{s}\right)^{1-\sigma}}{\sum_k \left(P_{k,1}^{s}\tau_{ki,1}^{s}\right)^{1-\sigma}}$$

More specifically, $\widetilde{\phi}_{ni,1}^{s}$ captures all variations in import prices and variable trade costs, or equivalently, the intensive margin of trade. Given that similar terms exist in the expression for the intermediate demand system (2.16), I can use this variable to isolate the sourcing probability $\alpha_{ni,1}^{s',s}$:

$$
\begin{aligned}
a_{ni,1}^{s',s} &= \frac{\alpha_{ni,1}^{s',s}\left(P_{n,1}^{s'}\tau_{ni,1}^{s'}\right)^{\frac{(1-\eta_i^s)(1-\sigma)}{1-\delta_i^s\eta_i^s(1-\sigma)}}}{\sum_k \alpha_{ki,1}^{s',s}\left(P_{k,1}^{s'}\tau_{ki,1}^{s'}\right)^{\frac{\left(1-\eta_i^s\right)(1-\sigma)}{1-\delta_i^s\eta_i^s(1-\sigma)}}} = \frac{\alpha_{ni,1}^{s',s}\left(\widetilde{\phi}_{ni,1}^{s'}\right)^{\frac{(1-\eta_i^s)}{1-\delta_i^s\eta_i^s(1-\sigma)}}}{\sum_k \alpha_{ki,1}^{s',s}\left(\widetilde{\phi}_{ki,1}^{s'}\right)^{\frac{\left(1-\eta_i^s\right)}{1-\delta_i^s\eta_i^s(1-\sigma)}}} \Rightarrow \\
\alpha_{ni,1}^{s',s} &= \frac{a_{ni,1}^{s',s}/\left(\widetilde{\phi}_{ni,1}^{s'}\right)^{\frac{(1-\eta_i^s)}{1-\delta_i^s\eta_i^s(1-\sigma)}}}{\sum_k a_{ki,1}^{s',s}/\left(\widetilde{\phi}_{ki,1}^{s'}\right)^{\frac{\left(1-\eta_i^s\right)}{1-\delta_i^s\eta_i^s(1-\sigma)}}} \qquad (2.28)
\end{aligned}
$$

In order to fully pin down the sourcing probability, I need to impose $D_{ni}^s = D_i^s, \forall n$ so that they are destination country-sector specific and do not exhibit any home bias.

2.4.3 Counterfactual 1: US-China Trade Conflict

In the first counterfactual analysis, I apply my theoretical framework to study a real-world inspired policy change between the United States and China. Based on the information from the World Input-Output Database (WIOD), in 2014, about 11.7% of US imported non-services intermediate inputs came from China, and the United States was the world's largest buyer of Chinese exported intermediate inputs (around 13.6%). These numbers highlight the significant trade and supply chain reliance between these two countries. Moreover, as documented by many recent studies, this trade dispute between the world's two largest economies could induce significant reallocations on global supply chains and influence many other countries through input-output linkages.

Given that the major targets of the "Trump tariffs" are intermediate inputs[13], I simplify the tariff schedule to be a hypothetical 25% uniform increase in import tariffs on US intermediate im-

[13] Bown and Zhang (2019) show that around 60 percent of new US tariffs targeted intermediate inputs.

ports from China (excluding trade in services)[14]. Although this counterfactual analysis abstracts from detailed tariff schedules across disaggregated industries and products in the real world, it provides a useful example for evaluating the role of supply chain reallocations in transmitting trade shocks, the focus of this paper[15].

The variables of interest in this exercise are equilibrium changes in country-specific welfare and US imports from China, as well as other close substitutes for Chinese imports such as Japan, South Korea, Taiwan, and NAFTA countries who are important trade partners of US. More specifically, I want to explore the following policy-related questions: (i) How would endogenous supply chain reallocations change the effects of this 25% import tariff on the United States and China? (ii) What are the trade and welfare consequences of the US-China trade conflict to other countries, especially US close trade partners?

To answer these questions, I consider two counterfactual scenarios. In the first scenario, the United States unilaterally applies its additional 25% import tariffs on intermediate inputs against China. The second scenario incorporates China's retaliation on intermediate imports against the US, with the same magnitude of tariff increase, covering the same range of sectors. For each scenario, I implement two model specifications: the baseline specification with endogenous global sourcing (the "flexible" specification) and a more restricted one where the sourcing probability α and the size of producers Ω are fixed (the "fixed" specification). The difference between these two model specifications captures the role of supply chain reallocations in trade and welfare evaluations. Finally, there is also evidence that some trade restrictions applied during the recent US-China trade war were non-tariff barriers which tend to increase fixed sourcing costs. I com-

[14]During this trade conflict, some restrictions did involve service goods. However, their impacts are difficult to measure compared to simple tariff changes. Including service trade does not create a qualitative difference in the results.

[15]Counterfactuals with more realistic tariff changes will be considered in future updates.

pare the differences in trade and welfare consequences generated by trade shocks in variable and fixed costs by looking at an artificial increase to the fixed sourcing cost US producers face when they decide to source intermediate inputs from China. More specifically, I calibrate the level change of this fixed cost trade shock only so that it generates the same impact on US aggregate import shares from China as those generated by the unilateral 25% tariff increase.

It is worth mentioning that my model does not feature government use of tariff revenue in each country; thus all quantitative results in this section abstract from the tariff revenue channel.

2.4.3.1 Trade and Welfare: Endogenous vs. Fixed Sourcing

Figure 2.2: The US-China Trade Conflict: Welfare

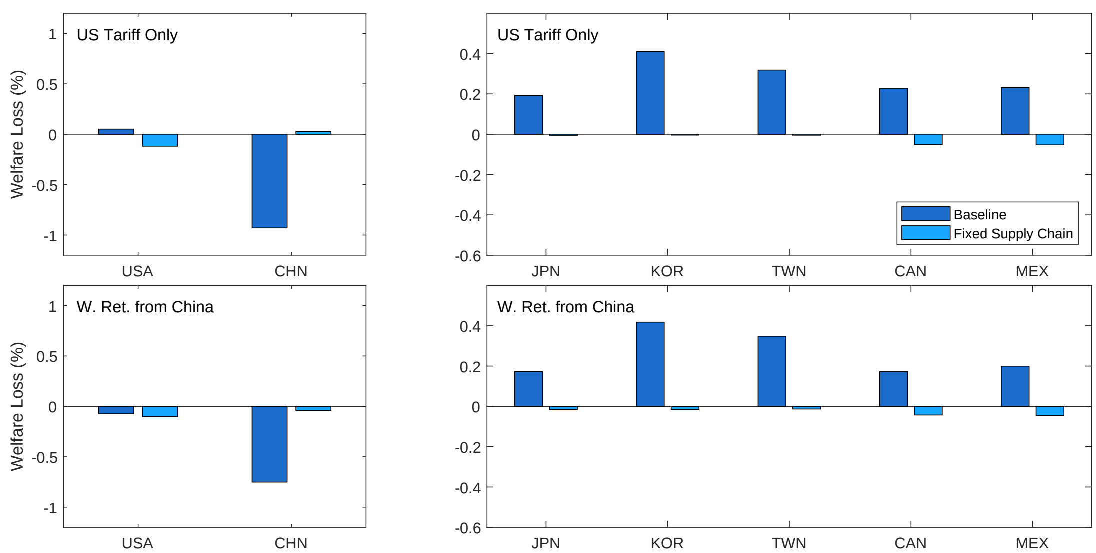


Figure 2.2 demonstrates the welfare consequences for selected countries[16]. The upper panels show Scenario 1, where the United States unilaterally increases import tariffs on intermediate inputs from China; and the bottom panels show Scenario 2, where China chooses to retaliate with

[16]Results for all sample countries can be found in Appendix B.

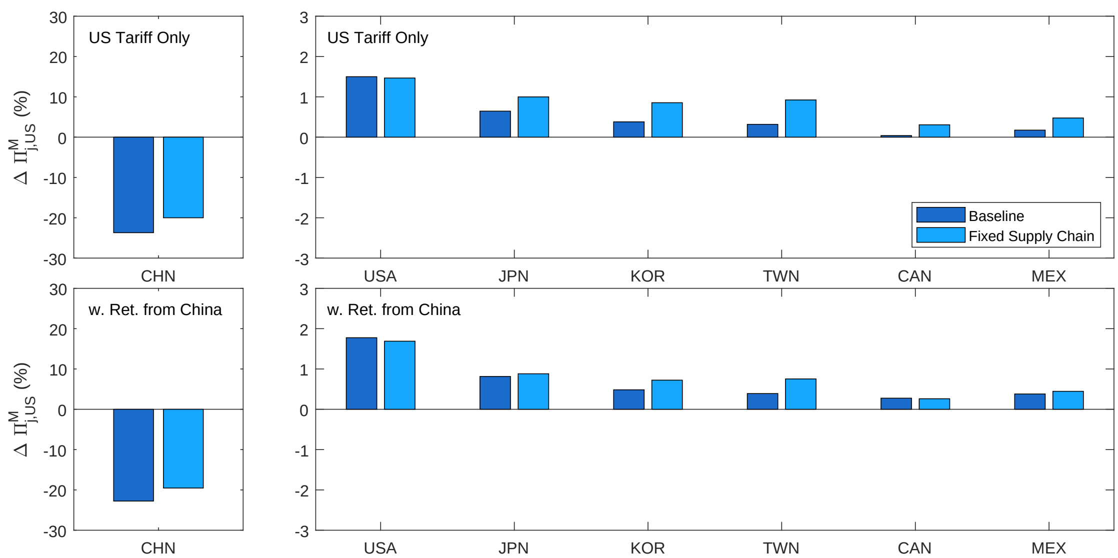
the same magnitude of import tariffs on the US intermediate goods. “Baseline” means the model with endogenous supply chain reallocations, and “Fixed Supply Chain” means an alternative model that does not allow supply chain structures (α and Ω) to respond.

As illustrated by the dark blue bars, with endogenous adjustments of the input sourcing and domestic production structures, the United States receives a positive welfare effect, while China suffers a considerable contraction in real income, approximately -0.93%. However, once China retaliates on US intermediate inputs with the same 25% tariff increase, the United States welfare change becomes negative.

Compared to an alternative model specification with fixed supply chain structures, the baseline model generates a much larger contraction in Chinese real income. Given that the United States purchases 13.6% of Chinese exports of intermediate inputs, distortions in the US demand would significantly affect the entry and production decisions of upstream Chinese producers and the real incomes of Chinese households. This additional supply chain reallocation amplifies the negative impact of this 25% tariff increase on China. Intuitively, with endogenous responses of supply chains, the United States can pass through more negative impacts of this higher trade barrier to the Chinese economy and offset the remaining impact by increasing sourcing from other countries.

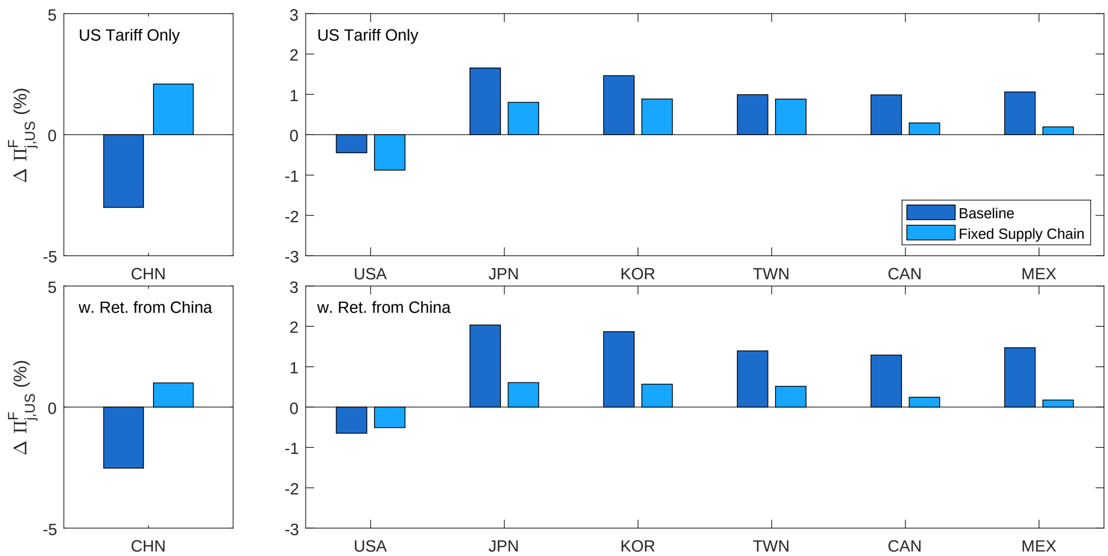
Another significant difference between the two model specifications is the spillover effect on third countries. As we can see from the right panels of Figure 2.2, other US trade partners slightly benefit from reallocations of supply chains due to this trade war, especially for those economies that are close substitutes for Chinese products such as South Korea and Taiwan. However, as shown in the lower-right panel, the third-country welfare implication with a fixed global sourcing structure is close to zero. Clearly, supply chain reallocations from China toward these countries could also stimulate domestic production and real incomes in them. This channel is absent when endogenous supply chain adjustments are restricted. Also, this channel can partially justify the positive welfare effect on the US economy without China's tariff retaliation.

Figure 2.3: The US-China Trade Conflict: Intermediate Imports



Figures 2.3 and 2.4 illustrate the trade consequences to US bilateral imports from China as well as other selected trade partners. The y-axis demonstrates changes in US import shares for intermediate inputs (M) or final goods (F) in both figures. Figure 2.3 shows results that are consistent with the trade diversion story. In both model specifications, US input import shares from China decline significantly, while those input import shares from other countries slightly increase. Furthermore, the comparison between the dark and light blue bars reflects two interesting distinctions: first, responses in bilateral import shares are generally larger with endogenous supply chain reallocations for the directly impacted trade relationship, with a magnitude around 18%; second, when China chooses to retaliate, third-country trade effects tend to be larger instead of smaller with flexible global sourcing compared to the "fixed" specification. Figure 2.4

Figure 2.4: The US-China Trade Conflict: Final Goods Imports



shows similar trade diversion effects on final goods, but the opposite for US final good imports from China under endogenous supply chain reallocations. This is where the domestic production reallocation takes place: when the expected production gains for Chinese producers decline due to the increasing import tariffs applied by the United States, local entrepreneurs have less incentive to become active variety producers, reducing the number of available varieties and pushing up the production costs for Chinese final good producers. This cost disadvantage dominates the trade diversion effect from input trade and causes negative trade effects on final good imports.

Finally, I conduct several robustness checks with different values of the (inverse) origin-switching elasticity ν to study its impact on the transmission of trade shocks. These results are summarized in Appendix B. Generally, a higher value of ν implies a smaller magnitude of supply chain adjustments due to the same tariff changes, and hence smaller trade and welfare consequences. But the patterns of welfare impacts on the United States and China are still similar to the baseline results.

This counterfactual exercise on the US-China trade conflict highlights the importance of endogenous supply chain reallocation in shaping trade and welfare consequences. Even though we only consider trade shocks through the variable cost margin, the flexible sourcing framework can generate consistent welfare predictions from the existing literature and capture richer third-country effects.

2.4.3.2 Input Sourcing Pattern vs. Mass of Producers

In the baseline model specification, there are two types of endogenous supply chain adjustments, namely the input sourcing pattern (sourcing probability) and the mass of supply chains (domestic producers). Intuitively speaking, the amplification in input trade flows is mainly due to higher flexibility in producers' input sourcing decisions, as reflected by adjustments in the aggregate input sourcing pattern $\alpha_{ni,1}^{s',s}$. Alternatively, the differential welfare impacts on domestic downstream production and foreign upstream production primarily result from producers' endogenous market entry and exit decisions, which affect the size of production $\Omega_{i,1}^{s',s}$ in each market. This section provides a semi-decomposition approach to investigate how much of these impacts are accounted for by each component.

To do so, I introduce another model specification where producers are allowed to adjust their input sourcing decisions but not market entry decisions. That means, the aggregate input sourcing probability $\alpha_{ni,1}^{s',s}$ can respond endogenously to trade shocks, but the mass of active domestic producers $\Omega_{i,1}^{s',s}$ is fixed. I call this model specification the "semi-fixed" specification. The difference between "fixed" and "semi-fixed" specification captures the role of input sourcing pattern adjustments, while the difference between "semi-fixed" and "flexible" specifications indicates the role of endogenous mass of supply chains.

