Armington Elasticities and the Third-Country Effects of Trade Wars

Wei Li*[1], Bin Qiu†[2], Zi Wang‡[1], Yanbo Zeng§[2], and Yuan Zi¶[3]

[1]College of Business, Shanghai University of Finance and Economics
[2]School of Economics and Management, Southeast University
[3]Graduate Institute of International and Development Studies

June 23, 2022

Abstract

We revisit the Armington model developed by Feenstra, Luck, Obstfeld, and Russ (2018) that allows the elasticity of substitution between the domestic and foreign varieties to be different from that between alternative foreign varieties. We develop a novel two-stage gravity-based framework to estimate these two elasticities using data on bilateral trade flows, tariffs, and domestic production, exactly the same set of data used for counterfactual analysis. Our estimates suggest that the elasticity of substitution between the domestic and foreign varieties is 43% lower than that between alternative foreign varieties. We apply the model to quantify the global consequences of the US-China trade war starting from 2018. Counterfactual analysis suggests that imposing a uniform elasticity of substitution across all varieties would lead to (i) considerable underestimation of the third-country welfare gains from the US-China trade war, and (ii) overestimation of the noncooperative tariffs between the U.S. and China.

JEL classification: F10; F13; F14
Keywords: Trade Elasticities; Gravity Equation; Trade War

*li.wei@mail.shufe.edu.cn
†qiubin@seu.edu.cn
‡wang.zi@mail.shufe.edu.cn
§zyan9841@gmail.com
¶yuan.zi@graduateinstitute.ch

1 Introduction

A conventional justification for protectionism import tariffs is that these tariffs can bring demand and hence jobs back to the home country. The effectiveness of such policies depends on the elasticity of substitution between foreign and home products. As a result, correctly specifying and estimating these elasticities is crucial in quantifying the global implications of trade policies (Arkolakis, Costinot, and Rodriguez-Clare, 2012).

It has long been noticed by the trade literature that the elasticity of substitution between home and foreign products tends to be lower than that between two foreign products.[1] If so, protectionism tariffs on imports from a particular country may not be very effective in bringing jobs back home since these jobs are likely to move to third countries. While this perception is intuitive, estimating these elasticities of substitution is challenging. Previous estimation frameworks (e.g. Feenstra et al., 2018; Fajgelbaum, Goldberg, Kennedy, and Khandelwal, 2020) require data on prices (measured by unit values) of domestic production, which is unavailable in most circumstances.

This paper aims to estimate these elasticities of substitution in a structural model and understand their implications for the consequences of protectionism tariffs. To this end, we revisit the multi-sector Armington model developed by Feenstra et al. (2018) featuring a nested-CES preference that allows the elasticity of substitution between the domestic and foreign varieties to be different from that between alternative foreign varieties. We show analytically that the difference between these two elasticities is key for the consequences of protectionism tariffs in the recent US-China trade war. As the elasticity of substitution between alternative foreign varieties becomes larger than that between home and foreign varieties, the U.S. protectionism tariffs on imports from China are more likely to shift demand towards third countries than to bring jobs back to the U.S., leading to

[1] Feenstra et al. (2018) have summarized that "Traditionally, CGE models applied to international trade have used a nested CES structure on preferences, with an upper-level macroelasticity governing the substitution between home and foreign goods and a lower-level microelasticity governing the substitution between varieties of foreign goods". The calibrated values of the macroelasticity were lower than those of the microelasticity, as justified by the differing elasticities estimated from data at various levels of aggregation.

larger welfare gains in third countries.

We then develop a novel two-stage gravity-based framework to estimate these two Armington elasticities. Our empirical framework only requires three sets of data: bilateral trade flows, bilateral tariffs, and domestic production value. Our first stage is identical to the fixed-effect estimator developed by Head and Mayer (2014). Using data on changes in bilateral trade flows and tariffs between 2003 and 2013, our baseline estimate of the elasticity of substitution between alternative foreign varieties is 4.127, which is in line with the estimates in the literature.

Our second stage utilizes data on changes in domestic production shares and the fixed effects estimated in the first step to recover the elasticity of substitution between the domestic and foreign varieties. The identification of this elasticity comes from the linkage between changes in the domestic production share and changes in the *average* import tariff. With a higher average import tariff, a country would have a larger share of domestic products in its total expenditure. Our baseline estimates suggest that the elasticity of substitution between the domestic and foreign varieties is 2.327, much smaller than the elasticity of substitution between alternative foreign varieties. We do robustness checks by using data for different years, by allowing these Armington elasticities to be heterogeneous across groups of sectors, and by developing an alternative estimator that uses data in levels. In all these robustness exercises, our estimates suggest that the elasticity of substitution between the domestic and foreign varieties is significantly lower than that between alternative foreign varieties.

Our two-stage gravity-based framework has two advantages. First, unlike previous studies such as Feenstra et al. (2018) and Fajgelbaum et al. (2020), it does not require data on domestic prices. We show that the linkage between the domestic production share and the average import tariff is sufficient to identify the elasticity of substitution between domestic and foreign varieties. Indeed, the data used for estimating two Armington elasticities is exactly identical with the data used for our counterfactual analysis – *no additional data is required*. Second, our two-stage framework is guided by our structural gravity model and makes full use of the fixed effects estimated in the gravity equation. This model-based approach is in line with the recent literature aiming to recover structural parameters from the fixed effects estimated in the gravity equation. For example, Freeman, Larch, Theodorakopoulos, and Yotov (2021) makes use of these fixed effects to recover the trade effects of country-specific shocks.

We then evaluate how our estimated model fits the observed changes in trade shares over 2003-2013. To this end, we recover changes in non-tariff trade costs and sectoral productivities from changes in trade flows, given changes in tariffs and our estimates of Armington elasticities. Then we insert these shocks into our model and simulate changes in trade shares over 2003-2013. The results suggest that our baseline model with the nested-CES preference fits the observed changes in trade shares over 2003-2013 better than the standard quantitative trade model with a uniform elasticity of substitution across all varieties.

Armed with the estimated model, we conduct our first counterfactual exercise to understand to what extent the protectionism tariffs imposed by the Trump administration can bring demand back to the U.S.[2] We find that the U.S. gains *less* (in terms of real income) from Trumpian tariffs in our model (0.004%) than implied by the standard model with a uniform elasticity of substitution across all varieties (0.016%). Moreover, the standard model considerably *underestimates* the third-country welfare gains from Trumpian tariffs. Among others, the Mexican welfare gain increases from 0.12% in the standard model to 0.215% in our model, Canada from 0.005% to 0.032%, Japan from 0.011% to 0.027%, and Korea from −0.001% to 0.024%. These results are consistent with our analytical results that if the Armington elasticity is greater across foreign varieties than between foreign and domestic varieties, the protectionism tariffs targeting on a particular country would, instead of bringing demand back home, shift demand to third countries.

We then quantify the consequences of the US-China trade war (Trumpian tariffs +

[2]Notice that in our model national labor supply is exogenous. Therefore, changes in labor demand are reflected by changes in real income.

Chinese retaliation tariffs). Both China and the U.S. would suffer from the trade war, with greater losses predicted by our model than by the standard model. In contrast, other countries such as Canada, Mexico, Japan, and Korea benefit from the US-China trade war. If the trade war further escalates and finally both countries impose prohibitive tariffs, the U.S. (Chinese) welfare loss would be -0.51% (-0.552%), whereas the real incomes in other countries would increase considerably.

Finally, we investigate the implications of our nested-CES preference for the Nash tariffs between the U.S. and China. We consider a noncooperative tariff game between the U.S. and China and compute the Nash equilibrium using our model. We find that in the Nash equilibrium the U.S. would impose protectionism tariffs averaged 11.6% on the Chinese imports. These tariffs are higher than the U.S. pre-trade-war tariffs on the Chinese imports (averaged 2.6%) but much lower than the actual Trumpian tariffs (averaged 21.3%). Our Nash tariffs are lower than ones calculated by Ossa (2014) and Lashkaripour (2021) because these studies consider global tariff wars but we consider a local tariff war. Moreover, we find that the Nash tariffs between the U.S. and China are *lower* in our baseline model than in the standard model with a uniform elasticity of substitution across all varieties. Intuitively, countries are less likely to start local tariff wars if these protectionism tariffs mainly shift demand into non-participation countries. This result is particularly policy-relevant since local tariff wars are much more likely to occur than global tariff wars.

Related Literature. This paper first relates to the literature of the empirical estimates of trade elasticities. Feenstra et al. (2018) consider the nested-CES preference in the Armington model and estimate the Armington elasticities using data on trade flows and domestic production and prices. Fajgelbaum et al. (2020) estimate a U.S. demand system that accommodates reallocations across imported products and between imported and domestic products, utilizing tariff changes as instruments. As discussed above, these studies require data on domestic prices, which is unavailable in most circumstances. We contribute to this literature by developing a novel two-stage gravity-based framework and estimating two Armington elasticities using only data on domestic production, bilateral trade flows, and tariffs. There is also an extensive literature estimating the trade elasticity using bilateral tariffs and trade flows (*e.g.* Ruhl, 2008; Simonovska and Waugh, 2014; Imbs and Mejean, 2015). Unlike our work, these papers assume a uniform elasticity of substitution across all varieties.

This paper also relates to the literature about the structure of trade elasticities. Lind and Ramondo (2018) extend Eaton and Kortum (2002) by allowing productivity draws to be correlated with each other. This extension leads to a generalized extreme value import demand system featured with a complicated structure of trade elasticities. Boehm, Levchenko, and Pandalai-Nayar (2020) consider differential trade elasticities in the long and short run. Fontagne, Martin, and Orefice (2018) consider differential elasticities of firm exports to export price, tariff, and real exchange rate shocks. Adao, Arkolakis, and Ganapati (2020) propose a semi-parametric estimator for trade elasticities, finding that trade elasticities vary substantially across country pairs. Our work contributes to this literature by considering a specific structure of trade elasticities generated by the nested-CES preference, estimating these elasticities in a transparent way, and quantifying their welfare implications.

This paper also relates to the theoretical explorations of tariffs and tariff wars. Bagwell and Staiger (1999) emphasize the terms-of-trade effect of trade agreements. The model developed by Mosssay and Tabuchi (2014) has shown that third countries would be hurt by the terms-of-trade effect of the preferential trade agreement signed by two countries. Our work contributes to this literature by quantitatively investigating to what extent the third-country effects of trade policies depend on the difference between two Armington elasticities.

Finally, this paper contributes to the recent studies on the impacts of the US-China trade war starting from 2018. Most recent studies focus on the partial equilibrium effects of the Trumpian tariffs on trade, prices, employment, and other economic activities (*e.g.* Amiti, Redding, and Weinstein, 2019; Fajgelbaum et al., 2020; Cavallo, Gopinath, Neiman, and Tang, 2019; Chor and Li, 2021; Cigna, Meinen, Schulte, and Steinhoff, 2022). Few studies (*e.g.* Zhou, 2020) consider general equilibrium effects. Our paper shows that the nested-CES preference and the associated structure of trade elasticities are important to the welfare effects of US-China trade conflicts, in particular on third countries. This paper is also the first attempt to quantify the general equilibrium effects of the US-China trade war under the nested-CES preference.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 estimates the Armington elasticities and evaluates its fit to data. In Section 4, we perform counterfactual exercises to quantify the consequences of the US-China trade war. Section 5 concludes.

2 The Model

In this section, we build a multi-country-multi-sector Armington model with a nested-CES preference *à la* Feenstra et al. (2018). The model also includes input-output linkages to account for the relevance of trade in intermediates. We first describe the model setup and then discuss the implications of Armington elasticities for the impacts of protectionism tariffs.

