Trade Restrictiveness Indexes and Welfare: A Structural Approach

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Abstract

Trade restrictiveness indexes (TRIs) have become a staple for practitioners and policy makers to summarize international trade barriers. TRIs theoretically found a measure of trade restrictiveness by calculating the uniform tariff that is welfare equivalent to the observed distribution of applied tariffs within a country. Here we incorporate importer market power and exporter heterogeneity into calculations of TRIs and welfare globally. To do so we structurally estimate a quantitative model of international trade. The structure of the model allows tractable estimation of importer and exporter welfare and TRIs for every country in the world from 1990-2007. Canonical estimates, which ignore exporter heterogeneity and importer market power, are shown to overstate efficiency losses from tariffs by a factor of 5 for the average importer. Additionally, by not accounting for importer market power canonical methods fail to measure substantial welfare losses to exporters that are captured by importers through tariffs. These channels are shown to significantly impact the measurement and interpretation of TRIs. To conclude, we employ the methodology to evaluate China's WTO accession and a counterfactual renegotiation of the NAFTA.

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1 Introduction

An importer's trade restrictiveness index is calculated by asking what is the uniform tariff that if applied to imports would yield the same welfare as the current structure of actual tariffs. This methodology provides a concise way of evaluating importers' trade policy that is theoretically founded. These indexes therefore do not suffer from the critiques levied against weighted average tariff measures, and allow for meaningful cross country comparisons. Trade restrictiveness indexes (TRI) have consequently become a staple of international policy analysis.

While there have been a wide range of theoretical contributions on TRIs under various assumptions of importer and exporter characteristics (c.f., Anderson and Neary (2005) for a survey), empirical work has remained relatively stagnant. Empirically, the industry standard to calculate TRIs is drawn from Feenstra (1995), and take similar forms as Kee et al. (2009).[1] This methodology relies on strong assumptions of exporter homogeneity and small countries (i.e., perfectly elastic export supply). In this paper, we extend the welfare analysis to allow for exporter heterogeneity and large country assumptions in ways that are commonplace in the theoretical literature.[2]

The impact on calculations of welfare and TRIs from extending the model is substantial. Canonical empirical results are shown to load all of the distortions to the economy from a tariff on importer efficiency losses. This is a direct result of small country (i.e., perfectly elastic export supply) assumptions. Relaxing these assumptions, our extended model highlights the importance of terms of trade effects resulting from tariffs. When export supply is not perfectly elastic, exporters pass-through a portion of the tariff to their shipped prices. These so called terms of trade effects are shown to be a significant portion of importer welfare. Given our estimates, we show the canonical model overestimates importer deadweight

[1] In speaking of these industry standards, Irwin (2010) explains, "On the other hand, the estimates here do not account for any improvement in the terms of trade as a result of import tariffs (Broda et al. (2008)). Still, with these caveats in mind, such welfare calculations are still routinely made and it should be interesting to see how historical estimates of these costs compare with more recent estimates."

[2] Chen et al. (2014) claim to extend the empirical literature on TRIs to account for terms of trade effects. However, they make an inaccurate assumption regarding the pass-through of the tariff to shipped prices. By association, their welfare and TRI calculations are misspecified given their model. We will precisely estimate the pass-through of tariffs in the model, and highlight its importance in welfare calculations.

(efficiency) losses from tariffs by a factor of five. Additionally, the average importer is shown to extract significant welfare gains at the expense of exporters due to terms of trade effects. For the average importer, we estimate nearly a 50% pass-through of the tariff to exporter prices, which results in a net welfare gain from applied tariffs of around $2 billion or 0.4% of the value of imports.

Introducing these new channels into importer and exporter welfare also impacts TRIs. Our model delivers a wealth of mechanisms impacting importer welfare absent from previous studies. We show how to decompose these channels in our welfare calculations. Through these decompositions, we demonstrate how to calculate a number of TRIs. The canonical estimates of TRIs only consider the uniform tariff that yields identical importer efficiency losses as the vector of applied tariffs in the data. In our model this accounts for only one portion of welfare.