Figure 2.5: The US-China Trade Conflict: Decomposition of Channels

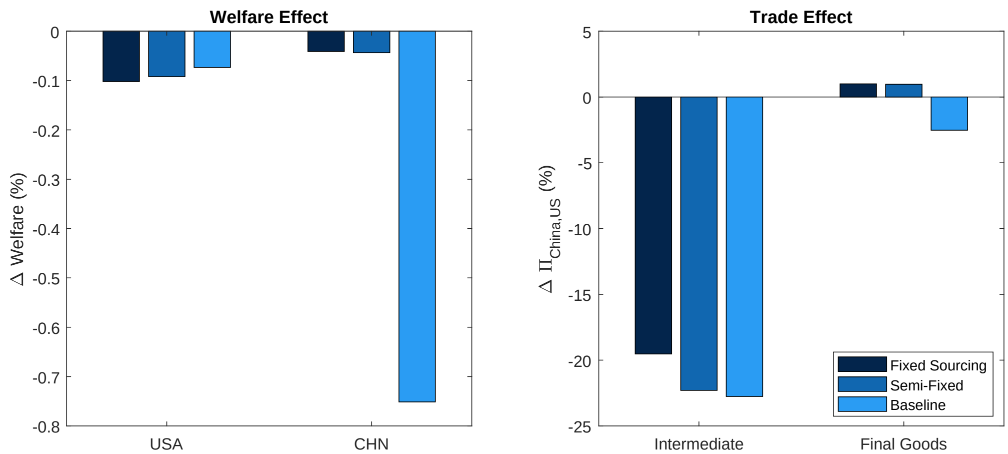


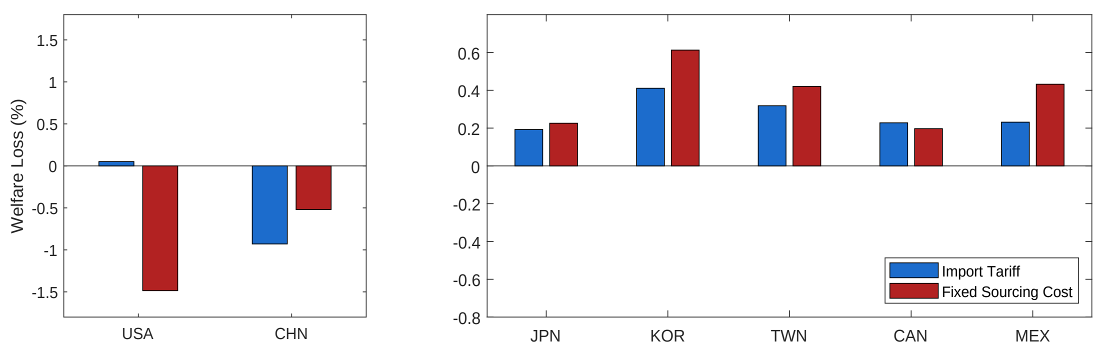
Figure 2.5 shows consistent quantitative evidence with intuition. The left panel illustrates the welfare responses of the United States and China due to this tariff war. While the welfare loss for the US economy is partially attenuated in the "semi-fixed" specification, there is only a tiny change in welfare loss for the Chinese economy; the majority of welfare effect amplification comes from the introduction of producers' endogenous market entry decisions, as represented by the sharp contrast between "semi-fixed" and "flexible" specifications.

On the other hand, the amplification of input trade flows is largely due to producers' endogenous input sourcing decisions. In terms of US intermediate imports from China, the difference between "fixed" and "semi-fixed" specifications represents most of the additional response. However, responses in final good trade driven by general equilibrium effects, hence show a more similar pattern as welfare responses across three specifications.

2.4.3.3 Alternative Trade Shocks: Variable vs. Fixed

During the US-China trade war, the United States executed severe trade restrictions on some Chinese companies such as Huawei and Zhongxing Telecommunication Equipment Corporation. Compared to import tariffs, these trade and investment restrictions cover more policy areas and are likely to influence fixed sourcing costs as well. To understand how changes in fixed sourcing costs affect the trade and welfare consequences of this conflict, I calibrate a US fixed sourcing cost increase against China that matches the effect on the US aggregate intermediate import share from China with a 25% unilateral tariff increase[17]. Figure 2.6 summarizes the welfare implications on the United State and China, as well as the selected trade partners.

Figure 2.6: The US-China Trade Conflict: Variable vs. Fixed Costs



While generating the same trade effect on intermediate imports, trade policies through fixed sourcing cost changes tend to generate more welfare impacts on the US domestic market than those created by import tariffs. This is due to the different transmission mechanisms between the two types of trade shocks. While changes in variable trade shocks mainly affect import prices,

[17]This exercise can also be applied to match other targets, such as the overall aggregate import shares. Since the import tariff only applies to intermediate imports, it is most reasonable to use the intermediate import share as the target moment.

changes in fixed trade shocks mostly affect the extensive margin of sourcing. These properties are evident in Table 2.2, where around 81.7% of the trade effect generated by variable cost trade shocks is on the intensive margin. The response of the US import share from China to fixed cost trade shock is almost fully characterized by changes in the extensive margin. Given the limited and even slightly opposite reaction on the intensive margin, increases in fixed sourcing costs would significantly reduce the expected gains from variety production, discourage entry of producers, and generate a large contraction in US domestic production. Thus, trade protections involving fixed sourcing costs might be a double-edged sword for policymakers.

Table 2.2: Comparison of Trade Shocks

Trade Shock	$\Delta\Pi^M_{China,US}$	$\Delta\Pi^M_{China,US}$ from ext.	$\Delta\Pi^M_{China,US}$ from int.	$\Delta W_{US+China}$
Variable Cost	-23.69%	12.5%	87.5%	-0.30%
Fixed Cost	-23.69%	104.5%	-4.5%	-1.14%

In the last column of Table 2.2, I compute the overall welfare effects on the United States and China using a income-weighted average approach for both types of trade shocks. Trade shocks to fixed sourcing costs cause greater welfare losses to the US and China as a whole than shocks to variable trade costs, with a magnitude about 2-3 times larger.

2.4.4 Counterfactual 2: Evaluation of PTAs

As a second application, this section quantifies the trade and welfare effects of preferential trade agreements (PTAs). PTAs, signed between countries, aim to remove trade barriers and facilitate bilateral or multilateral commercial cooperation. Examples are the North American Free Trade Agreements (NAFTA) and European Union. As the key driving force of world integration, the number of PTAs proliferated in recent decades. At the same time, more policy areas, such as investment, local market regulation, and the protection of intellectual property rights are covered by PTAs. The inclusion of these provisions indicates that PTAs may not only affect variable trade costs between countries through lower preferential import tariffs, but also the fixed sourcing costs faced by importers. My quantitative framework is especially suitable for evaluating the overall impact of PTAs.

The counterfactual scenario investigated in this analysis is a global disintegration of PTAs, where all existing PTA partners stop using their preferential tariff rates and remove all policy areas covered in the agreements. Specifically, I impose two trade shocks on the world economy. The first trade shock is an import tariff shock through the variable cost margin, where all effectively applied import tariffs for PTA partners are set back to the corresponding Most-Favored-Nation (MFN) rates according to the World Trade Organization (WTO). By doing so, I effectively isolate the impact of additional preferential tariffs from those already negotiated by WTO. The second trade shock is a fixed sourcing cost shock, where all fixed sourcing costs for PTA partners are increased by amounts proportional to their PTA depth:

$$\Delta f_{ni,0}^{s',s} = \lambda_1 PTA_{ni}$$

where the value of λ_1 is taken from the structural estimation. The function of this trade shock is to capture the impact of PTA provisions which focus on reducing fixed sourcing costs and are additional to tariff reductions. I define "beyond-tariff" as synonymous with fixed sourcing costs and use them interchangeably in this section.

To understand the relative contribution of variable and fixed cost channels, I focus on three parallel counterfactuals: the first one has both import tariff shocks and fixed sourcing cost shocks, and the second and third counterfactuals have each of these two shocks applied individually. I use the PTA depth measure based on the number of legally enforceable provisions to capture the heterogeneous effect across bilateral PTAs.

It might be a concern that import tariffs only affect non-services sectors, while changes in fixed sourcing costs have uniform effects across all sectors. Although this could be a potential reason that the beyond-tariff channel is more critical to the services sector, I restrict the impact of PTAs on fixed sourcing costs of the services sector to be zero as to achieve a clearer comparison to other sectors[18].

Additional calibration and descriptive illustrations on import tariff and fixed sourcing cost changes can be found in Appendix B.

2.4.4.1 Welfare Effects of Global Disintegration on PTAs

Figure 2.7 shows the geographic distribution of welfare implications under the counterfactual global disintegration scenario. Countries respond heterogeneously, with a wide range from -21.4% (Czech Republic) to 6.3% (China). European and North American countries on average suffer more from PTA decoupling (and hence gain most from having PTAs). However, the heterogeneity of welfare implications is not only the consequence of PTA coverages on trade. Other macroeconomic conditions such as the size of the economy and cross-country supply chain linkages also matter. For example, China experiences the most substantial third-country effect from the global disintegration of other countries, while the United States suffers less than other NAFTA members when deep trade agreements are broken. Eastern European countries experience larger losses resulting from their stronger dependence on supply chain linkages with other European economies.

[18] The unrestricted counterfactuals yield very similar patterns in quantitative results.

Figure 2.7: Welfare Implications of Global Disintegration

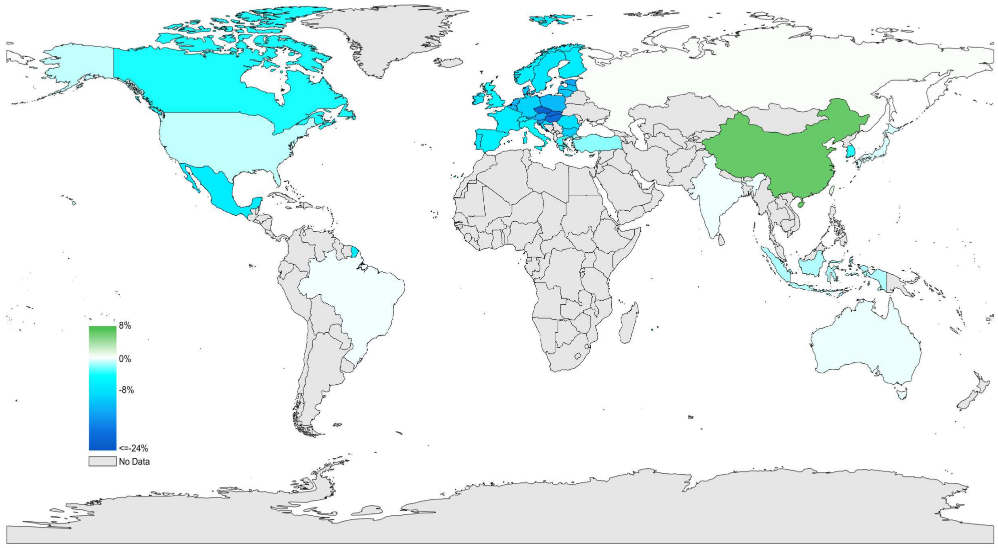
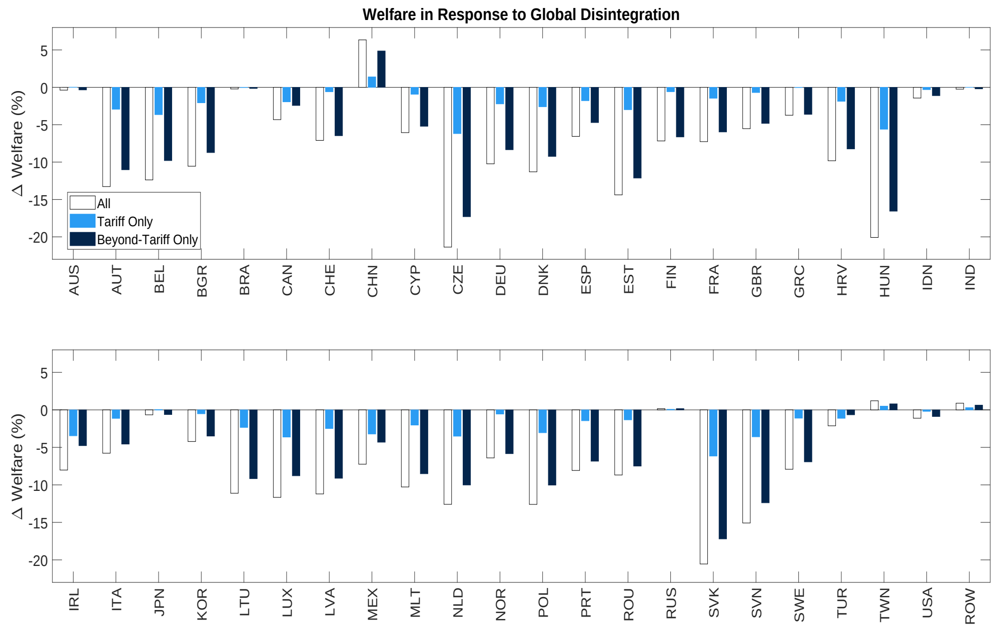


Figure 2.8 shows the decomposition of the overall PTA effect and the relative strengths of two channels. The beyond-tariff channel accounts for a significant fraction of the total welfare effect, more than two-thirds in most countries. Even though I do not account for its impact on services sectors, the beyond-tariff channel undoubtedly has more significant policy implications than import tariffs.

2.4.4.2 Model Comparison: The Role of Supply Chain Reallocation

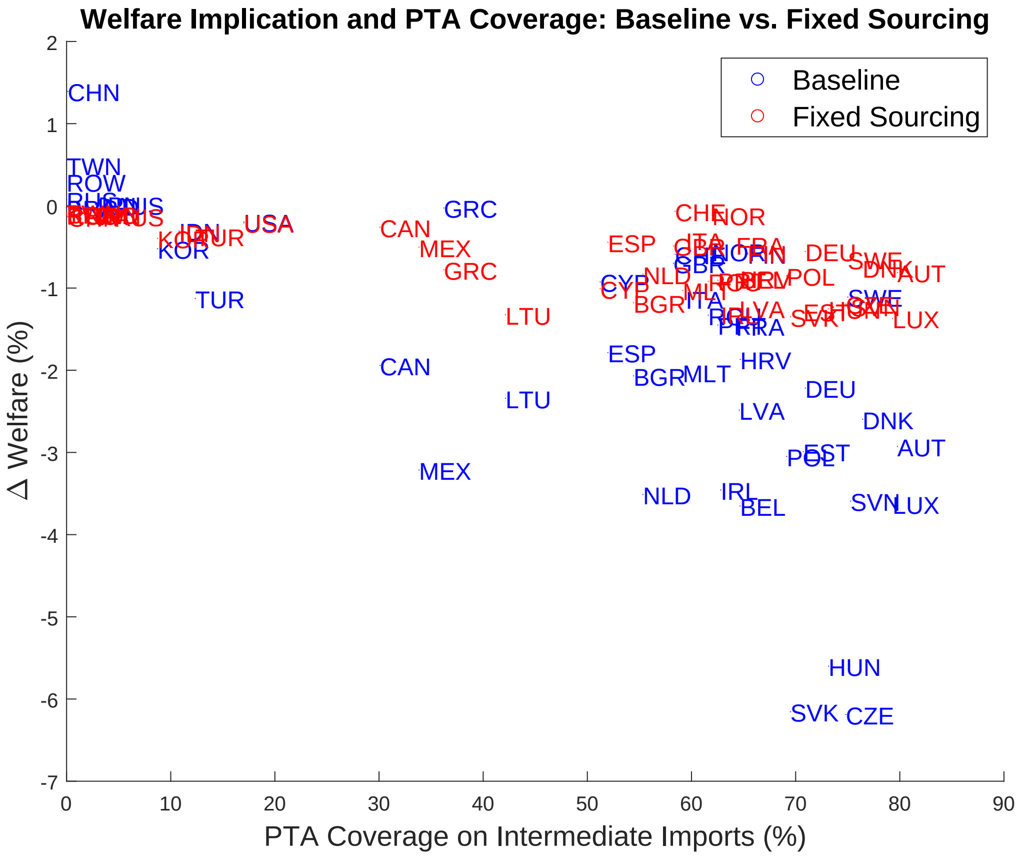
As in the first counterfactual, I compare my baseline model (the "flexible" specification) with another specification where the sourcing probability α and mass of active entrepreneurs Ω are fixed (the "fixed" specification). In the second model specification, changes in fixed sourcing costs have no effects on international trade and production. Hence, I only consider the import tariff channel through the variable cost margin in this exercise.

Figure 2.8: Welfare Implications of Global Disintegration



Distinctions between these two specifications emphasize the importance of endogenizing supply chain reallocations in evaluating trade policies. Figure 2.9 shows the relationship between welfare effects from PTAs and PTA coverage of intermediate imports. Without adjustments to sourcing structures and domestic production, welfare impacts are relatively homogenous across the sample countries. When endogenous supply chain reallocations are considered, these blue scatter plots not only indicate a much sharper relationship between PTA coverage on intermediate imports and welfare changes, but also a larger dispersion in the welfare responses. With more degrees of freedom in adjusting input sourcing and production structures, countries behave more differently from each other in response to this global disintegration shock.

Figure 2.9: Welfare Implication and PTA Coverage on Intermediate Imports



2.5 Concluding Remarks

This paper explores two model features in evaluating the trade and welfare implications of trade cost shocks that have not been extensively studied: the role of fixed sourcing costs and the endogenous reallocation of supply chains. I introduce a global sourcing framework that explicitly models producers' trade-offs between variable and fixed costs in input sourcing decisions in a general equilibrium setup. Based on this quantitative framework, I document that both model features are important in shaping the economic effects of trade policies.

Theoretically, this endogenous global sourcing framework generates an extended-gravity specification for input trade, featuring amplified impacts of variable trade cost changes through endogenous supply chain reallocations. Trade effects generated by shocks to fixed sourcing costs are mainly loaded on the extensive sourcing margin, as opposed to those caused by variable trade costs. This mechanism further indicates a more substantial pass-through from fixed sourcing cost changes to the domestic market.

I then apply my theoretical framework to evaluate the trade and welfare consequences of two policy-related issues. The first counterfactual exercise investigates a trade conflict scenario between the US and China, and the second investigates the economic impact of existing preferential trade agreements based on a global disintegration counterfactual. Both quantitative results highlight the role of endogenous supply chain reallocations in transmitting trade shocks, under which the magnitude of trade effects is 25% larger and the responses of welfare are stronger and more heterogeneous. Trade shocks through fixed sourcing costs generate more significant welfare consequences than similar trade shocks through variable trade costs.

This quantitative framework is capable of further extensions that incorporate producers' intertemporal sourcing decisions and dynamic responses of the economy to trade shocks. Additionally, considering economic and policy uncertainties as the extra channel might be an interesting aspect for further research.