2.1 Model Setup

There are N countries indexed by i, n, and J sectors indexed by s, j, with each country produces a distinct variety in each sector. Consumer preferences over composite goods from different sectors are Cobb-Douglas with share parameter α_i^j. Within each sector, preferences over varieties from different countries are nested-CES:

$$Q_n^j = \left[\left(q_{nn}^j\right)^{\frac{\sigma-1}{\sigma}} + \left(\sum_{i \neq n} \left(q_{in}^j\right)^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \quad (1)$$

where Q_n^j is the composite good j (or consumption aggregate) in country n, and q_{in}^j is the quantity of the variety produced by country i and consumed in country n. The elasticity of substitution between domestic and foreign varieties is given by σ and ρ is the elasticity of substitution across foreign varieties.[3]

Two type of inputs are used to produce the varieties: labor and composite goods from all sectors. Each country i is endowed with L_i unit of labor, which is inelastically supplied and perfectly mobile across sectors. The production technology is Cobb-Douglas:

$$q_i^j = \frac{1}{\iota_i^j} T_i^j L_i^{j\beta_i^j} \prod_{s=1}^{J} \left(Q_i^{sj}\right)^{\gamma_i^{js}} \tag{2}$$

where T_i^j is the productivity, L_i^j and Q_i^{sj} are labor and composite goods used for production, respectively. The variable ι_i^j is the normalization constant[4] and $\beta_i^j + \sum_{s=1}^{J} \gamma_i^{js} = 1$. The unit input cost to produce variety j in country i therefore:

$$c_i^j = w_i^{\beta_i^j} \prod_{s=1}^{J} \left(P_i^s\right)^{\gamma_i^{js}}, \tag{3}$$

where w_i is the wage rate and P_i^s is the price of the composite good s.

Bilateral trade is subject to the iceberg trade cost t_{in}^j and ad-valorem flat-rate tariff t_{in}^j. Let $\kappa_{in}^j = \left(1 + t_{in}^j\right) \tau_{in}^j$, where $\kappa_{in}^j > 1$ for $i \neq n$ and $\kappa_{nn}^j = 1$. Tariff revenues are assumed to be redistributed equally to the workers of a country.

[3]Notice that Feenstra et al. (2018) also assume that their "macro-elasticities" between domestic and foreign varieties are identical across sectors due to the challenges in identification. The challenges mainly come from the limited variation of tariffs within sector. Moreover, if we allow σ to be sector-specific, the sample for estimation would be too small to get any significant results. In our robustness exercises, we allow (σ, ρ) to vary across groups of sectors.

[4]Specifically, $\iota_i^j = \beta_i^{j\beta_i^j} \prod_{s=1}^{J} \left(\gamma_i^{js}\right)^{\gamma_i^{js}}$.

2.2 Equilibrium

Given the setup, let X_{in}^j be the value of good j exported from country i to n, and X_n^j be the total expenditure of country n on good j. Then country n's share of expenditure on the variety from sector j, country i is given by:

$$\lambda_{in}^j \equiv \frac{X_{in}^j}{X_n^j} = \frac{\left(\kappa_{in}^j c_i^j / T_i^j\right)^{1-\rho}}{\sum_{k\neq n}\left(\kappa_{kn}^j c_k^j / T_k^j\right)^{1-\rho}} \frac{\left[\sum_{k\neq n}\left(\kappa_{kn}^j c_k^j / T_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}}}{\left[\sum_{k\neq n}\left(\kappa_{kn}^j c_k^j / T_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \left(c_n^j / T_n^j\right)^{1-\sigma}}, \quad i \neq n, \tag{4}$$

$$\lambda_{nn}^j \equiv \frac{X_{nn}^j}{X_n^j} = \frac{\left(c_n^j / T_n^j\right)^{1-\sigma}}{\left[\sum_{k\neq n}\left(\kappa_{kn}^j c_k^j / T_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \left(c_n^j / T_n^j\right)^{1-\sigma}}.$$

The price of the composite good j in country n therefore is:

$$P_n^j = \left\{ \left[\sum_{k\neq n}\left(\kappa_{kn}^j c_k^j / T_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \left(c_n^j / T_n^j\right)^{1-\sigma} \right\}^{\frac{1}{1-\sigma}}. \tag{5}$$

Total revenue in each location equals total expenditure on goods produced in that location for both consumption and intermediate usage. Thus:

$$X_i^j = \alpha_i^j Y_i + \sum_{s=1}^{J} \gamma_i^{sj} \sum_{n=1}^{N} \frac{\lambda_{in}^s X_n^s}{1+t_{in}^s}, \tag{6}$$

where $Y_i = w_i L_i + \sum_{j=1}^{J}\sum_{k=1}^{N} \frac{t_{ki}^j}{1+t_{ki}^j}\lambda_{ki}^j X_i^j$ is the national income of country i. Finally, labor market clearing implies:

$$w_i L_i = \sum_{j=1}^{J} \beta_i^j \sum_{n=1}^{N} \frac{\lambda_{in}^j X_n^j}{1+t_{in}^j}. \tag{7}$$

We have completed the characterization of the equilibrium.

Equilibrium Given T_i^j, τ_{in}^j and t_{in}^j, an equilibrium is a wage vector $\{w_i\}_{i\in N}$, output levels

$\{X_i^j\}_{i\in N, j\in J}$ and goods price $\{P_i^j\}_{i\in N, j\in J}$ that satisfy equilibrium conditions (7), (6), and (5) for all i, j.

How would the equilibrium change when tariffs change? We proceed as in Dekle, Eaton, and Kortum (2008) and solve the equilibrium in relative changes. Using the $\hat{x} = x'/x$ notation, where x' is the value of x in the new equilibrium and x is the initial value, the expenditure share (4) and the equilibrium equation system (7), (6), and (5) can be rewritten as follows:

$$\hat{\lambda}_{in}^j = \frac{\left(\hat{\kappa}_{in}^j \hat{c}_i^j / \hat{T}_i^j\right)^{1-\rho}}{\sum_{k\neq n} \psi_{kn}^j \left(\hat{\kappa}_{kn}^j \hat{c}_k^j / \hat{T}_k^j\right)^{1-\rho}} \frac{\left[\sum_{k\neq n} \psi_{kn}^j \left(\hat{\kappa}_{kn}^j \hat{c}_k^j / \hat{T}_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}}}{\left(1-\lambda_{nn}^j\right)\left[\sum_{k\neq n} \psi_{kn}^j \left(\hat{\kappa}_{kn}^j \hat{c}_k^j / \hat{T}_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \lambda_{nn}^j \left(\hat{c}_n^j / \hat{T}_n^j\right)^{1-\sigma}}, \quad i \neq n,$$

$$\hat{\lambda}_{nn}^j = \frac{\left(\hat{c}_n^j / \hat{T}_n^j\right)^{1-\sigma}}{\left(1-\lambda_{nn}^j\right)\left[\sum_{k\neq n} \psi_{kn}^j \left(\hat{\kappa}_{kn}^j \hat{c}_k^j / \hat{T}_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \lambda_{nn}^j \left(\hat{c}_n^j / \hat{T}_n^j\right)^{1-\sigma}}; \tag{8}$$

$$\hat{P}_n^j = \left\{\left(1-\lambda_{nn}^j\right)\left[\sum_{k\neq n} \psi_{kn}^j \left(\hat{\kappa}_{kn}^j \hat{c}_k^j\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \lambda_{nn}^j \left(\hat{c}_n^j\right)^{1-\sigma}\right\}^{\frac{1}{1-\sigma}}; \tag{9}$$

$$\hat{X}_i^j X_i^j = \alpha_i^j \hat{Y}_i Y_i + \sum_{s=1}^{J} \gamma_i^{sj} \sum_{n=1}^{N} \frac{\hat{\lambda}_{in}^s \hat{X}_n^s \lambda_{in}^s X_n^s}{\widehat{1+t_{in}^s}\left(1+t_{in}^s\right)}; \tag{10}$$

$$\hat{Y}_i Y_i = \hat{w}_i w_i L_i + \sum_{j=1}^{J} \sum_{k=1}^{N} \frac{\left(t_{ki}^j\right)'}{\widehat{1+t_{ki}^j}\left(1+t_{ki}^j\right)} \hat{\lambda}_{ki}^j \hat{X}_i^j \lambda_{ki}^j X_i^j; \tag{11}$$

$$\hat{w}_i w_i L_i = \sum_{j=1}^{J} \beta_i^j \sum_{n=1}^{N} \frac{\hat{\lambda}_{in}^j \lambda_{in}^j \hat{X}_n^j X_n^j}{\widehat{1+t_{in}^j}\left(1+t_{in}^j\right)}, \tag{12}$$

where $\psi_{in}^j \equiv \frac{\left(\kappa_{in}^j c_i^j / T_i^j\right)^{1-\rho}}{\sum_{k\neq n}\left(\kappa_{kn}^j c_k^j / T_k^j\right)^{1-\rho}}$ and $\hat{c}_i^j \equiv \hat{w}_i^{\beta_i^j} \prod_{s=1}^{J} \left(\hat{P}_i^s\right)^{\gamma_i^{js}}$. The relative change in welfare of the representative consumer in country i is given by

$$\frac{\hat{w}_n}{\hat{P}_n} = \prod_{j=1}^{J} \left(\hat{\lambda}_{nn}^j\right)^{-\frac{1}{\sigma-1}\frac{\alpha_n^j}{\beta_n^j}} \prod_{s=1}^{J} \left(\frac{\hat{P}_n^s}{\hat{P}_n^j}\right)^{-\alpha_n^j \frac{\gamma_n^{js}}{\beta_n^j}}, \tag{13}$$

which share the same formula as standard models with a uniform elasticity of substitution across all varieties (Arkolakis et al., 2012).

2.3 Third-Country Effects of Tariffs: An Illustrative Example

The equation (13) suggests that the welfare effects of trade shocks are independent of ρ conditional on $\hat{\lambda}^j_{nn}$ and $\hat{P}^j_n$. However, $\hat{\lambda}^j_{nn}$ and $\hat{P}^j_n$ themselves are directly affected by ρ in response to tariff changes. Before turning to quantification using the full model in Section 4, it is instructive to provide a qualiative discussion of how the effects of protective tariffs depend on the elasticity of substitution among foreign varieties.

To this end, consider an illustrative example of our model: there are three identical countries, with $T_i = L_i = \tau_{in} = 1$ for all i, n, and one sector without intermediate inputs. Without loss of generality, one can think the country 1 as the North, the country 2 as the South, and the country 3 as the rest of the world. With a unilateral protectionism tariff imposed by the North on its imports from the South, *i.e.* an increase in t_{21}, we have the following results:

Proposition 1 (Third-country effects of a unilateral protectionism tariff) *Suppose that $\rho \geq \sigma > 1$. In the three-country world described above, the first-order welfare effects of t_{21} are*

$$\begin{aligned} \frac{\partial \log W_1}{\partial \log(1+t_{21})} &= \frac{1}{9}\left(1 - \frac{\rho-\sigma}{\rho+\sigma}\right) > 0 \\ \frac{\partial \log W_2}{\partial \log(1+t_{21})} &= -\frac{2}{9} - \frac{1}{9}\frac{\rho-\sigma}{\rho+\sigma} < 0 \\ \frac{\partial \log W_3}{\partial \log(1+t_{21})} &= \frac{1}{9} + \frac{2}{9}\frac{\rho-\sigma}{\rho+\sigma} > 0 \end{aligned} \tag{14}$$

Moreover, the welfare gain for country 3 from trade war increases with ρ:

$$\frac{\partial^2 \log W_3}{\partial \log(1+t_{21})\,\partial\rho} > 0. \tag{15}$$

And

$$\frac{\partial^2 \log W_1}{\partial \log(1+t_{21})\,\partial\rho} < 0, \quad \frac{\partial^2 \log W_2}{\partial \log(1+t_{21})\,\partial\rho} < 0. \tag{16}$$

Proposition 1 shows that the rest of the world will benefit from an increase in t_{21} if $\rho \geq \sigma$. More importantly, this welfare benefit increases as ρ increases. Intuitively, as ρ increases, goods from the South and the rest of the world become more similar in the eyes of Northern consumers. Therefore, an increase in t_{21} would lead to a greater trade diversion and thus a greater welfare gain to the rest of the world. This third-country effect tends to reduce the welfare gains the North derives from the increase in t_{21}. In other words, as ρ becomes larger, the North has less incentive to raise t_{21}, since trade protection mainly shifts demand to the rest of the world. In the extreme case where $\rho \to \infty$, i.e., when foreign varieties are perfect substitutes, the gains from raising tariffs become zero, as suggested by the first equation of (14).