Our estimates of these importer efficiency TRIs are roughly in line with the existing empirical literature. However, the departures from applying our model are informative. For example, canonical methods overestimate the efficiency TRI for the US by around 50%. Our method describes how these differences are closely related to importer terms of trade gains. The US is particularly apt to influence terms of trade with its policies. We highlight this fact by decomposing TRIs into their contribution to terms of trade gains and efficiency losses. For the US, the terms of trade and foreign efficiency loss TRIs are relatively large. By ignoring these channels, the canonical TRI overstates US efficiency losses as it lumps these channels into one metric.

Lastly, we introduce a net TRI that simultaneously accounts for the efficiency and terms of trade effects from importer policy. We argue that this net TRI is best thought of as the importer's ability to extract welfare from exporters through tariffs via terms of trade effects. Our net TRI consolidates the channels of the full model. We document that the US, for instance, has one of the largest estimated net TRIs in the data. We describe how our estimates indicate a strong tendency for US trade policy to target industries with large terms of trade effects and small efficiency losses (i.e., inelastically supplied exports). These targeted policies are shown to lead to net welfare gains accrued through applied tariffs.

One difficulty of extending our empirical TRI models along the proposed dimensions is credibly estimating the underlying import demand and export supply elasticities for every importer-exporter-good in the entire world. Overcoming this hurdle in practice requires placing structure on importers' markets and welfare. We do so by adopting the quantitative model of trade as proposed in Soderbery (2018). This model has the benefit of fitting many prevailing assumptions in the trade literature (e.g., CES import demand, exporter heterogeneity and importer market power) while remaining flexible enough to structurally estimate. The model's flexibility lends itself to our empirical extension of TRIs and welfare calculations globally.

A related analysis to ours is Costinot and Rodríguez-Clare (2014), who examine the move from Armington (1969) to Melitz (2003) models of international trade and evaluate the predicted effects of trade and trade policy (including an application to TRIs). Since their focus is on exposing the evolution of the microeconomic and macroeconomic channels between the models, their policy evaluations are designed for illustration rather than quantification. Here we are focused on quantifying welfare and policy in a parsimonious way so that our methodology can be readily applied across the universe of trading countries. Fundamentally, Costinot and Rodríguez-Clare (2014) is an exercise in letting models speak to the impact of trade and policy on welfare, while ours is aimed at relaxing some of the constraints of the model to put the onus on the data. In this way our study is more closely related to Kee et al. (2009) who analyze TRIs across many countries. However, we will demonstrate that their assumptions are overly restrictive and ignore important channels impacting welfare.

Broadly, this paper can be thought of as bridging the gap between new trade theory with heterogeneity (e.g., Costinot and Rodríguez-Clare (2014)) and reduced form empirical studies of welfare and trade policy (e.g., Kee et al. (2009)). We do so by incorporating exporter heterogeneity and by extension importer market power into our calculations of the impact of trade policy on welfare and our resulting measures of trade restrictiveness. We conclude by demonstrating the tractability of the model and its predictions by examining the effect on TRIs and welfare from observed and hypothetical policy changes. Specifically, we analyze China's WTO accession and a hypothetical renegotiation of the North American free trade agreement (NAFTA).

Our results warrant a word of caution. We estimate unilateral terms of trade gains derived by importers with market power from tariffs. As such, our measures and indexes are best thought of as measuring the terms of trade incentives and the degree to which these incentives are targeted by existing tariffs. Our concluding exercises (renegotiating NAFTA in particular) will highlight the pitfalls of unilateral policy. Specifically, policy retaliation is especially costly to exporters when trade partners also possess market power.

We proceed as follows. Section **2** presents our quantitative trade model. Section **3** demonstrates how to calculate welfare and TRIs in our model with importer market power and exporter heterogeneity. Section **4** presents our estimates of welfare and TRIs, and Section **4.1** analyzes the impact of China's accession to the WTO contrasting our results with the canonical estimates and Section **4.2** examines the counterfactual effects of a hypothetical renegotiation of the NAFTA. Section **5** concludes.