Chapter 3: Global Supply Chains and the Trade Effects of Preferential Trade Agreements During the Great Trade Collapse

3.1 Introduction

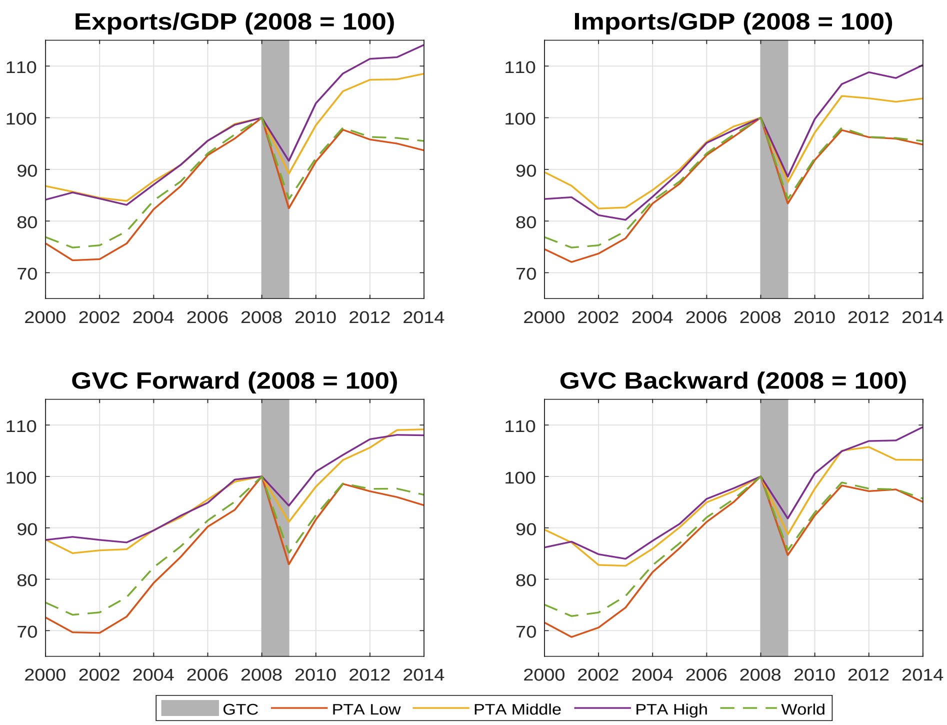
In Chapters 1 and 2, I formally study how endogenous global supply chain reallocations change our understanding of the trade and welfare implications generated by trade shocks and policy changes. Three features of global supply chains have been discussed: the existence of fixed sourcing costs, time-varying input sourcing patterns generated by producers' endogenous input sourcing decisions, and cross-country, cross-sector transmission in a GE framework. In Chapter 3, I further explore whether these features are supported by real-world evidence. I will use the terms global supply chain and global value chain (GVC) interchangeably in this chapter.

More specifically, I focus on the event of the Great Trade Collapse (GTC) that occurred between 2008 and 2009. Following the onset of the 2008 Global Financial Crisis, the reduction in global demand brought a significant downturn to the development of GVC. During the GTC, international trade flows collapsed by 15%, a magnitude around four times the collapse in real GDP[1]. This significant trade collapse also induced a structural break in global integration and the development of global supply chains. As we can see from Figure 3.1, the magnitude of world trade flows (measured by exports or imports per GDP) increased drastically before 2007 but

[1] Source: IMF Global Data Source database.

demonstrated divergent patterns across different country groups after the GTC. More specifically, countries with more bilateral PTA relations typically have stronger recoveries in their trade flows than do those with limited PTA relations. This phenomenon is especially pronounced in exports.

Figure 3.1: Integration vs. Divergence: Trade Pattens and GVC Participations across PTA Depth (Source: WIOD, World Bank Deep Trade Agreement Database)



In the meantime, countries' participation in global productions also behaved heterogeneously across PTA depth. The bottom two panels of Figure 3.1 replicate the same comparisons for GVC participation indices introduced by Wang et al. (2017)[2]. These measures are used to capture the domestically produced value-added that is embedded in intermediate trade flows and used for further productions. The dynamics of GVC participation indices are very similar to those of exports and imports, implying that the same integration and divergence patterns also exist in GVC activities.

[2]For a detailed derivation of these measures, see Appendix C.

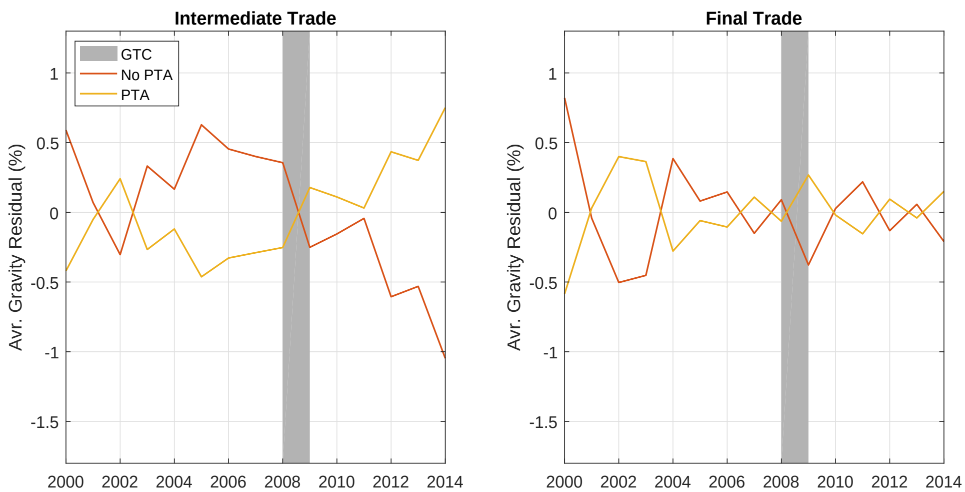
These figures highlight two facts about international trade and global integration. First, GVC activities, mostly characterized by intermediate goods trade, behave differently across PTA depth. Second, this impact seems to have become enlarged after the GTC. Typically, trade agreements can affect international trade in two ways: through tariff reductions and removal of trade barriers on the border, or through behind-border regulations that enhance market access and market potential in the host country. The existing literature provides evidence that the PTA relationship can significantly enhance bilateral intermediate trade flows (Johnson and Noguera, 2012; Osnago et al., 2016), but to my knowledge, there is little attention has been given to the pre- versus post-GTC comparison of this impact, along with the amount of effect belongings to each channel. In this paper, therefore, I want to fill the gaps in the literature by tackling the following research questions: Does the PTA relationship generate different impacts on GVC activities before and after the Great Trade Collapse? How much can each of the two channels account for?

I first evaluate the empirical impact of the PTA relationship on bilateral trade flows before and after the GTC. The gravity estimation with trade agreement and tariff rate variables identified a significant effect of PTA relations on the post-GTC recovery in intermediate goods trade, with a magnitude up to 9%. This effect is absent for the final goods trade. Figure 3.2 demonstrates the average growth residuals of bilateral trade volumes using this gravity specification, categorized by PTA status and trade flow types. The classification of PTA groups is based on whether a country pair had a bilateral PTA relation in 2007[3], and growth residuals are computed from a simple gravity specification with tariff rate controls and bilateral and country-year fixed effects[4]. One observation is that the growth residuals diverged after the GTC for intermediate goods trade,

[3]Patterns are similar while using a time-varying classification of country pairs. See Appendix D for details.
[4]The expression of this gravity specification is included in Appendix D.

but this is not observed in the final good trade. More specifically, country pairs with bilateral PTA relations tend to have higher growth in GVC-related or intermediate goods trade, especially after the GTC. Given that intermediate trade accounts for more than half of the aggregate gross trade[5], this fact indicates that the distinct impact of PTA provisions on GVC activities after the GTC might be a major driving force for the divergent trade patterns.

Figure 3.2: Bilateral Trade Growth Residual by PTA Status (2000-2014) (Source: World Bank Deep Trade Agreement Database, WIOD and author's calculation)



Based on the structure of the World Input-Output Table (WIOT), I then use a simplified framework based on the framework I introduced in Chapter 2, to separate the impact of PTA relations into two parts: the variation through relative border prices and trade costs, and the behind-border regulations that affect the market access of origin countries. With such a deconstruction, I find that PTA relations generally increase the relative intermediate input demand by around 18% before the collapse and 26% after the collapse. Though the second behind-border channel did not play a significant role before the GTC, it became more important during the post-GTC recovery,

[5]For example, in 2014 the share of intermediate good exports in gross exports was around 66% for NAFTA and approximately 50% for China and EU.

contributing up to one-quarter of the total effect.

These empirical findings are consistent with firms' "wait-and-see" effect when they face uncertainty in investment decisions (Handley and Limao, 2015; Handley et al., 2020b), and the significant collapse of global demand had made PTAs a safeguard for global supply chains against uncertainty during the recovery period (Carballo et al., 2018; Eaton et al., 2016). Moreover, as I extensively discussed in the first two chapters, since cross-border production typically requires fixed investment to facilitate market entry costs and production line regulations, it depends more on stable economic and trade environments. First, having a PTA relationship ensures that final goods producers maintain efficient production decisions and, therefore, more easily survive during demand collapse. The PTA relationship not only secures import tariffs at low levels but also eliminates additional fixed costs to ensure compatible inputs. Second, the PTA relationship can reduce production-side uncertainty which is critical for multistage production. Because production is fragmented into different stages, the investment decision at the current production stage relies on the prices and output of all previous stages. The intermediate inputs at downstream stages are only valuable when all prior production processes have finished. This property provides additional vulnerability to value chain productions, as production uncertainty from the upstream stage would stack up and affect the downstream stages. This concern could be relieved by PTAs, especially for regional trade agreements such as NAFTA and the European Union.

The rest of this chapter is organized as follows: Section 2 reviews the related literature. Section 3 is a brief introduction to the World Input-Output Table (WIOT), the main dataset that my empirical works rely on, and descriptions of other data. Section 4 explains the gravity estimation and its results, as well as a description of other data. Section 5 demonstrates the main results of this paper, where I propose a method to disentangle the impact of PTAs into two channels as well as quantify them. Section 6 brings together concluding remarks.

3.2 Literature Review

This chapter mainly relates to two strands of literature. My work is close to the growing literature on the evolution of preferential trade agreements. Based on initial works by Horn et al. (2010b) and Hofmann et al. (2017), who classify 52 PTA provisions into two categories: (i) WTO+, which includes provisions falling under the current mandate of the WTO and already subject to some form of commitment in WTO agreements; and (ii) WTO X, which contains provisions beyond the current mandate of the WTO. Limão (2016) provides a comprehensive survey of PTA provisions and analyzes their trade and welfare impacts. He also characterizes two measures of PTA cooperation: depth (tariffs, NTBs, and other policies that may affect market access) and breadth (horizontal coverage of provisions). Using panel data of PTAs and intermediate trade flows from 1980 to 2015, Osnago et al. (2016) estimate the effect of PTA status on GVC related activities, demonstrating that PTA depth (measured as the fraction of bilateral legally enforced provisions over the maximum number of provisions), especially for those provisions regarding competition and investment, is vital in enhancing bilateral intermediate trade flows. This impact is more pronounced for North-South trade and South-South trade. My empirical work is based on Osnago et al. (2016) and Johnson and Noguera (2012). Following their approaches to gravity estimation, I further explore the effects of the PTA relationship on GVC activities, proposing a method to decompose this effect into a border price variation channel and a behind-border market access channel.

My research is also related to a number of works that focus on the Great Trade Collapse and the subsequent slow recovery. There are many explanations for the reason why trade collapsed so severely relative to GDP in 2008. Bems et al. (2011) and Eaton et al. (2016) argued that demand-side spillover could explain around 70-80%. Amiti and Weinstein (2011) and Chor and Manova (2012) indicated that supply-side financial imperfections be response for around 20-30%. Whether GVC interactions mitigated or amplified trade collapses, however, is ambiguous, with mixed evidence. While Bems et al. (2011) found that declines in vertical specialization trade fell by more than value-added trade, Altomonte and Ottaviano (2009) found that rather than exacerbating the drop in global demand, trade flows associated with GVC were more resilient than other types of trade, because of long-lasting relations through supply chains. Carballo (2018) and Carballo et al. (2018) focused on the impact on international trade of the increasing uncertainty after the Global Financial Crisis, underscoring the importance of PTAs in restricting such uncertainty. They showed that countries with essential bilateral PTAs not only suffered less during the GTC but also recovered their trade flows relatively more than those without such trade agreements. Among all the explanations, the underlying mechanism discussed in this chapter is most similar to the story told by Carballo (2018) and Carballo et al. (2018), that PTA relations can reduce policy and demand uncertainty and thus enhance trade recovery. I contend that the PTA relationship will provide additional strength for GVC activities during post-GTC recovery.

3.3 Data Description

3.3.1 The World Input-Output Table

As first introduced by Timmer et al. (2015), the World Input-Output Database (WIOD) provides time-series data on WIOT for 44 economies (28 EU members + 15 non EU countries

+ rest of the world (ROW)) and across 56 sectors at the 2 digit ISIC (version 3) sector level. In this section, I will demonstrate the basic structure of the World Input-Output Table (WIOT), and then provide a detailed discussion on how this table is constructed, what are the strengths of this dataset relative to other similar sources as well as potential issues in empirical analysis.

Table 3.1 provides an overview of the WIOT structure. Denote N as the number of countries and S as the number of sectors in WIOT. Based on the types of bilateral flows, we can decompose the table into 3 blocks. The first block is the intermediate supply and use matrix $\left\{X_{ij}^{s',s}\right\}$. It contains information on the bilateral trade flows for intermediate inputs at the country-sector level. If we divide each element of X by its destination sector's gross output:

$$a_{i,j}^{s',s} = \frac{X_{i,j}^{s',s}}{Y_j^s}$$

We can get an $NS \times NS$ matrix containing information on intermediate input expenditure shares for each country and sector. I call this part the *Supply Block*.

The second part is the final use matrix F located in the right-hand side of the WIOT. It contains information on bilateral trade flows for final use, such as consumption and investment[6]. I define the *Final Demand Block* by dividing each element of F with their destination country's gross expenditure (or GDP, if trade is balanced):

$$\pi_{ij}^s = F_{ij}^s / \sum_n F_{nj}^s$$

It is an $NS \times S$ matrix.

[6]In WIOT, this block might be larger because it has more detailed classification for final use. I sum them up at the destination country level so that the final use of each country can be represented by a single column.

The third block contains information for value-added terms or GDP at the country-sector level, which is located at the bottom part of WIOT. I called VA the *(Relative) Scale Block*. It is an $NS \times 1$ vector. It determines the scale of each country-sector duplet and controls for the between country-sector allocation of resources.

Finally, the whole table is balanced by market clearing conditions that all rows and columns should add up to the corresponding gross outputs, respectively. As long as the table is balanced by these market clearing conditions, the three building blocks above uniquely determine the whole structure of a WIOT.

The most important feature of WIOT is the detailed structure of both bilateral input-output linkage and final demand system. It builds on the national supply and use tables (SUTs) of sample countries and is connected by bilateral trade flows. The combined bilateral intermediate supply and use matrix provides information of intermediate trade flows not only within each sector but also across sectors. This part is crucial in analyzing the structure of global value chains and is typically missing in other data sources. As mentioned in Timmer et al. (2015), WIOT is built on official and publicly available data from statistical institutes to ensure a high level of data quality. Although as a drawback it covers limited number of countries, the input-output linkage is more reliable than other similar data sources that depend heavily on imputation.

The second advantage of WIOT is the rich dynamics across time. In Timmer et al. (2015), they describe that the WIOTs "have been specifically designed to trace developments over time through benchmarking to time-series of output, value-added, trade and consumption from national accounts statistics". More specifically, the dynamics of observations mainly comes from three origins: variation in the SUTs across different benchmark years, variation from aggregate variables, and variation from bilateral trade flows. While the later two components are much

Table 3.1: Illustration of WIOT Structure

			Input use & value added							Final use			Total use
			Country 1			$\cdots$	Country N			Country 1	$\cdots$	Country N	
			Sec. 1	$\cdots$	Sec. S	$\cdots$	Sec. 1	$\cdots$	Sec. S				
Intermediate inputs supplied	Country 1	Sec. 1	$X_{1,1}^{1,1}$	$\cdots$	$X_{1,1}^{1,S}$	$\cdots$	$X_{1,N}^{1,1}$	$\cdots$	$X_{1,N}^{1,S}$	$F_{1,1}^{1}$	$\cdots$	$F_{1,N}^{1}$	Y_1^1
		$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
		Sec. S	$X_{1,1}^{S,1}$	$\cdots$	$X_{1,1}^{S,S}$	$\cdots$	$X_{1,N}^{S,1}$	$\cdots$	$X_{1,N}^{S,S}$	$F_{1,1}^{S}$	$\cdots$	$F_{1,N}^{S}$	Y_1^S
	$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\ddots$	$\vdots$	$\cdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\vdots$
	Country N	Sec. 1	$X_{N,1}^{1,1}$	$\cdots$	$X_{N,1}^{1,S}$	$\cdots$	$X_{N,N}^{1,1}$	$\cdots$	$X_{N,N}^{1,S}$	$F_{N,1}^{1}$	$\cdots$	$F_{N,N}^{1}$	Y_N^1
		$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
		Sec. S	$X_{N,1}^{S,1}$	$\cdots$	$X_{N,1}^{S,S}$	$\cdots$	$X_{N,N}^{S,1}$	$\cdots$	$X_{N,N}^{S,S}$	$F_{N,1}^{S}$	$\cdots$	$F_{N,N}^{S}$	Y_N^S
Value dded			VA_1^1	$\cdots$	VA_1^S	$\cdots$	VA_N^1	$\cdots$	VA_N^S				
Gross output			Y_1^1	$\cdots$	Y_1^S	$\cdots$	Y_N^1	$\cdots$	Y_N^S				

easier to obtain at annual frequency from national or international institutes, most countries only update SUTs at lower frequencies (3-5 years). In order to generate time-series input-output tables at annual frequency, Timmer et al. (2015) apply a procedure that imputes SUT coefficients subject to hard data constraints from the National Account Statistics (NAS), which is updated annually. Although not perfect replications of the real world, the WIOTs contain enough variations across time and are more suitable for analyzing changes in GVC activities relative to other datasets.