The last point is further illustrated in Figure 1, where we characterize the incentives of countries to initiate tariff wars by numerically computing the Nash tariffs between the North and South. We fix $\sigma = 4$ and solve the Nash tariffs under different values of ρ. Intuitively, as ρ increases, the Nash tariff rate decreases. Because trade wars are more likely to shift demand to the rest of the world when ρ is high, this effectively reduces the incentives for the two countries to initiate local trade wars.

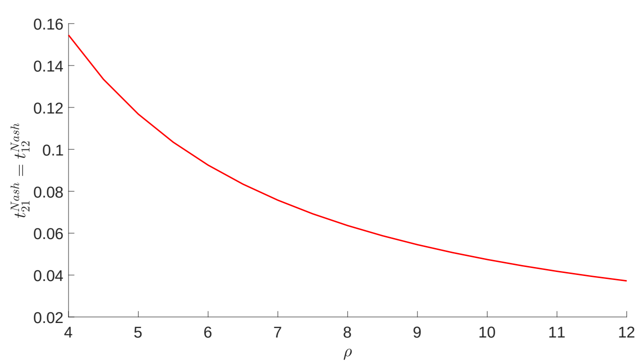


Figure 1: Nash Tariff Rates w.r.t. ρ: A Three-country Example

3 Estimation

To quantify the impact of the US-China trade war, the data needed are tariff changes, cost and consumption shares, beginning-of-period X_{in}^{j}, and the Armington elasticities ρ and σ. All variables, except for ρ and σ, can be directly observed from the data. In this section, we show how to utilize the structural of the model to estimate these two key elasticities in a two-stage gravity-based framework. In particular, in the first stage, we estimate ρ using the relationship between changes in bilateral trade flows and changes in bilateral tariffs. In the second stage, we estimate σ using the relationship between the changes in average import tariffs and the changes in domestic production shares, utilizing the fixed effects estimated in the first stage.

The dataset used to calibrate the share parameters, trade flows, and domestic production is the World Input-Output Database (WIOD). We use a sales-weighted average of HS6-level MFN applied tariffs from the TRAINS database to calculate tariff changes for each of the 22 tradable sectors in WIOD. The final dataset consists of 44 economies and 56 sectors from 2002 to 2014.[5] We use the same dataset to estimate ρ and σ. The estimation procedures are described below.

3.1 Stage I: Estimating ρ

The identification of ρ relies on the structural relationship between changes in bilateral trade flows and changes in bilateral tariffs given by equation (8). Taking the logarithm of equation (8) for $i \neq n$, we obtain:

$$\Delta \log \left(\lambda_{in}^{j} \right) = (1-\rho)\, \Delta \log \left(1 + t_{in}^{j} \right) + D_{i}^{j} + \mathcal{D}_{n}^{j} + \epsilon_{in}^{j}. \tag{17}$$

[5] The economies include Australia, Austria, Belgium, Bulgaria, Brazil, Canada, Switzerland, China, Cyprus, Czech, Germany, Denmark, Spain, Estonia, Finland, France, the United Kingdom, Greece, Croatia, Hungary, Indonesia, India, Ireland, Italy, Japan, Korea, Lithuania, Luxembourg, Latvia, Mexico, Malta, the Netherlands, Norway, Poland, Portugual, Romania, Russia, Slovakia, Slovenia, Sweden, Turkey, Taiwan, the United States, and the rest of the world. Sectors include the agriculture sector, 21 manufacturing sectors, and 34 service sectors. The list of sectors is reported in the Appendix.

where D_i^j and $\mathcal{D}_n^j$ capture the exporter-sector and importer-sector specific component of the equation, respectively. We assume changes in bilateral iceberg trade costs, like in Fajgelbaum et al. (2020), are orthogonal to changes in t_{in}^j and hence are summarized by ϵ_{in}^j.

We use 10-year long-difference data between 2003 and 2013 for our estimation because tariffs in most countries do not change much in the short run, and we want to consider (ρ, σ) in our model as the long-term Armington elasticity.[6] We estimate equation (17) using OLS and the result is reported in Table 1. We obtain an R-squared of 0.437 and an estimate of the trade elasticity, $1 - \rho$, of -3.127, significant at 1% level. The estimate suggests that the elasticity of substitution across foreign varieties, ρ, is 4.127. Our estimate of ρ is in line with the literature: Feenstra et al. (2018) obtain medium estimate of ρ of 3.22 (TSLS) and of 4.05 (two-step GMM). The benchmark estimate of the trade elasticity in Simonovska and Waugh (2014) is -4.14, implying that $\rho = 5.14$. The estimate of the aggregate trade elasticity in Caliendo and Parro (2015) is 4.55, implying that $\rho = 5.55$.

Table 1: Baseline Estimate of $1 - \rho$

	Dependent variable: $\Delta \log \left(\lambda_{in}^j\right)$
$\Delta \log \left(1 + t_{in}^j\right)$	-3.127^{***}
	(.834)
Importer-sector FEs	✓
Exporter-sector FEs	✓
R-squared	.437
Observations	13,075

Notes: We use the time difference between 2003 and 2013. The standard errors are clustered at the exporter-importer level. We drop the following sectors that have extreme dispersions of tariff changes: agriculture, forestry, fishing, food and tobacco, and motor vehicle.

[6] Imbs and Mejean (2015) has pointed out that estimates on trade elasticities using pooled or aggregated data tend to be biased toward 0 due to the covariance between sectoral trade elasticities and sectoral tariff dispersion. Therefore, to conduct our regression using pooled samples of tradable sectors, we exclude the following sectors that have extreme dispersions of tariff changes: agriculture, forestry, fishing, food and tobacco, and motor vehicle. The dispersions of tariff changes are reported in Appendix Table B5.

3.2 Stage II: Estimating σ

The elasticity of subtitution between domestic and foreign varieties, σ, cannot be estimated directly from the logarithm of the equation (8) for all $i = n$, because countries do not impose tariffs on their own varieties. However, we can identify σ from changes in domestic production shares and changes in tariffs based on the following fact: *a country with a higher average import tariff tends to have a higher share of domestic products in its total expenditure*.

First, notice that estimating the equation (17) yields that, for $i \neq n$:

$$\hat{\kappa}_{in}^{j} = \exp\left[\Delta \log\left(1 + t_{in}^{j}\right) + \frac{\epsilon_{in}^{j}}{1-\rho}\right]. \tag{18}$$

From equation (8), we know that the importer-sector fixed effect in equation (17) is given by:

$$\exp(\mathcal{D}_{n}^{j}) = \frac{\left[\sum_{k\neq n} \psi_{kn}^{j}\left(\hat{\kappa}_{kn}^{j}\hat{c}_{k}^{j}/\hat{T}_{k}^{j}\right)^{1-\rho}\right]^{\frac{\rho-\sigma}{1-\rho}}}{\left(1-\lambda_{nn}^{j}\right)\left[\sum_{k\neq n} \psi_{kn}^{j}\left(\hat{\kappa}_{kn}^{j}\hat{c}_{k}^{j}/\hat{T}_{k}^{j}\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \lambda_{nn}^{j}\left(\hat{c}_{n}^{j}/\hat{T}_{n}^{j}\right)^{1-\sigma}}. \tag{19}$$

While the exporter-sector fixed effect equals:

$$\exp(D_{i}^{j}) = \left(\hat{c}_{i}^{j}/\hat{T}_{i}^{j}\right)^{1-\rho}. \tag{20}$$

Combining the expression of $\hat{\lambda}_{nn}^{j}$ in (8), we can simplify equation (19) as:

$$\exp(\mathcal{D}_{n}^{j}) = \frac{\hat{\lambda}_{nn}^{j}\left[\sum_{k\neq n} \psi_{in}^{j}\left(\hat{\kappa}_{kn}^{j}\right)^{1-\rho}\exp\left(D_{k}^{j}\right)\right]^{\frac{\rho-\sigma}{1-\rho}}}{\exp(D_{n}^{j})^{\frac{1-\sigma}{1-\rho}}}. \tag{21}$$

Write the above expression in logs and rearrange terms, we obtain:

$$\underbrace{(\rho-1)\Delta log\hat{\lambda}^j_{nn} - (\rho-1)\mathcal{D}^j_n - \rho\log\left[\sum_{k\neq n}\psi^j_{in}\left(\hat{\kappa}^j_{kn}\right)^{1-\rho}\exp\left(D^j_k\right)\right] + D^j_n}_{\text{Augmented Changes in Domestic Expenditure Share, } \mathcal{Y}^j_n} \tag{22}$$
$$= \sigma\underbrace{\left\{D^j_n - \log\left[\sum_{k\neq n}\psi^j_{in}\left(\hat{\kappa}^j_{kn}\right)^{1-\rho}\exp\left(D^j_k\right)\right]\right\}}_{\Psi^j_n} + \varepsilon^j_n,$$

where ϵ^j_n is the measurement error. The right hand side of equation (22) can be viewed as an augmented expression of changes in domestic expenditure share, while Ψ^j_n in the left hand side of equation (22) is inversely correlated with the country n's protection levels. Intuitively, the term $\left[\sum_{k\neq n}\psi^j_{in}\left(\hat{\kappa}^j_{kn}\right)^{1-\rho}\exp\left(D^j_k\right)\right]$ in Ψ^j_n can be viewed as a weighted average change in import tariffs faced by the representative consumer in country n. Higher the tariff increase (hence the greater $\hat{\kappa}^j_{kn}$), greater the expenditure share on domestic varieties.

Backing out $\mathcal{Y}^j_n$ and Ψ^j_n from the first stage, we estimate equation (22) using OLS. We also include country and sector fixed effects to control for potential country- or sector-specific confounders. We obtain an R-squared of 0.407 and an estimate of the elasticity of substitution between domestic and foreign varieties σ of 2.237, which is significant at 1% level and is reported in Table 2. Compared to the estimates of $1-\rho$ in Table 1, our baseline estimate of σ is almost halved, suggesting that the elasticity of substitution between domestic and foreign varieties is much lower than the elasticity of substitution between alternative foreign varieties.

The novel part of our strategy for identifying σ is that we make full use of the structural gravity equation derived from our Armington model with nested-CES preferences. By exploiting the estimates of importer-sector- and exporter-sector-fixed effects, we identify σ from the linkage between changes in domestic expenditure share and average changes in import tariffs. Unlike Feenstra et al. (2018) and Fajgelbaum et al. (2020), this

Table 2: Baseline Estimate of σ

	Dependent Variable: $\mathcal{Y}_n^j$
Ψ_n^j	2.327***
	(.329)
Sector FEs	✓
Country FEs	✓
R-squared	.407
Observations	555

Notes: We use the time difference between 2003 and 2013. The definitions of "Augmented Changes in Domestic Expenditure Share" and "Weighted Average of Changes in Import Tariffs" are given by equation (22). We drop the following sectors that have extreme dispersions of tariff changes: agriculture, forestry, fishing, food and tobacco, and motor vehicle.

identification strategy does not require data on domestic prices, which is only available in very few developed countries. Our novel two-stage gravity-based framework allows us to estimate Armington elasticities (ρ, σ) using data on bilateral trade flows, tariffs, and domestic production, which is available in several commonly used databases (*e.g.* the combination of WIOD and TRAINS) and and is exactly identical with the data used for our counterfactual analysis.

3.3 Robustness

In this subsection, we conduct several robustness checks for our estimates on (ρ, σ). First, we use data between 2005 and 2014 instead to estimate (ρ, σ), probing whether $\rho > \sigma$ holds for different sample periods. Using the two-stage gravity-based framework, we find that $\rho = 4.592$ and $\sigma = 2.696$, both are statistically significant at 1% level. These results are reported in Table B1 and Table B2 in Appendix B.1, and is close with our baseline estimates in Table 1 and 2, confirming that $\rho > \sigma$.

