Measuring the Cost of a Tariff War:
A Sufficient Statistics Approach

Ahmad Lashkaripour
Indiana University

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Abstract

Tariff wars have attracted renewed interest, but measuring the *prospective* cost of a full-fledged tariff war remains a computationally burdensome task. Consequently, most studies on this topic are confined to a small set of countries and overlook input-output linkages. This paper develops a new methodology that measures the prospective cost of a full-fledged tariff war in one simple step, as a function of observable (a) *trade volumes*, and (b) *input-output shares*, as well as estimable industry-level (c) *trade elasticities*, and (d) *markup wedges*. Applying this methodology to data on 44 economies and 56 industries, I find that (i) the prospective cost of a tariff war to global GDP has more-than-doubled over the past fifteen years, with small downstream economies being the most vulnerable. Moreover, (ii) many countries can lose significantly from a US-China tariff war even if they are not directly involved.

1 Introduction

The global economy is entering a new era of tariffs, with many economic leaders warning against the eminent threat of a global tariff war. Just recently, Christine Lagarde, head of the International Monetary Fund, labeled the escalating US-China tariff war as "the biggest risk to global economic growth."[1]

Concurrent with these real-world developments, there has been a growing academic interest in measuring the cost of a tariff war. One natural approach

[1] Source: https://www.bloomberg.com/news/articles/2019-06-09/lagarde-says-u-s-china-trade-war-looms-large-over-global-growth

is the "ex-post" approach adopted by Amiti et al. (2019) and Fajgelbaum et al. (2019). This approach, uses data on observed tariff hikes; employs economic theory to estimate the passthrough of tariffs onto consumer prices; and measures the welfare cost of these *already-applied* tariffs.

With all its merits, the "ex-post" approach does not address an important question facing policy-makers: *what is the prospective cost of a full-fledged tariff war?* To answer such "what if" questions, we first need to determine what Nash tariff levels will prevail under a full-fledged tariff war. The "ex-ante" approach developed by Perroni and Whalley (2000) and Ossa (2014) accomplishes this exact task. They use economic theory to estimate the Nash tariff levels that will prevail and the welfare cost that will result from a hypothetical (but now imminent) tariff war that has fully escalated.

The "ex-ante" approach has been quite influential, and recent methodological advances by Ossa (2014) have made it more accessible to researchers. However, existing methods are still plagued with the curse of dimensionality when applied to many countries and industries. The methodology in Ossa (2014), for instance, computes the Nash tariffs using an iterative process where each iteration performs a country-by-country constrained optimization given the output of the previous iterations. As the number of countries or industries grows, the computational burden underlying this approach can raise significantly. This is perhaps why the current implementations of the "ex-ante" approach are often limited to a smaller set of countries and do not account for input-output linkages.[2]

In this paper I present a simple sufficient statistics methodology to measure the prospective cost of a full-fledged global tariff war.[3] The proposed methodology (i) circumvents the computational challenges facing existing "ex-ante" methodologies, and (ii) sheds fresh light on the degree to which input-output linkages amplify the burden of a tariff war. Moreover, due to its computational simplicity, the methodology can be readily applied to data from multiple years and many small, emerging economies. Doing so, indicates that the prospective cost of a global tariff war has risen dramatically over the past two decades, with

[2]In the existing literature, the set of countries is often reduced by aggregating countries into a few large economic regions. This approach allows researchers to reduce computational burden; but as I will show later in the paper, such aggregations can also overstate the cost of a tariff war rather significantly.

[3]The sufficient statistics methodology developed here is akin to the Arkolakis et al. (2012) methodology, and exhibits key differences with the sufficient statistics approach popularized by Chetty (2009) in the public finance literature. See Chapter 7 in Costinot and Rodríguez-Clare (2014) for more discussion on these differences.

small downstream economies being –by far– the most vulnerable.

My methodology relies on the analytical characterization of Nash tariffs in an important class of quantitative trade models that accommodate multiple industries, input-output linkages, market distortions, and political economy pressures. Here, Nash tariffs refer to tariff levels that will (in theory) prevail in the event of a tariff war. In characterizing the Nash tariffs, I build on and extend the previous characterizations in Beshkar and Lashkaripour (2019) and Lashkaripour and Lugovskyy (2019) to a multi-country setup where all countries strategically impose tariffs against each other. The analytical formulas that result, describe the Nash tariffs for each country as a function of only structural parameters and observables.

Using my analytic formulas and the exact hat-algebra methodology, popularized by Dekle et al. (2007), I can compute the Nash tariffs and their welfare effects in one simple step, by solving a system of equations that depends on only (i) *observable trade volumes*, (ii) *input-output shares*, (iii) *industry-level trade elasticities*, and (iv) *industry-level markup wedges*. This method is remarkably fast and reliable for two main reasons. First, it does not involve any iterations or any constrained global optimizations. Second, the analytic formulas indicate that Nash tariffs are uniform along certain dimensions, which itself reduces dimensionality to a remarkable degree.

I apply my methodology to the World Input-Output Database (WIOD, Timmer et al. (2012)) from 2000 to 2014, covering 43 major countries and 56 industries. For each country in the WIOD sample in a given year, I compute the prospective cost of a full-fledged global tariff war as well as a two-way US-China tariff war. I first perform my analysis using a baseline multi-industry Eaton and Kortum (2002) model. Subsequently, I introduce (a) market distortions and political pressures, as well (b) input-output linkages into my baseline analysis to determine how these additional factors contribute the cost of a tariff war. May analysis delivers four basic insights:

i. The prospective cost of a full-fledged tariff war is immense. Especially, when we account for the dependence of countries on global value chains and the fact that a trade war will exacerbate market distortions. In 2014, for instance, the prospective cost of a full-fledged tariff war was \$1.5 trillion in terms of global GDP, which is the equivalent of erasing South Korea from the global economy.

ii. The prospective cost of a global tariff war has more-than-doubled from

2000 to 2014. The rising cost is driven by two distinct forces. First, the rise of global market power, which prompts countries to impose more-targeted (i.e., more-distortionary) Nash tariffs in the event of a tariff war. Second, the increasing dependence of emerging economies on the global value chain since 2000.

iii. Small downstream economies are the main casualties of a global tariff war. Take Estonia, for example, where imported intermediates account for 30% of the national output, inclusive of the service sector. Due to its strong dependence on imported intermediates, 10% of Estonia's real GDP will be wiped out by a global tariff war. Similar losses will be incurred by other small, downstream economies like Bulgaria, Latvia, and Luxembourg.

iv. A two-way US-China tariff war can shave off $34 billion from the global economy, the equivalent of Paraguay's GDP. The US economy is the biggest loser, but many other countries can incur losses without even being directly involved in the tariff war. To give specific examples, Australia's economy can lose $58 million or Irelands's economy can lose $26 million from a US-China tariff war. These are losses incurred without the US-China tariffs directly targeting either country.

Putting aside the estimated magnitudes, the above findings highlight a previously-overlooked determinant of tariff war outcomes. Dating back to Johnson (1953), a rich body of literature has emphasized how country size determines the winners and losers from a tariff war.[4] My analysis shows that a country's degree of "upstream-ness" in the global value chain is an equally-determining factor. For instance, based on my analysis, Norway that is an upstream economy (due its commodity exports) can gain from a tariff war despite being small. These gains obviously come at expense of small downstream economies incurring immense losses.

Finally, on the flip side, the approach developed here can be viewed as a sufficient statistics methodology to quantify the gains from global trade agreements. In that regard, it contributes to Arkolakis et al. (2012), Costinot and Rodríguez-Clare (2014), and Arkolakis et al. (2015) who propose sufficient statistics methodologies that quantify the gains from trade relative to autarky

[4] See also Grossman and Helpman (1995) who introduce political economy considerations into the framework analyzed by Johnson (1953); as well as Bagwell and Staiger (1999) who study the role of trade agreements in dealing with the terms-of-trader externality highlighted in Johnson (1953).

in an important class of trade models. Like the aforementioned studies, my proposed methodology quantifies the gains from trade, but it does so relative to a world without trade agreements as opposed to autarky.

This paper is organized as follows. Section 2 presents the theoretical model, based on which a sufficient statistics approach is developed to measure the prospective cost of a tariff war. Section 3 presents a quantitative implementation using actual trade data. Section 4 concludes.

2 Theoretical Framework

The present methodology applies to a range of quantitative trade models. In the interest of exposition, I begin my analysis with a *baseline* multi-industry, multi-country Ricardian model that nests the Eaton and Kortum (2002) and Armington models as a special case. I subsequently extend the baseline model to account for (a) political economy pressures and profit-shifting effects à la Ossa (2014), and (b) intermediate input trade à la Caliendo and Parro (2015).

Throughout my analysis, I consider a global economy consisting of $i = 1, ..., N$ countries and $k =, 1, .., K$ industries, with $\mathbb{C}$ and $\mathbb{K}$ respectively denoting the set of countries and industries. Labor is the only *primary* factor of production. Each country i is populated with L_i workers, each supplying one unit of labor inelastically. Workers are perfectly mobile across industries but immobile across countries.

Demand. In the Ricardian model, all varieties in industry k are differentiated by country of origin, with the triplet ji, k denoting a variety supplied by country j, to market i, in industry k— from the perspective of the Eaton and Kortum (2002) model, national product differentiation of this kind can be interpreted as the outcome of Ricardian specialization within industries. The representative consumer in country i maximizes a general utility function, which yields an indirect utility function as follows:

$$V_i(Y_i, \tilde{\boldsymbol{P}}_i) = \max_{\boldsymbol{Q}_i} \quad U(\boldsymbol{Q}_i)$$
$$s.t. \quad \sum_k \sum_j \tilde{P}_{ji,k} Q_{ji,k} = Y_i. \tag{1}$$

In the above problem, Y_i denotes total income; $\boldsymbol{Q}_i = \{Q_{ji,k}\}$ denotes the vector of composite consumption quantities, and $\tilde{\boldsymbol{P}}_i = \{\tilde{P}_{ji,k}\}$ denotes the corresponding vector of *"consumer"* price indexes. I should emphasize here that, as a choice of notation, I use the *tilde* to distinguish between "consumer" and "producer" prices throughout this paper. The above problem yields the following national-level Marshallian demand function,

$$Q_{ji,k} = \mathcal{D}_{ji,k}\left(Y_i, \tilde{\boldsymbol{P}}_i\right), \tag{2}$$

which can be summarized by a set of reduced-form demand elasticities facing each composite variety ji, k. Namely, the own-price elasticity of demand,

$$\varepsilon_{ji,k} \equiv \partial \ln \mathcal{D}_{ji,k}(.)/\partial \ln \tilde{P}_{ji,k}, \tag{3}$$

and the cross-price elasticity of demand between varieties ji, k and $ji, g \neq ji, k$,

$$\varepsilon_{ji,k}^{ji,g} \equiv \partial \ln \mathcal{D}_{ji,k}(.)/\partial \ln \tilde{P}_{ji,g}.$$

I assume that the aggregate demand functions are well-behaved such that $\varepsilon_{ji,k}$<-1 and $\varepsilon_{ji,k}^{ji,g} \geq 0$. The income elasticity of demand plays a less prominent role in my analysis, so I relegate its definition to the appendix.

Production. In the Ricardian model, production only employs labor and the average unit labor cost of production and transportation is also invariant to policy. Correspondingly, the "producer" price of composite variety ji, k can be expressed as a function of the labor wage rate in country j, w_j, times the constant unit labor cost of production and transportation, $\bar{a}_{ji,k}$:

$$P_{ji,k} = \bar{a}_{ji,k} w_j. \tag{4}$$

The "consumer" price, by definition, equals the "producer" price times the tariff applied by country i on variety ji, k, namely, $t_{ji,k}$:

$$\tilde{P}_{ji,k} = (1 + t_{ji,k}) P_{ji,k}. \tag{5}$$

Keep in mind that the assumption that $\bar{a}_{ji,k}$ is invariant to policy, corresponds to a flat export supply curve. In other words, it implies that the passthrough of taxes on to consumer prices is complete (once we net of general equilibrium wage effects). This assumption is consistent with ex-post studies of the recent tariff war, like Amiti et al. (2019) and Fajgelbaum et al. (2019).

Equilibrium. For any given vector of tariffs, $\boldsymbol{t} = \{t_{ji,k}\}$, equilibrium is a vector of wages, $\boldsymbol{w} = \{w_j\}$; a vector of "producer" and "consumer" price indexes, $\boldsymbol{P}_i = \{P_{ji,k}\}$ and $\tilde{\boldsymbol{P}}_i = \{\tilde{P}_{ji,k}\}$, that are described by Equations 4 and 5; as well as consumption quantities, $\boldsymbol{Q}_i$, given by 2, subject to total income in each country equaling the wage bill, $w_i L_i$, plus tax revenues:

$$Y_i = w_i L_i + \sum_j \sum_k t_{ji,k} P_{ji,k} Q_{ji,k}.$$

The above equation along with the representative consumer's budget constraint, insure that trade is balanced between countries, i.e., $\sum_{j \neq i} \sum_k P_{ji,k} Q_{ji,k} = \sum_{j \neq i} \sum_k P_{ij,k} Q_{ij,k}$ for all i. Moreover, provided that equilibrium is unique, all equilibrium outcomes can be uniquely characterized as a function of tariff rates, $\boldsymbol{t}$, applied by various countries. For the reader's convenience, Table 1 reports a summary of the key variables featured in my analysis.

Importantly, throughout this paper, I assume that every country i is sufficiently small or closed with respect to the rest of the world so that its tariff (i) affects that country's wage, w_i, relative to wages in the rest of the world; but (ii) has a negligible effect on the wage of other countries relative to one-another, i.e., on w_j / w_ℓ, where j and $\ell \neq i$. Using actual trade and production data from 2014, Appendix E shows that this assumption quite-perfectly approximates even the largest economies in the world.[5]

Nash Tariffs. In the event of a tariff war, each country i chooses their vector of non-cooperative optimal tariffs $\boldsymbol{t}_i^* = \{t_{ji,k}^*\}$, as a function of the tariffs applied by all other countries, namely, $\boldsymbol{t}_{-i}$. Stated formally, country i's best tariff response solves the following problem:

$$\boldsymbol{t}_i^*(\boldsymbol{t}_{-i}) = \arg\max \; V_i\left(Y_i(\boldsymbol{t}_i; \boldsymbol{t}_{-i}), \tilde{\boldsymbol{P}}_i(\boldsymbol{t}_i; \boldsymbol{t}_{-i})\right). \tag{6}$$

In what follows, I will analytically characterize the solution to this problem. But before doing that, let me briefly outline why calculating the Nash tariffs (that prevail under a tariff war) is plagued by the curse of dimensionality. By

[5]This is a much weaker assumption than the one featured in many standard "partial equilibrium" theories, where the presence of a costlessly traded homogeneous sector, leads to wages being *equal* and *constant* across all countries.

Table 1: *Summary of Key Variables*

Variable	Description
$\tilde{P}_{ji,k}$	Consumer price index of variety ji,k (exporter j–importer i–industry k)
$P_{ji,k}$	Producer price index of variety ji,k (exporter j–importer i–industry k)
$Q_{ji,k}$	Consumption quantity/Output of variety ji,k
$X_{ji,k}$	F.O.B. export value: $X_{ji,k} = P_{ji,k}Q_{ji,k}$
Y_i	Total income in country i
w_iL_i	Wage income in country i (wage×population size)
Π_i	Total profits in country i
$t^*_{ji,k}$	Nash/Optimal tariff imposed by country i on variety ji,k
$\bar{t}_{ji,k}$	Applied (status-quo) tariff on variety ji,k
$\beta_{i,k}$	Country i's expenditure share on industry k
$\lambda_{ji,k}$	Expenditure share on variety ji,k: $\lambda_{ji,k} = \tilde{P}_{ji,k}Q_{ji,k}/\beta_{i,k}Y_i$
$\varepsilon_{ji,k}$	Own-price elasticity of demand: $\varepsilon_{ji,k} = \partial \ln Q_{ji,k}/\partial \ln \tilde{P}_{ji,k}$
$\varepsilon^{ji,g}_{ji,k}$	Cross-price elasticity of demand: $\varepsilon_{ji,k} = \partial \ln Q_{ji,k}/\partial \ln \tilde{P}_{ji,g}$
$\epsilon_k - 1$	Constant trade elasticity under the CES parmaterization
μ_k	Constant markup/profit margin in industry k
$\alpha_{j,k}(\ell, g)$	Share of input variety $\ell j, g$ in variety ji,k's output, $\forall i$
$\gamma_{j,k}$	Share of labor in variety ji,k's output, $\forall i$
$\tilde{\gamma}_{j,k}(\ell)$	Share of country ℓ's labor in *country j-industry k*'s output in the reformulated IO model

definition, the Nash tariffs solve the following system

$$\begin{cases} \boldsymbol{t}_1 = \boldsymbol{t}^*_1(\boldsymbol{t}_{-1}) \\ \vdots \\ \boldsymbol{t}_N = \boldsymbol{t}^*_N(\boldsymbol{t}_{-N}) \end{cases},$$

where $\boldsymbol{t}^*_i(\boldsymbol{t}_{-i})$ can be obtained by solving Problem 6 separately for each country i. The curse of dimensionality underlying above system is driven by two factors. First, the above system involves $N(N-1)K$ tariff rates—a number than can grow rapidly with sample size. Second, to solve the above system numerically, one has to solve $\boldsymbol{t}_i^* = \boldsymbol{t}_i^*(\boldsymbol{t}_{-i})$ iteratively for all N countries. That is, the optimal tariffs are first computed for each country by conducting N constrained global optimizations, assuming zero tariffs in the rest of the world. Then, the optimal tariffs are updated by performing another N constrained global optimization that condition on the optimal tariff levels obtained in the first step. This procedure is repeated iteratively until we converge to the unique solution of the above system.