In addition, the WIOT also provides information on trade in services and intangibles. As it becomes more and more important in international transactions, trade in services may reflect significant information on the impact of PTA provisions. By integrating various international data sources including UN, OECD, Eurostat, IMF and WTO data (Mode 1 or cross-border) and data on consumption abroad by resident consumers or firms (Mode 2), the WIOTs are eligible for a comprehensive analysis on international trade and GVCs. However, due to inaccuracy in data collecting, the disaggregate level data for services sectors are still quite noisy. I will discuss and try to address this issue later.

3.3.2 Trade Agreements and Tariffs

Another essential variable in my empirical analysis is the bilateral preferential trade agreements. I obtain observations of PTA provisions from the World Bank Deep Trade Agreement Database. This database covers 279 agreements signed by 189 countries between 1958 and 2015. According to Horn et al. (2010b) and Hofmann et al. (2017), the overall 52 provisions can be classified into 2 categories based on their contents: WTO+, which are provisions falling under the current mandate of the WTO and already subject to some form of commitment in WTO agreements; and WTO X, which are provisions outside the current mandate of the WTO. The former one mainly focuses on tariff reductions or removal of trade barriers for certain products, and the later one is usually related to regulations in the local market that facilitate investment and production. I construct two PTA variables from this database: PTA status (or dummy), which is based on whether a country pair has legally enforced provisions; and PTA depth, which is based on the number of legally enforceable provisions. The calculation of PTA depth can be found in Appendix D.

I also include import tariff rates in my empirical analysis to see how much a PTA relationship can explain beyond tariff reductions. I obtain the Most Favored Nation (MFN) tariffs from the World Integrated Trade Solution (WITS) at the bilateral level. The tariff measures are averaged across all imported goods using their import values as weights. Given this feature, this variable may not absorb all border variation in prices and trade costs, especially for trade in services. But it is still a very useful measure to control for trade policy related changes in bilateral trade costs. As a robustness check, I will also use trade in commodities instead in my empirical analysis to keep consistency between variables.

3.3.3 Sample Coverage and Descriptive Statistics

For my gravity estimation, I construct a combined panel from the WIOT and other data sources that I mentioned above. The dependent variable is bilateral import flows, which can be either intermediate goods trade or final goods trade. The explanatory variables are trade agreements and import tariff rates. The final combined dataset has bilateral observations between 41 countries from 2000 to 2014. Descriptive statistics of these variables are included in Appendix

D.

One concern is whether this combined dataset can represent the features of international trade and GVC activities. Table 3.2 summarizes the sample coverage on GDP, international trade and number of PTA provisions at annual basis. All numbers are computed as shares of sample aggregates in world aggregates.

Table 3.2: Sample Coverage: GDP, Trade, and PTA (2000-2014)

Year	GDP	Trade	PTA No.	Year	GDP	Trade	PTA No.
2000	0.86	0.71	0.40	2008	0.84	0.71	0.40
2001	0.86	0.72	0.39	2009	0.84	0.70	0.39
2002	0.87	0.72	0.39	2010	0.83	0.70	0.38
2003	0.87	0.72	0.36	2011	0.82	0.69	0.39
2004	0.87	0.72	0.54	2012	0.81	0.67	0.38
2005	0.86	0.71	0.53	2013	0.81	0.67	0.37
2006	0.85	0.71	0.51	2014	0.81	0.67	0.36
2007	0.85	0.71	0.49				

As we can see from Table 3.2, although I only have 41 countries in my sample, they account for a great fraction of world production and international transactions, with 81%-87% of the world GDP and 67%-72% of international trade. The coverage on PTA provisions is much lower, but my sample still represents a considerable part of overall bilateral PTA relations. As showed in Appendix D, my sample provide enough variation in both PTA status and PTA provisions for identification purpose.

3.4 Gravity Estimation

The goal of this empirical analysis is to explore how PTAs influence bilateral GVC activities before and after the GTC through trade in intermediate and final goods. To do so, I utilize the following gravity specification:

$$\begin{aligned} \ln(export_{ijt}) &= \beta_1 PTA_{ijt} + \beta_2 \ln(1 + Tariff_{ijt}) \\ &+ \beta_3 \mathbf{postGTC_t} \times \mathbf{PTA_{ijt}} \\ &+ \lambda_{it} + \lambda_{jt} + \phi_{ij} + \epsilon_{ij,t} \end{aligned}$$

In this specification, $trade_{ijt}$ represents exports (gross, intermediate or final goods) from country i to country j at year t, TA_{ijt} is the trade agreement variable (either PTA dummy or PTA depth) between country i and country j, and $Tariff_{ijt}$ is the MFN weighted average import tariff rates of country j while importing from country i. Following Baier and Bergstrand (2007), I use bilateral fixed effect ϕ_{ij} to absorb some constant gravity variations such as distance and common language; I use country-time fixed effects λ_{it} and λ_{jt} to absorb time-varying country-specific factors such as GDP, price index and financial development.

My specification differs from those in the literature by adding the interaction term between post-GTC indicator (which is 1 from 2010) and trade agreement variable, in order to see quantitatively how much the divergent patterns I observed from the motivation figures can be explained by heterogeneity in bilateral PTA status.

The separation of intermediate goods trade and final goods trade in WIOTs enables me to compare the behaviors of these two types of trade flows under different PTA status naturally. More specifically, GVC activities are mostly characterized by intermediate goods trade, as production could be fragmented into several countries and connected by intermediate inputs from one to another. Thus intermediate goods trade should contain richer information on GVC activity. On the other hand, final goods trade is the most downstream side of the whole production chain and may react differently to trade agreements and import tariffs, as we observe in Figure 3.2.

The regression results are showed in Table 3.3, while I use PTA status and PTA depth as trade policy variables, respectively.

Table 3.3: Intermediates vs. Final: Impacts of Preferential Trade Agreement Status

	(1) Int. Non-Service	(2) Final Non-Service	(3) Int. Non-Service	(4) Final Non-Service
log MFN tariff, weighted average	-0.639***	0.0845	-0.586***	0.0834
	(0.170)	(0.175)	(0.174)	(0.178)
PTA Dummy	-0.0561**	0.0289		
	(0.0218)	(0.0224)		
PostGTC * PTA Dummy	0.0474*	-0.0165		
	(0.0248)	(0.0255)		
PTA Depth (Normalized)			-0.0321	0.0292
			(0.0335)	(0.0344)
PostGTC * PTA Depth			0.0899**	-0.0107
			(0.0368)	(0.0377)
Observations	22910	22910	22910	22910
Bilateral FE	Yes	Yes	Yes	Yes
Country-Time FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.976	0.975	0.976	0.975

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

With controls for country-time and bilateral fixed effects, the only variation left comes from the bilateral-time level. Column (1) and (3) in Table 3.3 demonstrates how bilateral gross exports flows are affected by import tariffs and trade agreements. While the tariff rates are negatively correlated with trade flows, during the pre-crisis period PTAs have almost no effect; but having PTA relations can boost trade growth significantly after the GTC. This impact is stronger when bilateral trade cooperation is deeper (higher PTA depth). Notice that the estimated impact of import tariffs on bilateral exports flows are relatively smaller than those in the lterature (Limão, 2016).

Another important takeaway is the comparison between the intermediate goods trade and the final goods trade, which is summarized in the second and third columns. The regression results show that these two types of trade flows behaved very differently across PTA status and PTA depth, especially before the GTC. For the intermediate goods trade, after controlling for tariff changes, PTA has negative influences during the pre-GTC period[7]. While its impact on final goods trade is positive but insignificant. This difference is insignificant when using the PTA depth measure. However, PTA relationship becomes very important in securing intermediate trade flows after the crisis. As we can see, the coefficients of the interaction terms are positive and significant, and the overall effect after GTC is more significant for intermediate trade, with an additional magnitude of around 9% if we use the PTA depth measure. This distinction implies GVC activities, which mainly captured by intermediate goods trade, recover and growth faster for country pairs with bilateral PTA relations during the post-crisis period[8].

As demonstrated in Table D.1 of Appendix D, these empirical results are robust when I exclude the crisis period (2008 and 2009) from the sample, or I exclude country pairs that sign new PTAs after the GTC. Thus, the evidence of a stronger recovery in input trade for PTA partners is not a result of a smaller trade collapse during the GTC and is mainly a long-lasting effect of the existing PTA relationship. These empirical results are also not driven by the mean-reverting mechanism after sharper trade collapses for PTA partners, as we observed a much larger decline in trade openness and GVC participation for "PTA low" countries in Figure 3.1.

[7]The reason of a negative coefficient before PTA dummy could be the overestimated coefficients of import tariffs, or some mismatch between categories of sectors for tariff data and WIOTs.

[8]The reason of a negative coefficient before PTA dummy could be the overestimated coefficients of import tariffs, or some mismatch between categories of sectors for tariff data and WIOTs.

PTA provisions can be classified into two categories: provisions that are related to tariff reductions or removal on cross-border NTBs, and provisions that are related to local market/legal system regulations and usually take effect behind the border. Including tariff rates in the regression can control for the influence of the first channel, but may not completely. In the next subsection, I will introduce a method to disentangle these two channels and focus on the impact of the second one on GVC activities, which is the focus of this paper.

3.5 Disentangling the Impact of PTAs

Standard gravity estimation has several weaknesses in identifying the actual impact of PTAs, especially the part beyond tariff reductions and removal of trade barriers. First, given the limited coverage on services sectors, the MFN weighted-average tariff rates cannot control for all the on-the-border variations in relative prices and trade costs that are induced by PTA provisions. Second, the effects of border and behind-border channels are often highly interacted. For example, while making the entry decisions, firms typically trade off between the sunk investment of entry and furture profits of entry. Then future variations in the variable costs on the border would also affect their entry decisions today.

In order to provide a meaningful decomposition of these two channels, I use a simple framework based on Chapter 2 and following De Gortari (2019), which is based on the Armington model with roundabout production structure[9] and has a straightforward mapping to the WIOT. Different from the purely cross-sectional approach, I utilize the time series property of WIOT and allow structural parameters to change over time. As we can see in the following parts, the relative

[9] In De Gortari (2019), he does not restrict the production structure to be roundabout. I put on this restriction for simplification purpose now.

changes of these parameters potentially capture variation in market access and market potential that are not directly affected by price and trade costs, which I called the behind-border channel or fixed cost channel. These structural parameters are a useful starting point to study how PTA relations affect GVC activities through the behind-border channel.

3.5.1 Environment

The model environment I am going to describe in this chapter is similar to that in Chapter 2, except for two aspects: First, I use a representative producer to make all the production and input sourcing decisions. Second, I do not explicitly model fixed sourcing costs; instead, I assume the input sourcing pattern to be exogenous and time-varying.

The world economy consists of N countries, and within each country there are S sectors who are symmetric in market structures. Production requires both value-added inputs (labor) and material inputs (other sectors' final goods). More specifically, material inputs are provided by domestic intermediate input suppliers, who decide where to source their inputs and produce a unique variety of intermediate goods.

3.5.2 Production

There is one representative firm in each country-sector duplet, which uses (i) domestic factor L at cost w; (ii) intermediate inputs X from all sectors and countries at a price $p\tau$ to produce its sectoral output. This output would be used either as intermediate inputs to other countries and sectors or final goods consumption by consumers. The production function has a nested CES structure: across different sectors there is a Cobb-Douglas aggregation; and within each sector, the composite input of this sector is produced by a CES aggregation across all sourcing countries:

$$
\begin{aligned}
Y_{i,t}^{s} &= A_{i,t}^{s}\left(L_{i,t}^{s}\right)^{\beta_i^s}\prod_{s'\in S}\left(X_{i,t}^{s',s}\right)^{\gamma_i^{s',s}\left(1-\beta_i^s\right)} \qquad (3.1)\\
X_{i,t}^{s',s} &= \left(\sum_n\left(\alpha_{ni,t}^{s',s}x_{ni,t}^{s',s}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}
\end{aligned}
$$

Where i is the location of production and s is the sector of production. β_i^s and $\gamma_i^{s',s}$ is the Cobb-Douglas shares of domestic factor and intermediate inputs respectively. We have $\sum_{s'}\gamma_i^{s',s} = 1$ for all i and s so that the production technology is CES. $A_{i,t}^{s}$ is the total factor productivity of the final goods production; $L_{i,t}^{s}$ is the labor usage and $X_{i,t}^{s',s}$ is the material input from sector s'; σ is the elasticity of substitution between country-specific inputs[10].

$\alpha_{ni,t}^{s',s}$ is the set of structural parameters that control for the relative importance of sourcing sectoral product s' from country n to produce sectoral product s in country i. These parameters are the main focus to reveal the supply chain reallocation patterns.

Similar to Chapter 2, producers' optimization behaviors together with budget constraints yield the following intermediate input demand system:

$$
\begin{aligned}
a_{ni,t}^{s',s} &= \frac{\alpha_{ni,t}^{s',s}\left(P_{n,t}^{s'}\tau_{ni,t}^{s'}\right)^{1-\sigma}}{\sum_k\alpha_{ki,t}^{s',s}\left(P_{k,t}^{s'}\tau_{ki,t}^{s'}\right)^{1-\sigma}}\\
&= \frac{X_{ni,t}^{s',s}}{\sum_k X_{ki,t}^{s',s}}
\end{aligned}
$$

[10]The elasticity of substitution does not required to be the same across sectors. I use the same symbol for concise illustration

While $a^{s',s}_{ni,t}$ are the input shares from country n and sector s' in gross output, which has a clear counterpart in WIOT. Now consider changes in intermediate input shares between two periods. These changes might come from several reasons: prices or trade costs changes, which would induce reconsideration of sourcing decisions through variable cost margins; or changes in relative structural parameters, which may contain information on market access changes that are not directly affected by on-the-border prices and trade costs. Define relative change across two periods as $\widehat{x}_t = x_{t+1}/x_t$ and apply it to the expression above, we can clearly see these two components in the following condition:

$$\begin{aligned} \widehat{a}^{s',s}_{ni,t} &= \frac{\widehat{\alpha}^{s',s}_{ni,t}\left(\widehat{P}^{s'}_{n,t}\widehat{\tau}^{s'}_{ni,t}\right)^{1-\sigma}}{\sum_k a^{s',s}_{ki,t}\widehat{\alpha}^{s',s}_{ki,t}\left(\widehat{P}^{s'}_{k,t}\widehat{\tau}^{s'}_{ki,t}\right)^{1-\sigma}} \\ &\Rightarrow \frac{\widehat{a}^{s',s}_{ni,t}}{\widehat{a}^{s',s}_{mi,t}} = \frac{\widehat{\alpha}^{s',s}_{ni,t}}{\widehat{\alpha}^{s',s}_{mi,t}}\left(\frac{\widehat{P}^{s'}_{n,t}\widehat{\tau}^{s'}_{ni,t}}{\widehat{P}^{s'}_{m,t}\widehat{\tau}^{s'}_{mi,t}}\right)^{1-\sigma} \end{aligned} \tag{3.2}$$

Equation (3.2) provides a possible way to separate the intermediate input expenditure shares into pure cost effect and others that are not directly affected by price and trade costs changes (captured by $\alpha^{s',s}_{ni,t}$). Investigating the components of this structural parameter could be an interesting approach to look at GVC reallocations from the behind-border perspectives and see how PTAs shape the evolution of them.

Comparing this framework to other models, some initial inferences can be made for the structural parameter $\alpha^{s',s}_{ni,t}$. For example, in standard EK (2002) model, this parameter is mainly governed by country-specific relative technology positions T; in the multistage GVC framework characterized by Antràs and de Gortari (2019), this parameter captures the probability of all the possible GVC paths that contain production stages in country i and sector s which source from country n and sector s'. Thus, I assume the following structure of $\alpha_{ni,t}^{s',s}$:

$$\alpha_{ni,t}^{s',s} = T_i^s T_n^{s'} \eta_{ni}^{s',s}$$

where T_i^s and $T_n^{s'}$ are exporter and importer-specific technology or demand shifters, such as the relative technology positions in Eaton and Kortum (2002); $\eta_{ni}^{s',s}$ potentially captures the GVC linkages between these two nodes in global production, and I want to utilize this variable to identify the effect of PTAs through the behind-border channel.

3.5.3 Demand

A representative consumer in each country has demand for final products from all sectors and sources them from all countries with imperfect substitution. The demand function has a similar nested-CES structure as the production function:

$$U_{i,t} = \prod_{s \in S} \left(\sum_{n \in N} \left(D_{ni,t}^s C_{ni,t}^s \right)^{\frac{\sigma}{\sigma-1}} \right)^{\frac{\sigma-1}{\sigma} \xi_i^s}$$

Where $C_{ni,t}^s$ is the quantity of country n, sector s final goods consumed by country i's representative consumer, $D_{ni,t}^s$ is the (exogeneous) demand shifter which is country pair and sector specific, and ξ_i^s is the Cobb-Douglas coefficient or expenditure share and satisfies $\sum_s \xi_i^s = 1$. The variation in $D_{ni,t}^s$ would capture all the final demand side stories.

Together with the first order conditions, we can get the following final demand system:

$$\phi^s_{ni,t} = \frac{D^s_{ni,t}\left(P^s_{n,t}\tau^s_{ni,t}\right)^{1-\sigma}}{\sum_k D^s_{ki,t}\left(P^s_{k,t}\tau^s_{ki,t}\right)^{1-\sigma}} = \frac{F^s_{ni,t}}{\sum_k F^s_{ki,t}}$$

Again, calculate the relative changes across two periods and we have:

$$\begin{aligned}
\widehat{\phi}^s_{ni,t} &= \frac{\widehat{D}^s_{ni,t}\left(\widehat{P}^s_{n,t}\widehat{\tau}^s_{ni,t}\right)^{1-\sigma}}{\sum_k \phi^s_{ki,t}\widehat{D}^s_{ki,t}\left(\widehat{P}^s_{k,t}\widehat{\tau}^s_{ki,t}\right)^{1-\sigma}} \\
&\Rightarrow \frac{\widehat{\phi}^s_{ni,t}}{\widehat{\phi}^s_{mi,t}} = \frac{\widehat{D}^s_{ni,t}}{\widehat{D}^s_{mi,t}}\left(\frac{\widehat{P}^s_{n,t}\widehat{\tau}^s_{ni,t}}{\widehat{P}^s_{m,t}\widehat{\tau}^s_{mi,t}}\right)^{1-\sigma}
\end{aligned} \tag{3.3}$$

Equation (3.3) is the counterpart of equation (3.2) at the final demand side. The variation in relative final goods expenditure shares comes from either changes in relative prices and trade costs, or changes in relative demand shifters $D^s_{ni,t}$.