Second, we instead estimate (ρ, σ) using the gravity equations in levels. Similar to the baseline case, this alternative estimation method identifies σ from the link between the domestic production share and the average tariff. To perform the estimation, we use the gravity controls such as physical distance, contiguity, and common language to proxy the *level* of trade costs. We estimate (ρ, σ) year by year, from 2002 to 2014. All estimates are bare in broad agreement with our baseline results and suggest that $\rho > \sigma$. The detailed results are reported in Appendix B.2.

Table 3: Heterogeneous $1 - \rho$

	Dependent variable: $\Delta \log \left(\lambda_{in}^{j}\right)$	
	Low-elasticity	High-elasticity
$\Delta \log \left(1 + t_{in}^{j}\right)$	-2.007^{*}	-7.942^{***}
	(1.058)	(1.356)
Importer-sector FEs	✓	✓
Exporter-sector FEs	✓	✓
R-squared	.490	.454
Observations	5,768	4,972

Notes: We use the time difference between 2003 and 2013. The "high-elasticity" group includes mining, textile and leather, paper, basic metals, metal product, and other machinery. The "low-elasticity" includes includes wood, print, chemical, non-metallic mineral, electronic and optical, other transport equipment, and other manufacturing.

Finally, we check whether our estimates are robust to sector-specific Armington elasticities. The challenge to estimate the sector-specific elasticities, *i.e.* $\left(\rho_j, \sigma_j\right)_{j=1}^{J}$, is the lack of variation as sectors are very aggregated in WIOD data. To address this issue, we split sectors in our sample into "low-elasticity" and "high-elasticity" groups, based on the estimates of trade elasticities in Broda and Weinstein (2006) and Caliendo and Parro (2015).[7] We assume that $\left(\rho_j, \sigma_j\right)$ are identical within each group. Doing so, we allow (ρ, σ) to vary across sectors and preserve sufficient variations of tariff changes.

The estimation results in Table 3 suggest that the "low-elasticity" group has $\rho = 3.007$ and the "high-elasticity" group has $\rho = 8.942$. And the results in table 4 show that the "low-elasticity" group has $\sigma = 2.033$ and the "high-elasticity" group has $\sigma = 4.467$. Not only does $\sigma < \rho$ hold for each group, but in both cases the elasticity of substitution between domestic and foreign varieties is about half of the elasticity of substitution between foreign varieties (consistent with the baseline), confirming the robustness of our results.

[7] The "high-elasticity" group includes mining, textile and leather, paper, basic metals, metal product, and other machinery. The "low-elasticity" includes includes wood, print, chemical, non-metallic mineral, electronic and optical, other transport equipment, and other manufacturing.

Table 4: Heterogeneous σ

	Dependent Variable: $\mathcal{Y}_n^j$	
	Low-elasticity	High-elasticity
Ψ_n^j	2.033***	4.467***
	(.112)	(1.390)
Sector FEs	✓	✓
Country FEs	✓	✓
R-squared	.632	.254
Observations	243	209

Notes: We use the data between 2003 and 2013. The "high-elasticity" group includes mining, textile and leather, paper, basic metals, metal product, and other machinery. The "low-elasticity" includes includes wood, print, chemical, non-metallic mineral, electronic and optical, other transport equipment, and other manufacturing.

3.4 Model's Fit

In a standard model with uniform elasticity, equation (17) is sufficient for estimation. In this case, one will bring the model to data with $\sigma = \rho = 4.127$. How well does our model fit the data, especially compared to the standard case? In this subsection, we evaluate the fit of the model and compared it with the fit of a standard model with uniform elasticity.

Notice that the trade shares, λ_{in}, is observable over time. To assess the model's fit, we can recover exogenous shocks that lead to changes in λ_{in}, inserting these shocks into the model, computing the *model-predicted* post-shock λ_{in} and comparing them with the data.

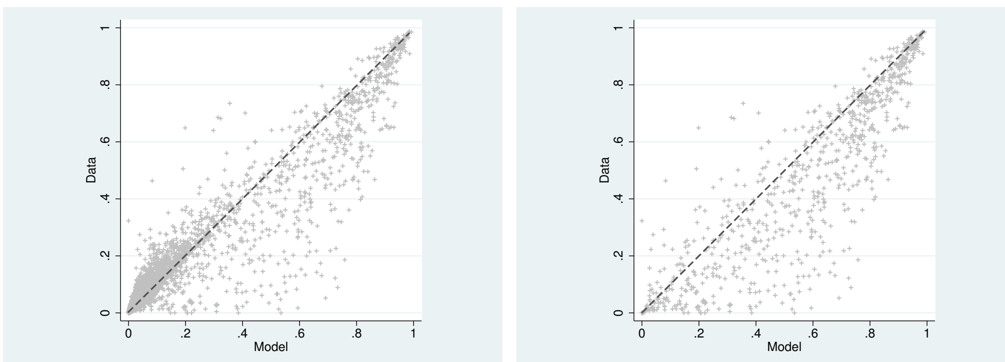
Specifically, according to equation (4), $\hat{\lambda}_{in}$ are driven by exogenous shocks $\{\widehat{1+t_{in}^j}, \hat{\tau}_{in}^j, \hat{T}_i^j\}$. We obtain $\widehat{1+t_{in}^j}$ from 2003 to 2013 directly from the data. According to equation (17), $\hat{\kappa}_{in}^j$ can be computed by

$$\hat{\kappa}_{in}^j = \exp\left[\frac{\log \hat{\lambda}_{in}^j - D_i^j - \mathcal{D}_i^j}{1-\rho}\right], \tag{23}$$

then we obtain $\hat{\tau}_{in}^j = \hat{\kappa}_{in}^j / \widehat{1+t_{in}^j}$. Finally, we recover $\hat{T}_i^j$ from the exporter-fixed effects. Notice that

$$\exp\left(D_i^j\right) = \left(\frac{\hat{c}_i^j}{\hat{T}_i^j}\right)^{1-\rho} \Rightarrow \hat{T}_i^j = \frac{\hat{c}_i^j}{\exp\left(D_i^j\right)^{\frac{1}{1-\rho}}}. \tag{24}$$

We compute $\left(\hat{T}_i^j\right)$ as follows. First, we get initial guesses for $\left(\hat{T}_i^j\right)$. Then we compute $\hat{c}_i^j$ by solving equation (9), (10), and (12). Then, with $\left(D_i^j\right)$ in hand, we update $\left(\hat{T}_i^j\right)$ by equation (24). We iterate until the input values of $\left(\hat{T}_i^j\right)$ are equal to the updated values. Armed with $\{\hat{\tau}_{in}^j, \widehat{1+t_{in}^j}, \hat{T}_i^j\}$, we then calibrate the model to the initial year 2003, compute the model-predicted change in λ_{in}^j over the 2003-2013 period, and obtain the simulated trade shares (i.e., λ_{in}^j) in 2013. Notice that we take trade shares in 2003 directly from the data to conduct the "exact-hat" algebra. Therefore, the simulated trade shares in 2013 can be used to evaluate the model's fit to changes in trade shares between 2003 and 2013.



(a) All (i, n) (b) $i = n$

Figure 2: $\{\lambda_{in}^j\}$ in 2013: Data vs. Model Simulations

Note: The 45-degree reference line is plotted.

Figure 2 plots simulated trade shares (i.e., λ_{in}^j) from our baseline model against those of data in 2013. Panel (a) include all sector and country pairs while panel (b) focus on the

Table 5: Model's Fit to Trade Shares in 2013

	Dependent Variable: λ_{in}^j in Data			
	All (i, n)		$i = n$	
	$\rho > \sigma$	$\rho = \sigma$	$\rho > \sigma$	$\rho = \sigma$
λ_{in}^j in Model	.871***	.815***	.921***	.810***
	(.007)	(.009)	(.014)	(.018)
R-squared	.923	.881	.777	.651
Observations	34848	34848	792	792

case where $n = i$. The model fits the actual trade shares tightly. This is not surprising: gravity models have been shown to fit bilateral trade shares well. What is more important is that the baseline model with $\rho = 4.127$ and $\sigma = 2.237$, fits the data better than the standard Armington model with uniform elasticity (i.e., $\rho = \sigma = 4.127$).[8] As shown in Table 5, when regress observed λ_{in}^{j} on simulated λ_{in}^{j} from our baseline model (i.e., $\rho > \sigma$), the point estimator is closer to 1 and with a greater R-square compared to that from the uniform elasticity model (R-squared = 0.923 vs. 0.881). For the observations $i = n$, the baseline model fits the data even better – the point estimate is as high as 0.921. Intuitively, by imposing $\rho = \sigma$, the standard Armington model tends to overestimate σ and thus the change in $\{\lambda_{in}^{j}\}$, especially for $i = n$.

4 The Welfare Effects of the US-China Trade War

Armed with the estimated elasticities, we quantify the impacts of the US-China trade war starting from 2018, highlighting the implications of $\rho > \sigma$. First, we solve for the welfare changes under the protectionism tariffs imposed by the Trump administration on imports from China and China's retaliation tariffs. We compare the results in our baseline model with ones in the standard model where $\sigma = \rho$. Second, we consider a noncooperative tariff game between the U.S. and China and compute the Nash tariffs.

4.1 Consequences of the US-China Trade War starting from 2018

The official "Section 301" report was issued on April 3, 2018, which marked the start of tariff war and retaliations between the two largest countries in the world. Since then, there have been altogether five waves of protectionism tariffs implemented by the Trump administration, on July and August 2018, September 2018, May 2019, September 2019,

[8] To evaluate the fit of the standard Armington model with $\rho = \sigma = 4.127$, we re-compute $\left(\hat{T}_i^j\right)$ using the standard model.

and December 2019, respectively. Adopting a "tic-for-tat" strategy, China's retaliation immediately followed each wave of the U.S. tariffs.

We conduct our counterfactual exercises as follows. First, we get ρ, σ from our baseline estimates, λ^j_{in}, X^j_n from the WIOD for 2014 (the last year in WIOD), t^j_{in} from the TRAINS database for 2017 (the last year before the US-China trade war). Then, we set $t^{j'}_{in}$ at their levels on December 2019, after the last-wave of protectionism tariffs imposed by the Trump administration and the corresponding retaliation from China. These tariff rates, by sector and for both the U.S. and China, before and after the trade war, are reported in Table 6. The Trumpian tariffs are substantial in most of the sectors, increasing from less than 5% before 2018 to greater than 20% at the end of 2019. China immediately levied sizable retaliatory tariffs on imports from the U.S., concentrating on the agricultural sectors.

Table 6: The US-China Tariff War starting from 2018

Sector	WIOD code	US Tariff on Chinese Goods		Chinese Tariff on U.S. Goods	
		Pre-war	Trumpian	Pre-war	Retaliation
Agriculture	A01	.030	.237	.113	.365
Forestry	A02	.007	.214	.094	.347
Fishing	A03	.005	.223	.081	.323
Mining	B	.003	.099	.016	.147
Food and Tobacco	C10-C12	.111	.332	.164	.344
Textile and Leather	C13-C15	.089	.154	.125	.235
Wood	C16	.022	.223	.049	.283
Paper	C17	.000	.236	.056	.256
Print	C18	.001	.175	.037	.105
Petroleum	C19	.009	.186	.049	.272
Chemical	C20	.032	.182	.063	.213
Pharmaceutical	C21	.032	.040	.063	.050
Rubber and Plastic	C22	.033	.213	.100	.164
Non-metallic mineral	C23	.034	.222	.116	.192
Basic metals	C24	.014	.223	.052	.135
Metal product	C25	.025	.319	.104	.192
Electronic and Optical	C26	.018	.208	.066	.232
Electrical	C27	.020	.247	.080	.201
Machinery n.e.c.	C28	.013	.217	.086	.229
Motor vehicle	C29	.025	.258	.135	.220
Other transport equipment	C30	.019	.249	.078	.076
Other manufacturing	C31-C32	.028	.225	.141	.242

We consider the counterfactual welfare changes across countries in three scenarios: (i) unilateral protectionist tariffs imposed by the Trump administration, (ii) Trump tariffs and Chinese retaliation, and (iii) US-China trade decoupling, i.e., the case where the cost of trade between the U.S. and China reaches infinity. In each case, we use both our baseline model where $\rho = 4.127$ and $\sigma = 2.327$, as well as the standard model where $\rho = \sigma = 4.127$, to calculate the welfare change.