We can circumvent these issues, by obtaining an analytical characterization of $t_i^*(.)$. The following proposition takes an important step in this direction, which ultimately reduces the computational task highlighted above to that of solving "one" system of $3N$ equations and unknowns, which depend solely on structural elasticities and observables.

Proposition 1. *Country i's optimal non-cooperative import tariff is uniform and can be characterized as*

$$1 + t_i^* = \frac{\sum_{j \neq i} \sum_k \sum_g \chi_{ij,k} \varepsilon_{ij,k}^{ij,g}}{1 + \sum_{j \neq i} \sum_k \sum_g \chi_{ij,k} \varepsilon_{ij,k}^{ij,g}},$$

in terms of only (i) reduced-form demand elasticities, $\varepsilon_{ij,k}^{ij,g}$; and (ii) observable export revenue shares, $\chi_{ij,k} \equiv X_{in,k} / \sum_{\ell \neq i} \sum_k X_{i\ell,k}$.

A formal proof for the above proposition is provided in Appendix A.1, but let me provide a brief intuition for this result, here. The uniformity of tariffs across industries arises from the unit labor cost being invariant to policy—see Beshkar and Lashkaripour (2019) for a more elaborate discussion. The uniformity of tariffs across suppliers, on the other hand, follows from each country being sufficiently small relative to the rest of the world. Since the optimal import tariff is uniform, it is akin to a uniform export tax or a markup applied to w_i when a good is exported.[6] This interoperation elucidates the optimal tariff formula specified by Proposition 1, which is an optimal monopoly markup on w_i across all exported goods. These conclusions obviously derive from the assumption that country i is sufficiently small relative to the rest of the world. In Appendix E, I use actual data to show that this assumption approximates even

[6]The equivalence between uniform import and export taxes is a manifestation of the Lerner symmetry. The aforementioned symmetry is often articulated in the context of a two-country model. But the same arguments apply to a multi-country setup, provided that each country is sufficiently small relative to the rest of the world. This point aside, we can simply re-formulate the optimal tariff specified by Proposition 1, so that is corresponds to the optimal mark-down of a multi-product monopsonist. Such a reformulation simply involves using the wage in country i as the numeraire.

the largest economies, remarkably well.

Measuring the Cost of a Tariff War. We can employ Proposition 1 to measure the prospective cost of a full-fledged tariff war. But to do so, we first need to impose additional structure on the utility function, $U_i(.)$. One commonly-used specification in the quantitative trade literature is the Cobb-Douglas-CES specification, displayed below:

$$U_i(\mathbf{Q}_i) = \prod_k \left(\sum_i \varsigma_{ji,k} Q_{ji,k}^{\rho_k} \right)^{\beta_{i,k}/\rho_k}. \tag{7}$$

Adopting the above specification, the bilateral trade shares ($\lambda_{ji,k} \equiv \tilde{P}_{ji,k} Q_{ji,k} / \beta_{i,k} Y_i$) assume the following formulation:

$$\lambda_{ji,k} = \varsigma_{ji,k} \tilde{P}_{ji,k}^{-\epsilon_k} / \sum_\ell \left(\varsigma_{\ell i,k} \tilde{P}_{\ell i,k}^{-\epsilon_k} \right), \tag{8}$$

where $\epsilon_k \equiv \rho_k / (\rho_k - 1)$ denotes the *industry-level trade elasticity*. Moreover, under this specification, the cross-price elasticities of demand between varieties from different industries collapse to zero, while the own-price elasticity of demand reduces to

$$\varepsilon_{ji,k} = -1 - \epsilon_k \left(1 - \lambda_{ji,k}\right). \tag{9}$$

Using Equations 8 and 9 as well as Proposition 1; and employing the hat-algebra notation ($\hat{x} \equiv x'/x$); we can solve for Nash tariffs and their welfare effects in one simple step. The following proposition outlines this claim.

Proposition 2. *If preferences are described by functional form 7, the Nash tariffs, $\{t_i^*\}$, and their effect on wages, $\{\hat{w}_i\}$, and total income, $\{\hat{Y}_i\}$, can be solved as a solution to the following system:*

$$\begin{cases} 1 + t_i^* = \frac{1+\sum_{j\neq i} \sum_k \left[\hat{\chi}_{ij,k} \chi_{ij,k} \epsilon_k (1-\hat{\lambda}_{ij,k}\lambda_{ji,k})\right]}{\sum_{j\neq i} \sum_k \left[\hat{\chi}_{ij,k} \chi_{ij,k} \epsilon_k (1-\hat{\lambda}_{ij,k}\lambda_{ij,k})\right]} \\ \hat{\chi}_{ij,k} \chi_{ij,k} = \frac{\hat{\lambda}_{ij,k} \lambda_{ij,k} \beta_{j,k} \hat{Y}_j Y_j / (1+t_j^*)}{\sum_{n\neq i} \hat{\lambda}_{in,k} \lambda_{in,k} \beta_{n,k} \hat{Y}_n Y_n / (1+t_n^*)} \\ \hat{\lambda}_{ji,k} = \left(\frac{1+t_i^*}{1+\bar{t}_{ji,k}} \hat{w}_j \right)^{-\epsilon_k} \hat{\tilde{P}}_{i,k}^{\epsilon_k} \\ \hat{\tilde{P}}_{i,k}^{-\epsilon_k} = \sum_j \left[\left(\frac{1+t_i^*}{1+\bar{t}_{ji,k}} \hat{w}_j \right)^{-\epsilon_k} \lambda_{ji,k} \right] \\ \hat{w}_i w_i L_i = \sum_k \sum_j \left[\hat{\lambda}_{ij,k} \lambda_{ij,k} \beta_{j,k} \hat{Y}_j Y_j / \left(1 + t_j^*\right) \right] \\ \hat{Y}_i Y_i = \hat{w}_i w_i L_i + \sum_k \sum_j \left(\frac{t_i^*}{1+t_i^*} \hat{\lambda}_{ji,k} \lambda_{ji,k} \beta_{i,k} \hat{Y}_i Y_i \right) \end{cases},$$

which features only three set of observables: (i) applied tariffs, $\bar{t}_{ji,k}$, (ii) expenditure shares, $\lambda_{ji,k}$ and $\beta_{i,k}$, and (iii) national expenditure and wage revenue, Y_i and $w_i L_i$; as well as structural industry-level trade elasticities, $\{\epsilon_k\}$.

Let me briefly elaborate on the significance of Proposition 2. The system specified by the above proposition involves $3N$ independent equations and unknowns: N Nash tariff rates, $\{t_i^*\}$; N wage changes, $\{\hat{w}_i\}$; and N income changes, $\{\hat{Y}_i\}$. Solving this system requires a set of sufficient statistics that are either observable or estimable: (a) data on observable applied tariffs, expenditure shares and total income in each country (namely, $\bar{t}_{ji,k}$, $\lambda_{ji,k}$, $\beta_{i,k}$, and Y_i); as well as (b) estimates for the trade elasticities, ϵ_k.[7]

Let us compare the procedure outlined by Proposition 2 to the standard approach whereby Nash tariffs are solved using an iterative global optimization procedure. Recall that in the standard approach, each iteration alone performs N constrained global optimizations over $2N + (N-1)K$ state variables. Using Proposition 2 we can not only bypass the need to iterate but also the need to perform a full-blown global optimization. In fact, we only need to solve one system of $3N$ equations and unknowns.

The solution to the system specified by Proposition 2 immediately pins down the prospective cost of a tariff war for each country i as

$$\%\Delta \text{Real GDP}_i = \hat{Y}_i \cdot \prod_k \left(\hat{\tilde{P}}_{i,k}^{-\beta_{i,k}} \right).$$

In the following subsections, I discuss how the above methodology easily extends to richer frameworks that accommodate political pressures, profit-shifting effects, and intermediate input trade. Later, in Section 3, I use the above Proposition2 and the subsequent propositions to quantify the cost of a global tariff war.

2.1 Accounting for Market Distortions and Political Pressures

In the Ricardian model, the market equilibrium is efficient and Nash tariffs only internalize the terms-of-trade gains resulting from improving one's wage relative to the rest of the world. Ideally, we should also account for market dis-

[7]Note that with data on $\bar{t}_{ji,k}$, $\lambda_{ji,k}$, $\beta_{i,k}$, and Y_i, we can immediately pin down $w_i L_i$ as

$$w_i L_i = \sum_k \sum_j \left[\lambda_{ij,k} \beta_{j,k} Y_j / (1 + \bar{t}_{ij,k}) \right].$$

tortions, which give rise to profit-shifting motives behind tariff imposition and political economy pressures. To introduce these two channels, I consider a generalized multi-industry Krugman (1980) model with restricted entry that nests Ossa (2014) as a special case. In this extension, firms enjoy market power and collect profits. As a result, tariffs can induce a profit-shifting externality that was absent in the baseline model. Moreover, as in Grossman and Helpman (1995), governments can assign different weights to profits collected in different industries in response to political pressures.

For the sake of exposition, I start with the case where governments assign the same political weight to all industries. Then, I show how introducing political pressures modifies the baseline results. The model that follows extends the Ricardian model in two key dimensions. First, on the demand side, each composite country-level variety aggregates over differentiated firm-level varieties indexed by ω,

$$Q_{ji,k} = \left(\int_{\omega \in \Omega_{j,k}} q_{ji,k}(\omega)^{\varrho_k} d\omega \right)^{1/\varrho_k},$$

where $\varrho_k > 1$, and $\Omega_{j,k}$ denotes the set of firms serving industry k from country j. Noting the above specification, the Ricardian model can be viewed as a special case of the generalized Krugman model where $\varrho_k \to 1$.

Second, on the supply side, industry k in country j hosts a fixed number of firms, $\bar{M}_{j,k}$, that compete under monopolistic competition and charge a constant markup, $1 + \mu_k \equiv \rho_k$, over marginal cost. Each firm employs labor as the sole factor of production, with $a_{ji,k}(\omega)$ denoting the constant unit labor cost of production and transportation for goods sold by firm ω in market i. Note that since firms incur no fixed marketing costs, the heterogeneity in $a_{ji,k}(\omega)$'s is inconsequential to my analysis.[8]

Combining these features, the "producer" price index of composite variety ji, k can be expressed as a function the labor wage rate in country j, w_j; the average unit labor cost of production and transportation, $\bar{a}_{ji,k}$;[9] the number of firms located in country j, $\bar{M}_{j,k}$; and the constant markup wedge, μ_k. In particular,

$$P_{ji,k} = (1 + \mu_k) \bar{a}_{ji,k} \bar{M}_{j,k}^{-\mu_k} w_j.$$

[8]As I will discuss later in Section 2.3, the present framework is isomorphic to one where $a_{ji,k}(\omega)$'s have a Pareto distribution and the fixed marketing costs is paid in terms of labor in the destination country.

[9]Stated formally, $\bar{a}_{ji,k} = \left(\int_{\omega \in \Omega_{j,k}} a_{ji,k}(\omega)^{\varrho_k/(\varrho_k - 1)} d\omega \right)^{(\varrho_k - 1)/\varrho_k}$.

Correspondingly, the "consumer" price index is given by $\tilde{P}_{ji,k} = (1 + t_{ji,k})P_{ji,k}$. Also, as in the Ricardian model, the pass-through of tariffs on to consumer prices is complete, once we net out general equilibrium wage effects.[10]

Equilibrium in the generalized Krugman model has a similar definition as the Ricardian model, except that total income in each country equals the wage bill, $w_i L_i$, plus total profits, $\Pi_i = \sum_k \sum_j (\mu_k/1+\mu_k) P_{ij,k} Q_{ij,k}$, and tariff revenues:

$$Y_i = w_i L_i + \Pi_i + \sum_j \sum_k t_{ji,k} P_{ji,k} Q_{ji,k}.$$

In the above setup, country i's tariffs have two distinctive effects on welfare. First, as in the Ricardian model, tariffs can alter country i's wage relative to the rest of the world. Second, tariffs can increase country i's profits, Π_i, by restricting imports and promoting domestic output in high-markup (high-μ) industries. Both of these effects also inflict a negative externality on the rest of the world. Despite this added layer of complexity, the Nash tariffs can still be analytically characterized in terms of reduced-form demand elasticities and observable shares, as outlined by the following proposition.[11]

Proposition 3. *Country i's optimal import tariff can be solved alongside a uniform shifter, τ_i^*, using the following system:*

$$\left[\frac{1+\bar{\tau}_i^*}{1+t_{ji,k}^*}\right]_{j\neq i} = \boldsymbol{\mathcal{E}}_{i,k}^{-1}\left(\mathbf{1}_{(N-1)\times 1} + \left[\frac{\lambda_{ii,k}\varepsilon_{ii,k}^{ji,k}}{\lambda_{ji,k}(1+\mu_k)}\right]_{j\neq i}\right), \quad \forall k$$

$$1+\bar{\tau}_i^* = \frac{\sum_{j\neq i}\sum_k \left[\chi_{ij,k}\varepsilon_{ij,k} - (t_{ji,k}^* - \bar{\tau}_i^*)\chi'_{ji,k}\varepsilon_{ji,k}^{ii,k}\right]}{1+\sum_{j\neq i}\sum_k \chi_{ij,k}\varepsilon_{ij,k}},$$

which features only (i) reduced-form demand elasticities that are partially contained in

[10] Allowing for free entry, the pass-through of tariffs on to consumer prices will no longer be complete in the case of a large economy—see Lashkaripour and Lugovskyy (2019) for a formal analysis of tariffs under free entry. But if country i is sufficiently small relative to the rest of the world, the passthrough would remain complete, even under free entry.

[11] As before (an in the absence of political pressures) optimal non-cooperative tariffs maximize welfare given applied tariffs in the rest of the world. In particular,

$$\boldsymbol{t}_i^*(\boldsymbol{t}_{-i}) = \arg\max\; V_i\left(Y_i(\boldsymbol{t}_i;\boldsymbol{t}_{-i}), \tilde{\boldsymbol{P}}_i(\boldsymbol{t}_i;\boldsymbol{t}_{-i})\right).$$

Also, it should be noted that the formula specified by Proposition 3 assumes zero cross-substitutability between industries, which is the relevant case for my quantitative analysis. But as shoen in Appendix A.2, we can readily extend the above formula to account for an arbitrary pattern of cross-substitutability between industries.

the $(N-1)\times(N-1)$ *matrix,* $\boldsymbol{\mathcal{E}}_{i,k} \equiv \left[\varepsilon^{ji,k}_{ji,k}\right]_{j,j\neq i}$*; (ii) constant markup wedges,* μ_k*; as well as (iii) observable export and import revenue shares,* $\chi_{ij,k} = / \sum_{\ell\neq i}\sum_k X_{i\ell,k}$ *and* $\chi'_{ji,k} = X_{ji,k} / \sum_{\ell\neq i}\sum_k X_{\ell i,k}$.

As with the baseline model, the above proposition can be used to measure the cost of a tariff war provided that we impose additional structure on preferences. Specifically, assuming that preferences have a Cobb-Douglas-CES parmaterization (as in Equation 7), Proposition 3 implies that country i's Nash tariff is uniform across exporters and given by[12]

$$1+t^*_{i,k} = \left[\frac{\sum_{j\neq i}\sum_g X_{ij,g}\left[1+\epsilon_g\left(1-\lambda_{ij,g}\right)\right]}{\sum_{j\neq i}\sum_k\left[X_{ij,g}\epsilon_g\left(1-\lambda_{ij,g}\right)+\mathcal{X}_{ji,k}\epsilon_k\lambda_{ii,s}\right]}\right]\frac{\left(1+\mu_k\right)\left(1+\epsilon_k\lambda_{ii,k}\right)}{1+\mu_k+\epsilon_k\lambda_{ii,k}}. \tag{10}$$

where $\mathcal{X}_{ji,k} \equiv \sum_g\left[\frac{\mu_g\epsilon_g\lambda_{ii,g}}{1+\mu_g+\epsilon_g\lambda_{ii,g}}\right]X_{ji,k}$. To provide a brief intuition, the first term in the bracket reflects the uniform optimal markup over w_i, which is applied to all exported goods. This term was also present in the Ricardian model. The second term, which is industry-specific, reflects country i's incentive to protect and promote high-profit (high-μ) industries. This second term imposes a profit-shifting externality on the rest of world that was absent in the baseline Ricardian model.[13]

Importantly, when all countries simultaneously protect their high-μ industries, global output in these industries shrinks below its already sub-optimal level. As a result, a full-fledged tariff war exacerbates misallocation in the global economy in a way that was absent in the baseline model. Later, when I map the model to data, it will become apparent that the cost of exacerbated misallocation is comparable to pure of cost of trade reduction in the event of a full-fledged tariff war.

Moving forward, we can appeal to Equation 10 in order to compute the Nash tariffs and the welfare cost associated with them in one simple step as a function of only observable shares and structural elasticities. The following proposition formally outlines this point.

Proposition 4. *If preferences are described by functional form 7, the Nash tariffs,*

[12]In the above equation, the uniform term is stated in terms of export/import levels (X) instead of shares (χ). But dividing the numerator and denominator of the uniform term by $\sum_{j\neq i}\sum_k X_{ji,k} = \sum_{j\neq i}\sum_k X_{ij,k}$ will express the same equation in terms of shares, as specified by Proposition 3.