3.5.4 Isolating the Behind-Border Channel

Combining equation (3.2) and (3.3), we can get the following expression:

$$\frac{\widehat{a}^{s',s}_{ni,t}}{\widehat{a}^{s',s}_{mi,t}}\frac{\widehat{\alpha}^{s',s}_{mi,t}}{\widehat{\alpha}^{s',s}_{ni,t}} = \frac{\widehat{\phi}^{s'}_{ni,t}}{\widehat{\phi}^{s'}_{mi,t}}\frac{\widehat{D}^{s'}_{mi,t}}{\widehat{D}^{s'}_{ni,t}} = \left(\frac{\widehat{P}^{s'}_{n,t}\widehat{\tau}^{s'}_{ni,t}}{\widehat{P}^{s'}_{m,t}\widehat{\tau}^{s'}_{mi,t}}\right)^{1-\sigma}$$

Where the right hand side captures the relative prices and trade costs changes. If we further assume that the demand shifter $D^{s'}_{ni,t}$ only has domestic variation: $D^{s'}_{ni,t} = D^{s'}_i$, then it is clear that changes in relative expenditure shares $\widehat{\phi}^{s'}_{ni,t}/\widehat{\phi}^{s'}_{mi,t}$ would capture all changes on the variable cost margin. Given this, we can use changes in relative expenditure shares to separate the variable cost channel from the relative changes in intermediate input expenditure shares:

$$\frac{\widehat{\alpha}_{ni,t}^{s',s}}{\widehat{\alpha}_{mi,t}^{s',s}} = \frac{\widehat{\phi}_{mi,t}^{s'}}{\widehat{\phi}_{ni,t}^{s'}} \frac{\widehat{a}_{ni,t}^{s',s}}{\widehat{a}_{mi,t}^{s',s}} \tag{3.4}$$

This is the main identification of the structural framework. The relative changes in $\alpha_{ni,t}^{s',s}$ capture the sourcing problems faced by the firms in country i and sector s, which is not accounted by contemporaneous variable cost margin changes.

A nice property of this method is that we do not need to estimate the trade elasticity, or equivalently, the elasticity of substitution σ at the sector level. It has been long debated about the curvatures of demand in both macro- and microeconomics, and people with data of different aggregation levels may have very different estimates for this parameter. Although assuming the same elasticity of substitution for intermediate and final goods demand might be restrictive, avoiding this estimation helps me increase the tractability of my method and reduce the dependence on extra information on price and trade cost changes. This method can be easily modified to adapt heterogenous demand elasticities between intermediate and final goods with sufficient information.

Conceptually, this variation can be generated for many reasons. For example, it may depend on the existing production connections between country i and country n, m. If a multinational corporate previously built up a new export platform in country n, or signed a new contract with a local intermediate good supplier, then it is likely that changes in relative structural parameters would favor country n to country m. One factor that could potentially affect firms' outsourcing decisions is whether the source countries have preferential trade agreement relations. Typically, having stronger PTA relations not only guarantees the tariff rates to be maintained at lower levels but also facilitates long-lasting partner relationship and offshoring (reflected by lower entry or searching costs). In the later section, I will introduce an empirical specification based on this decomposition, and test whether PTA provisions, especially those targeting behind-border regulations could be effective in enhancing GVC activities.

3.5.5 A Simple Counterfactual

A straightforward thought of quantifying GVC reallocation is to see what will happen if there is no change in supply-side IO structure, or $\alpha_{ni,t}^{s',s}$, while allowing the demand side to track the real world. One challenge for this counterfactual is that we cannot directly identify these structural parameters from WIOT data without thoroughly document the sectoral prices and bilateral trade costs[11].

But if we only focus on the dynamics of this IO structure, the method I introduced above provides a natural and feasible approach to treat with this issue. Instead of estimating them directly, I infer changes in prices and trade costs from the final demand side, and use them to isolate relative changes in $\alpha_{ni,t}^{s',s}$ from variation in intermediate expenditure shares. Equivalently, with appropriate normalizations, I can use the IO structure in a benchmark year to produce the counterfactual IO structures in other years by incorporating prices and trade costs changes. Then with both the inferred IO structure and demand-side information from the real world, I can recap a new WIOT in every counterfactual year and look at the aggregate implications.

In this section, I conduct a counterfactual exercise, where I fix the supply block of post-GTC periods at the reference year. I use 2007 as the reference year to represent the IO structure

[11] In many general equilibrium trade models, prices can be endogenously determined by trade costs and market clearing conditions. However, we still need additional information on technology and labor force, as in Eaton and Kortum (2002)

before the Great Trade Collapse. More specifically, for years after 2007, I replace the supply block of those WIOTs with that in 2007, and allow the demand block to keep in track with the real world:

$$\alpha_{ni,t}^{s',s} = \begin{cases} \alpha_{ni,t}^{s',s} & \text{if } t <= 2007 \\ \alpha_{ni,2007}^{s',s} & \text{if } t > 2007 \end{cases}$$

By doing so, I shut down all the behind-border post-GTC reallocations of GVC within any sector. That means, the only source of variation in sectoral sourcing decisions on intermediate inputs would be changes in prices and trade costs. Thus the difference between real and counterfactual worlds will reflect the effect of post-GTC reallocation of GVC activities.

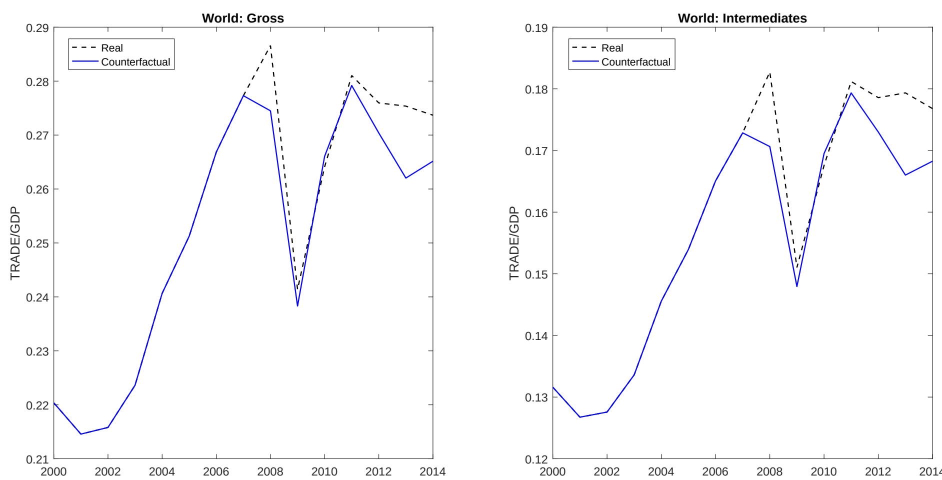
Theoretically, I can do this counterfactual at any possible disaggregation level provided by WIOT. However, as discussed above, sector level data has issues that cannot fit this framework. There are many zeros and some negative observations that are not only infeasible for calculating changes across periods but also not consistent with the theory. Thus for this exercise and extended further empirical analysis, I rely on a WIOT that aggregate up sectoral observations to 4 composite industries defined by Johnson and Noguera (2012). This aggregation can reduce the noise of data at the most disaggregate level and retain some sectoral variation, which makes the counterfactual results more reliable.

Figure 3.3 demonstrates the comparison between the real world and counterfactual at the world aggregate level. We can see that the counterfactual world replicates the Great Trade Collapse pretty well, but predicts smaller trade openness during the subsequent recovery period[12].

[12]In order to see whether GVC reallocations would also generate differences before the crisis, I conduct a similar counterfactual exercise but set the reference year at 2000, which is the initial year of my sample. As we can see in Figure D.2, although there might be some fluctuations comparing to the real world, the upward-sloping trend is

Remember that all the demand side variations, including the final demand structure (demand block) and country-specific relative final use levels (relative scale block), are the same with the real world. This is consistent with the GTC literature that demand side alone can explain most of the trade collapse during the GTC (Bems et al., 2011; Eaton et al., 2016). The difference between counterfactual and real worlds during the recovery period is mostly reflected by intermediate goods trade (since the final demand is the same).

Figure 3.3: Real vs. Counterfactual: World Aggregation (Reference Year: 2007)

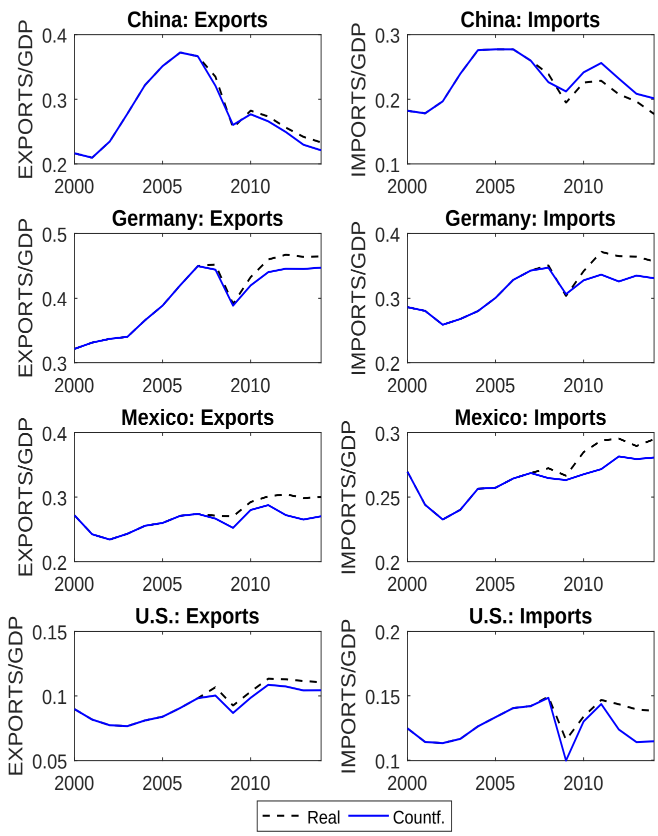


Despite the difference between the real world and counterfactual is not very large, there are significant cross-country variations that worth mention. Figure 3.4 illustrates the comparison of trade patterns for several selected countries using 2007 as the reference year. While most countries tend to trade less in the counterfactual world, China would import more relative to what occurred. Notice that all the countries except China are involved in deep regional trade agreements (Germany in the EU, Mexico and the U.S. in NAFTA). This evidence partially supports the argument that GVC-related activities may be stronger for countries engaging in deeper PTA

generally the same, as well as the divergence patterns during the recovery period.

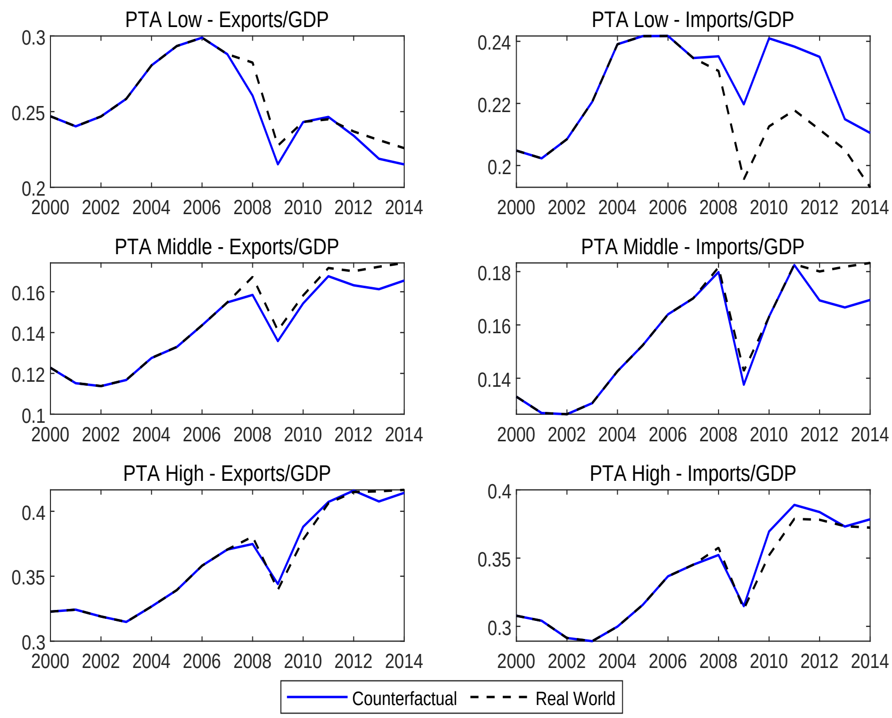
relations after the GTC, even we take into account the on-the-border price variations.

Figure 3.4: Real vs. Counterfactual: Selected Countries (Reference Year: 2007)



It is much clearer if we look at country groups with different PTA depths. Figure 3.5 demonstrates such comparison based on the same classification in Figure 3.1. On the export side, countries with low and middle PTA depth tend to trade less relative to what actually happened, but the differences are not very large compared to those at the world aggregate level. The most significant divergence comes from the import side. Countries with limited bilateral PTA relations tend to increase their imports (mostly intermediate imports since final imports are the same), but those with some degree of PTA depth (PTA middle countries) are likely to import less instead. Countries with strong bilateral PTA connections (typically EU members) are generally unaffected. These results provide supporting evidence that some underlying reallocation of GVC activities might take place from “PTA low” to “PTA middle” countries after the GTC. However, “PTA high” countries may have already built up their GVCs in 2007. The insignificant difference between real and counterfactual in their trade patterns indicates more resilient supply chain structures for these countries, which recovered quickly to their pre-crisis level after the GTC.

Figure 3.5: Real vs. Counterfactual: PTA Depth (Reference Year: 2007)



This simple counterfactual exercise shades some lights on the relationship between PTA and GVC participations and the country level, especially through the behind-border channel. Simply fixing the IO structure at the pre-GTC level can somehow explain the divergence in aggregate imports, but not too much on the export side. In the next subsection, I will explore this impact at a more disaggregate level, based on a mode-implied specification.

3.5.6 Link GVC Reallocation to PTA

Given the panel structure of WIOT, we can construct the counterpart of $\widehat{\alpha}^{s',s}_{ni,t}$ from the data. More specifically, I compute $\widetilde{\alpha}^{s',s}_{ni,t}$ in each year as follow:

$$\widetilde{\alpha}^{s',s}_{ni,t} = \frac{\phi^{s'}_{ii,t}}{\phi^{s'}_{ni,t}} \frac{a^{s',s}_{ni,t}}{a^{s',s}_{ii,t}}$$

That is, normalizing both intermediate input and final demand expenditure shares by their domestic absorption and take ratio of them. This measure is not exactly what $\alpha^{s',s}_{ni,t}$ is, but with a multiplier at the bilateral-sector-year level, and can be controlled by corresponding fixed effect. Moreover, it retains the property that

$$\widehat{\left(\frac{\widetilde{\alpha}^{s',s}_{ni,t}}{\widetilde{\alpha}^{s',s}_{mi,t}}\right)} = \frac{\widehat{\alpha}^{s',s}_{ni,t}}{\widehat{\alpha}^{s',s}_{mi,t}}$$

Replacing the subscription m by i, the terms above is just its own variation over time. And under this normalization, the domestic absorption $\widetilde{\alpha}^{s',s}_{ii,t}$ for every sector pair (s', s) is fixed at 1.

Recall that $\alpha^{s',s}_{ni,t}$ is potentially related to three aspects of variations: importer side technology T^s_i, exporter side technology $T^{s'}_n$, and bilateral GVC connection $\eta^{s',s}_{ni}$. The last term would capture effects by PTAs on GVC-related activity dynamics.

Plugging in the decomposition above, my empirical specification based on this structural approach is described in the following equation:

$$
\begin{aligned}
\log\left(\frac{\widehat{\widetilde{\alpha}_{ji,t}^{s',s}}}{\widetilde{\alpha}_{ii,t}^{s',s}}\right) &= \log\left(\frac{\widehat{T}_j^{s'}\widehat{\eta}_{ji}^{s',s}}{\widehat{T}_i^{s'}\widehat{\eta}_{ii}^{s',s}}\right) \\
&= \log\left(\widehat{\eta}_{ji}^{s',s}\right) + \lambda_i^{s',s} + \lambda_j^{s'} \\
&= f\left(PTA_{ij,t}^{s',s}\right) + \lambda_i^{s',s} + \lambda_j^{s'}
\end{aligned}
$$

Here I use importer-sector-pair fixed effect $\lambda_i^{s',s}$ to control domestic technology variations as well as changes in domestic absorption, exporter-sector fixed effect $\lambda_j^{s'}$ to control foreign technology variations, and express the bilateral GVC reallocation term $\log\left(\widehat{\eta}_{ji}^{s',s}\right)$ as a function of PTAs. Since the left hand side is changes across two periods, it is equivalent to move the lag term to the right-hand side and rewrite the above specification into:

$$
\begin{aligned}
\ln\left(\widetilde{\alpha}_{ji,t}^{s',s}\right) &= \rho\ln\left(\widetilde{\alpha}_{ji,t-1}^{s',s}\right) + \beta_1 PTA_{ji,t-1} + \beta_2 postGTC_t \times PTA_{ji,t-1} \\
&\quad + \lambda_i^{s',s} + \lambda_j^{s'} + \varepsilon_{ji,t}^{s',s}
\end{aligned}
$$

Where the variables on the right-hand side try to capture three things: (i) existing GVC connections, as represented by $\widetilde{\alpha}_{ji,t}^{s',s}$; (ii) PTA relationship between two countries, as represented by the dummy variable PTA which takes 1 if there exists legally enforced preferential trade agreements and 0 otherwise; and (iii) potential structural break of PTA influence before and after GTC. All these variables take one period lag relative to the left-hand side variable, because typically the effect of PTAs takes time to materialize[13]. The two fixed effects $\lambda_i^{s',s}$ and $\lambda_j^{s'}$ are

[13] I also use the contemporaneous PTA dummy as a robustness check, and there's no statistical difference

included to absorb other variations that are not related to my research interests, as discussed above. Finally, since we are looking at changes between two periods, I exclude the crisis period (2008-2010) in my sample to avoid abnormal observations[14].