2 Welfare and Trade Restrictiveness Indexes

A daunting number of channels and decompositions have been explored by the theoretical literature on computable welfare and trade restrictiveness measures. However, the empirical literature has focused on a narrower range. The result has been widespread estimates of TRIs drawing from Feenstra (1995) which focuses the welfare analysis by invoking on small country assumptions, linear approximations of supply and demand, and exporter homogeneity in order to tractably calculate welfare and TRIs. Here we extend the methodology to a richer framework and investigate its implications for estimates of welfare and TRIs.

2.1 A Quantitative Trade Model

We begin by adopting the generic welfare function from Feenstra (1995). Our focus, as is customary, is on the effect on the sum of importer welfare good by good through the efficiency and terms of trade effects generated by the tariff. Under common assumptions of the market conduct of domestic firms and separability of welfare across goods, Feenstra

(1995) shows the marginal effect on welfare from a change in tariffs is generically,

$$\frac{\partial W^I}{\partial \tau^I_{gv}} = \tau^I_{gv} p^*_{gv} \frac{\partial x^I_{gv}}{\partial \tau^I_{gv}} - x^I_{gv} \frac{\partial p^*_{gv}}{\partial \tau^I_{gv}}, \tag{1}$$

where τ^I_{gv} is the tariff set by importer I on the variety v of good g, x^I_{gv} is the imported quantity and p^*_{gv} is the exporter (at the origin) price. In practice, it is convenient to recast Equation (1) in terms of values and trade elasticities.[3] Such that,

$$\frac{\partial W^I}{\partial \tau^I_{gv}} = \tau^I_{gv} p^*_{gv} x^I_{gv} \frac{\partial log(x^I_{gv})}{\partial log(p^I_{gv})} \frac{\partial log(p^I_{gv})}{\partial \tau^I_{gv}} - p^*_{gv} x^I_{gv} \frac{\partial log(p^*_{gv})}{\partial \tau^I_{gv}}. \tag{2}$$

The first term in (2) represents the total efficiency (deadweight) losses associated with higher delivered prices (p^I_{gv}) increasing the tariff applied to good g. The second term are terms of trade gains to importers as exporters may partially absorb some of the tariff in delivered prices. Specifically, if export supply is upward sloping tariff pass-through is incomplete. That is, exporters will lower their shipped price (p^*_{gv}) in response to tariffs, which leads to welfare gains through tariff revenues for the importer.

Historically, the literature has ignored these terms of trade effects on welfare and TRIs by applications of small country assumptions (i.e., perfectly elastic export supply implies $\frac{\partial log(p^*_{gv})}{\partial \tau^I_{gv}} = 0$). Additionally, the literature has simplified welfare calculations through first order approximations of supply and demand. Here, we will allow for upward sloping export supply and focus on CES preferences for the importer, which are both commonplace in the theoretical literature. That is to say, we apply standard structure from new trade theory to calculate welfare and investigate the extent to which the prevailing assumptions from the empirical literature overlook important channels determining welfare and TRIs.

In order to estimate the welfare effects of a tariff using Equation (2) we need to specify import demand and export supply. Our goal is to stay true to key assumptions from new trade theory while maintaining the ability to estimate the key parameters of the model. We thus adopt the quantitative model of trade developed in Soderbery (2018). Import demand will be CES and export supply curves are heterogenous across exporters and potentially

[3] While not made explicit in Feenstra (1995), this transformation underlies his discussion on pg. 1560.

upward sloping.[4] These features of the model capture the specific channels of interest in this paper, and make it amenable to structural estimation as described in Soderbery (2018). It is however worth noting that the model is quantitative by nature and focused on describing aggregate changes in the flows of goods between countries. This implies that we are foregoing deep analysis of the microeconomic origins (e.g., firm entry and exit or factor reallocation) of changes in welfare. While the microeconomic channels are potentially interesting, our goal is to make meaningful decompositions of aggregate importer and exporter surpluses in a way that is directly tied to the model and is computationally feasible on a large scale (i.e., every importer-exporter-product triplet in the world).