[13]As noted in Lashkaripour and Lugovskyy (2019), the industry-specific term is an artifact of governments not having access to domestic subsidies. As a result, they resort to tariffs as a second-best policy for enhancing allocate efficiency in their local economy.

$\{t^*_{i,k}\}$, and their effect on wages, $\{\hat{w}_i\}$, and total income, $\{\hat{Y}_i\}$, can be solved as solution to the following system:

$$\begin{cases} 1+t^*_{i,k} = (1+\bar{\tau}^*_i)\left[\frac{1+\mu_k-\epsilon_k\hat{\lambda}_{ii,k}\lambda_{ii,k}}{(1+\mu_k)(1-\epsilon_k\hat{\lambda}_{ii,k}\lambda_{ii,k})}\right] \\ 1+\bar{\tau}^*_i = \frac{\sum_{j\neq i}\sum_k \hat{X}_{ij,k}X_{ij,k}\left[1+\epsilon_k(1-\hat{\lambda}_{ij,k}\lambda_{ji,k})\right]}{\sum_{j\neq i}\sum_k\left[\hat{X}_{ij,k}X_{ij,k}\epsilon_k(1-\hat{\lambda}_{ij,k}\lambda_{ij,k})+\hat{\mathcal{X}}_{ji,k}\mathcal{X}_{ji,k}\epsilon_k\hat{\lambda}_{ii,s}\lambda_{ii,s}\right]} \\ \hat{X}_{ij,k}X_{ij,k} = \hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1+t^*_{j,k}) \\ \hat{\mathcal{X}}_{ji,k}\mathcal{X}_{ji,k} = \sum_g\left(\frac{\mu_g\epsilon_g\hat{\lambda}_{ii,g}\lambda_{ii,g}}{1+\mu_g+\epsilon_g\hat{\lambda}_{ii,g}\lambda_{ii,g}}\right)\hat{X}_{ji,k}X_{ji,k} \\ \hat{\lambda}_{ji,k} = \left(\frac{1+t^*_{i,k}}{1+\bar{t}_{ji,k}}\hat{w}_j\right)^{-\epsilon_k}\hat{\tilde{P}}^{\epsilon_k}_{i,k} \\ \hat{\tilde{P}}^{-\epsilon_k}_{i,k} = \sum_j\left[\left(\frac{1+t^*_{i,k}}{1+\bar{t}_{ji,k}}\hat{w}_j\right)^{-\epsilon_k}\lambda_{ji,k}\right] \\ \hat{w}_iw_iL_i = \sum_k\sum_j\left[\hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1+t^*_{j,k})(1+\mu_k)\right] \\ \hat{\Pi}_i\Pi_i = \sum_k\sum_j\left[\mu_k\hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1+t^*_{j,k})(1+\mu_k)\right] \\ \hat{Y}_iY_i = \hat{w}_iw_iL_i+\hat{\Pi}_i\Pi_i+\sum_k\sum_j\left(\frac{t^*_{i,k}}{1+t^*_{i,k}}\hat{\lambda}_{ji,k}\lambda_{ji,k}\beta_{i,k}\hat{Y}_iY_i\right) \end{cases},$$

which features only three set of observables: (i) applied tariffs, $\bar{t}_{ji,k}$, (ii) expenditure shares, $\lambda_{ji,k}$ and $\beta_{i,k}$, and (iii) national expenditure and wage revenue, Y_i and w_iL_i; as well as two (vector of) structural parameters: (a) industry-level trade elasticities, $\{\epsilon_k\}$, and (b) industry-level markup wedges, $\{\mu_k\}$.

Compared to the Ricardian model, the above system involves $N(K+2)$ unknowns, namely, NK Nash tariff rates, $\{t_{i,k}\}$; N wage changes, $\{\hat{w}_i\}$; and N income changes, $\{\hat{Y}_i\}$. Also, in addition to data on $\bar{t}_{ji,k}$, $\lambda_{ji,k}$, $\beta_{i,k}$, and Y_i; and estimates for ϵ_k, we need estimates for industry-level markup margins, μ_k, in order to solve the above system.[14] Once the system is solved, the solution immediately pins down the prospective cost of a tariff war for each country as

$$\%\Delta\text{Real GDP}_i = \hat{Y}_i\cdot\prod_k\left(\hat{\tilde{P}}^{-\beta_{i,k}}_{i,k}\right).$$

Introducing Political Pressures. To introduce political pressures, I follow Ossa's (2014) adaptation of Grossman and Helpman (1995). His approach

[14]Note that with data on $\bar{t}_{ji,k}$, $\lambda_{ji,k}$, $\beta_{i,k}$, and Y_i, we can immediately pin down w_iL_i and Π_i as

$$\begin{cases} w_iL_i = \sum_k\sum_j\left[\lambda_{ij,k}\beta_{j,k}Y_j/(1+\bar{t}_{ij,k})(1+\mu_k)\right] \\ \Pi_i = \sum_k\sum_j\left[\lambda_{ij,k}\beta_{j,k}Y_j/(1+\bar{t}_{ij,k})(1+\mu_k)\right] \end{cases}.$$

builds on the fact that under the Cobb-Douglas-CES utility, social welfare in country i can be expressed as $W_i \equiv V_i(.) = \sum_{k,j}\left(X_{ij,k}/\tilde{P}_i\right)$, where $\tilde{P}_i = \prod_k \left(\sum \tilde{P}_{ji,k}^{-\epsilon_k}\right)^{-\beta_{i,k}/\epsilon_k}$ is the aggregate consumer price index. Instead of the government in country i maximizing the plain social welfare, he assumes that it maximizes a politically-weighted welfare function:

$$W_i = \sum_{k,j} \theta_{i,k} \frac{X_{ij,k}}{\tilde{P}_i},$$

where $\theta_{i,k}$ is the political economy weight assigned to industry k, with the weights normalized such that $\sum_k (\theta_{i,k})/K = 1$. As shown in Appendix D, Propositions 3 and 4 characterize the Nash tariffs and their effects in this setup with no further qualification except that μ_k in all the formulas be replaced with

$$\tilde{\mu}_{i,k} = \frac{\theta_{i,k}\mu_k}{1 + (1-\theta_{i,k})\,\mu_k}.$$

Considering this, when mapping the model to data, accounting for political pressures involves the extra step of determining the political weights, $\theta_{i,k}$.

2.2 Accounting for Intermediate Input Trade

Now, I consider an extended version of the baseline Ricardian model that features input-output linkages with tariffs that are subject to "duty drawbacks." In the interest of convenience, I hereafter refer to this model as the *IO model*. The drawback condition in the IO model corresponds to tariffs being applied on imported goods net of their re-exported content. Duty drawbacks are currently prevalent in many countries. More importantly, they are typically adopted voluntarily by governments. In the US, for instance, duty drawbacks have been an integral part of the tariff scheme since 1789. So, it is safe to assume that in the event of a tariff war, governments will maintain the voluntarily-adopted duty drawbacks.

To present the IO model, let me temporarily abstract from tariffs. Here, production in each country combines labor and intermediate input varieties sourced from various international suppliers using a Cobb-Douglas aggregator. Assuming that the *final* and *intermediate* composite varieties are the same, the price index of composite variety ji,k can, thus, be expressed as,

$$P_{ji,k} = \bar{a}_{ji,k} w_j^{\gamma_{j,k}} \prod_{\ell,g} P_{\ell j,g}^{\alpha_{j,k}(\ell,g)}, \tag{11}$$

where $\gamma_{j,k} = 1 - \sum_{\ell,g} \alpha_{j,k}(\ell,g)$, with $\alpha_{j,k}(\ell,g)$ denoting the constant share of *country ℓ–industry g* inputs in the production of *country j–industry k* output. It is straightforward to verify that (from a welfare point of view) the IO model is isomorphic to a reformulated model where (i) instead of intermediate inputs crossing the borders, production employs labor from various locations, and (ii) only final goods (denoted by $\mathcal{F}$) are traded across borders. In this *reformulated IO model*, the price index of a final good variety ji,k can be expressed as

$$P_{ji,k}^{\mathcal{F}} = \tilde{a}_{ji,k} \prod_{\ell} w_\ell^{\tilde{\gamma}_{j,k}(\ell)}, \tag{12}$$

where $\tilde{a}_{ji,k}$ is composed of the constant unit labor costs (namely, the $\bar{a}_{ji,k}$'s), which are invariant to policy. $\tilde{\gamma}_{j,k}(\ell)$, meanwhile, denotes the share country ℓ's labor in the production of *country j–industry k's* final good. The full $NK \times K$ matrix of labor shares, $\tilde{\boldsymbol{\gamma}} = [\tilde{\gamma}_{j,k}(\ell)]_{jk,\ell}$, can be easily derived in terms of the input-output shares as follows,[15]

$$\tilde{\boldsymbol{\gamma}} = (\boldsymbol{I}_{NK} - \boldsymbol{\alpha})^{-1} \boldsymbol{\gamma} \boldsymbol{I}_K \tag{13}$$

where $\boldsymbol{\alpha} \equiv [\alpha_{j,k}(\ell,g)]_{jk,\ell g}$ is the $NK \times NK$ global input-output matrix; while $\boldsymbol{\gamma} = [\gamma_{j,k}]_{j,k}$ is a $NK \times 1$ vector. Let me provide a brief intuition behind the price formulation specified by Equation 12. There are two equivalent ways to interpret variety ji,k's production process. One where production employs intermediate inputs produced with labor from various countries, indexed by ℓ. Another, where production directly employs labor from various countries, indexed ℓ. Equation 12 corresponds to this latter interpretation. It is also straightforward to check that $\sum_\ell \tilde{\gamma}_{j,k}(\ell) = 1$ for all j and k.

Now, suppose tariffs are applied with duty drawbacks. The drawback scheme ensures that tariffs do not propagate due to input-output linkages. Or put differently, tariffs with drawbacks are akin to a tariff applied on the traded final goods in the *reformulated* IO model. Accordingly, in the reformulated IO

[15] Equation 13 can be obtained by a simple application of the implicit function theorem to Equation 11.

model, the consumer price index of the traded final goods can be expressed as

$$\tilde{P}^{\mathcal{F}}_{ji,k} = (1 + t_{ji,k})\tilde{a}_{ji,k} \prod_{\ell} w_{\ell}^{\tilde{\gamma}_{j,k}(\ell)}. \tag{14}$$

Equilibrium in the reformulated IO model also assumes a definition that is analogous to that of the baseline Ricardian model. That is, for any given vector of tariffs, $\boldsymbol{t} = \{t_{ji,k}\}$, equilibrium is a vector of wages, $\boldsymbol{w} = \{w_i\}$; a vector of "producer" and "consumer" final good price indexes, $\boldsymbol{P}^{\mathcal{F}}_i = \{P^{\mathcal{F}}_{ji,k}\}$ and $\tilde{\boldsymbol{P}}^{\mathcal{F}}_i = \{\tilde{P}^{\mathcal{F}}_{ji,k}\}$, specified by Equations 12 and 14; and consumption quantities, $\boldsymbol{Q}^{\mathcal{F}}_i$, given by $Q^{\mathcal{F}}_{ji,k} = \mathcal{D}_{ji,k}(Y_i, \tilde{\boldsymbol{P}}^{\mathcal{F}}_i)$, where $\mathcal{D}_{ji,k}(.)$ is implied by the utility-maximization Problem 1 subject to total income equaling

$$Y_i = w_i L_i + \sum_j \sum_k t_{ji,k} P^{\mathcal{F}}_{ji,k} Q^{\mathcal{F}}_{ji,k}.$$

Before moving forward, let me summarize the *reformulated* IO model one last time. Production in each economy employs labor from various locations to produce traded final goods, indexed by $\mathcal{F}$. Trade in the final good is subject to regular tariffs. In terms of welfare implications, the reformulated IO model is isomorphic to our original IO model where production employs local labor plus intermediate inputs, but with tariffs applied subject to duty drawbacks. Note that if tariffs were not subjected to drawbacks, they will multiply due to input-output linkages and the original and reformulated IO models will no longer be isomorphic.

In the above setup, we can first show that the optimal tariff is again uniform and a function of observable revenue shares, reduced form demand elasticities, and input-output shares. The following proposition formally outlines this claim.

Proposition 5. *Country i's optimal import tariff is uniform and can be characterized as*

$$1 + t_i^* = \frac{\sum_{j \neq i} \sum_k \sum_g \phi_{ij,k} \varepsilon^{ij,g}_{ij,k}}{1 + \sum_{j \neq i} \sum_k \sum_g \phi_{ij,k} \varepsilon^{ij,g}_{ij,k}},$$

in terms of only (i) reduced-form demand elasticities, and (ii) observable "value-added" export shares, $\phi_{ij,k} = \tilde{\gamma}_{i,k}(i) X^{\mathcal{F}}_{ij,k} / \sum_{j \neq i} \sum_g \tilde{\gamma}_{i,g}(i) X^{\mathcal{F}}_{ij,g}$*, with* $\tilde{\gamma}_{i,k}(i)$*'s given by the input-out matrix per Equation 13.*

The intuition behind the uniformity of tariffs is similar to that provided by

Beshkar and Lashkaripour (2019). To repeat that intuition, due to duty drawbacks, tariffs in country i can only influence the terms-of-trade through their effect on the vector of economy-wide wages, $\boldsymbol{w}$. As a result, Nash or optimal tariffs are uniform across industries even if county i is excessively large relative to the rest of the world. The fact that tariffs are also uniform across exporters is due to country i being sufficiently small or closed with respect to the rest of the world; so that the effect of country i's tariffs on $\boldsymbol{w}$, are restricted to a change in w_i relative to wages in other countries.[16]

The key distinction between the IO model and the baseline Ricardian model is that Nash tariff levels vary with country i's dependence on imported intermediate inputs. Specifically, strong dependence on imported intermediates, which is reflected in a low $\tilde{\gamma}_{i,k}(i)$, leads to less export market power and lower Nash tariffs. I will elaborate more on this issue on Section 3, where I fit the model to actual data.

As before, using Proposition 5 and imposing further structure on preferences, we can solve the Nash tariffs and the corresponding losses in one simply step. More importantly, doing so, we only need information on observable export revenue and input-output shares, as well as industry-level trade elasticities. The following proposition outlines this result.

Proposition 6. *If preferences are described by functional form 7, the Nash tariffs, $\{t_i^*\}$, and their effect on wages, $\{\hat{w}_i\}$, and total income, $\{\hat{Y}_i\}$, can be solved as solution to the following system:*

$$\begin{cases} 1+t_i^* = \frac{1+\sum_{j\neq i}\sum_k\left[\hat{\phi}_{ij,k}\phi_{ij,k}\epsilon_k(1-\hat{\lambda}^{\mathcal{F}}_{ij,k}\lambda^{\mathcal{F}}_{ij,k})\right]}{\sum_{j\neq i}\sum_k\left[\hat{\phi}_{ij,k}\phi_{ij,k}\epsilon_k(1-\hat{\lambda}^{\mathcal{F}}_{ij,k}\lambda^{\mathcal{F}}_{ij,k})\right]} \\ \hat{\phi}_{ij,k}\phi_{ij,k} = \frac{\tilde{\gamma}_{i,k}(i)\hat{\lambda}^{\mathcal{F}}_{ij,k}\lambda^{\mathcal{F}}_{ij,k}\beta^{\mathcal{F}}_{j,k}\hat{Y}_jY_j/(1+t_j^*)}{\sum_{n\neq i}\sum_k\tilde{\gamma}_{i,k}(i)\hat{\lambda}^{\mathcal{F}}_{in,k}\lambda^{\mathcal{F}}_{in,k}\beta^{\mathcal{F}}_{n,k}\hat{Y}_nY_n/(1+t_n^*)} \\ \hat{\lambda}^{\mathcal{F}}_{ji,k} = \left[\frac{1+t_i^*}{1+\bar{t}_{ji,k}}\prod_\ell \hat{w}_\ell^{\gamma_{j,k}(\ell)}\right]^{-\epsilon_k}\left(\hat{P}^{\mathcal{F}}_{i,k}\right)^{\epsilon_k} \\ \hat{P}^{\mathcal{F}}_{i,k} = \sum_j\left(\left[\frac{1+t_i^*}{1+\bar{t}_{ji,k}}\prod_\ell \hat{w}_\ell^{\gamma_{j,k}(\ell)}\right]^{-\epsilon_k}\lambda^{\mathcal{F}}_{ji,k}\right)^{-1/\epsilon_k} \\ \hat{w}_iw_iL_i = \sum_k\sum_j\left[\hat{\lambda}^{\mathcal{F}}_{ij,k}\lambda^{\mathcal{F}}_{ij,k}\beta^{\mathcal{F}}_{j,k}\hat{Y}_jY_j/\left(1+t_j^*\right)\right] \\ \hat{Y}_iY_i = \hat{w}_iw_iL_i + \sum_k\sum_j\left(\frac{t_i^*}{1+t_i^*}\hat{\lambda}^{\mathcal{F}}_{ji,k}\lambda^{\mathcal{F}}_{ji,k}\beta^{\mathcal{F}}_{i,k}\hat{Y}_iY_i\right) \end{cases},$$

[16]To be more specific, while Country 1's tariffs impact Country 1's wage relative to Countries 2 and 3 (i.e., w_1/w_3 and w_1/w_3), they have a negligible impact on the relative wage of Countries 2 and 3 (i.e., w_2/w_3). Appendix E shows that this assumption closely approximates even the largest countries in the global economy.

which features only three set of observables: (i) *final good expenditure shares* $\lambda^{\mathcal{F}}_{ji,k}$ *and* $\beta^{\mathcal{F}}_{i,k}$, (ii) *, total final good expenditure and wage income,* Y_i *and* $w_i L_i$, (iii) *input-output shares,* $\alpha_{j,k}(\ell, g)$*; as well as structural industry-level trade elasticities,* ϵ_k.