Ideally, the estimated coefficient of ρ should equal to 1. If it is lower than 1 (but still positive), the structural parameter $\widetilde{\alpha}_{ji,t}^{s',s}$ would follow a stationary AR(1) process where its current sourcing decision depends on its previous level. If it is greater than 1, then the non-stationary property of this structural parameter may imply an unbounded growth/decline to shocks either from PTAs or from unobservable error terms $\varepsilon_{ij,t}^{s',s}$. This is not consistent with the real world. Thus, I will expect a reasonable estimated value of ρ between 0 and 1, but close to 1.

The main results are summarized in Table 3.4. Standard errors are clustered at destination-sector-pair-time level[15]. Descriptive statistics of the variables in this specification are included in Appendix D.

Table 3.4: GVC Reallocation and PTA: Model Specification

	(1)	(2)
	α_t	a_t
α_{t-1} (a_{t-1})	0.770***	0.875***
	(0.00489)	(0.00242)
L.PTA Dummy	0.0151	0.182***
	(0.00930)	(0.00933)
Post GTC * Lag PTA Dummy	0.0555***	0.0813***
	(0.0173)	(0.0132)
Observations	286044	288148
Dest. Sec.-Pair Time FE	Yes	Yes
Origin Sec. Time FE	Yes	Yes
Adjusted R^2	0.845	0.933

Standard errors in parentheses and clustered at the destination-sector-time level.

First, the regression coefficients before the lagged measure of $\alpha_{ji,t}^{s',s}$ is positive and big (al-

[14]The inclusion of crisis periods does not change the main results much but makes pre-GTC PTAs also significant

[15]Remember I can only identify α up to a normalization at this level

though smaller than 1), which indicates a stationary AR(1) process for the structural parameter, as expected. This dynamic property may imply that GVC-related activities would depend on their existing levels as well as existing PTA status. As a robustness check, I conduct alternative model specifications such as AR(2) and AR(3) for this dynamic structure in Appendix D. The implied time-series models are all stationary, indicating attenuated dynamic impacts from more distant lag terms.

Second, PTA has different impacts on GVC reallocations before and after GTC. Column (1) illustrates the estimated results for the model-implied specification. Although PTA relation has insignificant effect on $\alpha_{ji,t}^{s',s}$ during the pre-GTC period, it can significantly induce GVC-related activities after GTC, with a magnitude of 5%. This point is consistent with the results in previous gravity estimation.

By construction, the structural parameter $\alpha_{ji,t}^{s',s}$ itself should not be directly affected by contemporaneous tariff reductions, it is necessary to check whether behind-border PTAs can provide insurance to GVC activities after the GTC. In Appendix D, I use another PTA measure following Osnago et al. (2016) which features the behind-border provisions[16]. Results are robust for alternative measures of PTA status.

Notice that $a_{ji,t}^{s',s}$, the intermediate expenditure share, contains variation not only in behind-border market access but also in on-the-border price and trade cost. If we consider this IO coefficient would capture the total effect of PTA status, we can make a straightforward comparison between the regression coefficients between α and a. Column (2) replicate the same specification but replace $\alpha_{ji,t}^{s',s}$ with $a_{ji,t}^{s',s}$. Again, the estimated coefficient ρ is still within the range of zero and

[16]According to their classification, this measure includes provisions on state-owned enterprises, state aid, competition policies, IPR, investment, public procurement and GATS.

one and close to 1. Different from the scenario of α, PTA status can increase the relative intermediate expenditure share significantly before the GTC, with a magnitude of 18%. This is consistent with findings in Osnago et al. (2016)[17]. This impact is also magnified after the GTC, with an additional reinforcement about 8% during the post-GTC recovery. And if we compare the magnitude of coefficients for column (1) and (2), then based on the decomposition (3.4), the behind-border channel (represented by α) would contributed up to 26% $((0.0151 + 0.0555)/(0.182 + 0.0813))$ of the total effect and 68% $(0.0555/0.0813)$ of the additional effect after the Collapse, which are very sizable.

As a summary of this section, my empirical analysis identified a significant impact of PTA status on GVC activities through the behind-border channel after the GTC. Even taking out the on-the-border variations in prices and trade costs (which are directly affected by tariff reductions), trade agreements still have influences on GVC activities behind the border, especially after the Great Trade Collapse.

3.5.7 Potential Channels of PTA Effect

There are several potential explanations why PTAs supported stronger GVC recovery after the GTC. First, the empirical analysis in Chapter 1 indicates that PTA partners tend to have lower fixed input sourcing costs than others. When global demand recovers, producers in these countries can rebuild their supply chain relationships easier, which supports a more resilient GVC structure compared to other countries.

Second, there could be another channel of PTAs as a safeguard against trade policy uncer-

[17]In their works, they find that signing preferential trade agreements is associated to 26 percent more intermediate trade flows.

tainties (Carballo et al., 2018; Handley and Limao, 2015; Handley et al., 2020b). For example, as documented in Chapter 1, the post-GTC period is associated with higher input sourcing uncertainty. A more consistent trade policy ensured by PTAs may reduce this input sourcing uncertainty and increase the efficiency of supply chain organization between PTA partners. As a result, countries involved in many PTAs tend to have a fast recovery pace in GVC activities and hence trade in intermediate inputs.

Finally, these two channels could be amplified through input-output linkages across countries. With endogenous input sourcing decisions, a sourcing country with limited PTA participation tends to face low foreign input demand and a high input sourcing uncertainty, which makes its trade and production hard to recover after a crisis. A more comprehensive framework that incorporates these PTA features is required for further exploration and could be an interesting extension for this dissertation.

3.6 Concluding Remarks

The emergence of global supply chains enabled countries to specialize not only in final goods production but also to engage in different production stages where they have comparative advantages. The sequential nature of production structure and compatible input requirement, however, makes GVC activities more fragile to adverse shocks and uncertainties than ordinary trade, thus demanding a more stable trade environment. This raises the issue of the importance of preferential trade agreements to world market integration. As observed in recent decades, the increasing magnitude of international trade is truly accompanied by the soaring of PTAs. On the other hand, PTA status can also protect GVC activities against adverse shocks. PTA provisions, especially those that facilitate compatible inputs and reduce production uncertainties, can isolate cross-country productions from local frictions to a considerable extent and, hence, secure trade flows. This effect is more pronounced during the post-crisis period.

The gravity estimation verified that PTAs provide additional strength for post-GTC recovery of international trade flows, especially those that are GVC-related. I then introduce a method based on the global sourcing framework introduced in Chapter 1 to separate cost and price changes from other sourcing decisions that may not be directly affected by tariff reductions. The model-implied specification demonstrates that PTA provisions can significantly influence GVC reallocations after the GTC, even if we remove their direct impacts on prices and trade costs. This behind-border channel is also economically significant, contributing up to a quarter of the total effect and around 68% of additional effect during the post-GTC recovery. Counterfactuals that fix the Input-Output structures for the post-GTC period to the 2007 level also indicate significant reallocations of GVC activities across countries with different PTA depths. These results suggest that PTAs especially those related to behind-border regulations can greatly enhance and secure GVC activities after the crisis.

Consistent with my findings in the previous two chapters, these empirical results indicate the essential role of PTAs in the growth of GVC activities beyond the scope of import tariffs. This impact is stronger when the global economy is recovering from a downturn and when economic and policy uncertainty is high. Reduction in the fixed sourcing cost faced by foreign producers is a plausible explanation of these beyond-tariff PTA effects, and the assurance of a stable economic and trade environment is another important function of PTAs, as documented in the trade literature.

Appendix A: Proof of Proposition 1

Starting from the gravity expression for input trade (1.17). Holding the source and destination market conditions ($\psi_{i,1}^{s',s}$ and $\psi_{n,1}^{s',s}$) constant, the partial derivative of $\log\left(a_{ni,1}^{s',s}\right)$ with respect to the variable trade cost $\log\left(\tau_{ni,1}^{s'}\right)$ is:

$$\begin{aligned}
\frac{\partial \log\left(a_{ni,1}^{s',s}\right)}{\partial \log\left(\tau_{ni,1}^{s'}\right)} &= \frac{\beta}{\nu}\frac{\partial E_0\pi_{ni,1}^{s',s}}{\partial \log\left(\tau_{ni,1}^{s'}\right)} + (1-\epsilon_i^s) \\
&= \frac{\beta}{\nu}\frac{\partial E_0\pi_{ni,1}^{s',s}}{\partial \log\left(\pi_{ni,1}^{s',s}\right)}\frac{\partial \log\left(\pi_{ni,1}^{s',s}\right)}{\partial \log\left(\tau_{ni,1}^{s'}\right)} + (1-\epsilon_i^s) \\
&= \frac{\beta E_0\pi_{ni,1}^{s',s}}{\nu}(1-\epsilon_i^s) + (1-\epsilon_i^s)
\end{aligned}$$

which leads to the result (1.18) in Proposition 1.

Appendix B: Additional Calibration and Illustration for Chapter 2

B.1 Counterfactual 1: Alternative Value of ν

Table B.1: Robustness: Alternative Values of ν

Shock	ΔW_{US}	ΔW_{China}	$\Delta\Pi^{M}_{China,US}$	$\Delta\Pi^{F}_{China,US}$
Baseline ($\nu = 10$)				
$\Delta\tau^{M}_{China,US} = 0.25, \Delta\tau^{M}_{US,China} = 0$	0.05%	-0.93%	-23.69%	-3.00%
$\Delta\tau^{M}_{China,US} = 0.25, \Delta\tau^{M}_{US,China} = 0.25$	-0.07%	-0.75%	-22.76%	-2.52%
More Elastic ($\nu = 4$)				
$\Delta\tau^{M}_{China,US} = 0.25, \Delta\tau^{M}_{US,China} = 0$	0.19%	-1.88%	-29.02%	-6.71%
$\Delta\tau^{M}_{China,US} = 0.25, \Delta\tau^{M}_{US,China} = 0.25$	0.01%	-1.33%	-27.36%	-4.96%
Less Elastic ($\nu = 20$)				
$\Delta\tau^{M}_{China,US} = 0.25, \Delta\tau^{M}_{US,China} = 0$	0.01%	-0.68%	-22.06%	-1.93%
$\Delta\tau^{M}_{China,US} = 0.25, \Delta\tau^{M}_{US,China} = 0.25$	-0.10%	-0.57%	-21.27%	-1.67%

B.2 Derivation of Equilibrium Conditions

In this section, I characterize the counterfactual ”hat” equilibrium (relative changes to the original equilibrium) by first showing how the three equations in Proposition 1 are derived. Then I complete the entirely derivation by demonstrating the rest of equilibrium conditions.

B.2.1 Proof of Proposition 2

The final and intermediate demand system in my model can be characterized by conditions (2.2) and (1.16):

$$
\begin{aligned}
\phi_{ni,t}^{s} &= \frac{D_{ni,t}^{s}\left(P_{n,t}^{s}\tau_{ni,t}^{s}\right)^{1-\sigma}}{\sum_{k} D_{ki,t}^{s}\left(P_{k,t}^{s}\tau_{ki,t}^{s}\right)^{1-\sigma}} \\
a_{ni,t}^{s',s} &= \frac{\alpha_{ni,t}^{s',s}\left(P_{n,t}^{s'}\tau_{ni,t}^{s'}\right)^{\frac{(1-\eta_{i}^{s})(1-\sigma)}{1-\delta_{i}^{s}\eta_{i}^{s}(1-\sigma)}}}{\sum_{k}\alpha_{ki,t}^{s',s}\left(P_{k,t}^{s'}\tau_{ki,t}^{s'}\right)^{\frac{\left(1-\eta_{i}^{s}\right)(1-\sigma)}{1-\delta_{i}^{s}\eta_{i}^{s}(1-\sigma)}}}
\end{aligned}
$$

Consider a counterfactual equilibrium with all variables labeled as $x' = x \cdot \widehat{x}$. We can express the new equilibrium final demand system as

$$
\phi_{ni,t}^{s}\cdot\widehat{\phi}_{ni,t}^{s} = \frac{D_{ni,t}^{s}\left(P_{n,t}^{s}\widehat{P}_{n,t}^{s}\tau_{ni,t}^{s}\widehat{\tau}_{ni,t}^{s}\right)^{1-\sigma}}{\sum_{k} D_{ki,t}^{s}\left(P_{k,t}^{s}\widehat{P}_{k,t}^{s}\tau_{ki,t}^{s}\widehat{\tau}_{ki,t}^{s}\right)^{1-\sigma}}
$$

Divide both the numerator and the denominator by $\sum_{k} D_{ki,t}^{s}\left(P_{k,t}^{s}\tau_{ki,t}^{s}\right)^{1-\sigma}$, we have

$$
\begin{aligned}
\phi_{ni,t}^{s}\cdot\widehat{\phi}_{ni,t}^{s} &= \frac{\frac{D_{ni,t}^{s}\left(P_{n,t}^{s}\tau_{ni,t}^{s}\right)^{1-\sigma}}{\sum_{k} D_{ki,t}^{s}\left(P_{k,t}^{s}\tau_{ki,t}^{s}\right)^{1-\sigma}}\left(\widehat{P}_{n,t}^{s}\widehat{\tau}_{ni,t}^{s}\right)^{1-\sigma}}{\sum_{k}\frac{D_{ki,t}^{s}\left(P_{k,t}^{s}\tau_{ki,t}^{s}\right)^{1-\sigma}}{\sum_{m} D_{mi,t}^{s}\left(P_{m,t}^{s}\tau_{mi,t}^{s}\right)^{1-\sigma}}\left(\widehat{P}_{k,t}^{s}\widehat{\tau}_{ki,t}^{s}\right)^{1-\sigma}} \\
&= \frac{\phi_{ni,t}^{s}\left(\widehat{P}_{n,t}^{s}\widehat{\tau}_{ni,t}^{s}\right)^{1-\sigma}}{\sum_{k}\phi_{ki,t}^{s}\left(\widehat{P}_{k,t}^{s}\widehat{\tau}_{ki,t}^{s}\right)^{1-\sigma}} \Rightarrow \\
\widehat{\phi}_{ni,t}^{s} &= \frac{\left(\widehat{P}_{n,t}^{s}\widehat{\tau}_{ni,t}^{s}\right)^{1-\sigma}}{\sum_{k}\phi_{ki,t}^{s}\left(\widehat{P}_{k,t}^{s}\widehat{\tau}_{ki,t}^{s}\right)^{1-\sigma}}
\end{aligned}
$$

Which is exactly condition (2.25) in Proposition 1. Similarly, we can apply the same method to the intermediate trade demand system:

$$
\begin{aligned}
a^{s}_{ni,t}\cdot\widehat{a}^{s}_{ni,t} &= \frac{a^{s}_{ni,t}\widehat{\alpha}^{s',s}_{ni,t}\left(\widehat{P}^{s'}_{n,t}\widehat{\tau}^{s'}_{ni,t}\right)^{\frac{\left(1-\eta^{s}_{i}\right)(1-\sigma)}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}}}{\sum_{k} a^{s}_{ki,t}\widehat{\alpha}^{s',s}_{ki,t}\left(\widehat{P}^{s'}_{k,t}\widehat{\tau}^{s'}_{ki,t}\right)^{\frac{\left(1-\eta^{s}_{i}\right)(1-\sigma)}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}}} \Rightarrow \\
\widehat{a}^{s}_{ni,t} &= \frac{\widehat{\alpha}^{s',s}_{ni,t}\left(\widehat{P}^{s'}_{n,t}\widehat{\tau}^{s'}_{ni,t}\right)^{\frac{\left(1-\eta^{s}_{i}\right)(1-\sigma)}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}}}{\sum_{k} a^{s}_{ki,t}\widehat{\alpha}^{s',s}_{ki,t}\left(\widehat{P}^{s'}_{k,t}\widehat{\tau}^{s'}_{ki,t}\right)^{\frac{\left(1-\eta^{s}_{i}\right)(1-\sigma)}{1-\delta^{s}_{i}\eta^{s}_{i}(1-\sigma)}}}
\end{aligned}
$$

Which is condition (2.26) in Proposition 1.

My global sourcing framework also allows endogenous changes in the sourcing probability $\alpha^{s',s}_{ni,t}$. According to condition (1.6), the new equilibrium sourcing probability can be expressed as

$$
\begin{aligned}
\alpha^{s',s}_{ni,t+1}\cdot\widehat{\alpha}^{s',s}_{ni,t+1} &= \frac{\exp\left(\beta E_t\left[\pi^{s',s}_{ni,t+1}+\Delta\pi^{s',s}_{ni,t+1}\right]-\left[f^{s',s}_{ni,t}+\Delta f^{s',s}_{ni,t}\right]\right)^{1/\nu}}{\sum_k \exp\left(\beta E_t\left[\pi^{s',s}_{ki,t+1}+\Delta\pi^{s',s}_{ki,t+1}\right]-\left[f^{s',s}_{ki,t}+\Delta f^{s',s}_{ki,t}\right]\right)^{1/\nu}} \\
&= \frac{\alpha^{s',s}_{ni,t+1}\exp\left(\beta E_t\left[\Delta\pi^{s',s}_{ni,t+1}\right]-\left[\Delta f^{s',s}_{ni,t}\right]\right)^{1/\nu}}{\sum_k \alpha^{s',s}_{ki,t+1}\exp\left(\beta E_t\left[\Delta\pi^{s',s}_{ki,t+1}\right]-\left[\Delta f^{s',s}_{ki,t}\right]\right)^{1/\nu}} \Rightarrow \\
\widehat{\alpha}^{s',s}_{ni,t+1} &= \frac{\exp\left(\beta E_t\left[\Delta\pi^{s',s}_{ni,t+1}\right]-\left[\Delta f^{s',s}_{ni,t}\right]\right)^{1/\nu}}{\sum_k \alpha^{s',s}_{ki,t+1}\exp\left(\beta E_t\left[\Delta\pi^{s',s}_{ki,t+1}\right]-\left[\Delta f^{s',s}_{ki,t}\right]\right)^{1/\nu}}
\end{aligned}
$$

Which is condition (2.27) in Proposition 1.