Table 7 reports the results. Columns (1) and (2) show that the unilateral protectionist tariffs imposed by the Trump administration do bring a small welfare gain to the United States (0.004%), but the standard model with $\rho = \sigma$ greatly overestimates this gain (0.016%). With $\rho > \sigma$, instead of bringing consumer demand back to the U.S., Trump's tariffs on imports from China shift demand to third countries such as Canada and Mexico.

Column (3) of table 7 shows that with China's retaliation, the trade war between China and the United States resulted in considerable welfare losses for China (-0.155%) and the United States (-0.033%). At the same time, the tariff war between the two largest countries in the world also benefited other economies, with real income increasing by 0.046% in Canada, 0.217% in Mexico, 0.029% in Japan, and 0.037% in South Korea. This is mainly due to trade diversion, which can be seen in the blue bars of the figure 3, where we present changes in the US imports under scenario (ii) for major economies.

Comparing the results in column (4) with those in column (3), we find that imposing $\rho = \sigma$ substantially underestimates the impact of the US-China trade war on third countries. In this case, as shown in column (4), Canada's real income increases by only 0.005% (contrary to 0.046% in the baseline case), while Mexico's increases by only 0.106% (contrary to 0.217% in the baseline). The standard model suggests that Taiwan would lose from a trade war with the US (-0.010%), while our baseline model suggests a positive welfare effect for Taiwan (0.035%). Figure 3 presents the predicted changes in U.S. imports of the baseline model and the standard model with uniform elasticity in blue and yellow bars, respectively. As can be seen from figure 3, the imposition of $\rho = \sigma$ results in a significant underestimation of the trade diversion due to the US-China trade war.

Table 7: Welfare Effects of the US-China Trade War

%Δ in Welfare:	Trumpian Tariff		US-China Trade War		US-China Trade Decoupling	
	$\rho > \sigma$	$\rho = \sigma$	$\rho > \sigma$	$\rho = \sigma$	$\rho > \sigma$	$\rho = \sigma$
	(1)	(2)	(3)	(4)	(5)	(6)
United States	.004	.016	-.033	-.013	-.510	-.402
China	-.149	-.122	-.155	-.122	-.552	-.437
Australia	-.010	-.015	-.004	-.010	-.001	-.018
Austria	.007	.002	.009	.002	.026	.008
Belgium	-.006	-.009	.001	-.006	.023	-.006
Bulgaria	.004	.004	.004	.003	.008	.006
Brazil	.005	-.003	.015	-.001	.042	.001
Canada	.032	.005	.046	.005	.167	.023
Switzerland	.002	.001	.003	.001	.018	.006
Cyprus	.008	.006	.003	.004	-.004	.006
Czech	.027	.019	.024	.014	.062	.031
Germany	.014	.001	.022	.002	.083	.012
Denmark	.006	.000	.008	.001	.033	.007
Spain	.010	.007	.009	.005	.020	.010
Estonia	.027	.022	.023	.016	.057	.035
Finland	.018	.007	.023	.007	.065	.019
France	.002	-.002	.005	-.001	.038	.003
United Kingdom	.008	.004	.008	.003	.026	.006
Greece	.002	.002	.002	.001	.003	.003
Croatia	.004	.002	.004	.002	.009	.006
Hungary	.030	.021	.029	.017	.083	.039
Indonesia	.024	.011	.026	.009	.078	.029
India	.015	.008	.014	.006	.039	.016
Ireland	-.031	-.040	-.004	-.025	.074	-.022
Italy	.015	.008	.015	.007	.044	.017
Japan	.027	.011	.029	.010	.084	.024
Korea	.024	-.001	.037	.003	.138	.020
Lithuania	.019	.017	.012	.011	.017	.019
Luxembourg	-.079	-.110	-.030	-.064	.029	-.071
Latvia	.007	.005	.006	.004	.011	.007
Mexico	.215	.120	.217	.106	.644	.273
Malta	.002	-.005	.004	-.001	.019	.006
Netherlands	.010	.002	.015	.002	.056	.011
Norway	-.003	-.006	.002	-.004	.014	-.004
Poland	.016	.012	.014	.009	.034	.018
Portugal	.001	.002	.002	.001	.007	.006
Romania	.005	.005	.004	.004	.008	.009
R.O.W.	.021	.000	.032	.002	.119	.020
Russia	.009	.004	.007	.002	.016	.005
Slovakia	.014	.010	.013	.007	.033	.014
Slovenia	.030	.023	.024	.017	.053	.035
Sweden	.010	.003	.014	.003	.049	.012
Turkey	.011	.008	.010	.006	.029	.015
Taiwan	.012	-.021	.035	-.010	.130	-.001

Notes: $\rho > \sigma$ refers to the baseline case in which $\rho = 4.127$ and $\sigma = 2.327$. $\rho = \sigma$ refers to the standard case in which $\rho = \sigma = 4.127$. Trumpian tariff refers to the scenario under the tariffs imposed by President Trump on imports from China on December, 2019. The US-China trade war refers to Trumpian tariff associated with China's retaliation. The US-China trade decoupling refers to the case in which $\tau_{CN,US} = \tau_{US,CN} = \infty$.

In the event of an escalation and eventual decoupling of trade between the U.S. and China, both countries would suffer significant losses in real income: 0.510% for the U.S. and 0.552% for China according to our baseline model. Thus, both countries have an incentive to prevent an escalation of the current trade conflict. Moreover, in a $\rho > \sigma$ scenario, third countries such as Canada, Mexico, and South Korea would gain significantly from decoupling trade between the U.S. and China.

We also quantify the US-China trade war under heterogeneous Armington elasticities, based on the estimates in Table 3 and 4. Table 8 reports the welfare change for selected major economies. Not surprisingly, the main message of the quantification exercises remain robust under heterogeneous Armington elasticities across sectors: imposing a uniform elasticity of substitution across all varieties overestimates the gains from unilateral protectionism tariffs and underestimates the losses to China and the U.S. from a trade war as well as the third-country welfare gains from the US-China trade war.

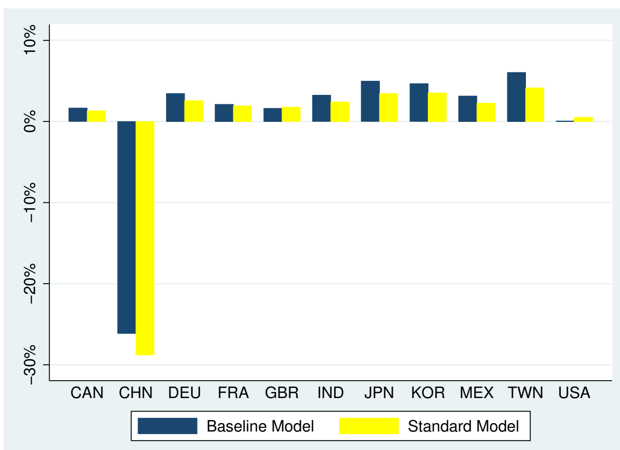


Figure 3: Changes in the US Imports under the US-China Trade War (Selected Economies)

Notes: The baseline model refers to the case in which $\rho = 4.127$ and $\sigma = 2.327$. The standard model refers to the case in which $\rho = \sigma = 4.127$. The US-China trade war refers to Trump tariff associated with China's retaliation.

Table 8: Welfare Effects with Heterogeneous Armington Elasticities (Selected Economies)

%Δ in Welfare:	Trumpian Tariff		US-China Trade War		US-China Trade Decoupling	
	$\rho_j > \sigma_j$	$\rho_j = \sigma_j$	$\rho_j > \sigma_j$	$\rho_j = \sigma_j$	$\rho_j > \sigma_j$	$\rho_j = \sigma_j$
	(1)	(2)	(3)	(4)	(5)	(6)
United States	.006	.015	-.032	-.015	-.608	-.516
China	-.133	-.108	-.138	-.109	-.572	-.479
Canada	.025	.008	.040	.008	.129	.018
Germany	.011	-.001	.022	.002	.065	.007
France	.000	-.002	.004	-.001	.032	.002
United Kingdom	.007	.002	.008	.001	.023	.003
Indonesia	.021	.010	.020	.008	.054	.020
India	.011	.006	.010	.005	.024	.010
Japan	.023	.009	.027	.008	.070	.021
Korea	.018	-.001	.030	.002	.116	.019
Mexico	.153	.087	.157	.074	.482	.204
Taiwan	.012	-.015	.033	-.007	.114	.002

Notes: Trumpian tariff refers to the scenario under the tariffs imposed by President Trump on imports from China on December, 2019. The US-China trade war refers to Trumpian tariff associated with China's retaliation. The US-China trade decoupling refers to the case in which $\tau_{CN,US} = \tau_{US,CN} = \infty$. $\rho_j > \sigma_j$ refers to the Armington elasticities listed in Table B5. $\rho_j = \sigma_j$ refers to the case in which σ_j is set to be equal to ρ_j in Table B5.

4.2 Nash Tariffs between the U.S. and China

Our second set of counterfactual exercises characterizes the noncooperative tariff game between the U.S. and China, aiming to set a benchmark for understanding the trade conflicts between the world's two largest economies. In particular, we solve the Nash equilibrium in which the U.S. (China) optimally sets its tariffs on imports from China (the U.S.). We are interested in the implications of our nested-CES preferences for these noncooperative tariffs.

Table 9 shows that in the Nash equilibrium, the U.S. would impose protectionist tariffs on imports from China ranging from 8.7% to 18.5% (averaged 11.6%). These tariffs are higher than the U.S. pre-trade-war tariffs on the Chinese imports (averaged 2.6%) but lower than the Trumpian tariffs (averaged 21.3%). Similarly, in the Nash equilibrium, China would impose an average tariff of 13.4% on imports from the U.S., which is higher than its pre-trade-war levels (an average of 8.5%), but much lower than China's retaliation tariffs in the US-China trade war (an average of 21.9%).

Table 9: Nash Tariffs between the U.S. and China

Name	Nash Tariffs under $\rho > \sigma$		Nash Tariff under $\rho = \sigma$	
	$t_{\text{CHN,USA}}$	$t_{\text{USA,CHN}}$	$t_{\text{CHN,USA}}$	$t_{\text{USA,CHN}}$
Agriculture	.081	.152	.106	.176
Forestry	.020	.100	.026	.121
Fishing	.013	.090	.017	.101
Mining	.112	.096	.140	.137
Food and Tobacco	.155	.155	.180	.184
Textile and Leather	.121	.147	.122	.178
Wood	.140	.130	.159	.165
Paper	.132	.138	.161	.161
Print	.047	.087	.068	.108
Petroleum	.128	.115	.156	.153
Chemical	.141	.134	.158	.161
Pharmaceutical	.146	.140	.165	.174
Rubber and Plastic	.149	.161	.156	.178
Non-metallic mineral	.145	.135	.153	.149
Basic metals	.124	.122	.138	.162
Metal product	.141	.158	.158	.171
Electronic and Optical	.121	.127	.133	.149
Electrical	.120	.142	.132	.163
Machinery n.e.c.	.125	.154	.147	.171
Motor vehicle	.115	.185	.141	.181
Other transport equipment	.139	.173	.169	.179
Other manufacturing	.127	.109	.154	.131
Simple average	.116	.134	.134	.157

Notes: $\rho > \sigma$ refers to the baseline case in which $\rho = 4.127$ and $\sigma = 2.327$. $\rho = \sigma$ refers to the standard case in which $\rho = \sigma = 4.127$. $t_{\text{CHN,USA}}$ refers to the U.S. tariffs on imports from China. $t_{\text{USA,CHN}}$ refers to China's tariffs on imports from the U.S.

These Nash tariffs are lower than those computed in Ossa (2014) and Lashkaripour (2021) because these papers consider global tariff wars but we consider a local tariff war. Our counterfactual analysis suggests that the current protectionism tariffs imposed by the U.S. and China are higher than their Nash tariffs provided that the rest of the world keeps their tariffs at pre-trade-war levels, suggesting the possibility of future tariff negotiations.