The system specified above involves the same set of unknowns as the baseline Ricardian model. However, solving it requires data on "final" good trade and expenditure, $\lambda^{\mathcal{F}}_{ji,k}$, $\beta^{\mathcal{F}}_{i,k}$, and Y_i; as well as data on the input-output table, $\boldsymbol{\alpha}$, with the latter determining the $\tilde{\gamma}_{i,k}(i)$'s through Equation 13.[17] Once we solve the above system, the cost of a tariff war can be immediately pinned down as $\%\Delta \text{Real GDP}_i = \hat{Y}_i \cdot \prod_k \left(\hat{\tilde{P}}^{\mathcal{F}}_{i,k}\right)^{-\beta_{i,k}}$.

2.3 Discussion

Before moving forward, let me discuss a few possible concerns with the above methodology. Some of these concerns are easy to address, but some others are more consequential and actually apply to the broader literature on this topic.

A first concern is my assumption on restricted entry. This assumption was adopted in line with Ossa (2014), with the justification that it makes the model amenable to the introduction of political pressures. But what happens if we replace the *restricted entry* assumption with *free entry*? It is easy to verify that the optimal tariff formulas will remain intact. But the predicted losses from a tariff war can be quite different, and presumably larger under free entry–see Lashkaripour and Lugovskyy (2019) for a similar discussion but in the context of unilateral trade taxes.

A second concern is my abstraction from firm-selection effects. This concern is misplaced if we believe that the firm-level productivity distribution is Pareto and that the fixed marketing cost is paid in terms of labor in the destination country. In this *very* particular case, the heterogeneous firm model with selection effects, becomes isomorphic to the generalized Krugman model introduced in Section 2.1.[18] Beyond this particular case, the concern is not easy to address. Mostly, because producing analytic formulas for Nash tariffs becomes

[17] Y_i in this setup has a slightly different interpretation than national income. More specifically, it denotes total spending on final goods, which is still a readily observable variable. Moreover, solving the system specified by Proposition 6 requires information on total wage income, $w_i L_i$, which is both readily observable and can also be uniquely calculated using data on $\lambda^{\mathcal{F}}_{ji,k}$, $\beta^{\mathcal{F}}_{i,k}$, Y_i, and $\tilde{\gamma}_{i,k}(i)$.

[18] Kucheryavyy et al. (2016) establish this isomorphism. But the same isomorphism argument applies readily to the case of restricted entry.

increasingly difficult under arbitrary selection effects.[19]

A third and perhaps more serious concern, is that my analysis overlooks dynamic adjustment costs. This concern applies to a broader literature that employs static trade models when analyzing tariff wars. For instance, by imposing balanced trade, my analysis inevitably overlooks the losses from adjustments to the trade balance. Recently, several papers in the international macroeconomic literature, including Balistreri et al. (2018), Barattieri et al. (2018), and Bellora and Fontagné (2019), have used dynamic models to quantify these adjustments costs. The general consensus arising from these studies is that dynamic adjustment costs are non-trivial.

3 Quantitative Implementation

In this section I employ Propositions 2, 4, and 6 to compute the prospective cost of a tariff war for 43 major economies. I also study how the prospective cost of a tariff war has evolved over time. First, I present a formal description of the data used in my analysis.

Data on Trade Values and Input-Output Shares. To solve the system specified by Propositions 2 and 4, I need data on the full matrix of industry-level bilateral trade values, $X_{ji,k} \equiv P_{ji,k}Q_{ji,k}$. These values in turn pin down total income, $Y_i = \sum_i \sum_k X_{ji,k}$, and expenditure shares, $\beta_{i,k} = \sum_i \left(X_{ji,k}\right)/Y_i$, and $\lambda_{ji,k} = X_{ji,k}/\beta_{i,k}Y_i$. The 2016 release of the World Input-Output Database (WIOD, see Timmer et al. (2012)), reports this information for years 2000 to 2014, covering 43 economies (plus an aggregate of the rest of the world) and 56 industries. The 43 countries featured in the WIOD are listed in the first column of Table 2. Following Costinot and Rodríguez-Clare (2014), I aggregate each of the 56 industries into 15 traded industries plus an aggregated service sector—the details of the aggregation plus a complete list of the industries is provided in Table 4 of Appendix C.

Solving the system specified by Propositions 6 requires some additional data points. First, I need the full matrix of "final good" trade values, $\{X^{\mathcal{F}}_{ji,k}\}$. This information is readily available in each version of the WIOD. Second, I need data on international input-output shares in order to construct the labor share

[19] Costinot et al. (2016) have taken a notable step in this direction, by characterizing the optimal micro-level policy in a two-country model with general firm-selection effects.

matrix, $\tilde{\gamma}$, using Equation 13. For each each country, the WIOD reports input-output shares at the industry-level. With this information, I can construct the variety-level input-output shares, $\alpha_{j,k}(\ell, g)$, as the variety-level import share, $\lambda_{ji,k}$, times the reported industry-level input-output share. The total wage bill in country i can be calculated as $w_i L_i = \sum_j \sum_n \sum_k \gamma_{j,k}(i) X^{\mathcal{F}}_{jn,k}$. Similarly, total final good consumption can be calculated as, $Y_i = \sum_i \sum_k X^{\mathcal{F}}_{ji,k}$. With information on Y_i, we can simply construct the final good expenditure shares as $\beta^{\mathcal{F}}_{i,k} = \sum_j (X^{\mathcal{F}}_{ji,k})/Y_i$ and $\lambda^{\mathcal{F}}_{ji,k} = X^{\mathcal{F}}_{ji,k}/\beta^{\mathcal{F}}_{i,k} Y_i$.

To make the original WIOD data compatible with the model, I also need to purge it from trade imbalances. To elaborate, Propositions 2, 4, and 6 implicitly assume balanced trade. So applying these propositions to imbalanced trade data would identify the sum of the (i) actual cost of the tariff war, plus (ii) the cost associated with balancing global trade. In order to compute the pure cost of the tariff war, I purge the data from trade imbalances, closely following the methodology in Dekle et al. (2007).

Data on Applied Tariffs. To evaluate Propositions 2, 4, and 6, I also need information on applied tariffs for each of the countries and industries in the WIOD sample. For this purpose, I use data on applied tariffs from the United Nations Statistical Division, Trade Analysis and Information System (UNCTAD-TRAINS). The UNCTAD-TRAINS for 2014 covers 31 two-digit (in ISIC rev.3) sectors, 185 importers, and 243 export partners. In line with Caliendo and Parro (2015), I use the *simple tariff line average* of the *effectively applied tariff* (AHS) to measure each of the $\bar{t}_{ji,k}$'s. When tariff data are missing for 2014, I use tariff data for the nearest available year, giving priority to earlier years. Moreover, for the purpose of my analysis, I aggregate the UNCTAD-TRAINS data into the 16 WIOD industries described earlier, closely following the methodology in Kucheryavyy et al. (2016). Finally, I have to deal with fact that individual European Union (EU) member countries are not represented in the 2014 UNCTAD-TRAINS data. Here, I rely on the fact that the EU itself is featured as a reporter. Specifically, to construct tariffs for EU members, I use the fact that intra-EU trade is subject to zero tariffs and that all EU members impose a common external tariff on non-members.

Industry-Level Trade Elasticities. To conduct my analysis I also need estimates for the industry-level trade elasticities, $\{\epsilon_k\}$, as well as constant industry-level profit margins, $\{\mu_k\}$. In the case of the Ricardian and IO models, where data on μ_k is not needed, the trade elasticities are estimated using aggregate flows, $\{X_{ji,k}\}$, and applied tariff rates, $\bar{t}_{ji,k}$. To do so, I choose 2014 as the base year; I employ the triple-difference methodology developed by Caliendo and Parro (2015); and I estimate a trade elasticity for each of the 15 traded WIOD industries featured in my analysis. Further details regarding the trade elasticity estimation are provided in Appendix C. The estimated elasticities are reported in Table 4 of the same appendix.[20]

In the case of the generalized Krugman model, I need mutually-consistent estimates for the constant industry-level markup wedges and the trade elasticities. Attaining such estimates requires micro-level data, and is not possible with the macro-level data reported by the WIOD. Considering this, for each of the 15 WIOD industries, I borrow the estimated μ_k and ϵ_k's from Lashkaripour and Lugovskyy (2019). These adopted values are also reported in Table 5 of Appendix C. To make the analysis more transparent, I assume equal political economy weights for all industries, which is motivated by Ossa's (2016) point that "average optimal tariffs and their average welfare effects are quite similar with and without political economy pressures." The reason behind this apparent insignificance is that "political economy pressures are more about the intranational rather than the international redistribution of rents."[21]

3.1 The Cost of a Tariff War for Different Nations

Table 2 reports (i) the computed Nash tariff levels, as well as (ii) the per-cent loss in real GDP as a result of the tariff war for various countries and under various modeling assumptions. Recall that in the baseline Ricardian model, tariffs are only targeted at improving a country's wage relative to the rest of the world. Hence, the Nash tariffs are uniform, standing around 40% for the average economy. The cross-national variation in Nash tariffs, here, is driven primarily by the average trade elasticity underlying a country's exports. For instance, the Nash tariffs are significantly lower in Australia, Norway, and Russia that export predominantly in primary, high-ϵ industries.

The losses from Nash tariffs in the baseline model are driven by pure trade reduction. Moreover, all countries lose from a global tariff war irrespective of

[20] I normalize the trade elasticity for the service sector to 10, which is in between the two normalizations chosen by Costinot and Rodríguez-Clare (2014).

[21] There are specific cases, however, where political economy pressures lead to a higher efficiency loss to a global economy in the event of a tariff war. Specifically, as shown in Appendix D, if governments assign higher political economy weights to high-profit (high-μ) industries, the Nash tariffs will be more distortionary than in the absence of political economy weights.

their Nash tariff level, with losses averaging around 2.5% of the real GDP. As expected, the losses are more pronounced for (i) smaller economies as well as (ii) economies with a relatively low export market power (i.e, with a relatively high export share in high-ϵ industries).

In the generalized Krugman model where the economy is plagued by market distortions, Nash tariffs are non-uniform and include two components: a *terms-of-trade-driven* component and a *profit-shifting-driven* component. As a result, Nash tariffs are higher, averaging around 44% across all countries and industries. Accordingly, the predicted losses for a tariff war are also more significant, averaging around 2.9% of the real GDP.

There is a simple intuition for why the presence of market distortions amplify the cost of a tariff war. In the presence of market distortions, a tariff war inflicts two types of inefficiency on the global economy: (i) an efficiency loss that is driven purely by trade reduction, and (ii) an efficiency loss due to the exacerbation of exiting market distortions. To elaborate on this latter effect, note that global output in high-markup industries is already sub-optimal prior to the tariff war. In the event of a tariff war, countries impose tariffs that are more targeted towards high-markup industries. These targeted tariffs drag the global economy further away from its efficiency frontier, as they lower output in high-markup industries below the already sub-optimal level. Now, all countries lose from these developments; but economies like Korea and Taiwan that are net exporters in high-markup industries experience the greatest efficiency loss.[22]

In the presence of IO linkages too, the Nash tariffs and the corresponding losses are larger (2.6%, on average) and more heterogenous across countries relative to the baseline model. Somewhat surprisingly, once we account for IO linkages, some countries like Brazil, Norway, and Australia gain –though modestly– from a tariff war. These gains, however, come at an immense cost to economies like Malta, Slovakia, or Romania. More surprisingly, these supposed winners are not the largest economies by any account. Instead, they are economies that are positioned further upstream in the global value chain. On the flip, the major losers are also small, downstream economies that depend heavily on imported intermediates. I will elaborate more on these patterns in Subsection 3.3.

[22]It should be noted that using tariffs as a profit-shifting device is an artifact of domestic taxes being unavailable to the governments—see Lashkaripour and Lugovskyy (2019) for a more detailed discussion.

Before going forward, let me briefly address an outstanding question: *How believable are these numbers?* To get a "rough" answer, we can contrast the present numbers with those following the only documented full-fledged tariff war in history. Namely, the tariff war triggered by the Smoot-Hawley Tariff Act of 1930. The tariffs that where imposed during this documented tariff war averaged around 50%, a number strikingly close to the numbers reported in Table 2.[23] Despite this stark resemblance, one should still keep in mind that the models considered here overlook many relevant cost channels. So, they should be interpreted with great caution nonetheless.

3.2 The Cost of a Tariff War Over Time

A key advantage of the approach developed here is computational speed. Building on this advantage, I can employ my method to compute the cost of a full-fledged tariff war under different modeling specifications and across many years, so far as data availability permits. Here, I do this for the entire span of the WIOD data from 2000 to 2014, with result displayed in Figure 1. For every year, the cost is calculated as the change in real global GDP. To calculate this change, I use yearly data on real GDP from the Penn World Tables. I multiply and add the percent loss in GDP for each country by its real GDP level in that year. This task is performed using not only the baseline Ricardian model, but also the extended models that allow for market distortions and IO linkages.

Evidently, the prospective cost of a tariff war has risen rather dramatically from 2000 to 2014. Especially so, if we account for the global input-output structure and the exacerbation of market distortions by a tariff war. To provide numbers, if we account for exacerbation of market distortions, the prospective cost has risen from \$707 billion in 2000 to around \$1,395 billion in 2014. If we account for IO linkages, the prospective cost has risen even more dramatically from \$624 billion to \$1,542 billion.

Why has the prospective cost of a tariff war risen so much? The rise is driven by three independent factors:

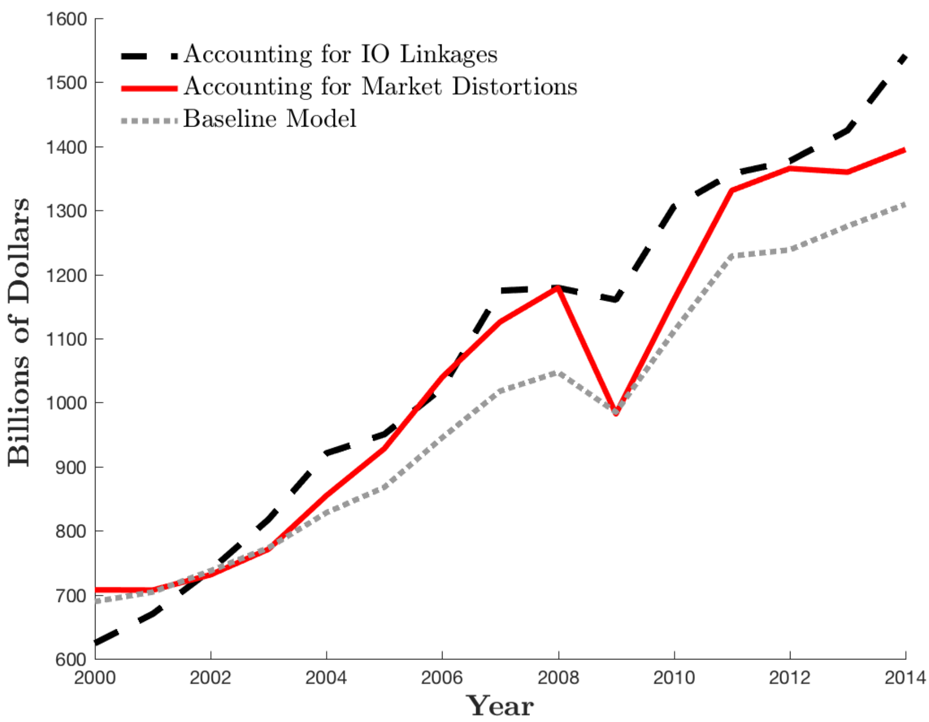
i. The increased openness of small economies to foreign trade. The importance of this factor is evident from the fact the even from the perspective of the baseline Ricardian model, the cost of a tariff war has multiplied over time.

[23]See Bagwell and Staiger (2004) for more details regarding the tariff war that followed the Smoot-Hawley Tariff Act.