Explicitly, consumers nest their consumption of domestic and imported goods via Cobb-Douglas and face CES preferences across imported varieties.[5] This yields demand for each imported variety v of good g,

$$x^I_{gv} = \xi^I_X \phi^I_g b^I_{gv} (p^I_{gv})^{-\sigma^I_g} (\mathcal{P}^I_g)^{\sigma^I_g - 1}, \tag{3}$$

where $\mathcal{P}^I_g = \left(\sum_v b^I_{gv} (p^I_{gv})^{1-\sigma^I_g} \right)^{\frac{1}{1-\sigma^I_g}}$ is the standard CES price index over the delivered prices p^I_{gv}, and ξ^I_X and ϕ^I_g are the fractions of consumer income spent on imported good and on imported varieties of a good, respectively. A random taste shock b^I_{gv} will facilitate the estimation of the import demand elasticity σ^I_g. Import demand combines with export supply

[4] Recently, Costinot et al. (2019) have shown that the US exports pharmaceuticals following a downward sloping export supply curve. They demonstrate this result is upheld in New Trade Theory at local approximations of equilibrium with fully symmetric countries. Allowing for this possibility is the beyond the scope of this paper, but hopefully warrants future research into the generalizability and implications of this result.

[5] These assumptions are commonplace in much of the international trade literature (especially empirical evaluations, including TRIs as in Kee et al. (2009) and heteroskedastic supply and demand estimation as in Broda and Weinstein (2006)). However, they are not innocuous. For instance, while our welfare and TRI measures capture changes in domestic producer surplus associated with tariff induced movements along supply and demand curves, Cobb-Douglas nesting does rule out richer possibilities such as potential shifts in supply or demand for domestically produced varieties. Ultimately, greater richness governing the responses by domestic industry to changes in import competition as a result of tariff changes hinges on available data. In order to estimate the model, we require data covering every product and country in the analysis. One hypothetical expansion of the methodology would be to eliminate the nest between domestic and foreign goods. This could be easily achieved by including the domestic variety in the CES aggregator allowing for richer substitution between domestic and foreign goods. The methodology could easily accommodate this extension, but would require domestic sales data at the HS4 product level for every country in the world. Simply, these data do not exist.

of the form,

$$p^*_{gv} = exp(\eta^I_{gv})(x^I_{gv})^{\omega^I_{gv}}. \tag{4}$$

Exporters thus have unique supply curves for their variety both within and across countries. The destination-variety-specific inverse export supply elasticity is ω^I_{gv}. The literature, in contrast, tends to specify an export supply elasticity that is importer-variety specific or simply assume export supply is perfectly elastic. We are allowing for exporter specific supply technologies that may include increasing marginal costs, imperfect factor mobility, and returns to scale. Allowing export supply to vary additionally across destinations and products we are also allowing for importer specific effects such as importer market power to affect export supply. Finally, we also allow for unobservable variety specific supply shocks η^I_{gv} to facilitate estimation.

Calculating welfare in this model requires solving for the trade equilibrium where import demand equals export supply taking into account competitive equilibrium effects (e.g., changes in the price index) of tariffs. Clearing the import and export market implies the equilibrium shipped price of variety v:[6]

$$p^*_{gv} = \left(\varphi_{gv}(1+\tau^I_{gv})^{-\sigma^I_g}(\mathcal{P}^I_g)^{\sigma^I_g - 1}\right)^{\frac{\omega^I_{gv}}{1+\omega^I_{gv}\sigma^I_g}}. \tag{5}$$

The term $\varphi_{gv} \equiv \frac{\xi^I_X \phi^I_g b_{gv}}{exp(-\eta_{gv}/\omega^I_{gv})}$ is an unobservable variety-specific shock that is independent of the tariff. Solving for the aggregate price level allows us to represent each exported variety's price as a function of tariffs. To do so, we aggregate the individual variety prices given by the market clearing condition in (5) to match the CES price index. This aggregation yields,

$$\mathcal{P}^I_g = (1+\overline{\tau}^I_{go})^{\frac{1}{1+\overline{\omega}^I_{go}}}\Phi_g. \tag{6}$$