B.2.2 Other Equilibrium Conditions

On the final demand side, we can express the relative changes in the domestic aggregate price index as

$$
\begin{aligned}
\widehat{P}_{i,t} &= \prod_{s} \left(\widehat{P}_{i,t}^{s,F}\right)^{\xi_i^s} \\
&= \prod_{s} \left(\sum_{n} \phi_{ni,t}^{s} \left(\widehat{P}_{n,t}^{s} \widehat{\tau}_{ni,t}^{s}\right)^{1-\sigma}\right)^{\xi_i^s/(1-\sigma)}
\end{aligned}
$$

On the final goods production side, changes in sectoral final goods prices are

$$
\begin{aligned}
\widehat{P}_{i,t}^{s} &= \prod_{s'} \left(\widehat{P}_{i,t}^{s',s}\right)^{\gamma_i^{s',s}} / \widehat{A}_{i,t}^{s} \\
&= \prod_{s'} \left(\widehat{\Omega}_{i,t}^{s',s} \sum_{n} a_{ni,t}^{s',s} \widehat{\alpha}_{ni,t}^{s',s} \left(\widehat{p}_{ni,t}^{s',s}\right)^{1-\sigma}\right)^{\gamma_i^{s',s}/(1-\sigma)} / \widehat{A}_{i,t}^{s}
\end{aligned}
$$

And the relative changes in prices of intermediate varieties $p_{ni,t}^{s',s}$ can be expressed as

$$
\begin{aligned}
\widehat{p}_{ni,t}^{s',s} &= \left(\widehat{\widetilde{D}}_{i,t}^{s',s}\right)^{\frac{\delta_i^s \eta_i^s}{1-\delta_i^s \eta_i^s (1-\sigma)}} \left(\widehat{w}_{i,t}\right)^{\frac{(1-\delta_i^s)\eta_i^s}{1-\delta_i^s \eta_i^s (1-\sigma)}} \left(\widehat{\tau}_{ni,t}^{s'} \widehat{P}_{n,t}^{s'}\right)^{\frac{1-\eta_i^s}{1-\delta_i^s \eta_i^s (1-\sigma)}} \\
&= \left[\left(\widehat{P}_{i,t}^{s',s}\right)^{\sigma-1} \widehat{R}_{i,t}^{s}\right]^{\frac{\delta_i^s \eta_i^s}{1-\delta_i^s \eta_i^s (1-\sigma)}} \left(\widehat{w}_{i,t}\right)^{\frac{(1-\delta_i^s)\eta_i^s}{1-\delta_i^s \eta_i^s (1-\sigma)}} \left(\widehat{\tau}_{ni,t}^{s'} \widehat{P}_{n,t}^{s'}\right)^{\frac{1-\eta_i^s}{1-\delta_i^s \eta_i^s (1-\sigma)}}
\end{aligned}
$$

To determine the relative changes in the mass of active entrepreneurs $\widehat{\Omega}_{i,t}^{s',s}$, we need to evaluate the free entry conditions. First, changes in gross returns of intermediate goods producers are

$$
\begin{aligned}
\widehat{\pi}_{ni,t}^{s',s} &= \left(\widehat{p}_{ni,t}^{s',s}\right)^{1-\sigma}\left(\widehat{P}_{i,t}^{s',s}\right)^{\sigma-1}\widehat{R}_{i,t}^{s} \\
\Delta\pi_{ni,t}^{s',s} &= \left[\left(\widehat{p}_{ni,t}^{s',s}\right)^{1-\sigma}\left(\widehat{P}_{i,t}^{s',s}\right)^{\sigma-1}\widehat{R}_{i,t}^{s}-1\right]\pi_{ni,t}^{s',s}
\end{aligned}
$$

Second, consider the difference between free entry conditions between two equilibria. Since there is no changes in the fixed investment of entry, the expected value of returns should be the same in two equilibria[1]. This leads to

$$
1=\sum_{n}\alpha_{ni,t+1}^{s',s}\exp\left(\beta E_t\left[\Delta\pi_{ni,t+1}^{s',s}\right]-\Delta f_{ni,t}\right)^{1/\nu}
$$

The above two conditions implicitly determine $\widehat{P}_{i,t}^{s',s}$ and hence $\widehat{\Omega}_{i,t}^{s',s}$.

Finally, relative changes in sectoral revenue $R_{i,t}^{s}$ are characterized by the following transformation of market clearing conditions:

$$
\begin{aligned}
\widehat{R}_{i,t}^{s} = & \sum_{n}\frac{\phi_{in,t}^{s}\xi_{n}^{s}\lambda_{i,t}\Pi_t}{R_{i,t}}\widehat{\phi}_{in,t}^{s}\widehat{\Pi}_t+\sum_{n}\sum_{s'}\frac{\phi_{in,t}^{s}\xi_{n}^{s}\left(1-\delta_{n}^{s'}\right)\eta_{n}^{s'}R_{n,t}^{s'}}{R_{i,t}}\widehat{\phi}_{in,t}^{s}\widehat{R}_{n,t}^{s'} \\
& +\sum_{n}\sum_{s'}\frac{a_{in,t}^{s',s}\gamma_{i}^{s,s'}\left(1-\eta_{n}^{s'}\right)R_{n,t}^{s'}}{R_{i,t}}\widehat{a}_{in,t}^{s',s}\widehat{R}_{n,t}^{s'}
\end{aligned}
$$

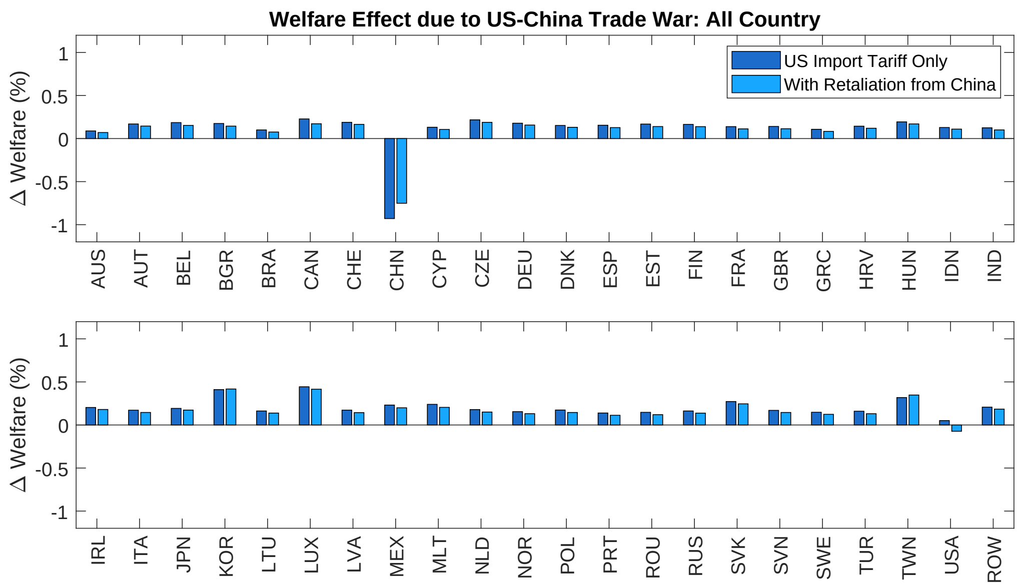
where

[1]This can be relaxed by introducing market clearing conditions for productional capital.

$$\widehat{\Pi}_t = \sum_i \sum_s \frac{\delta_i^s \eta_i^s R_{i,t}^s}{\Pi_t} \widehat{R}_{i,t}^s$$

B.3 Additional Figures on Quantitative Analysis

Figure B.1: The US-China Tradewar: Welfare (Baseline, All Sample Countries)



B.4 Calibration: Impacts of PTAs

I obtain bilateral import tariffs at the sector breakdown from the World Integrated Trade Solution (WITS). I use the weighted-average import tariff rates from two types to compute the counterfactual changes, the effectively applied (AHS) tariff rates and the Most-Favored-Nation (MFN) tariff rates:

$$\widehat{\tau}_{ni,1}^s = \frac{1 + Tariff_{ni,1}^{s,MFN}}{1 + Tariff_{ni,1}^{s,AHS}}$$

Figure B.2: Trade Effect of Global Disintegration: Intermediate Imports

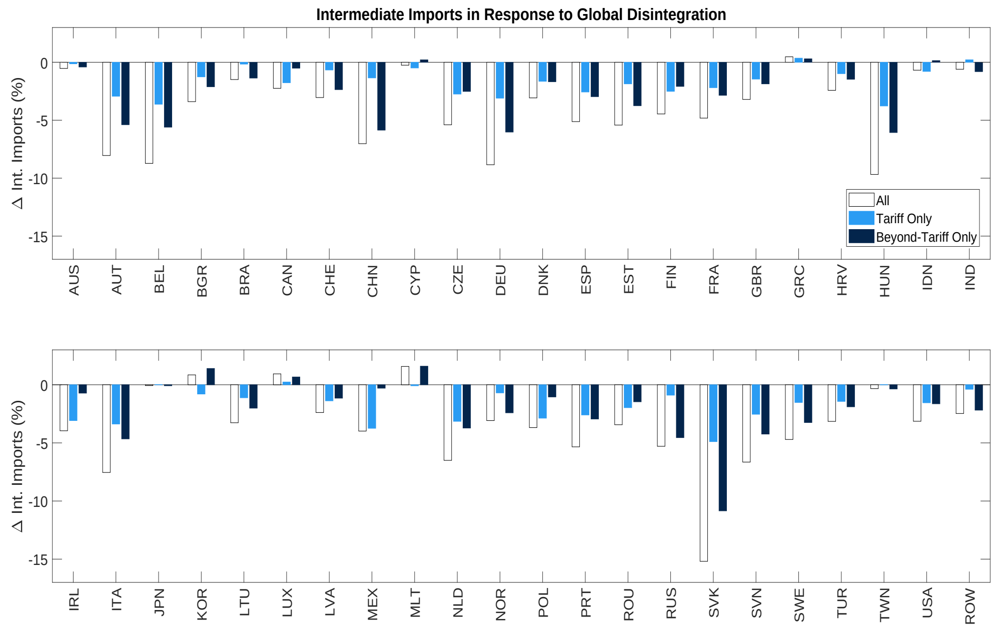
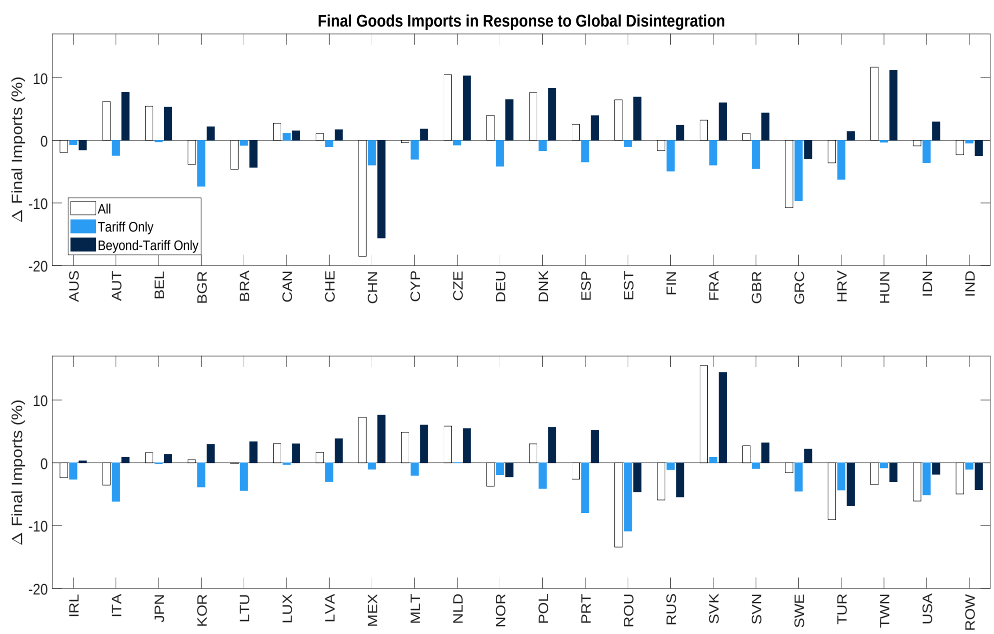


Figure B.3: Trade Effect of Global Disintegration: Final Good Imports



In most cases, the AHS rate coincides with the preferential (PRF) rate when the importing and exporting countries have signed a PTA. This import tariff data only covers trade in goods.

I construct the PTA depth measure based on the number of legally enforceable provisions and normalized to be within the range of [0,1]. The detailed provision information covered by each PTA comes from the World Bank Content of Deep Trade Agreement Database. The impact of PTA depth on the corresponding fixed sourcing costs, λ_1, is estimated jointly with the (inverse) origin-switching elasticity with a magnitude of -0.48 (see Chapter 1).

B.5 PTA Coverage and Import Tariffs on Foreign Imports

This section provides a descriptive summary of the two shocks in my counterfactual analysis: changes in import tariffs; and changes in fixed sourcing costs based on existing PTA status. I construct two country-level measures that characterize their dependence on PTAs: PTA coverage on imports, and the average import tariff change each country would face during the counterfactual global disintegration. More specifically, these two measures are defined as follows:

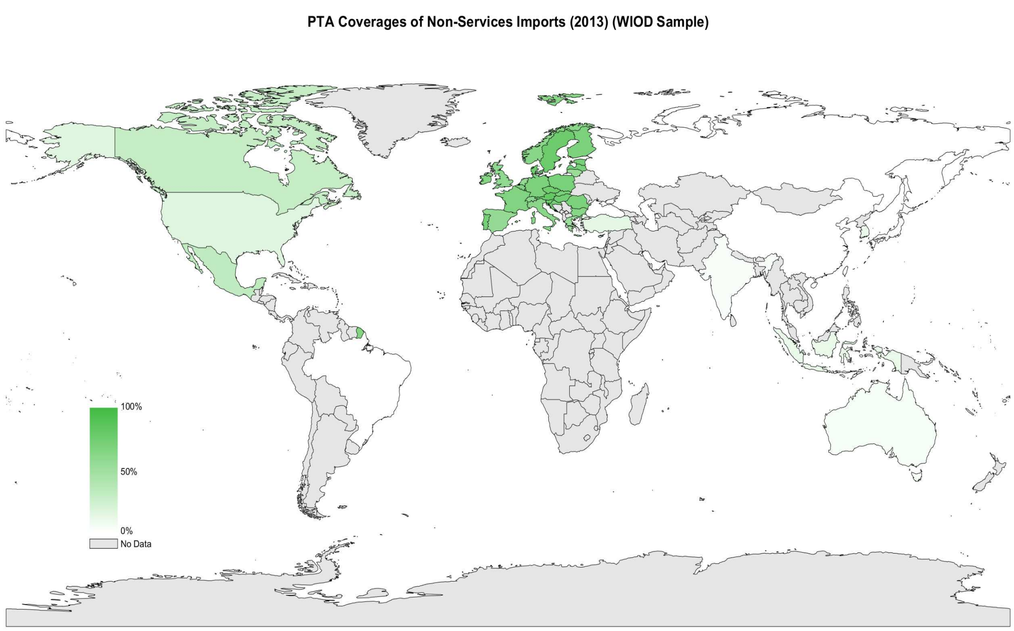
$$\begin{aligned}\text{PTA Coverage}_i &= \sum_{n\neq i}\sum_{s}\omega_{ni}^{s} PTA_{ni}\\ \Delta\text{Avr. Tariff}_i &= \sum_{n\neq i}\sum_{s}\omega_{ni}^{s}\Delta t_{ni}^{s}\end{aligned}$$

where ω_{ni}^{s} is the share of imports from country n and sector s in total foreign imports of country i, PTA_{ni} is the bilateral PTA depth measure as described earlier and within the range of [0,1], and Δt_{ni}^{s} is the corresponding distances in tariff rates between MFN tariffs and preferential tariffs.

The first measure captures the degree of foreign imports that are governed by PTAs, and the second measure characterizes the benefits on import tariffs compared to other WTO members who do not have any PTAs.

The coverage of PTAs on foreign imports is very different across countries. In Figure B.4 I demonstrate the percentage coverage on foreign imports by PTAs for each country in my sample. Among the 44 economies, Euro Area and North American countries have larger shares of their imports covered by PTAs. Thus, the global decoupling of PTAs is expected to have more impacts on these countries.