Table 2: *The welfare cost of a tariff war*

	Baseline Model		Model w/ Distortions		Model w/ IO Linkages	
Country	Nash Tariff	%Δ Real GDP	Nash Tariff	%Δ Real GDP	Nash Tariff	%Δ Real GDP
AUS	13.6%	-1.45%	31.3%	-1.59%	84.6%	-0.35%
AUT	45.7%	-2.95%	38.4%	-3.74%	56.8%	-1.49%
BEL	56.6%	-3.56%	32.9%	-4.78%	75.1%	-2.16%
BGR	38.1%	-2.57%	34.6%	-2.73%	39.0%	-4.70%
BRA	103.5%	-0.39%	39.9%	-0.83%	86.8%	0.04%
CAN	22.9%	-2.74%	33.9%	-2.66%	49.7%	-2.97%
CHE	51.9%	-2.22%	28.8%	-3.02%	67.7%	0.01%
CHN	41.0%	-0.24%	42.1%	-0.42%	42.7%	-0.22%
CYP	12.6%	-3.74%	22.5%	-3.74%	17.6%	-7.72%
CZE	49.4%	-3.05%	44.0%	-3.80%	54.3%	-3.17%
DEU	59.1%	-1.09%	51.5%	-0.95%	66.1%	0.71%
DNK	56.6%	-2.39%	28.5%	-3.84%	80.9%	-1.07%
ESP	61.2%	-1.64%	42.7%	-1.64%	77.8%	-0.82%
EST	28.6%	-4.39%	25.6%	-6.59%	42.0%	-4.86%
FIN	31.5%	-1.90%	47.4%	-1.98%	38.4%	-1.65%
FRA	52.2%	-1.84%	34.7%	-2.12%	65.0%	-1.32%
GBR	27.9%	-2.14%	31.8%	-1.52%	46.6%	-2.60%
GRC	12.5%	-2.88%	31.1%	-2.33%	15.1%	-5.79%
HRV	37.0%	-3.15%	29.2%	-3.74%	59.2%	-2.90%
HUN	52.6%	-4.36%	38.6%	-5.84%	57.1%	-2.17%
IDN	51.7%	-0.90%	39.8%	-1.43%	45.6%	0.15%
IND	47.5%	-0.53%	39.2%	-0.48%	50.5%	-0.02%
IRL	117.3%	-1.40%	24.8%	-6.60%	97.3%	-0.76%
ITA	49.6%	-0.89%	51.3%	-0.87%	57.5%	-0.05%
JPN	44.3%	-0.85%	44.1%	-1.04%	46.4%	-0.73%
KOR	43.6%	-1.29%	42.1%	-1.97%	46.7%	0.34%
LTU	31.6%	-4.51%	32.8%	-5.35%	64.4%	-2.41%
LUX	12.0%	-6.32%	19.9%	-6.03%	15.0%	-20.95%
LVA	26.0%	-3.33%	25.8%	-4.18%	47.6%	-6.66%
MEX	38.6%	-2.41%	38.8%	-2.52%	54.5%	-1.24%
MLT	12.4%	-5.68%	23.4%	-5.15%	18.2%	-18.79%
NLD	37.3%	-4.51%	27.9%	-5.32%	77.6%	1.46%
NOR	17.1%	-2.23%	34.5%	-2.24%	91.7%	2.46%
POL	46.1%	-2.83%	37.4%	-2.80%	59.4%	-2.54%
PRT	35.0%	-3.01%	35.6%	-2.44%	49.7%	-3.15%
ROU	32.7%	-2.70%	32.9%	-2.23%	40.2%	-3.67%
RUS	12.1%	-2.24%	33.4%	-1.96%	32.5%	-1.37%
SVK	41.7%	-4.69%	39.7%	-4.42%	46.1%	-4.78%
SVN	46.1%	-3.39%	36.5%	-4.11%	56.0%	-2.85%
SWE	38.4%	-2.06%	38.4%	-2.26%	54.3%	-0.18%
TUR	46.7%	-1.51%	43.7%	-1.81%	56.3%	-0.86%
TWN	35.4%	-2.60%	32.0%	-4.06%	35.7%	1.66%
USA	39.2%	-0.87%	36.8%	-0.64%	45.9%	-1.10%
Average	40.6%	-2.52%	35.4%	-2.94%	53.3%	-2.63%

Figure 1: The prospective cost of a tariff war over time



ii. The rise of global market power, which encourages countries to apply more-targeted Nash tariffs in the event of a tariff war. Recall that targeted tariffs exacerbate market distortions, and drag the global economy further way from its efficiency frontier. This factor perhaps explains the divergence between the losses predicted with and without accounting for market distortions.

iii. The increased dependence of individual economies on the global value chain. Again, this factor explains why the prospective loss predicted by the model with IO linkages has risen rather dramatically relative to the cost predicted by the baseline model.

In any case, the present analysis indicates that given the current state of the global economy, the prospective cost of a full-fledged tariff war is immense. Take for instance the year 2014, where the prospective cost of a tariff war was \$1,542 billion once we account for the global IO structure. That is the equivalent of erasing South Korea from the global economy.

3.3 Position in the Global Value Chain

The present analysis provides a novel glimpse into how global value chains have exposed some countries more than ever to a tariff war. To make this point formally, let me fix ideas by using the baseline Ricardian model as a conceptual benchmark. In this baseline, a country's market power is driven by its monopoly over differentiated varieties produced with local labor. Now, add global value chains into the mix. In this case, local labor will account for a smaller fraction of a country's differentiated output the more it specializes in downstream industries. So, downstream-ness will diminish a country's market power relative to the rest of the world. The intuition being that a downstream economy's tariffs has a relatively small effect on its terms-of-trade, as measured by its wage relative to the rest of the world. On the flip side of this, the market power of upstream economies multiplied by global value chains.

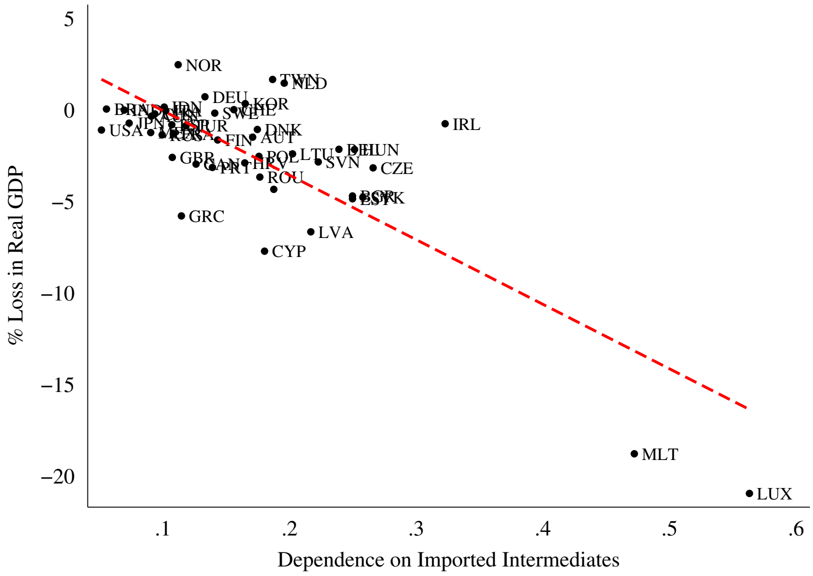
To make this point even more formally, I plot the national cost of tariff war against a country's dependence on intermediate inputs in Figure 2. The dependence index (on the x-axis) is measured as one minus a trade-weighted average of $\gamma_{i,k}(i)$'s. Roughly speaking, this index tells us what percentage of a country's output is comprised of local labor content.

It is evident from Figure 2 that small downstream economies like Malta and Luxembourg, which depend more heavily on imported intermediates, incur the greatest loss from a tariff war. This outcome is aligned with my earlier assertion that IO linkages diminish market power for downstream economies. By contrast, a country like Norway that exports predominantly in upstream industries (like crude oil) can even gain from the tariff war. Simply, because if its upstream position in the global value chain.

On a broader level, the above arguments qualify an old belief that large countries can win a tariff war, whereas small countries always lose (Johnson (1953)). My analysis indicates that a country's degree of "upstream-ness" in the global value chain is as important of a factor as its size. consider again the case of Norway, which gains around 2.5% in the event of a tariff war once we account for IO linkages. By every account, Norway is a small economy. However, it exports primarily in upstream industries like Oil. Based on Johnson's (1953) theory, Norway should lose from a tariff war. The baseline Ricardian model, which neglects global value chains, confirm this view. But this prediction is overturned, once we account for the global IO structure.

It should be noted once again that these results hinge on countries providing

Figure 2: *Cost of a tariff war vs. Dependence on imported intermediates*



duty drawbacks in the event of a tariff war. As noted earlier, duty drawbacks are voluntarily adopted by many countries, and there is no reason to rule them out in face of a tariff war.[24] Nonetheless, absent duty drawbacks, a country's market power also depends on its *extraterritorial taxing power* (see Beshkar and Lashkaripour (2019)). That is, a small downstream economy that re-exports a significant fraction of its imports, can levy tax on goods that are produced and eventually consumed outside its borders. As a result, it can raise revenue from foreign entities while imposing minimal distortion on the local economy. Duty drawbacks render extraterritorial taxing power obsolete, but so does retaliation. So, even without duty drawbacks, downstream economies will still experience immense losses, but the gains experienced by upstream economies will also diminish.

3.4 The Cost of a US-China Tariff War on the Global Economy

The recent tariff face-off between the US and China has been the source of revived academic interest in tariff wars. Currently, a feared scenario is one where the US and China engage in a two-way tariff war, without necessarily raising tariffs on other, non-involved trading partners. The methodology developed

[24]From a pure social welfare perspective, duty drawbacks act as an export subsidy and harm a country's terms-of-trade. So, their voluntary adoption is perhaps motivated by political economy considerations, which will prevail in the event of a tariff war.

Table 3: The main winners and Losers from a US-China tariff war

Main Losers		Main Winners	
Country	ΔReal GDP (millions of dollars)	Country	ΔReal GDP (millions of dollars)
United States	-$24,680	Mexico	$2,028
China	-$15,774	India	$678
Australia	-$58	Japan	$581
Ireland	-$26	Canada	$460

here, can be equally applied to compute the cost associated with this two-way tariff war scenario.

In Appendix B, I show that an analog of Propositions 2, 4, and 6 can be produced for the case where *only* two (or any number of) countries engage in a two-way tariff war. Using these analog propositions, we can compute the cost of a two-way tariff war in one step, with knowledge of observable as well as the structural markup wedges and trade elasticities (μ_k and ϵ_k).

I apply this method to analyze a two-way tariff war involving the US and China, using the WIOD data from 2014. The results indicate that the bilateral Nash tariffs adopted by China and the US are slightly lower than those adopted in a full-fledged global tariff war. Perhaps encouragingly, the baseline Ricardian model predicts that the US would impose a 25% China-specific Nash tariff—a number that is remarkably close to what the US authorities have been pointing to in light of their recent face-off with China. The model that accounts for market distortions, however, predicts higher bilateral Nash tariffs that are closer to 50%.

My analysis indicates that a US-China tariff war would shave $34 billion off the global GDP, which is the equivalent of Paraguay's economy.[25] The US-China tariff war also creates winners and losers. Table 3 lists the countries that experience the largest negative effects as well as those that experience the largest positive effects. Expectedly the US and China are the main losers, respectively losing $25 and $16 billion worth of real GDP.

These numbers resonate with those estimated by Amiti et al. (2019), who use the "ex-post" approach described in the Introduction. Specifically, they estimate a $16.8 billion loss for the US economy, implied by already-applied

[25]These are numbers implied by the generalized Krugman model. The losses implied by the Ricardian and IO models are somewhat smaller. In the generalized Krugman model targeted (non-uniform) tariffs inflict an additional efficiency loss to the global economy, by lowering output in high-profit industries below its already sub-optimal level.

US tariff rates ranging between 10% and 50% and retaliatory Chinese tariffs averaging 16%. The $25 billion loss predicted here corresponds to a full-fledged version of the US tariff war, which involves Nash tariffs averaging around 45% for the US and 52% for China.

An interesting finding here is that many countries can lose from a US-China tariff war, even without being directly involved. Australia and Ireland, for instance, lose from trade destruction and diversion. Specifically, as total income in the US and China drops, these two economies lose part of their international demand. Moreover, some markets divert their imports from Australia and Ireland to the US and China, to benefit from the reduced wages in the latter two economies. On the flip side, Mexico, Canada, India, and Japan experience significant gains from trade diversion. That is because the two-way tariff war induces the US and China to divert imports from each other to the likes of Mexico, India, Canada, and Japan.

4 Concluding Remarks

Building on recent advances in quantitative trade theory, I developed a simple, sufficient statistics methodology to compute the prospective cost of a full-fledged global tariff war. My proposed methodology has two basic advantages. First, by relying on analytic formulas, it is incredibly fast, delivering a more than 100-fold increase in computational speed relative to alternatives. Second, it can account for input-output linkages, which are a missing ingredient in existing ex-ante analyses of tariff wars.

Applying my methodology to data across many countries, industries, and years, and by accounting for the global input-structure, my analysis shed fresh light on the consequences of a full-fledged global tariff war. Among other results, I highlighted that (*i*) a significant fraction of the cost associated with a full-fledged tariff war due to the exacerbation of already-existing market distortions; (*ii*) the prospective cost of a tariff war to the global economy has more-than-doubled over the past 15 years; (*iii*) that small downstream economies are the main losers; and (*iv*) that countries can incur significant losses from a US-China tariff war without even if they are not directly involved.

Moving forward, a natural next step is to apply the proposed methodology to an even broader set of countries and industries using richer, confidential data. Previously, such applications were partially impeded by computational burden; but practitioners can employ the present methodology to circumvent this particular obstacle. Another avenue for future research is to extend the methodology itself by incorporating multiple factors of production and other short-run adjustment costs.

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A Proofs

In the proofs that follow, I will express all equilibrium outcomes as a function of feasible tariff-wage combinations, i.e., $(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})$. For instance, welfare in country i can be expressed as $W_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})$, where $\boldsymbol{w}$ is the vector of equilibrium wages that implicitly depend on the applied tariffs. This combination is feasible in that the tariff and wage rates satisfy the equilibrium conditions outlined in Section 2.

A.1 Proposition 1

The first order condition for a tariff on imported variety ji, k can be expressed as follows

$$\begin{aligned}\frac{d \ln W_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{d \ln(1+t_{ji,k})} =& \frac{\partial \ln V(.)}{\partial \ln Y_i} \frac{\partial \ln Y_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln(1+t_{ji,k})} + \frac{\partial \ln V(.)}{\partial \ln \tilde{P}_{ji,k}} \frac{\partial \ln \tilde{P}_{ji,k}(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln(1+t_{ji,k})} \\ &+ \sum_{\ell} \left[\frac{\partial \ln V(.)}{\partial \ln Y_i} \frac{\partial \ln Y_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln w_\ell} \frac{d \ln w_\ell}{d \ln(1+t_{ji,k})} \right] \\ &+ \sum_{\ell} \sum_{g} \left[\frac{\partial \ln V(.)}{\partial \ln \tilde{P}_{\ell i,g}} \frac{\partial \ln \tilde{P}_{\ell i,g}(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln w_\ell} \frac{d \ln w_\ell}{d \ln(1+t_{ji,k})} \right] = 0. \end{aligned} \tag{15}$$

The first term in the F.O.C. accounts for the effect of tariffs on income through tax revenues. Noting that (i) $Y_i = w_i L_i + \sum_j \sum_k t_{ji,k} P_{ji,k} Q_{ji,k}$, and (ii) $Q_{ji,k} = \mathcal{D}_{ji,k}(Y_i, \tilde{\boldsymbol{P}}_i)$, this term can be expressed as

$$\frac{\partial \ln Y_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln(1+t_{ji,k})} = Y_i^{-1} \left\{ \tilde{P}_{ji,k} Q_{ji,k} + \sum_g \sum_j \left(t_{ji,g} P_{ji,g} Q_{ji,g} \left[\frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln \tilde{P}_{ji,k}} \frac{\partial \ln \tilde{P}_{ji,k}(.)}{\partial \ln(1+t_{ji,k})} + \frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln Y_i} \frac{\partial \ln Y_i(.)}{\partial \ln(1+t_{ji,k})} \right] \right) \right\} \tag{16}$$

The second term in the F.O.C. accounts for the effect of tariffs on consumer prices. Given Roy's identity, $\frac{\partial V(.)/\partial P_{ji,k}}{\partial V(.)/Y_i} = -Q_{ji,k}$, and the complete passthrough of tariffs on to consumer prices, $\partial \ln \tilde{P}_{ji,k}(.)/\partial \ln(1+t_{ji,k}) = 1$, this term can be expressed as

$$\frac{\partial \ln V(.)}{\partial \ln \tilde{P}_{ji,k}} \frac{\partial \ln \tilde{P}_{ji,k}(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln(1+t_{ji,k})} = -\frac{\partial \ln V(.)}{\partial \ln Y_i} \frac{\tilde{P}_{ji,k} Q_{ji,k}}{Y_i}. \tag{17}$$

Importantly, given that country i is a small economy (and assigning w_j as the numeraire), we can set $dw_\ell/d(1+t_{ji,k}) = 0$ for all $\ell \neq i$ in Equation 15. That is, while country i's tariff affects the wage in country i relative to the rest of the world, it has a negligible effect of the relative wage between *other* countries. Considering this; using our earlier definition for the demand elasticity, $\varepsilon_{ji,k} \equiv \partial \ln \mathcal{D}_{ji,k}(.)/\partial \ln \tilde{P}_{ji,k}$; letting $\eta_{ji,k} \equiv \partial \ln \mathcal{D}_{ji,k}(.)/\partial \ln Y_i$ denote the income elasticity; noting that $\lambda_{ji,k} = \tilde{P}_{ji,k} Q_{ji,k}/Y_i$; and plugging Equations 16 and 17 back into 15, implies the following optimality condition:

$$\lambda_{ji,k}+\frac{t_{ji,k}}{1+t_{ji,k}}\lambda_{ji,k}\varepsilon_{ji,k}+\sum_{j}\sum_{g}\left[\frac{t_{ji,g}}{1+t_{ji,g}}\lambda_{ji,g}\eta_{ji,g}\right]\frac{\partial\ln Y_i(.)}{\partial\ln(1+t_{ji,k})}$$
$$-\lambda_{ji,k}+\left(\frac{\partial\ln Y_i(.)}{\partial\ln w_i}+\sum_{g}\frac{\partial\ln V(.)/\partial\ln\tilde{P}_{ii,g}}{\partial\ln V(.)/\partial\ln Y_i}\frac{\partial\ln\tilde{P}_{ii,g}(.)}{\partial\ln w_i}\right)\frac{d\ln w_i}{d\ln(1+t_{ji,k})}=0$$