Compared to the baseline case, imposing a uniform elasticity of substitution would result in higher Nash tariffs for both China and the U.S., as suggested in the last two columns of Table 9. While the tariff variation across sectors remain qualitatively similar, they are on average 17% (15%) higher in levels, for the U.S. (China) tariffs imposed on Chinese (U.S.) imports compared to the baseline. Consistent with the three-country example, countries are less likely to impose prohibitive protectionist tariffs when ρ is greater

Table 10: Welfare Effects of Nash Tariffs between the U.S. and China (Selected Economies)

%Δ in Welfare:	Nash Tariffs under $\rho > \sigma$	Nash Tariffs under $\rho = \sigma$
United States	-.001	.005
China	-.087	-.078
Canada	.024	.003
Germany	.013	.001
France	.005	.000
United Kingdom	.005	.002
Indonesia	.013	.006
India	.008	.004
Japan	.017	.006
Korea	.022	.001
Mexico	.121	.069
Taiwan	.018	-.008

Notes: $\rho > \sigma$ refers to the baseline case in which $\rho = 4.127$ and $\sigma = 2.327$. $\rho = \sigma$ refers to the standard case in which $\rho = \sigma = 4.127$. This table reports the changes in welfare from the pre-trade-war tariffs to the Nash tariffs.

than σ because they shift demand primarily to third countries.

Table 10 reports the welfare impact of the Nash tariffs on the U.S. and China, as well as on selected major economies. The welfare loss is -0.001% for the U.S. and -0.087% for China. Other major economies experience a welfare gain. In contrast, in the standard model where $\rho = \sigma$, China has a more moderate welfare loss (-0.078%) and the U.S. even experiences a welfare gain (0.005%). In the case of uniform elasticity, there is less trade diversion and local tariff war between the U.S. and China is less beneficial to the rest of the world, with some countries such as Taiwan even experiencing welfare losses.

4.3 Extension: Economies of Scale

Economies of scale are considered key to understanding the motivation for trade wars (*e.g.* Ossa, 2014). In this subsection, we consider how the results of this paper would change in the presence of economies of scale. In particular, we extend our baseline model to assume that the unit input cost f good j in country i equals $c_i^j \left(L_i^j\right)^{-\eta_j}$ (instead of c_i^j).

We calibrate $\{\eta_j\}$ from Bartelme, Costinot, Donaldson, and Rodriguez-Clare (2019)[9]

[9] The calibrated values of $\{\eta_j\}$ are reported in Table B5.

and re-compute the welfare impacts of the US-China trade war. The results are reported in Table 11. Compared to the results in table 7, allowing economies of scale amplifies the welfare effects of the U.S.-China trade war, thereby amplifying the impact of nested-CES preferences on the welfare calculations. With increasing returns to scale, the demand shifted into third countries further increases demand due to reduction in production costs, leading to larger trade diversion and welfare gains in these countries. As the result, the welfare consequences of local trade wars assessed in a model that allows for different elasticities of substitution between domestic and foreign varieties are more different from those estimated in a model with uniform elasticities.

Table 11: Welfare Effects of the US-China Trade Wars: Sectoral Scale Economies

%Δ in Welfare:	Trumpian Tariff		US-China Trade War		US-China Trade Decoupling	
	$\rho > \sigma$ (1)	$\rho = \sigma$ (2)	$\rho > \sigma$ (3)	$\rho = \sigma$ (4)	$\rho > \sigma$ (5)	$\rho = \sigma$ (6)
United States	.002	.024	-.050	-.021	-.517	-.382
China	-.171	-.141	-.176	-.134	-.576	-.438
Canada	.058	.029	.069	.024	.233	.066
Germany	.016	-.001	.026	.003	.101	.013
France	.003	-.003	.008	.000	.051	.003
United Kingdom	.009	.002	.012	.003	.038	.005
Indonesia	.025	.012	.028	.009	.078	.022
India	.018	.009	.017	.008	.049	.019
Japan	.026	.010	.030	.009	.085	.021
Korea	.021	-.009	.038	-.003	.144	.008
Mexico	.179	.089	.174	.073	.531	.192
Taiwan	.001	-.172	.045	-.117	.171	-.186

Notes: $\rho > \sigma$ refers to the baseline case in which $\rho = 4.127$ and $\sigma = 2.327$. $\rho = \sigma$ refers to the standard case in which $\rho = \sigma = 4.127$. Trumpian tariff refers to the scenario under the tariffs imposed by President Trump on imports from China on December, 2019. The US-China trade war refers to Trumpian tariff associated with China's retaliation. The US-China trade decoupling refers to the case in which $\tau_{CN,US} = \tau_{US,CN} = \infty$.

5 Conclusion

Trade elasticity is one of the most important parameters in trade theories that shape our evaluation of the consequences of trade policies. There is a growing literature that aims to extend the standard quantitative trade models with constant trade elasticity (*e.g.* Eaton and Kortum, 2002; Anderson and van Wincoop, 2003) and to recover the *structure* of trade elasticities from rich macro and micro data. We contribute to this literature by revisiting the Armington model developed by Feenstra et al. (2018) that allows the elasticity of substitution between the domestic and foreign varieties to be different from that between alternative foreign varieties. We analytically characterize the implications of this specific structure of trade elasticities and develop a novel two-stage gravity-based framework to estimate these Armington elasticities, using data on bilateral trade flows, bilateral tariffs, and domestic production.

Our estimates suggest that the elasticity of substitution between alternative foreign varieties is much larger than that between the domestic and foreign varieties. This result is in particular relevant to the recent US-China trade war since it predicts that the protectionism tariffs targeting a particular country, instead of bringing demand, and hence jobs back home, tend to shift demand into third countries. This prediction is consistent with a wide range of observations during the US-China trade war. For example, the *New York Times* reported that "*Researchers at A. T. Kearney said last month that Mr. Trump's trade policies, including tariffs, had pushed factory activity not to the United States but to low-cost Asian countries other than China, like Vietnam*".[10]

In this paper, the micro foundation of the specific structure of trade elasticities is set on the demand side: consumers care about whether a good is domestically produced or imported, but care less about *which country* an imported good comes from. This micro foundation lead to a simple aggregate framework and a transparent gravity system for estimation. However, one can also set up the micro foundation on the supply side. For example, firms may face higher sunk costs when they start importing, but once they do, the fixed costs of adding new sourcing countries are lower. In this case, in the face of Trump's tariffs on Chinese imports, U.S. companies could easily switch to importing from other countries, rather than forgoing imports and turning to domestic sourcing. We leave this mechanism to future investigations.

[10] https://www.nytimes.com/2019/08/13/business/economy/donald-trump-jobs-created.html

References

ADAO, R., C. ARKOLAKIS, AND S. GANAPATI (2020): "Aggregate Implications of Firm Heterogeneity: A Nonparametric Analysis of Monopolistic Competition Trade Models," *NBER working paper*, 95.

AMITI, M., S. J. REDDING, AND D. E. WEINSTEIN (2019): "The Impact of the 2018 Tariffs on Prices and Welfare," *Journal of Economic Perspectives*, 33, 187–210.

ANDERSON, J. E. AND E. VAN WINCOOP (2003): "Gravity with Gravitas: A Solution to the Border Puzzle," *American Economic Review*, 93, 170–192.

ARKOLAKIS, C., A. COSTINOT, AND A. RODRIGUEZ-CLARE (2012): "New Trade Models, Same Old Gains?" *American Economic Review*, 102, 94–130.

BAGWELL, K. AND R. STAIGER (1999): "An Economic Theory of GATT," *American Economic Review*, 89, 215–248.

BARTELME, D., A. COSTINOT, D. DONALDSON, AND A. RODRIGUEZ-CLARE (2019): "The Textbook Case for Industrial Policy: Theory Meets Data," *mimeo*.

BOEHM, C., A. A. LEVCHENKO, AND N. PANDALAI-NAYAR (2020): "The Long and Short (Run) of Trade Elasticities," *mimeo*.

BRODA, C. AND D. WEINSTEIN (2006): "Globalization and the Gains From Variety," *Quarterly Journal of Economics*, 121, 541—-585.

CALIENDO, L. AND F. PARRO (2015): "Estimates of the Trade and Welfare Effects of NAFTA," *Review of Economic Studies*, 82, 1–44.

CAVALLO, A., G. GOPINATH, B. NEIMAN, AND J. TANG (2019): "Tariff Pass-through at the Border and at the Store: Evidence from US Trade Policy," *NBER working paper*.

CHOR, D. AND B. LI (2021): "Illuminating the Effects of the US-China Tariff War on China's Economy," *NBER working paper*.

CIGNA, S., P. MEINEN, P. SCHULTE, AND N. STEINHOFF (2022): "The impact of US tariffs against China on US imports: Evidence for trade diversion?" *Economic Inquiry*, 60, 162–173.

DEKLE, R., J. EATON, AND S. KORTUM (2008): "Global Rebalancing with Gravity: Measuring the Burden of Adjustment," *IMF Staff Papers*, 55, 511–540.

EATON, J. AND S. KORTUM (2002): "Technology, Geography, and Trade," *Econometrica*, 70, 1741–1779.

FAJGELBAUM, P. D., P. K. GOLDBERG, P. J. KENNEDY, AND A. K. KHANDELWAL (2020): "The Return to Protectionism," *Quarterly Journal of Economics*, 135, 1–55.

FEENSTRA, R. C., P. LUCK, M. OBSTFELD, AND K. N. RUSS (2018): "In Search of the Armington Elasticity," *Review of Economics and Statistics*, 100, 135–150.

FONTAGNE, L., P. MARTIN, AND G. OREFICE (2018): "The International Elasticity Puzzle Is Worse Than You Think," *Journal of International Economics*, 115, 115–129.

FREEMAN, R., M. LARCH, A. THEODORAKOPOULOS, AND Y. YOTOV (2021): "Unlocking new methods to estimate country-specific trade costs and trade elasticities," *Bank of England Staff Working Paper*.

HEAD, K. AND T. MAYER (2014): "Gravity Equations: Workhorse,Toolkit, and Cookbook," *Handbook of International Economics*, 4, 131–195.

IMBS, J. AND I. MEJEAN (2015): "Elasticity Optimism," *American Economic Journal: Macroeconomics*, 7, 43–83.

LASHKARIPOUR, A. (2021): "The Cost of a Global Tariff War: A Sufficient Statistics Approach," *Journal of International Economics*.

LIND, N. AND N. RAMONDO (2018): "Trade with Correlation," *NBER working paper*.

Mosssay, P. and T. Tabuchi (2014): “Preferential Trade Agreements Harm Third Countries,” *Economic Journal*, 125, 1964—1985.

Ossa, R. (2014): “Trade Wars and Trade Talks with Data,” *American Economic Review*, 104, 4104–4146.

Ruhl, K. J. (2008): “The International Elasticity Puzzle,” *mimeo*.

Simonovska, I. and M. Waugh (2014): “The Elasticity of Trade: Estimates and Evidence,” *Journal of International Economics*, 92, 34–50.

Zhou, Y. (2020): “The US-China Trade War and Global Value Chains,” *mimeo*.