Figure B.4: PTA Coverage on Foreign Imports

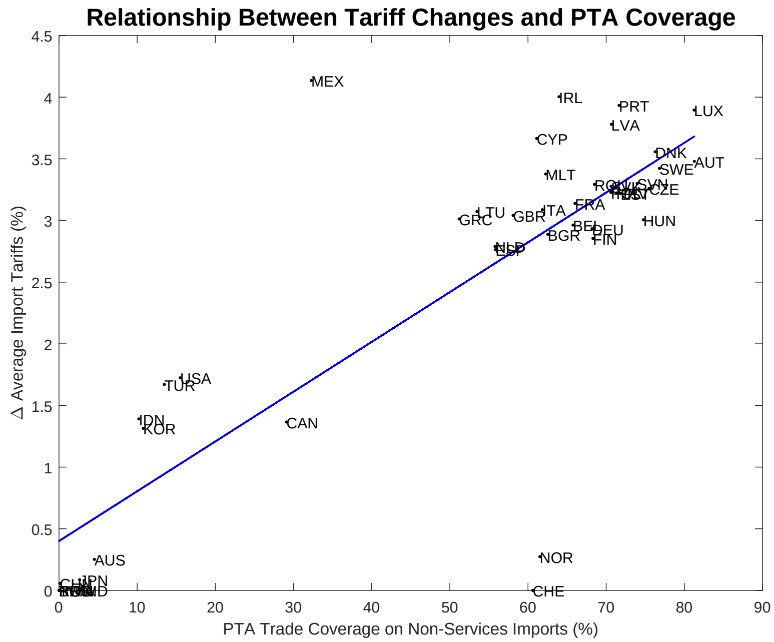


On the other hand, China, Brazil, and Russia have almost zero percent of imports covered by any deep trade agreements. Thus their welfare and trade responses to the global disintegration shock might fully reflect the third-country effect of PTAs.

Import tariffs changes are correlated with the depth of PTAs, but not perfectly. Figure B.5

shows the relationship between PTA imports coverage and the average import tariff changes[2] at the country level. Although generally, we observe a positive relationship between these two shocks, there is still significant dispersion around the fitted line.

Figure B.5: Relationship between PTA Coverage on Imports and Avrage Changes in Import tariffs



[2]These import tariff changes are weighted by import volumes.

Appendix C: Measures of GVC Activity

Before going to the details, let us first understand the market clearing conditions embedded in WIOT, and the basic notations I will use in this subsection. The balance of the WIOT through the horizontal direction can be translated in to $N \times S$ market clearing conditions (Johnson and Noguera (2017)):

$$y_i(s) = \sum_j f_{ij}(s) + \sum_j \sum_{s'} m_{ij}(s, s')$$

Where $y_i(s)$ is the gross output for sector s in country i, $f_{ij}(s)$ is the bilateral final expenditure used in country j and produced in sector s of country i, and $m_{ij}(s, s')$ is the bilateral intermediate trade flows from country-sector pair (i, s) to (j, s'). Writing in Matrix form, we have

$$y = F \cdot \iota_N + M \cdot \iota_{NS}$$

If we further define the Leontief Inverse $A = \{a_{ij}(s, s')\}$ where $a_{ij}(s, s') = m_{ij}(s, s') / y_j(s')$, then the second term on the RHS can be rewritten as Ay. Thus, these market clearing conditions can be expressed as

$$y = F \cdot \iota_N + Ay \Rightarrow y = (I - A)^{-1} F \cdot \iota_N$$

Following Johnson (2017), the market clearing conditions through the vertical direction of WIOT, which incorporate with value-added terms, can be expressed as

$$y = va' + \iota' A\widehat{y} = va' + y'B$$

Where $\widehat{y}$ is a diagonal matrix with elements in y on the diagonal, and $B = \widehat{y}^{-1} A\widehat{y}$ is the Gosh Inverse that records the share of output from one country-industry used by another downstream country-industry.

C.1 Value-Added Content in Exports

The definition of domestic value-added content in exports comes from Johnson and Noguera (2012, 2017). In WIOT, the value-added terms in gross output are just the difference between sectoral gross output at basic prices and sectoral total intermediate consumption at purchase prices:

$$va_i(s) = y_i(s) - \sum_j \sum_{s'} m_{ji}(s, s')$$

Assuming that value-added shares in gross output is the same in exports, we can compute bilateral value added exports by identifying the proportion of value added in each countries final expenditure:

$$va_{ij}(s) = \frac{va_i(s)}{y_i(s)} y_{ij}(s) = \frac{va_i(s)}{y_i(s)} (I - A)^{-1} f_{ij}$$

This is an $NS \times N$ matrix that identify bilateral value-added flows from every country-sector source to every destination country. Then we can compute value-added content of trade in exports at country and sector level.

C.2 GVC Participation Index

Another group of measures is the GVC participation indices introduced by Wang et al. (2017). Similar to the value added decomposition, the method of computing GVC participation indices starts from the WIOT identities:

$$y = Ay + f$$

Where $f_i(s) = \sum_j f_{ij}(s)$ is the total final use produced in country i and sector s. If we further decompose matrix A and final use f into domestic and foreign input/use, as

$$A = A^D + A^F, f = f^D + f^F$$

Rearranging the WIOT identities above, we have

$$\begin{aligned} y &= \left(I - A^D\right)^{-1} f^D + \left(I - A^D\right)^{-1} \left(f^F + A^F y\right) \\ &\equiv Lf^D + Lf^F + LA^F y \end{aligned}$$

Where $L = \left(I - A^D\right)^{-1}$ is defined as local Leontief inverse. If we define the value added share in gross output as $V = va\widehat{y}^{-1}$ where $\widehat{y}$ is the matrix that diagnoalize vector y (making elements of y on diagonal and zero otherwise), then diagonalize and multiply both sides by $\widehat{V}$ yield

$$\begin{aligned}
\widehat{V}B\widehat{f} &= \widehat{V}L\widehat{f^D} + \widehat{V}L\widehat{f^F} + \widehat{V}LA^F B\widehat{f} \\
&= \widehat{V}L\widehat{f^D} + \widehat{V}L\widehat{f^F} + \widehat{V}LA^F L\widehat{f^D} + \widehat{V}LA^F\left(B\widehat{f} - L\widehat{f^D}\right)
\end{aligned}$$

Where $B = (I - A)^{-1}$ is the standard Leontief inverse. The LHS is an $NS \times NS$ matrix containing bilateral value added usages from origin country-sector (each row) in destination country-sector (each column). This matrix has the nice properties that, while summing up along the row direction (horizontal), we have the country-sector specific total value added (va); while summing up along the column direction (vertical), we have the country-sector specific total expenditure (y).

The RHS of this equation is the four components of value added, classfied by their locations in final good production. The first term $\widehat{V}L\widehat{f^D}$ captures the value added in domestic final good production that are used or consumed domestically, which is called doemstic absorption; the second term $\widehat{V}L\widehat{f^F}$ captures the value added in domestic final good production that are exported to a certain destination, which is called regular trade; the third term $\widehat{V}LA^F L\widehat{f^D}$ captures the value added embeded in intermediates exports/imports that are used directly in destination country's final good production and absorbed in that country, which is called the simple GVC participation; and the fourth term $\widehat{V}LA^F\left(B\widehat{f} - L\widehat{f^D}\right)$ captures value added embeded in intermediates exports/imports that are used by partner country to produce exports (intermediate or final) for third countries, which is called the complex GVC participation.

Summing along row and column directions yield decomposition of value added/expenditure through exports/imports side. Summing up along the row direction would be

$$va = \widehat{V}Bf = \widehat{V}Lf^D + \widehat{V}Lf^F + \widehat{V}LA^F Lf^D + \widehat{V}LA^F \left(Bf - Lf^D\right)$$

Along the column direction would be

$$f' = VB\widehat{f} = VL\widehat{f^D} + VL\widehat{f^F} + VLA^F L\widehat{f^D} + VLA^F \left(B\widehat{f} - L\widehat{f^D}\right)$$

And the forward and backward GVC participation indices are defined as the shares of GVC activities (which are the sum of last two terms) in total value added/expenditure:

$$\begin{aligned} GVC_i^F &= \frac{GVC_i^{F,S} + GVC_i^{F,C}}{va_i} = \frac{\left[\widehat{V}LA^F Lf^D + \widehat{V}LA^F \left(Bf - Lf^D\right)\right]_i}{va_i} \\ GVC_i^B &= \frac{GVC_i^{B,S} + GVC_i^{B,C}}{f_i} = \frac{\left[VLA^F L\widehat{f^D} + VLA^F \left(B\widehat{f} - L\widehat{f^D}\right)\right]_i}{f_i} \end{aligned}$$

While the forward GVC participation index is more related to exports or downstream activities, the backward participation index is more related to imports or upstream activities.

Appendix D: Descriptive Statistics and Robustness for Chapter 3

D.1 PTA Depth and Categorization of Country

Following Osnago et al. (2016), PTA depth are computed as the count of legally enforced provisions in a PTA PTA_{ijt} divided by the maximum number of legally enforced provisions $\overline{PTA}_{ijt}$. The country-level PTA depth categorization is based on the PTA import coverage characterized in Appendix {app2.

PTA depth are computed for year 2007, but the order is quite stable across sample periods. The detailed classification in my sample for Figure B.4 is:

PTA Low: AUS, BRA, CAN, CHN, GBR, IDN, IND, ITA, JPN, KOR, RUS, TUR, TWN, USA;

PTA Middle: BGR, CHE, DEU, ESP, FIN, FRA, GRC, HRV, MEX, NLD, NOR, POL, PRT, ROU, SWE;

PTA High: AUT, BEL, CYP, CZE, DNK, EST, HUN, IRL, LTU, LUX, LVA, MLT, SVK, SVN

D.2 Growth Residuals and Bilateral PTA Status

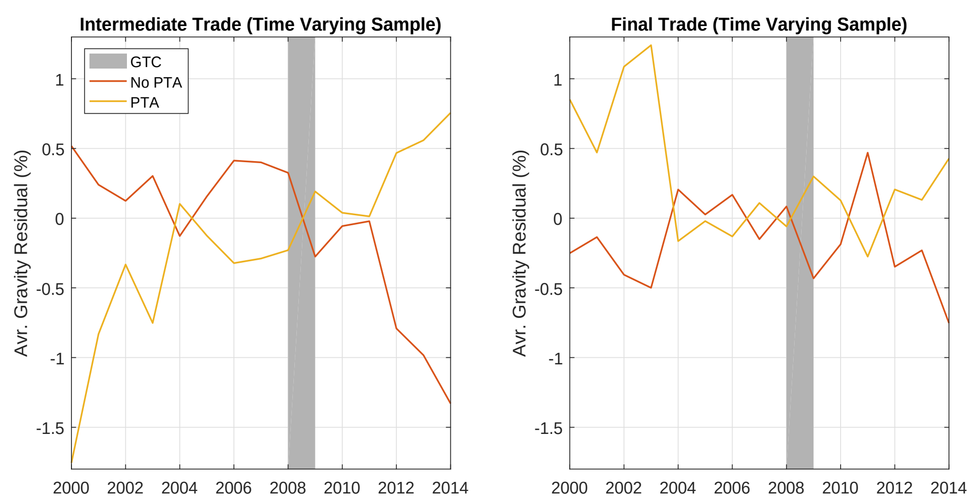
Bilateral trade growth residuals in Figure 3.2 are computed by the following gravity specification:

$$\ln\left(trade_{ijt}\right) = \beta_1 Tariff_{ijt} + \lambda_{it} + \lambda_{jt} + \phi_{ij}$$

Where $trade_{ijt}$ is the exports from country i to country j at year t, $Tariff_{ijt}$ is the import tariff rates of country j while importing from country i, and λ and ϕ are the fixed effects.

The classification of PTA status in Figure 3.2 is based on whether a country pair had bilateral PTA provisions that are legally enforceable in 2007. This fixed sample consists of 704 pairs in "No PTA" group and 936 in "PTA" group. I also tried another time-varying classification that based on bilateral PTA status in each year, and the number of PTA pairs varies from 342 (2000) to 1024 (2014). Similar comparisons are summarized in Figure D.1, and the divergence pattern in intermediate trade growth still exists after the GTC.

Figure D.1: Bilateral Trade Growth Residual by PTA status (2000-2014) (Variable Sample)



D.2.1 Robustness Check: Gravity Estimation

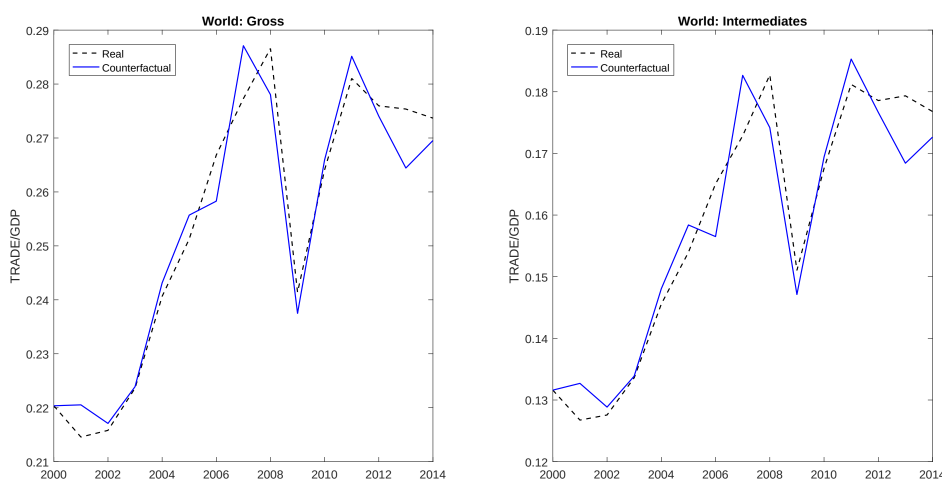
Table D.1: Gravity Estimation: Excluding Crisis Period and Newly Signed PTAs

	Exclude GTC Period (2008-2009)				Exclude New PTAs After 2007			
	Int	Final	Int	Final	Int	Final	Int	Final
log effective tariff, w.a.	-0.565***	0.253	-0.528***	0.247	-0.983***	0.438**	-0.927***	0.496**
	(0.182)	(0.188)	(0.185)	(0.191)	(0.191)	(0.195)	(0.193)	(0.198)
PTA Dummy	-0.0563**	0.0316			-0.0235	0.0242		
	(0.0236)	(0.0244)			(0.0244)	(0.0250)		
PostGTC * PTA Dummy	0.0558**	-0.0214			0.0788***	-0.0557*		
	(0.0269)	(0.0278)			(0.0300)	(0.0307)		
PTA Depth (Normalized)			-0.0375	0.0286			0.0190	0.0584
			(0.0358)	(0.0369)			(0.0354)	(0.0362)
PostGTC * PTA Depth			0.115***	-0.00985			0.156***	-0.0436
			(0.0398)	(0.0411)			(0.0405)	(0.0415)
Observations	19711	19711	19711	19711	21629	21629	21629	21629
Bilateral FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.975	0.974	0.975	0.974	0.976	0.976	0.976	0.976

Standard errors in parentheses

D.2.2 Counterfactuals: Different Reference Year

Figure D.2: Real vs. Counterfactual: World Aggregation (Reference Year: 2000)



D.2.3 Structural Approach: Alternative Dynamic Structure

Table D.2: Robustness: Alternative Dynamic Structure (Extra Lags)

	(1) Baseline	(2) w. 2nd Lag	(3) w. 3rd Lag
α_{t-1}	0.770***	0.571***	0.528***
	(0.00489)	(0.00688)	(0.00846)
α_{t-2}		0.268***	0.196***
		(0.00656)	(0.00852)
α_{t-3}			0.136***
			(0.00828)
L.PTA Dummy	0.0151	0.00840	0.0145
	(0.00930)	(0.00939)	(0.0104)
Post GTC * Lag PTA Dummy	0.0555***	0.0573***	0.0470**
	(0.0173)	(0.0178)	(0.0197)
Observations	286044	233583	181501
Dest. Sec.-Pair Time FE	Yes	Yes	Yes
Origin Sec. Time FE	Yes	Yes	Yes
Adjusted R^2	0.845	0.860	0.861

Standard errors in parentheses and clustered at the destination-sector-time level.

D.2.4 Structural Approach: Other Robustness

In this subsection, I use alternative measures of PTAs and alternative sample sizes to estimate the baseline specification. More specifically, I use the contemporary PTA dummy measure in Column (1), a sample including the crisis period in Column (2), and a PTA measure that only indicates behind-border related provisions following Laget et al. (2020). All columns show robust results to Table 3.4.

Table D.3: Robustness Check: Contemporaneous PTA, Whole Sample, and Behind-Border PTA

	(1) No Lags	(2) Whole Sample	(3) Behind-Border Measure
α_{t-1}	0.770***	0.762***	0.770***
	(0.00489)	(0.00452)	(0.00489)
PTA Dummy	0.00935		
	(0.00977)		
Post GTC * PTA Dummy	0.0634***		
	(0.0182)		
L.PTA Dummy		0.0253***	
		(0.00864)	
Post GTC * Lag PTA Dummy		0.0359**	
		(0.0168)	
L.PTA Dummy (behind-border)			0.0145
			(0.00917)
Post GTC * Lag PTA Dummy (behind-border)			0.0644***
			(0.0177)
Observations	286044	364270	286044
Adjusted R^2	0.845	0.840	0.845

Standard errors in parentheses and clustered at the destination-sector-time level.

D.3 Descriptive Statistics: Gravity Sample

Table D.4: Descriptive Statistics: Gravity Sample

Variable	Obs.	Mean	Std. Dev.	Min	Max
log(non-services int. trade)	24,600	5.30	2.59	-7.33	12.35
log(non-services final trade)	24,600	4.85	2.63	-8.24	12.30
PTA dummy	24,600	0.48	0.50	0	1
PTA depth	24,600	0.32	0.37	0	0.85
log(1 + MFN tariffs)	22,911	0.029	0.042	0	0.793

”commodity” means trade flows without trade in services

D.4 Descriptive Statistics: Strcutural Sample

Table D.5: Descriptive Statistics: Structural Sample

Variable	Obs.	Mean	Std. Dev.	Min	Max
$log(\widehat{\alpha})$	391,034	0.712	2.175	-23.112	34.768
$log(\widehat{a})$	393,142	-7.779	3.133	-42.710	4.407
$log(\widehat{\alpha})$ (No Crisis)	312,590	0.723	2.17	-23.112	34.768
$log(\widehat{a})$ (No Crisis)	314,486	-7.809	3.141	-42.302	1.871
PTA dummy	393,600	0.483	0.500	0	1
PTA dummy (No Crisis)	314,880	0.460	0.498	0	1

”No Crisis” means excluding observations in 2008, 2009 and 2010.

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