To evaluate the above condition, we can apply the Implicit Function Theorem to the balanced trade condition, $\sum_{j\neq i}\sum_k P_{ji,k}Q_{ji,k} = \sum_{j\neq i}\sum_k P_{ij,k}Q_{ij,k}$, to characterize $d\ln w_i/d\ln(1+t_{ji,k})$ as follows:

$$\begin{aligned}\frac{d\ln w_i}{d\ln(1+t_{ji,k})} &= -\frac{\frac{\partial}{\partial\ln(1+t_{ji,k})}\left[\sum_j\sum_g P_{ji,g}Q_{ji,g}-\sum_j\sum_g P_{ij,g}Q_{ij,g}\right]}{\frac{\partial}{\partial\ln w_i}\left[\sum_j\sum_g P_{ji,g}Q_{ji,g}-\sum_j\sum_g P_{ij,g}Q_{ij,g}\right]}\\
&= -\frac{\sum_j\sum_g\left(P_{ji,g}Q_{ji,g}\left[\frac{\partial\ln\mathcal{D}_{ji,g}(.)}{\partial\ln\tilde{P}_{ji,k}}\frac{\partial\ln\tilde{P}_{ji,k}(.)}{\partial\ln(1+t_{ji,k})}+\frac{\partial\ln\mathcal{D}_{ji,g}(.)}{\partial\ln Y_i}\frac{\partial\ln Y_i(.)}{\partial\ln(1+t_{ji,k})}\right]\right)}{\frac{\partial}{\partial\ln w_i}\left[\sum_j\sum_g P_{ji,g}Q_{ji,g}-\sum_j\sum_g P_{ij,g}Q_{ij,g}\right]}\\
&= -\frac{\sum_j\sum_g\left(\frac{\lambda_{ji,g}}{1+t_{ji,g}}\left[\varepsilon^{ji,k}_{ji,g}+\eta_{ji,g}\frac{\partial\ln Y_i(.)}{\partial\ln(1+t_{ji,k})}\right]\right)Y_i}{\frac{\partial}{\partial\ln w_i}\left[\sum_j\sum_g P_{ji,g}Q_{ji,g}-\sum_j\sum_g P_{ij,g}Q_{ij,g}\right]}.\end{aligned}$$

Defining,

$$\bar{\tau}_i\equiv\frac{\frac{\partial Y_i(.)}{\partial\ln w_i}+\sum_g\frac{\partial V(.)/\partial\tilde{P}_{ii,g}}{\partial V(.)/\partial Y_i}\frac{\partial\tilde{P}_{ii,g}(.)}{\partial\ln w_i}}{\frac{\partial}{\partial\ln w_i}\left[\sum_j\sum_g P_{ji,g}Q_{ji,g}-\sum_j\sum_g P_{ij,g}Q_{ij,g}\right]},\tag{18}$$

The optimality condition specified by Equation 15, reduces to the following:

$$\sum_j\sum_g\left((1-\frac{1+\bar{\tau}_i}{1+t_{ji,g}})\lambda_{ji,g}\left[\varepsilon^{ji,k}_{ji,g}+\eta_{ji,g}\frac{\partial\ln Y_i(.)}{\partial\ln(1+t_{ji,k})}\right]\right)=0.$$

Stated in the matrix form, Country i's optimal tariffs thus solve the following system,

$$\mathbf{\Omega}_i\left[1-\frac{1+\bar{\tau}_i}{1+t_{ji,g}}\right]_{j,k}=\mathbf{0},$$

where $\mathbf{\Omega}_i=\left[\lambda_{ji,g}(\varepsilon^{ji,k}_{ji,g}+\eta_{ji,g}\frac{\partial\ln Y_i(.)}{\partial\ln(1+t_{ji,k})})\right]_{jg,jk}$ is a $NK\times NK$ matrix. Provided that $\mathbf{\Omega}_i$ is non-singular, the unique solution to the above system is the trivial solution,

$$1+t^*_{ji,k}=1+\bar{\tau}_i,\quad\forall ji,k.$$

So, to determine the optimal tariff we simply need to characterize $\bar{\tau}_i$, supposing that $t^*_{ji,k}=\bar{\tau}_i$. Using my choice of notation for trade values ($X_{ji,k}=P_{ji,k}q_{ji,k}$), the aforementioned step yields the following:

$$
\begin{aligned}
\bar{\tau}_i \equiv & \frac{\frac{\partial Y_i(.)}{\partial \ln w_i} + \sum_g \frac{\partial V(.)/\partial \tilde{P}_{ii,g}}{\partial V(.)/\partial Y_i} \frac{\partial \tilde{P}_{ii,g}(.)}{\partial \ln w_i}}{\frac{\partial}{\partial \ln w_i}\left[\sum_{j\neq i}\sum_g P_{ji,g}Q_{ji,g} - \sum_{j\neq i}\sum_g P_{ij,g}Q_{ij,g}\right]} \\
= & \frac{w_i L_i + \sum_{j\neq i}\sum_g \left[\bar{\tau}_i X_{ji,g} \sum_s \left(\frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln \tilde{P}_{ii,s}} \frac{\partial \ln \tilde{P}_{ii,s}(.)}{\partial \ln w_i}\right)\right] - \sum_g X_{ii,g}}{\sum_{j\neq i}\sum_g \left[X_{ji,g}\sum_s \left(\frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln \tilde{P}_{ii,s}} \frac{\partial \ln \tilde{P}_{ii,s}(.)}{\partial \ln w_i}\right)\right] - \sum_{j\neq i}\sum_g \left[X_{ij,g}\left[\frac{\partial \ln \tilde{P}_{ij,g}(.)}{\partial \ln w_i} + \sum_s \left(\frac{\partial \ln \mathcal{D}_{ij,g}(.)}{\partial \ln \tilde{P}_{ij,s}} \frac{\partial \ln \tilde{P}_{ij,s}(.)}{\partial \ln w_i}\right)\right]\right]} \\
= & \frac{\sum_{j\neq i}\sum_g X_{ij,g}}{-\sum_{j\neq i}\sum_g X_{ij,g}\left[1+\sum_s \varepsilon_{ij,g}^{ij,s}\right]} = \frac{\sum_j \sum_g \sum_s \chi_{ij,g}\varepsilon_{ij,g}^{ij,s}}{1+\sum_j\sum_g\sum_s \chi_{ij,g}\varepsilon_{ij,g}^{ij,s}} - 1
\end{aligned}
$$

where the second line follows from Roy's identity that $\frac{\partial V(.)/\partial P_{ii,g}}{\partial V(.)/\partial Y_i} = -Q_{ii,k}$, and $\chi_{ij,g} \equiv X_{ij,g}/\sum_{j\neq i}\sum_g X_{ij,g}$.

A.2 Proposition 3

The first order condition for a tariff on imported variety ji, k can be expressed as follows

$$
\begin{aligned}
\frac{d \ln W_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{d \ln(1+t_{ji,k})} = & \frac{\partial \ln V(.)}{\partial \ln Y_i} \frac{\partial \ln Y_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln(1+t_{ji,k})} + \frac{\partial \ln V(.)}{\partial \ln \tilde{P}_{ji,k}} \frac{\partial \ln \tilde{P}_{ji,k}(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln(1+t_{ji,k})} \\
& + \sum_\ell \left[\frac{\partial \ln V(.)}{\partial \ln Y_i} \frac{\partial \ln Y_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln w_\ell} \frac{d \ln w_\ell}{d \ln(1+t_{ji,k})}\right] \\
& + \sum_\ell \sum_g \left[\frac{\partial \ln V(.)}{\partial \ln \tilde{P}_{\ell i,g}} \frac{\partial \ln \tilde{P}_{\ell i,g}(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln w_\ell} \frac{d \ln w_\ell}{d \ln(1+t_{ji,k})}\right] = 0.
\end{aligned}
$$

The above F.O.C. is similar to that analyzed earlier, with one basic difference. The first term in the F.O.C. that accounts for the effect of tariffs on total income, now includes the effect on both tariff revenue and total profits. Specifically, given that $Y_i = w_i L_i + \Pi_i + \sum_j \sum_k t_{ji,k} P_{ji,k} Q_{ji,k}$, we can write this terms as follows:

$$
\begin{aligned}
\frac{\partial \ln Y_i(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w})}{\partial \ln(1+t_{ji,k})} = & Y_i^{-1}\left\{\tilde{P}_{ji,k}Q_{ji,k} + \sum_g \sum_{j\neq i}\left(t_{ji,g}P_{ji,g}Q_{ji,g}\left[\frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln \tilde{P}_{ji,k}} \frac{\partial \ln \tilde{P}_{ji,k}(.)}{\partial \ln(1+t_{ji,k})} + \frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln Y_i} \frac{\partial \ln Y_i(.)}{\partial \ln(1+t_{ji,k})}\right]\right)\right. \\
& \left. + \sum_g \left(\frac{\mu_g}{1+\mu_g} P_{ii,g}Q_{ii,g}\left[\frac{\partial \ln \mathcal{D}_{ii,g}(.)}{\partial \ln \tilde{P}_{ji,k}} \frac{\partial \ln \tilde{P}_{ji,k}(.)}{\partial \ln(1+t_{ji,k})} + \frac{\partial \ln \mathcal{D}_{ii,g}(.)}{\partial \ln Y_{i,k}} \frac{\partial \ln Y_i(.)}{\partial \ln(1+t_{ji,k})}\right]\right)\right\}.
\end{aligned}
$$

Noting that Equations still apply under the *generalized Krugman model*, they (along with the above equation) imply the following optimality condition:

$$
\sum_g \sum_{j\neq i}\left[\left(t_{ji,g} - \bar{\tau}_i\right)\frac{\lambda_{ji,g}}{1+t_{ji,g}}\varepsilon_{ji,g}^{ji,k}\right] + \sum_g \left(\frac{\mu_g}{1+\mu_g}\lambda_{ii}\varepsilon_{ii,g}^{ji,k}\right) \tag{19}
$$

$$+\sum_g \sum_{j\neq i}\left[\left(\left(t_{ji,g}-\bar{\tau}_i\right)\frac{\lambda_{ji,g}}{1+t_{ji,g}}\eta_{ji,g}\right)+\sum_g\left(\frac{\mu_g}{1+\mu_g}\lambda_{ii,g}\gamma_{ii,g}\right)\right]\frac{\partial \ln Y_i(.)}{\partial \ln(1+t_{ji,k})}=0,$$

where $\bar{\tau}_i$ is defined as earlier. The second term in the above equation can be eliminated due to a redundancy in optimal tariffs. Specifically, since country i is a small open economy, multiplying wages in the rest of the world and dividing all of country i's tariff rates by (i.e., $1+t_{ji,k}$'s) by $1+\delta>0$, leads to the same exact equilibrium. Considering this, by choice of δ, there is always one optimal combination of tariffs and wages such that

$$\Delta(\boldsymbol{t}_i,\boldsymbol{t}_{-i};\boldsymbol{w})=\left[\sum_g\sum_{j\neq i}\left(\left(t_{ji,g}-\bar{\tau}_i\right)\frac{\lambda_{ji,g}}{1+t_{ji,g}}\gamma_{ji,g}\right)+\sum_g\left(\frac{\mu_g}{1+\mu_g}\lambda_{ii,g}\gamma_{ii,g}\right)\right]=0. \quad (20)$$

Considering this; assuming zero cross-substitutability between industries; and noting that $\sum_j \lambda_{ji,k}\varepsilon^{ji,k}_{ji,k}=-\lambda_{ji,k}$, one of the multiple optimal tariffs combinations is given by

$$\left[\frac{1+\tilde{\tau}_i}{1+t^*_{ji,k}}\right]_{j\neq i}=\boldsymbol{\mathcal{E}}^{-1}_{i,k}\left(\mathbf{1}_{(N-1)\times 1}+\left[\frac{\lambda_{ii,k}\varepsilon^{ji,k}_{ii,k}}{\lambda_{ji,k}(1+\mu_k)}\right]_{j\neq i}\right)\quad ,\forall k \quad (21)$$

where $\boldsymbol{\mathcal{E}}_{i,k}\equiv\left[\varepsilon^{ji,k}_{ji,k}\right]_{j,J}$ is a $(N-1)\times(N-1)$ matrix of demand elasticities, while $\tilde{\tau}_i$ is τ_i (as defined by 18) adjusted by the choice of δ that ensures 20. Note that the above solution is one of the multiple optimal tariff solutions. Depending on how wages are normalized in the rest of the world, Equation 21 with $\bar{\tau}_i$ replaced with $\tilde{\tau}_i$ specifies another solution. Considering this and following the same steps taken in Appendix A.1 to determine $\bar{\tau}_i$, we can show that country i's Nash tariffs solve the following system

$$\left[\frac{1+\bar{\tau}^*_i}{1+t^*_{ji,k}}\right]_{j\neq i}=\boldsymbol{\mathcal{E}}^{-1}_{i,k}\left(\mathbf{1}_{(N-1)\times 1}+\left[\frac{\lambda_{ii,k}\varepsilon^{ji,k}_{ii,k}}{\lambda_{ji,k}(1+\mu_k)}\right]_{j\neq i}\right),\quad \forall k$$

$$1+\bar{\tau}^*_i=\frac{\sum_{j\neq i}\sum_k\left[\chi_{ij,k}\varepsilon_{ij,k}-(t^*_{ji,k}-\bar{\tau}^*_i)\chi'_{ji,k}\varepsilon^{ii,k}_{ji,k}\right]}{1+\sum_{j\neq i}\sum_k\chi_{ij,k}\varepsilon_{ij,k}},$$

which features $(N-1)\times K$ tariff rates, $\{1+t^*_{ji,k}\}$ and a uniform shifter, $1+\bar{\tau}^*_i$. In the above expression, $\chi_{ij,k}\equiv X_{ij,k}/\sum_{n\neq i}\sum_k X_{in,k}$ and $\chi'_{ji,k}\equiv X_{ji,k}/\sum_{n\neq i}\sum_k X_{ni,k}$, as defined in the main text. The extra term showing up in the numerator of the expression for $\bar{\tau}^*$, accounts for the cross-cost passthrough facing country i, when acting as a multi-product monopolist. To elaborate more, a uniform tariff is akin to a markup applied on w_i for all exported goods. Such a markup, however, affects country i's tax revenues which can be viewed as revenue from selling a second product (aside from the output of local labor). The term $\sum_{j\neq i}\sum_k\sum_s(t^*_{ji,k}-\bar{\tau}^*_i)\nu_{ji,k}\varepsilon^{ii,s}_{ji,k}$ accounts for these crosspassthrough effects.

The above formula can be greatly simplified, if we we further assume that preferences are given by Cobb-Douglas-CES parametrization in Equation 7. Then, $t^*_{ji,k}$ becomes uniform across countries, i.e., $t^*_{ji,k} = t^*_{i,k}$ for all j. Moreover, given that (i) $\varepsilon^{ji,k}_{ii,k} = \epsilon_k \lambda_{ji,k}$, (ii) $\varepsilon_{ji,k} = -1 - \epsilon_k(1 - \lambda_{ji,k})$, and (iii) that $\sum_{j\neq i} \sum_k \chi_{ij,k} = 1$, it is straightforward to verify that

$$1 + t^*_{i,k} = \left[\frac{\sum_{j\neq i} \sum_g X_{ij,g} \left[1 + \epsilon_g \left(1 - \lambda_{ij,g}\right)\right]}{\sum_{j\neq i} \sum_g \left[X_{ij,g}\epsilon_g \left(1 - \lambda_{ij,g}\right) + \mathcal{X}_{ji,k}\epsilon_g \lambda_{ii,g}\right]} \right] \frac{\left(1 + \mu_k\right)\left(1 + \epsilon_k \lambda_{ii,k}\right)}{1 + \mu_k + \epsilon_k \lambda_{ii,k}}.$$

where $\mathcal{X}_{ji,g} \equiv \sum_s \left(\frac{\mu_s \epsilon_s \lambda_{ii,s}}{1+\mu_s+\epsilon_s\lambda_{ii,s}} \right) X_{ji,g}$. Note that in the above expression, the uniform term is stated using export levels. But dividing both the numerator and denominator of the uniform term by $\sum_{j\neq i} \sum_k X_{ij,k} = \sum_{j\neq i} \sum_k X_{ji,k}$, we can also express it in terms of export shares $\chi'_{ji,k}$ and $\chi_{ij,k}$.