A Theory

A.1 Proofs to Proposition 1

Notice that

$$\begin{aligned} \lambda_{in} &= \frac{(\kappa_{in} w_i/T_i)^{1-\rho}}{\sum_{k\neq n}(\kappa_{kn} w_k/T_k)^{1-\rho}} \frac{\left[\sum_{k\neq n}(\kappa_{kn} w_k/T_k)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}}}{\left[\sum_{k\neq n}(\kappa_{kn} w_k/T_k)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + (w_n/T_n)^{1-\sigma}}, \quad i\neq n \\ \lambda_{nn} &= \frac{(w_n/T_n)^{1-\sigma}}{\left[\sum_{k\neq n}(\kappa_{kn} w_k/T_k)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + (w_n/T_n)^{1-\sigma}} \end{aligned} . \tag{A1}$$

The total expenditure can be expressed as

$$X_n = \frac{w_n L_n}{1-\sum_k \frac{t_{kn}}{1+t_{kn}}\lambda_{kn}}. \tag{A2}$$

The equilibrium consists of (w_i) such that

$$w_i L_i = \sum_n \frac{1}{1+t_{in}}\lambda_{in}\left[\frac{w_n L_n}{1-\sum_k \frac{t_{kn}}{1+t_{kn}}\lambda_{kn}}\right]. \tag{A3}$$

The corresponding price index:

$$P_n = \left\{\left[\sum_{k\neq n}(\kappa_{kn} w_k/T_k)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + (w_n/T_n)^{1-\sigma}\right\}^{\frac{1}{1-\sigma}}. \tag{A4}$$

We consider changes in $1+t_{21}$. Let $\tilde{t}_{in} = \frac{d(1+t_{in})}{1+t_{in}}$. For any other variable Z, denote $\tilde{Z} = \frac{dZ}{Z}$. Then totally differentiating equation (A4) leads to

$$\tilde{P}_n = \lambda_{nn}\tilde{w}_n + (1-\lambda_{nn})\sum_{k\neq n}\psi_{kn}\left[\tilde{\kappa}_{kn} + \tilde{w}_k\right]. \tag{A5}$$

We also have

$$\tilde{\lambda}_{nn} = (1-\sigma)(1-\lambda_{nn})\tilde{w}_n - (1-\sigma)\sum_{k\neq n}\lambda_{kn}\left[\tilde{\kappa}_{kn}+\tilde{w}_k\right]. \tag{A6}$$

For $i \neq n$, we have

$$\tilde{\lambda}_{in} = (1-\rho)\tilde{\kappa}_{in} + (1-\rho)\tilde{w}_i - (1-\sigma)\lambda_{nn}\tilde{w}_n - \left[(1-\rho)-(1-\sigma)\lambda_{nn}\right]\sum_{k\neq n}\psi_{kn}\left[\tilde{\kappa}_{kn}+\tilde{w}_k\right]. \tag{A7}$$

At $t_{in} = 0$, we have

$$\tilde{X}_n = \tilde{w}_n + \sum_k \lambda_{kn}\tilde{t}_{kn}. \tag{A8}$$

Finally, let $\chi_{in} = \frac{1}{1+t_{in}}\frac{X_{in}}{w_i L_i}$. Then at $t_{in} = 0$ we have

$$\tilde{w}_i = \sum_n \chi_{in}\left[\tilde{\lambda}_{in} + \tilde{X}_n - \tilde{t}_{in}\right]. \tag{A9}$$

We normalize $w_1 = 1$. Then we have $\tilde{X}_1 = \lambda_{21}\tilde{t}_{21}$ and $\tilde{X}_n = \tilde{w}_n$ for $n = 2, 3$. Therefore, we have

$$\begin{aligned}
\tilde{w}_2 = {} & \chi_{21}\left[\left[(1-\rho) - \left[(1-\rho)-(1-\sigma)\lambda_{11}\right]\psi_{21}\right](\tilde{t}_{21}+\tilde{w}_2) - \left[(1-\rho)-(1-\sigma)\lambda_{11}\right]\psi_{31}\tilde{w}_3 - (1-\lambda_{21})\tilde{t}_{21}\right] \\
& + \chi_{22}\left[\left[1+(1-\sigma)(1-\lambda_{22})\right]\tilde{w}_2 - (1-\sigma)\lambda_{32}\tilde{w}_3\right] \\
& + \chi_{23}\left\{\left[(1-\rho) - ((1-\rho)-(1-\sigma)\lambda_{33})\psi_{23}\right]\tilde{w}_2 + \left[1-(1-\sigma)\lambda_{33}\right]\tilde{w}_3\right\}.
\end{aligned} \tag{A10}$$

Notice that

$$(1-\rho) - \left[(1-\rho)-(1-\sigma)\lambda_{11}\right]\psi_{21} = (1-\sigma)(1-\lambda_{21}) - (\rho-\sigma)(1-\psi_{21}) = (1-\sigma)(1-\lambda_{21}) - (\rho-\sigma)\psi_{31}. \tag{A11}$$

Similarly,

$$(1-\rho) - \left[(1-\rho)-(1-\sigma)\lambda_{33}\right]\psi_{23} = (1-\sigma)(1-\lambda_{23}) - (\rho-\sigma)\psi_{13}. \tag{A12}$$

Therefore,

$$\begin{aligned}
& \left\{1-\chi_{22} + (\sigma-1)\left[\chi_{21}(1-\lambda_{21}) + \chi_{22}(1-\lambda_{22}) + \chi_{23}(1-\lambda_{23})\right] + (\rho-\sigma)(\chi_{21}\psi_{31}+\chi_{23}\psi_{13})\right\}\tilde{w}_2 \\
& - \left[(\sigma-1)(\chi_{21}\lambda_{31}+\chi_{22}\lambda_{32}+\chi_{23}\lambda_{33}) + (\rho-\sigma)\chi_{21}\psi_{31}+\chi_{23}\right]\tilde{w}_3 \\
& = -\chi_{21}\left[\sigma(1-\lambda_{21}) + (\rho-\sigma)\psi_{31}\right]\tilde{t}_{21}.
\end{aligned} \tag{A13}$$

We also have

$$\begin{aligned}\tilde{w}_3 &= \chi_{31}\left[(1-\rho)\,\tilde{w}_3 - [(1-\rho)-(1-\sigma)\,\lambda_{11}]\,(\psi_{21}\tilde{w}_2 + \psi_{21}\tilde{t}_{21} + \psi_{31}\tilde{w}_3) + \lambda_{21}\tilde{t}_{21}\right] \\ &+ \chi_{32}\left[(1-\rho)\,\tilde{w}_3 - (1-\sigma)\,\lambda_{22}\tilde{w}_2 - [(1-\rho)-(1-\sigma)\,\lambda_{22}]\,\psi_{32}\tilde{w}_3 + \tilde{w}_2\right] \\ &+ \chi_{33}\left[(1-\sigma)\,(1-\lambda_{33})\,\tilde{w}_3 - (1-\sigma)\,\lambda_{23}\tilde{w}_2 + \tilde{w}_3\right].\end{aligned} \tag{A14}$$

Therefore,

$$\begin{aligned}&\{1-\chi_{33}+(\sigma-1)\,[\chi_{31}\,(1-\lambda_{31})+\chi_{32}\,(1-\lambda_{32})+\chi_{33}\,(1-\lambda_{33})]+(\rho-\sigma)\,(\chi_{31}\psi_{21}+\chi_{32}\psi_{12})\}\,\tilde{w}_3 \\ &-[(\sigma-1)\,(\chi_{31}\lambda_{21}+\chi_{32}\lambda_{22}+\chi_{33}\lambda_{23})+(\rho-\sigma)\,\chi_{31}\psi_{21}+\chi_{32}]\,\tilde{w}_2 \\ &=\chi_{31}\,[\sigma\lambda_{21}+(\rho-\sigma)\,\psi_{21}]\,\tilde{t}_{21}.\end{aligned} \tag{A15}$$

Let $\tilde{A}_2 = \chi_{21}\,(1-\lambda_{21}) + \chi_{22}\,(1-\lambda_{22}) + \chi_{23}\,(1-\lambda_{23})$ and $\tilde{A}_3 = \chi_{31}\,(1-\lambda_{31}) + \chi_{32}\,(1-\lambda_{32}) + \chi_{33}\,(1-\lambda_{33})$. Let $\tilde{B}_2 = \chi_{21}\psi_{31} + \chi_{23}\psi_{13}$ and $\tilde{B}_3 = \chi_{31}\psi_{21} + \chi_{32}\psi_{12}$. Let $\tilde{C}_2 = \chi_{21}\lambda_{31} + \chi_{22}\lambda_{32} + \chi_{23}\lambda_{33}$ and $\tilde{C}_3 = \chi_{31}\lambda_{21} + \chi_{32}\lambda_{22} + \chi_{33}\lambda_{23}$.

Since $1-\chi_{22}+(\sigma-1)\,[\chi_{21}\,(1-\lambda_{21})+\chi_{22}\,(1-\lambda_{22})+\chi_{23}\,(1-\lambda_{23})]+(\rho-\sigma)\,(\chi_{21}\psi_{31}+\chi_{23}\psi_{13})-[(\sigma-1)\,(\chi_{21}\lambda_{31}+\chi_{22}\lambda_{32}+\chi_{23}\lambda_{33})+(\rho-\sigma)\,\chi_{21}\psi_{31}+\chi_{23}] = \chi_{21}+(\sigma-1)\,(\chi_{21}\lambda_{11}+\chi_{22}\lambda_{12}+\chi_{23}\lambda_{13})+(\rho-\sigma)\,\chi_{23}\psi_{13} > 0$, and $1-\chi_{33}+(\sigma-1)\,[\chi_{31}\,(1-\lambda_{31})+\chi_{32}\,(1-\lambda_{32})+\chi_{33}\,(1-\lambda_{33})]+(\rho-\sigma)\,(\chi_{31}\psi_{21}+\chi_{32}\psi_{12})-[(\sigma-1)\,(\chi_{31}\lambda_{21}+\chi_{32}\lambda_{22}+\chi_{33}\lambda_{23})+(\rho-\sigma)\,\chi_{31}\psi_{21}+\chi_{32}] = \chi_{31}+(\sigma-1)\,[\chi_{31}\lambda_{11}+\chi_{32}\lambda_{12}+\chi_{33}\lambda_{13}]+(\rho-\sigma)\,\chi_{32}\psi_{12} > 0$,
we have

$$\begin{aligned}\tilde{\Xi} &\equiv \left(1-\chi_{22}+(\sigma-1)\,\tilde{A}_2+(\rho-\sigma)\,\tilde{B}_2\right)\left(1-\chi_{33}+(\sigma-1)\,\tilde{A}_3+(\rho-\sigma)\,\tilde{B}_3\right) \\ &-\left[(\sigma-1)\,\tilde{C}_2+(\rho-\sigma)\,\chi_{21}\psi_{31}+\chi_{23}\right]\left[(\sigma-1)\,\tilde{C}_3+(\rho-\sigma)\,\chi_{31}\psi_{21}+\chi_{32}\right] > 0.\end{aligned} \tag{A16}$$

If $T_i = L_i = \tau_{in} = 1$ for all (i,n), then

$$\tilde{A}_2 = \tilde{A}_3 = \frac{2}{3}, \quad \tilde{B}_2 = \tilde{B}_3 = \frac{1}{3}, \quad \tilde{C}_2 = \tilde{C}_3 = \frac{1}{3}, \quad \tilde{\Xi} = \frac{1}{12}\,(\rho+\sigma)^2. \tag{A17}$$

Therefore,

$$\tilde{w}_2 = -\frac{1}{3}\tilde{t}_{21}, \tag{A18}$$

$$\tilde{w}_3 = \frac{1}{3}\frac{\rho-\sigma}{\rho+\sigma}\tilde{t}_{21}. \tag{A19}$$

We also have

$$\tilde{P}_1 = \frac{1}{3}\,(\tilde{t}_{21}+\tilde{w}_2+\tilde{w}_3) = \frac{1}{9}\left(2+\frac{\rho-\sigma}{\rho+\sigma}\right)\tilde{t}_{21}. \tag{A20}$$

Then

$$\tilde{W}_1 = \tilde{X}_1 - \tilde{P}_1 = \frac{1}{9}\left(1 - \frac{\rho-\sigma}{\rho+\sigma}\right)\tilde{t}_{21}. \tag{A21}$$

Also

$$\tilde{P}_2 = \tilde{P}_3 = \frac{1}{3}\left(\tilde{w}_2 + \tilde{w}_3\right) = -\frac{1}{9}\left(1 - \frac{\rho-\sigma}{\rho+\sigma}\right)\tilde{t}_{21}. \tag{A22}$$

Then

$$\tilde{W}_2 = \tilde{X}_2 - \tilde{P}_2 = \left(-\frac{2}{9} - \frac{1}{9}\frac{\rho-\sigma}{\rho+\sigma}\right)\tilde{t}_{21}. \tag{A23}$$

And

$$\tilde{W}_3 = \tilde{X}_3 - \tilde{P}_3 = \left(\frac{1}{9} + \frac{2}{9}\frac{\rho-\sigma}{\rho+\sigma}\right)\tilde{t}_{21}. \tag{A24}$$

B Estimation and Quantification

B.1 Estimating Elasticities using Data between 2005 and 2014

We first estimate equation (17) using changes between 2005 and 2014. The result is presented in Table B1 and implies that $\rho = 4.592$, which is very similar to the baseline estimate $\rho = 4.127$. We proceed by estimating σ as in Section 3.2 using changes between the same period. The estimated result is reported in Table B2 is also quantitatively similar to the baseline σ presented in Table 2.