A.3 Proposition 5

The proof of the Proposition 3 is very similar to that of Proposition 1, except that $\tilde{P}_{ji,k}(.)$ depends on the wage rate in every country. Specifically,

$$\tilde{P}_{ji,k}(\boldsymbol{t}_i, \boldsymbol{t}_{-i}; \boldsymbol{w}) = \left(1 + t_{ji,k}\right) \tilde{a}_{ji,k} \prod_{\ell} w_{\ell}^{\tilde{\gamma}_{j,k}(\ell)}.$$

Hence, whereas in the Ricardian model $\partial \ln \tilde{P}_{ji,k}(.)/\partial \ln w_j = 1$, in the IO model, $\partial \ln \tilde{P}_{ji,k}(.)/\partial \ln w_j = \gamma_{j,k}(j)$. Considering this and following the same exact steps as those conducted in Section A.1, we can show that

$$1 + t^*_i = 1 + \bar{\tau}_i, \quad \forall i \in \mathbb{C}$$

where $\bar{\tau}_i$ is given by Equation 18. So, to prove Proposition 5, we need derive an expression for $\bar{\tau}_i$ subject to $\partial \ln \tilde{P}_{ji,k}(.)/\partial \ln w_j = \gamma_{j,k}(j)$. We can do so along the following lines (using $X^{\mathcal{F}} \equiv P^{\mathcal{F}} Q^{\mathcal{F}}$ to denote the value of "final good" trade in the reformulated IO model):

$$\bar{\tau}_i \equiv \frac{\frac{\partial Y_i(.)}{\partial \ln w_i} + \sum_g \frac{\partial V(.)/\partial \tilde{P}^{\mathcal{F}}_{ii,g}}{\partial V(.)/\partial Y_i} \frac{\partial \tilde{P}^{\mathcal{F}}_{ii,g}(.)}{\partial \ln w_i}}{\frac{\partial}{\partial \ln w_i} \left[\sum_{j\neq i} \sum_g P^{\mathcal{F}}_{ji,g} Q^{\mathcal{F}}_{ji,g} - \sum_{j\neq i} \sum_g P^{\mathcal{F}}_{ij,g} Q^{\mathcal{F}}_{ij,g} \right]}$$

$$= \frac{w_i L_i + \sum_{j\neq i} \sum_g \left[\bar{\tau}_i X^{\mathcal{F}}_{ji,g} \sum_s \left(\frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln \tilde{P}^{\mathcal{F}}_{ii,s}} \frac{\partial \ln \tilde{P}^{\mathcal{F}}_{ii,s}(.)}{\partial \ln w_i} \right) \right] - \sum_g X^{\mathcal{F}}_{ii,g}}{\sum_{j\neq i} \sum_g \left[X^{\mathcal{F}}_{ji,g} \sum_s \left(\frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln \tilde{P}^{\mathcal{F}}_{ii,s}} \frac{\partial \ln \tilde{P}^{\mathcal{F}}_{ii,s}(.)}{\partial \ln w_i} \right) \right] - \sum_{j\neq i} \sum_g \left[X^{\mathcal{F}}_{ij,g} \left[\frac{\partial \ln \tilde{P}^{\mathcal{F}}_{ij,g}(.)}{\partial \ln w_i} + \sum_s \left(\frac{\partial \ln \mathcal{D}_{ij,g}(.)}{\partial \ln \tilde{P}^{\mathcal{F}}_{ij,s}} \frac{\partial \ln \tilde{P}^{\mathcal{F}}_{ij,s}(.)}{\partial \ln w_i} \right) \right] \right]}$$

$$= \frac{\sum_{j\neq i}\sum_g \tilde{\gamma}_{i,g}(g) X^{\mathcal{F}}_{ij,g}}{-\sum_{j\neq i}\sum_g \tilde{\gamma}_{i,g}(g) X^{\mathcal{F}}_{ij,g}\left[1+\sum_s \varepsilon^{ij,s}_{ij,g}\right]} = \frac{\sum_{j\neq i}\sum_g\sum_s \phi_{ij,g}\varepsilon^{ij,s}_{ij,g}}{1+\sum_{j\neq i}\sum_g\sum_s \phi_{ij,g}\varepsilon^{ij,s}_{ij,g}} - 1,$$

where $\phi_{ij,g} \equiv \tilde{\gamma}_{i,g}(g) X_{ij,g} / \sum_{j\neq i}\sum_g \tilde{\gamma}_{i,g}(g) X_{ij,g}$ denotes the value-added export share.

B Measuring the Cost of a Two-Way Tariff War

Now, I consider the case where only two countries, namely, i and ℓ, engage in a two-way tariff war. I consider the Generalized Krugman model, noting that similar arguments apply to other models. In this two-way war, countries i and ℓ adopt an optimal tariff in response to each-other's tariffs, without changing the applied tariff on other trading partners. Country i's optimal tariff on country ℓ's exports in industry k (namely, $t^*_{\ell i,k}$) will, therefore, satisfy the F.O.C. implied by Equation 19, setting $t_{ji,g} = 0$ for all $j \neq \ell$. In particular,

$$\sum_g \left(t^*_{\ell i,g} - \bar{\tau}_i\right) \frac{\lambda_{\ell i,g}}{1+t_{\ell i,g}} \varepsilon^{\ell i,k}_{\ell i,g} + \sum_g \frac{\mu_g}{1+\mu_g} \lambda_{ii} \varepsilon^{\ell i,k}_{ii,g} = 0.$$

Setting cross-industry demand elasticities to zero, which is the relevant case for our quantitative analysis, the above condition implies

$$1 + t^*_{\ell i,g} = (1+\bar{\tau}_i)\left[1 + \frac{\frac{\mu_g}{1+\mu_g}\lambda_{ii}\varepsilon^{\ell i,k}_{ii,g}}{\lambda_{\ell i,g}\varepsilon_{\ell i,g}}\right]^{-1},$$

where $\bar{\tau}_i$ is defined as 18. To determine $1+\bar{\tau}_i$, we can follow the same steps as before using our notation for trade values ($X = PQ$):

$$\bar{\tau}_i \equiv \frac{\frac{\partial Y_i(.)}{\partial \ln w_i} + \sum_g \frac{\partial V(.)/\partial P_{ii,g}}{\partial V(.)/\partial Y_i}\frac{\partial P_{ii,g}(.)}{\partial \ln w_i}}{\frac{\partial}{\partial \ln w_i}\left[\sum_{j\neq i}\sum_g P_{ji,g}Q_{ji,g} - \sum_{j\neq i}\sum_g P_{ij,g}Q_{ij,g}\right]}$$

$$= \frac{w_i L_i + \sum_g \left[t_{\ell i,g} X_{\ell i,g}\sum_s\left(\frac{\partial \ln \mathcal{D}_{\ell i,g}(.)}{\partial \ln \tilde{P}_{ii,s}}\frac{\partial \ln \tilde{P}_{ii,s}(.)}{\partial \ln w_i}\right)\right] - \sum_g X_{ii,g}}{\sum_{j\neq i}\sum_g\left[X_{ji,g}\sum_s\left(\frac{\partial \ln \mathcal{D}_{ji,g}(.)}{\partial \ln \tilde{P}_{ii,s}}\frac{\partial \ln \tilde{P}_{ii,s}(.)}{\partial \ln w_i}\right)\right] - \sum_{j\neq i}\sum_g\left[X_{ij,g}\left[\frac{\partial \ln \tilde{P}_{ij,g}(.)}{\partial \ln w_i} + \sum_s\left(\frac{\partial \ln \mathcal{D}_{ij,g}(.)}{\partial \ln \tilde{P}_{ij,s}}\frac{\partial \ln \tilde{P}_{ij,s}(.)}{\partial \ln w_i}\right)\right]\right]}$$

$$= \frac{\sum_g\left(t_{\ell i,g}P_{\ell i,g}Q_{\ell i,g}\varepsilon^{ii,g}_{\ell i,g}\right) + \sum_{j\neq i}\sum_g X_{ij,g}}{-\sum_{j\neq i}\sum_g\left(X_{ij,g}\left[1+\sum_s \varepsilon^{ij,s}_{ij,g}\right] - X_{ji,g}\sum_s \varepsilon^{ii,s}_{ji,g}\right)}.$$

As a final step, we can use the last line in the above expression to produce the following characterization:

$$1+\bar{\tau}_i = \frac{-\sum_{j\neq i}\sum_g\left(X_{ij,g}\varepsilon^{ii,g}_{ij,g}\right)}{1 - \sum_{j\neq i}\sum_g\left(X_{ij,g}\varepsilon_{ij,g} + \mathcal{X}_{ji,g}\varepsilon^{ii,g}_{ji,g}\right)}$$

where $\mathcal{X}_{ji,g} = X_{ji,g}$ if $j \neq \ell$ and $\mathcal{X}_{ji,g} = \frac{\frac{\mu_g}{1+\mu_g}\lambda_{ii}\varepsilon_{ii,g}^{\ell i,k}}{\lambda_{\ell i,g}\varepsilon_{\ell i,g}}\left(1 + \frac{\frac{\mu_g}{1+\mu_g}\lambda_{ii}\varepsilon_{ii,g}^{\ell i,k}}{\lambda_{\ell i,g}\varepsilon_{\ell i,g}}\right)^{-1} X_{ji,g}$. Assuming a CES-Cobb-Douglas utility parametrization (as in Equation 7), the above equation reduces to the following:

$$1 + t^*_{\ell i,g} = \left(\frac{\sum_{j\neq i}\sum_g X_{ij,g}\left[1 + \epsilon_g\left(1 - \lambda_{ij,g}\right)\right]}{\sum_{j\neq i}\sum_g\left(X_{ij,g}\epsilon_g\left(1 - \lambda_{ij,g}\right) + \mathcal{X}_{ji,g}\epsilon_g\lambda_{ii,g}\right)}\right)\left[1 - \frac{\frac{\mu_g}{1+\mu_g}\lambda_{ii,g}\epsilon_g}{1 + \epsilon_g(1 - \lambda_{\ell i,g})}\right]^{-1}, \tag{22}$$

where $\mathcal{X}_{ji,g} = X_{ji,g}$ if $j \neq \ell$ and $\mathcal{X}_{ji,g} = \frac{\frac{\mu_g}{1+\mu_g}\lambda_{ii,g}\epsilon_g}{1+\epsilon_g(1-\lambda_{\ell i,g})}\left(1 - \frac{\frac{\mu_g}{1+\mu_g}\lambda_{ii,g}\epsilon_g}{1+\epsilon_g(1-\lambda_{\ell i,g})}\right)^{-1} X_{ji,g}$. A similar characterization applies to country ℓ's Nash tariff on country i, i.e., $t^*_{i\ell,k}$. Moreover, analogous the above equation, the two-way Nash tariff in the Ricardian and IO models would be uniform (across industries), but with an extra term in the denominator compared to the formulas specified by Propositions 1 and 3. This extra term accounts for the cross-cost passthrough facing country i, when it acts as a multi-product monopolist. More specifically, country i sells multiple goods to different international markets. The tariff on goods sold to market ℓ, internalize how country i's wage change affects the demand for the goods sold to all other (non-ℓ) markets. In the baseline specification, the tariff was applied uniformly on all exported goods, so this extra term canceled out.

Finally, given Equation 22, we can produce the following analog of Proposition 4, to compute the cost of two-way tariff war:

$$\begin{cases}
1 + t^*_{ji,k} = 1 + \bar{t}_{ji,k}, \quad j \neq \ell \\
1 + t^*_{\ell i,k} = (1 + \bar{\tau}^*_i)\left[1 - \frac{\frac{\mu_g}{1+\mu_g}\lambda_{ii,g}\epsilon_g}{1+\epsilon_g(1-\lambda_{\ell i,g})}\right]^{-1} \\
1 + \bar{\tau}^*_i = \frac{\sum_{j\neq i}\sum_k \hat{X}_{ij,k}X_{ij,k}\left[1+\epsilon_k(1-\hat{\lambda}_{ij,k}\lambda_{ji,k})\right]}{\sum_{j\neq i}\sum_k\left[\hat{X}_{ij,k}X_{ij,k}\epsilon_k(1-\hat{\lambda}_{ij,k}\lambda_{ij,k}) + \hat{\mathcal{X}}_{ji,k}\mathcal{X}_{ji,k}\epsilon_k\hat{\lambda}_{ii,s}\lambda_{ii,s}\right]} \\
\hat{X}_{ij,k}X_{ij,k} = \hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1 + t^*_{ij,k}) \\
\hat{\mathcal{X}}_{ji,k}\mathcal{X}_{ji,k} = \hat{X}_{ji,k}X_{ji,k}, \quad j \neq \ell \\
\hat{\mathcal{X}}_{\ell i,k}\mathcal{X}_{\ell i,k} = \frac{\frac{\mu_g}{1+\mu_g}\hat{\lambda}_{ii,g}\lambda_{ii,g}\epsilon_g}{1+\epsilon_g(1-\hat{\lambda}_{\ell i,g}\lambda_{\ell i,g})}\left(1 - \frac{\frac{\mu_g}{1+\mu_g}\hat{\lambda}_{ii,g}\lambda_{ii,g}\epsilon_g}{1+\epsilon_g(1-\hat{\lambda}_{\ell i,g}\lambda_{\ell i,g})}\right)^{-1}\hat{X}_{\ell i,k}X_{\ell i,k} \\
\hat{\lambda}_{ji,k} = \left(\frac{1+t^*_{ji,k}}{1+\bar{t}_{ji,k}}\hat{w}_j\right)^{-\epsilon_k}\hat{\tilde{P}}^{\epsilon_k}_{i,k} \\
\hat{\tilde{P}}^{-\epsilon_k}_{i,k} = \sum_j\left[\left(\frac{1+t^*_{ji,k}}{1+\bar{t}_{ji,k}}\hat{w}_j\right)^{-\epsilon_k}\lambda_{ji,k}\right] \\
\hat{w}_iw_iL_i = \sum_k\sum_j\left[\hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1 + t^*_{ij,k})(1 + \mu_k)\right] \\
\hat{\Pi}_i\Pi_i = \sum_k\sum_j\left[\mu_k\hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1 + t^*_{ji,k})(1 + \mu_k)\right] \\
\hat{Y}_iY_i = \hat{w}_iw_iL_i + \hat{\Pi}_i\Pi_i + \sum_k\sum_j\left(\frac{t^*_{ji,k}}{1+t^*_{ji,k}}\hat{\lambda}_{ji,k}\lambda_{ji,k}\beta_{i,k}\hat{Y}_iY_i\right)
\end{cases}.$$

Note that we can follow the same steps to characterize Nash tariffs and the corresponding costs for any localized tariff war. For instance, we can characterize the cost of a tariff war involving any $M \geq 2$ out of the total N countries.

C Estimation of Trade Elasticities

In this appendix I describe the estimation procedure used to attain the industry-level trade elasticities. Following the notation introduced in the main text, let $X_{ji,k} = \tilde{P}_{ji,k} Q_{ji,k}$ trade values, and let $\bar{t}_{ji,k}$ denote effectively applied tariffs. Following Caliendo and Parro (2015), the industry-level trade elasticity in the Ricardian model can be estimated using the following estimating equation that combine tariff and trade data for any countries j, i, and k:

$$\ln \frac{X_{ji,k} X_{in,k} X_{nj,k}}{X_{ij,k} X_{ni,k} X_{jn,k}} = -\hat{\epsilon}_k \ln \frac{\bar{t}_{ji,k} \bar{t}_{in,k} \bar{t}_{nj,k}}{\bar{t}_{ij,k} \bar{t}_{ni,k} \bar{t}_{jn,k}} + \varepsilon_{jin,k}.$$

The error term, $\varepsilon_{jin,k}$, is composed of (idiosyncratic) bilateral non-tariff trade barriers. Under the identifying assumption that bilateral non-tariff barriers are uncorrelated with bilateral tariffs, we can employ an OLS estimator to identify $\hat{\epsilon}_k$ for each industry k.

To perform the above estimation, I use the full sample of countries in the aggregated 2014 WIOD database, consisting of 44 economies and 16 industries. In line with Caliendo and Parro (2015), I drop zeros from the sample. I also apply Caliendo and Parro's (2015) trim, whereby exporters that with lowest/highest 2.5% share in each industry are dropped from sample.[26] Data on applied tariffs is from UNCTAD-TRAINS, as explained in Section . To repeat myself, the applied tariff is measured as the *simple tariff line average* of the *effectively applied tariff* .

The estimation results are reported in Table 4, the cross-industry variation in the trade elasticities broadly aligns with those in Caliendo and Parro (2015). Unfortunately for the "Mining" and "Metal" industries, my estimation did not render meaningful estimates for $\hat{\epsilon}_k$. Presumably, this is due to the main exporters in these two industries being WTO members in 2014, which leads to a lack of sufficient variation in discriminatory tariffs.[27] Considering this, I simply adopt Caliendo and Parro's (2015) for these two industries—the adopted values are highlighted in gray.

To measure the cost of a tariff war in the generalized Krugman model, I need

[26] The Caliendo and Parro (2015) estimation involves only 16 countries and uses data from 1993. In comparison, my estimation involves 44 countries, some of which of relatively small. To handle, extreme observation due to my larger sample size, I also drop observations with the highest/lowest 2.5% values for $\frac{X_{ji,k} X_{in,k} X_{nj,k}}{X_{ij,k} X_{ni,k} X_{jn,k}}$ and $\frac{\bar{t}_{ji,k} \bar{t}_{in,k} \bar{t}_{nj,k}}{\bar{t}_{ij,k} \bar{t}_{ni,k} \bar{t}_{jn,k}}$.

[27] Ossa (2016) also faced a similar issue when applying the Caliendo and Parro (2015) estimation methodology to more contemporary data. He attributed this to most countries in his sample being WTO members, which leads to a lack of variation in discriminatory tariffs. I am inclined to believe that the same caveat applies here.

Table 4: *List of industries and estimated trade elasticities.*

Number	**Description**	trade elasticity ϵ_k	std. err.	N
1	Crop and animal production, hunting Forestry and logging Fishing and aquaculture	0.69	0.12	11,440
2	Mining and Quarrying	13.53	3.67	...
3	Food, Beverages and Tobacco	0.47	0.13	11,440
4	Textiles, Wearing Apparel and Leather	3.33	0.53	11,480
5	Wood and Products of Wood and Cork	5.73	0.93	11,326
6	Paper and Paper Products Printing and Reproduction of Recorded Media	8.50	1.52	11,440
7	Coke, Refined Petroleum and Nuclear Fuel	14.94	2.05	8,798
8	Chemicals and Chemical Products Basic Pharmaceutical Products	0.92	0.96	11,440
9	Rubber and Plastics	1.69	0.78	11,480
10	Other Non-Metallic Mineral	1.47	0.89	11,440
11	Basic Metals Fabricated Metal Products	3.28	1.23	...
12	Computer, Electronic and Optical Products Electrical Equipment	3.44	1.07	11,480
13	Machinery and Equipment n.e.c	3.64	1.45	11,480
14	Motor Vehicles, Trailers and Semi-Trailers Other Transport Equipment	1.38	0.46	11,480
15	Furniture; other Manufacturing	1.64	0.60	11,480
16	All Service-Related Industries (WIOD Industry No. 23-56)	4	...	...

mutually-consistent estimates for both ϵ_k and μ_k. Attaining estimates for these parameters is only possible with micro-level data. That is, I cannot use the macro-level WIOD data to discipline both of these parameters. As an alternative solution, I borrow the estimates from Lashkaripour and Lugovskyy (2019), who use transaction-level data from 251 exporting countries during the 2007-2013 to estimate the ϵ_k and μ_k for each of the WIOD industries used in my analysis. These adopted estimates are reported in Table 5. For the service-related industries the parameters are normalized to $\epsilon = 5$ and $\mu = 0$.

Table 5: *The structural parameters used in the generalized Krugman model.*

Number	**Description**	Trade Ealsticity ϵ_k	Profit Margin μ_k
1	Crop and animal production, hunting Forestry and logging Fishing and aquaculture	6.212	0.14
2	Mining and Quarrying	6.212	0.141
3	Food, Beverages and Tobacco	3.333	0.265
4	Textiles, Wearing Apparel and Leather	3.413	0.207
5	Wood and Products of Wood and Cork	3.329	0.270
6	Paper and Paper Products Printing and Reproduction of Recorded Media	2.046	0.397
7	Coke, Refined Petroleum and Nuclear Fuel	0.397	1.758
8	Chemicals and Chemical Products Basic Pharmaceutical Products	4.320	0.212
9	Rubber and Plastics	3.599	0.162
10	Other Non-Metallic Mineral	4.561	0.186
11	Basic Metals and Fabricated Metal	2.959	0.189
12	Computer, Electronic and Optical Products Electrical Equipment	1.392	0.453
12	Machinery, Nec	8.682	0.100
14	Motor Vehicles, Trailers and Semi-Trailers Other Transport Equipment	2.173	0.133
15	Furniture; other Manufacturing	6.704	0.142
16	All Service-Related Industries (WIOD Industry No. 23-56)	4	0

A withstanding question here, is why the trade elasticities differ between the two models? A straightforward answer is that they are estimated using different datasets and different identification strategies. For instance, the correlation between non-tariff trade barriers and tariffs can bias the estimates implied by the Caliendo et al. (2015) methodology, but not those implied by the methodology in Lashkaripour and Lugovskyy (2019). A deeper answer, though, is that presumably tariffs trigger selection effects. In that case, the trade elasticity estimated in Lashkaripour and Lugovskyy (2019) has to be adjusted for selection effects. The exact adjustment, however, depends on wether tariffs are applied after or before markups are charged—see Footnote 30 in Costinot and Rodríguez-Clare (2014) for more details.

D Accounting for Political Economy Weights

In this appendix, I demonstrate how the methodology developed here can easily accommodate political economy considerations. To this end, consider the multi-industry Krugman model introduced in Section 2.1, where preferences have a Cobb-Douglas-CES parmaterization as in Equation 7. Also, following Ossa (2014), suppose that the policy maker in country i maximizes a weighted welfare function,

$$W_i = \sum_k \theta_{i,k} \frac{X_{i,k}}{\tilde{P}_i}$$

where $\theta_{i,k}$ is the political economy weight assigned to industry k, $X_{i,k} = \sum_j P_{ij,k} Q_{ij,k}$ is total sales of industry k in country i, and $\tilde{P}_i$ is the Cobb-Douglas-CES consumer price index, $\tilde{P}_i = \prod_k \left(\sum \tilde{P}_{ji,k}^{-\epsilon_k} \right)^{-\beta_{i,k}/\epsilon_k}$. Also, suppose that $\theta_{i,k}$'s are normalized such that $\sum_k (\theta_{i,k}) / K = 1$. Following the same steps covered in Appendix A.2, we can easily show that (for every i and k) the Nash tariff is given by

$$1 + t_{i,k}^* = \left[\frac{\sum_{j \neq i} \sum_g X_{ij,g} \left[1 + \epsilon_g \left(1 - \lambda_{ij,g} \right) \right]}{\sum_{j \neq i} \sum_k \left[X_{ij,g} \epsilon_g \left(1 - \lambda_{ij,g} \right) + \mathcal{X}_{ji,k} \epsilon_k \lambda_{ii,s} \right]} \right] \frac{(1 + \mu_k)(1 + \epsilon_k \lambda_{ii,k})}{1 + \mu_k + \epsilon_k \lambda_{ii,k}},$$

where $\mathcal{X}_{ji,k} \equiv \sum_g \left[\frac{\mu_g \epsilon_g \lambda_{ii,g}}{1 + \mu_g + \epsilon_g \lambda_{ii,g}} \right] X_{ji,k}$, with

$$\tilde{\mu}_{i,k} = \frac{\theta_{i,k} \mu_k}{1 + (1 - \theta_{i,k}) \mu_k}. \tag{23}$$

Note that without political economy considerations, i.e., $\theta_{i,k} = 1$, the above equation simply implies that $\tilde{\mu}_{i,k} = \mu_k$. Beholding the above result, suppose we estimate the political economy weights using data on non-cooperative tariffs à la Ossa (2014). Then, we can simply compute the political economy-adjusted Nash tariffs and the welfare losses associated with them, using the following variation of Proposition 4.

Proposition 7. *If preferences are described by functional form 7 and $\{\theta_{i,k}\}$ describes the political economy weights in each country, then the Nash tariffs, $\{t_{i,k}\}$, and their effect on wages,*

$\{\hat{w}_i\}$, and total income, $\{Y_i\}$, can be solved as solution to the following system:

$$\begin{cases} 1+t^*_{i,k} = (1+\bar{\tau}^*_i)\left[\frac{1+\tilde{\mu}_{i,k}-\epsilon_k\hat{\lambda}_{ii,k}\lambda_{ii,k}}{(1+\tilde{\mu}_{i,k})(1-\epsilon_k\hat{\lambda}_{ii,k}\lambda_{ii,k})}\right] \\ 1+\bar{\tau}^*_i = \frac{\sum_{j\neq i}\sum_k \hat{X}_{ij,k}X_{ij,k}\left[1+\epsilon_k(1-\hat{\lambda}_{ij,k}\lambda_{ji,k})\right]}{\sum_{j\neq i}\sum_k\left[\hat{X}_{ij,k}X_{ij,k}\epsilon_k(1-\hat{\lambda}_{ij,k}\lambda_{ij,k})+\hat{\mathcal{X}}_{ji,k}\mathcal{X}_{ji,k}\epsilon_k\hat{\lambda}_{ii,s}\lambda_{ii,s}\right]} \\ \hat{X}_{ij,k}X_{ij,k} = \hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1+t^*_{j,k}) \\ \hat{\mathcal{X}}_{ji,k}\mathcal{X}_{ji,k} = \sum_g\left(\frac{\tilde{\mu}_g\epsilon_g\hat{\lambda}_{ii,g}\lambda_{ii,g}}{1+\tilde{\mu}_g+\epsilon_g\hat{\lambda}_{ii,g}\lambda_{ii,g}}\right)\hat{X}_{ji,k}X_{ji,k} \\ \hat{\lambda}_{ji,k} = \left(\frac{1+t^*_{i,k}}{1+\bar{t}_{ji,k}}\hat{w}_j\right)^{-\epsilon_k}\hat{\hat{P}}^{\epsilon_k}_{i,k} \\ \hat{\hat{P}}^{-\epsilon_k}_{i,k} = \sum_j\left[\left(\frac{1+t^*_{i,k}}{1+\bar{t}_{ji,k}}\hat{w}_j\right)^{-\epsilon_k}\lambda_{ji,k}\right] \\ \hat{w}_iw_iL_i = \sum_k\sum_j\left[\hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1+t^*_{j,k})(1+\mu_k)\right] \\ \hat{\Pi}_i\Pi_i = \sum_k\sum_j\left[\mu_k\hat{\lambda}_{ij,k}\lambda_{ij,k}\beta_{j,k}\hat{Y}_jY_j/(1+t^*_{j,k})(1+\mu_k)\right] \\ \hat{Y}_iY_i = \hat{w}_iw_iL_i + \hat{\Pi}_i\Pi_i + \sum_k\sum_j\left(\frac{t^*_{i,k}}{1+t^*_{i,k}}\hat{\lambda}_{ji,k}\lambda_{ji,k}\beta_{i,k}\hat{Y}_iY_i\right) \end{cases},$$

which depends on only (i) observable expenditure shares and national output levels, $\lambda_{ji,k}$, $\beta_{i,k}$, and $Y_i = w_iL_i$; (ii) industry-level trade elasticities, ϵ_k; as well as (iii) $\tilde{\mu}_{i,k}$'s, which are given by the constant industry-level profit margins, μ_k, and the estimated political economy weights per Equation 23.

With the above results in hand, let me elaborate on how or when political economy considerations may alter the conclusions reached in my main analysis. Without political economy considerations, countries will target Nash tariffs at high-μ industries. These targeted tariffs are costly, as they shrink output in high-μ industries below their already sub-optimal level. Now, suppose countries assign a greater political economy weight to high-μ industries, which is analog to

$$\partial\theta_k/\partial\mu_k > 0.$$

In that case, political economy considerations will push the global economy even further away from the efficiency frontier. Hence, the global cost of a tariff war would be greater with than without political economy considerations. To the contrary, suppose countries assign a lower political economy weight to high-μ industries, which is analog to

$$\partial\theta_k/\partial\mu_k < 0.$$

In that case, political economy considerations countervail the profit-shifting incentives that motivate targeted tariffs. As a result, in the event of a tariff war, Nash tariffs will be relatively less targeted towards high-μ industries. The global cost of tariff war would, therefore, be smaller with than without political economy weights. Presumably, in practice, high-profit industries are better positioned to lobby for protection. So, it is highly possible that we are dealing with the former case. If so, my main analysis provides a lower bound for the global cost of a full-fledged global tariff war.

E Evaluating the Assumption on Country Size

A key assumption underlying the methodology in this paper is that, given the actual size of individual economies and their degree of openness to trade, (i) country i's tariffs have a significant effect on country i's wage rate relative to other countries; but (ii) country i's tariffs have a negligible effect on the wage of all other countries relative to each other. This assumption simply ensured that Nash tariffs are uniform across exporters. To evaluate this assumption, I compute Nash tariffs using the standard iterative methodology (like the one used in Ossa (2014)), without imposing any restriction on uniformity.

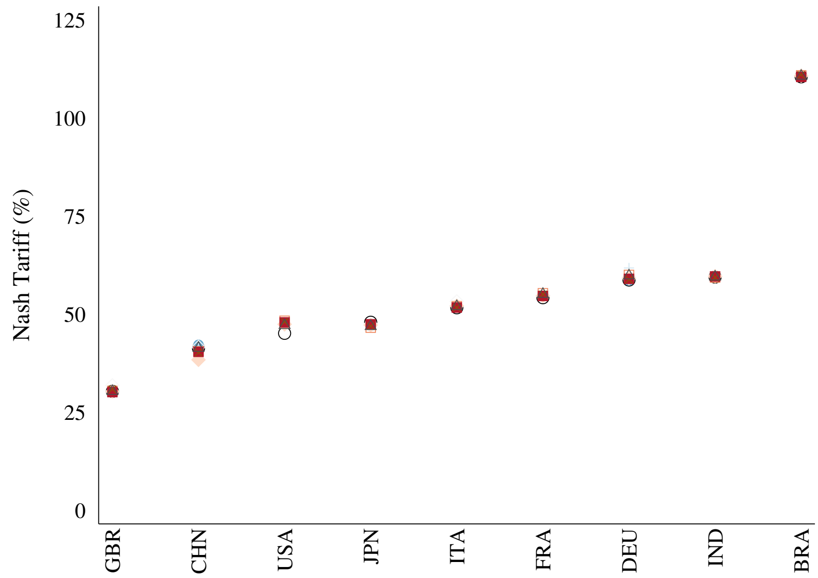
Since the standard methodology is computationally burdensome, I focus on the Ricardian model. I also aggregate the 2014 WIOD sample in to the 10 largest countries plus an aggregate of the rest of the world. That is, I focusing on the set of countries for which the size assumption is most suspect. To compute the Nash tariffs in this setup, I closely follow the iterative methodology in Ossa (2014), which is described more thoroughly in the main text. Note that in the Ricardian model, the Nash tariffs are uniform across industries even if a country is large. So, for each country in the aggregated sample, I can compute and plot the (uniform across industry) Nash tariff imposed by each country on individual export partners.

The computed Nash tariffs are displayed in Figure 3. Recall that if my assumption on country size is credible, the Nash tariffs should be uniform for any given importer. Evidently, this is indeed the case to a good approximation. Especially, if we consider two things. First, that these are the largest countries in the WIOD sample (i.e., these are the countries for which my assumption on country size is more suspect). Second, as I will elaborate below, the subtle level of non-uniformity observed in Figure 3 can be due to computational error rather than a violation of my assumption on country size.

Another, more straightforward way to evaluate my assumption on country size, is to compare the welfare losses implied by my sufficient statistics approach to those implied by the (standard) iterative optimization approach. The comparison in displayed in Figure 4. Once again it is clear that the two approaches deliver near-identical prediction. Albeit with different computational efficiency: one my personal computer, the sufficient statistics approached produced output well above 100-times faster than the iterative optimization approach.

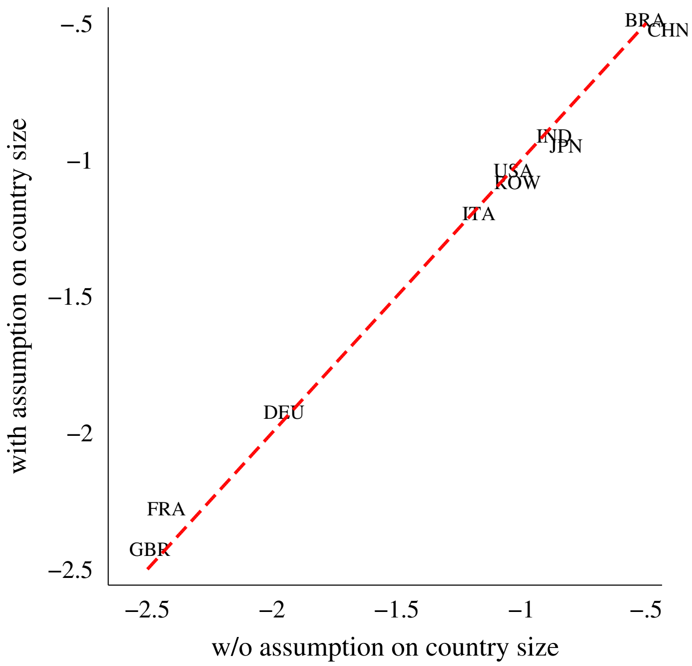
The above results bring to light the pitfall of using aggregated data to quantify the consequences of a tariff war. Accordingly, they highlight another advantage of the sufficient statistics approach over: that by increasing computational speed, it rids of the

Figure 3: *Nash tariffs computed using the standard method.*



Note: each dot corresponds to a Nash tariff applied on an individual export partner, by a country featured on the x-axis. The countries feature on the x-axis are the largest economies in the 2014 WIOD sample, excluding EU member countries.

Figure 4: *% Loss in real GDP from a tariff war*



need to aggregate data. Let me elaborate on this advantage in some depth. As noted earlier, the iterative optimization method is plagued by the curse of dimensionality as we increase the number of countries in the analysis. To circumvent computational burden, most studies that use the iterative method, aggregate data into a limited number of regions. My adoption of the iterative approach, for instance, aggregated the global economy 44 countries into 9 countries plus and aggregate of the rest of the world.

The problem with aggregating the data to such a degree is that it makes the rest of the world a large economy with extensive market power. Add to this the implicit assumption that (like other countries) the rest of the world sets Nash tariff as one collective unit. Considering this, the Nash tariffs set by the rest of the world will be excessively high, inflicting significant loss on the other economies. To give numbers, based on Table 2, Germany incurs a 1% loss if we do not aggregate the data. By comparison, if we aggregate the data Germany incurs a 2% loss in real GDP. That is to say, aggregation from 44 regions to 10 regions overstates the cost of a tariff war by 100% .

Now, is perhaps a good time to reflect on the computational speed of the standard method relative to the sufficient statistics methodology developed here. On the same computing device, my proposed methodology converges close to 1000-times faster than the standard methodology. Moreover, based on my experience, when smaller countries are included in the analysis, the standard methodology (based on the FMINCON solver in MATLAB) becomes increasingly sensitive to the choice of initial values. My purposed methodology, however, is no susceptible to this problem as it does not involve a global optimization and also imposes uniformity constraints, when implied by theory.

Finally, another word caution is that when I implemented the standard methodology using the FMINCON solver in MATLAB, I obtained output that did not actually correspond to a global optimum. I noticed this by cross-checking the output from FMINCON with that implied by my analytic formulas, and comparing objective function values. Considering this, it is possible that some of within-importer tariff heterogeneity embedded in Figure 3 is due to computational error.