Table B1: Estimate of ρ: Data between 2005 and 2014

	Dependent variable: $\Delta \log\left(\lambda_{in}^{j}\right)$
$\Delta \log\left(1 + t_{in}^{j}\right)$	-3.592^{***}
	(.986)
Importer-sector FEs	✓
Exporter-sector FEs	✓
R-squared	.384
Observations	13,247

Notes: We use the time difference between 2005 and 2014. The standard errors are clustered at the exporter-importer level. We drop the following sectors that have extreme dispersions of tariff changes: agriculture, forestry, fishing, food and tobacco, and motor vehicle.

Table B2: Estimate of σ: Data between 2005 and 2014

	Dependent Variable: $\mathcal{Y}_n^j$
Ψ_n^j	2.691^{***}
	(.629)
Sector FEs	✓
Country FEs	✓
R-squared	.386
Observations	599

Notes: We use the time difference between 2005 and 2014. The definitions of "Augmented Changes in Domestic Expenditure Share" and "Weighted Average of Changes in Import Tariffs" are given by equation (22). We drop the following sectors that have extreme dispersions of tariff changes: agriculture, forestry, fishing, food and tobacco, and motor vehicle.

B.2 Estimating the Armington Elasticities using Data in One Year

Equation (4) implies that for $i \neq n$,

$$\log\left(\lambda_{in}^j\right) = (1-\rho)\log\left(1+t_{in}^j\right) + (1-\rho)\log\tau_{in}^j + \mu_i^j + \nu_n^j, \tag{B1}$$

where μ_i^j is the exporter-sector fixed effect, and ν_n^j is the importer-sector fixed effect.

We express the iceberg trade costs in terms of observed gravity controls:

$$\log\tau_{in}^j = \delta_j^D \log \text{Dist}_{in} + \text{GVD}_{in}\delta_j^G + u_{in}^j, \tag{B2}$$

where Dist_{in} is the physical distance, GVD_{in} is a vector of gravity dummies such as common border, common language, and colonial relationship, and u_{in}^j are unobserved factors affecting iceberg trade costs.

Inserting equation (B2) into (B1), we have for $i \neq n$

$$\log\left(\lambda_{in}^j\right) = (1-\rho)\log\left(1+t_{in}^j\right) + \tilde{\delta}_j^D \log \text{Dist}_{in} + \text{GVD}_{in}\tilde{\delta}_j^G + \mu_i^j + \nu_n^j + \tilde{u}_{in}^j, \tag{B3}$$

where $\tilde{\delta}_j^D = (1-\rho)\,\delta_j^D$, $\tilde{\delta}_j^G = (1-\rho)\,\delta_j^G$, and $\tilde{u}_{in}^j = (1-\rho)\,u_{in}^j$. In this robustness check we use equation (B3) instead to estimate ρ.

To estimate σ, notice that estimating equation (B3) generates that for $i \neq n$

$$\kappa_{in}^{j} = \exp\left[\log\left(1+t_{in}^{j}\right) + \frac{\tilde{\delta}_{j}^{D}}{1-\rho}\log \text{Dist}_{in} + \text{GVD}_{in}\frac{\tilde{\delta}_{j}^{G}}{1-\rho} + \frac{\tilde{u}_{in}^{j}}{1-\rho}\right]. \tag{B4}$$

The importer-sector fixed effect in equation (B3), by definition, can be expressed as

$$\exp\left[\nu_{n}^{j}\right] = \frac{\left[\sum_{k\neq n}\left(\kappa_{kn}^{j}c_{k}^{j}/T_{k}^{j}\right)^{1-\rho}\right]^{\frac{\rho-\sigma}{1-\rho}}}{\left[\sum_{k\neq n}\left(\kappa_{kn}^{j}c_{k}^{j}/T_{k}^{j}\right)^{1-\rho}\right]^{\frac{1-\sigma}{1-\rho}} + \left(c_{n}^{j}/T_{n}^{j}\right)^{1-\sigma}}. \tag{B5}$$

The exporter-sector fixed effect in equation (B3) can be expressed as

$$\exp\left[\mu_{i}^{j}\right] = \left(c_{i}^{j}/T_{i}^{j}\right)^{1-\rho}. \tag{B6}$$

Combining equation (4), (B5), and (B6), we have

$$\Xi_{n}^{j} \equiv \frac{\exp\left[\nu_{n}^{j}\right]}{\lambda_{nn}^{j}} = \frac{\left[\sum_{k\neq n}\left(\kappa_{kn}^{j}\right)^{1-\rho}\exp\left[\mu_{k}^{j}\right]\right]^{\frac{\rho-\sigma}{1-\rho}}}{\left(\kappa_{nn}^{j}\right)^{1-\sigma}\left\{\exp\left[\mu_{n}^{j}\right]\right\}^{\frac{1-\sigma}{1-\rho}}}. \tag{B7}$$

By construction, $\kappa_{nn}^{j} = 1$ for all (n, j). Then we can estimate σ using the following linearized equation:

$$\underbrace{(1-\rho)\log\Xi_{n}^{j} - \rho\log\left[\sum_{k\neq n}\left(\kappa_{kn}^{j}\right)^{1-\rho}\exp\left[\mu_{k}^{j}\right]\right] + \mu_{n}^{j}}_{\text{Augmented Domestic Consumption Share}} = \sigma\underbrace{\left\{\mu_{n}^{j} - \log\left[\sum_{k\neq n}\left(\kappa_{kn}^{j}\right)^{1-\rho}\exp\left[\mu_{k}^{j}\right]\right]\right\}}_{\text{Weighted Average of Import Tariffs}} + \tilde{v}_{n}^{j}, \tag{B8}$$

where $\tilde{v}_{n}^{j}$ is the measurement error.

We estimate (ρ, σ) year by year, from 2002 to 2014. The results are reported in Tables B3 and B4, respectively. All estimates confirm that $\rho > \sigma$, and are broadly consistent with the baseline elasticity estimates quantitatively.

Table B3: Estimates of ρ: 2002-2014

	Dependent variable: $\log\left(X_{in}^{j}\right)$			
	$1-\rho$	s.e.	R-squared	Observations
2002	-1.601^{**}	.74	.86	17767
2003	-1.990^{**}	.788	.865	15567
2004	-1.965^{**}	.875	.863	14281
2005	-3.138^{***}	.85	.865	14981
2006	-1.879^{**}	.816	.866	14427
2007	-4.045^{***}	.848	.861	14744
2008	-3.448^{***}	.797	.867	14772
2009	-2.717^{***}	.820	.874	14744
2010	-3.124^{***}	.856	.871	14744
2011	-1.838^{**}	.861	.872	14783
2012	-3.408^{***}	.954	.87	13550
2013	-2.371^{**}	.997	.866	14141
2014	-2.458^{**}	1.048	.866	12701
2002-2014	-2.468^{***}	.241	.868	191202
$DDist1_{in}$			✓	
$DDist2_{in}$			✓	
Gravity Controls			✓	
Importer-sector FEs			✓	
Exporter-sector FEs			✓	

Notes: $DDist1_{in}$ is the dummy for the distance between 3000 and 9000 km. $DDist2_{in}$ is the dummy for the distance greater than 9000 km. For the pooled sample over 2002-2014, we control for FE_{it}^{j} and FE_{nt}^{j}. The standard errors are clustered at the exporter-importer level. We drop the following sectors that have extreme tariff dispersions: agriculture, forestry, fishing, food and tobacco, motor vehicle, and other manufacturing.

Table B4: Estimates of σ: 2002-2014

	σ	s.e.	R-squared	Observations
2002	1.565^{***}	0.059	0.953	607
2003	1.783^{***}	0.076	0.943	545
2004	1.884^{***}	0.17	0.792	606
2005	2.524^{***}	0.143	0.723	614
2006	2.195^{***}	0.29	0.743	604
2007	2.866^{***}	0.224	0.664	617
2008	3.029^{***}	0.632	0.555	618
2009	2.201^{***}	0.129	0.721	614
2010	2.803^{***}	0.515	0.757	613
2011	1.685^{***}	0.121	0.716	615
2012	3.534^{***}	0.761	0.484	585
2013	2.011^{***}	0.15	0.618	602
2014	2.399^{***}	0.421	0.553	568
2002-2014	2.245^{***}	0.089	0.683	7808

Note: In the regression for each year, we add country- and sector-specific fixed effects. For the pooled sample over 2002-2014, we add country-year- and sector-year-specific fixed effects.

B.3 Quantification

Table B5: Sectoral Tariff Variation, Armington Elasticities, and Scale Economies

Name	WIOD code	$Var\left(\Delta \log\left(1+t_{in}^{j}\right)\right)$	ρ_j	σ_j	η_j
Agriculture	A01	.137	3.007	2.033	.16
Forestry	A02	.098	3.007	2.033	.16
Fishing	A03	.065	3.007	2.033	.16
Mining	B	.038	8.942	4.467	.07
Food and Tobacco	C10-C12	.122	3.007	2.033	.16
Textile and Leather	C13-C15	.048	8.942	4.467	.12
Wood	C16	.039	3.007	2.033	.11
Paper	C17	.035	8.942	4.467	.11
Print	C18	.033	3.007	2.033	.11
Petroleum	C19	.032	8.942	4.467	.07
Chemical	C20	.035	3.007	2.033	.2
Pharmaceutical	C21	.035	3.007	2.033	.2
Rubber and Plastic	C22	.041	3.007	2.033	.25
Non-metallic mineral	C23	.043	3.007	2.033	.12
Basic metals	C24	.050	8.942	4.467	.11
Metal product	C25	.041	8.942	4.467	.13
Electronic and Optical	C26	.036	3.007	2.033	.09
Electrical	C27	.040	3.007	2.033	.09
Machinery n.e.c.	C28	.042	8.942	4.467	.13
Motor vehicle	C29	.071	3.007	2.033	.15
Other transport equipment	C30	.044	3.007	2.033	.16
Other manufacturing	C31-C32	.044	3.007	2.033	.1

Table B6: List of All Sectors

Name	WIOD code	Sector
Agriculture	A01	1
Forestry	A02	2
Fishing	A03	3
Mining	B	4
Food and Tobacco	C10-C12	5
Textile and Leather	C13-C15	6
Wood	C16	7
Paper	C17	8
Print	C18	9
Petroleum	C19	10
Chemical	C20	11
Pharmaceutical	C21	12
Rubber and Plastic	C22	13
Non-metallic mineral	C23	14
Basic metals	C24	15
Metal product	C25	16
Electronic and Optical	C26	17
Electrical	C27	18
Machinery n.e.c.	C28	19
Motor vehicle	C29	20
Other transport equipment	C30	21
Other manufacturing	C31-C32	22
Repairing	C33	23
Electricity and gas	D35	24
Water	E36	25
Waste	E37-E39	26
Construction	F	27
Wholesale and retail of motor vehicles	G45	28
Wholesale	G46	29
Retail	G47	30
Land transport	H49	31
Water transport	H50	32
Air transport	H51	33
Warehousing for transportation	H52	34
Postal	H53	35
Accommodation	I	36
Publishing	J58	37
Movie and Music	J59_J60	38
Telecommunications	J61	39
Computer programming	J62_J63	40
Finance	K64	41
Insurance	K65	42
Auxiliary to finance	K66	43
Real estate	L68	44
Legal	M69_M70	45
Architecture	M71	46
R&D	M72	47
Advertising	M73	48
Other professional	M74_M75	49
Administrative	N	50
Public administration	O84	51
Education	P85	52
Human health	Q	53
Other service	R_S	54
Households	T	55
Extraterritorial organizations	U	56