In order to aggregate prices, we must define an "average" variety that charges a price equal

[6] The market clearing condition equates import demand with export supply curves and is given by $\xi^I_X \phi^I_g b_{gv} p_{gv}^{-\sigma^I_g}(\mathcal{P}^I_g)^{\sigma^I_g - 1} = (exp(-\eta_{gv})p^*_{gv})^{1/\omega^I_{gv}}$.

to the price index.[7] Denote this average variety with subscript o, and let it be produced with technology denoted $\overline{\omega}^I_{go}$ and faces the tariff $\overline{\tau}^I_{go}$. In practice, $\overline{\omega}^I_{go} \equiv \frac{\sum_v p^I_{gv} x^I_{gv} \omega^I_{gv}}{\sum_v p^I_{gv} x^I_{gv}}$ and $\overline{\tau}^I_{go} \equiv \frac{\sum_v p^I_{gv} x^I_{gv} \tau^I_{gv}}{\sum_v p^I_{gv} x^I_{gv}}$ are the, within good, import weighted geometric means of the export supply elasticities and applied tariffs, respectively. The term $\Phi_g \equiv \varphi_{go}^{\overline{\omega}^I_{go}/1+\overline{\omega}^I_{go}}$ is an index of variety taste and technology parameters, which is unrelated to tariffs.

Fundamentally, our goal is to calculate the elasticity of imports, shipped prices and delivered prices with respect to the tariff. To do so, combine the price index with the market clearing price in (5), which yields the shipped price solely as a function of the tariff and unobservable shocks (unrelated to the tariff),

$$p^*_{gv} = (1+\tau^I_{gv})^{\frac{-\omega^I_{gv}(1+\overline{\omega}^I_{go}\sigma^I_g)}{(1+\overline{\omega}^I_{go})(1+\omega^I_{gv}\sigma^I_g)}} \left(\varphi_{gv}\Phi_g^{\sigma^I_g-1}\right)^{\frac{\omega^I_{gv}}{1+\omega^I_{gv}\sigma^I_g}} .$$

Heterogeneity in export supply elasticities drive differential price responses to the tariff across the imported varieties.[8] Additionally, we can write imports as a function of the tariff and variety-specific shocks,

$$x_{gv} = (1+\tau^I_{gv})^{\frac{-(1+\overline{\omega}^I_{go}\sigma^I_g)}{(1+\overline{\omega}^I_{go})(1+\omega^I_{gv}\sigma^I_g)}} exp(-\eta_{gv}) \left(\varphi_{gv}\Phi_g^{\sigma^I_g-1}\right)^{\frac{1}{1+\omega^I_{gv}\sigma^I_g}} .$$

This system of import demand and export supply has the desirable feature of nesting the canonical derivations of Feenstra (1995) and Kee et al. (2009). Applying their small country assumptions rules out exporter heterogeneity as $\omega^I_{gv} = 0 \, \forall \, v$, and results in $\frac{\partial W^I}{\partial \tau^I_{gv}} = \tau^I_{gv} p^*_{gv} x^I_{gv} \sigma^I_g$.[9] The small country assumption thus rules out terms of trade effects, leaving welfare calculation simply as a function of how much delivered prices ($\tau^I_{gv} p^*_{gv}$) and the change in imports ($x^I_{gv}\sigma^I_g$) are affected by the tariff . In familiar terms, the change in welfare is the Harberger (1964) triangle below the import demand curve above the exported price that emerges with the tariff.

[7]Given that each variety responds differently to the tariff as dictated by their supply elasticity, aggregation is not a superficial task. The details are presented by the appendix of Soderbery (2018).

[8]The elasticity of a variety's price with respect to the tariff is thus, $\frac{\partial log(p^*_{gv})}{\partial \tau^I_g}\Big|_{\tau^I_{gv}=0} = \frac{-\omega^I_{gv}(1+\overline{\omega}^I_{go}\sigma^I_g)}{(1+\overline{\omega}^I_{go})(1+\omega^I_{gv}\sigma^I_g)}$.

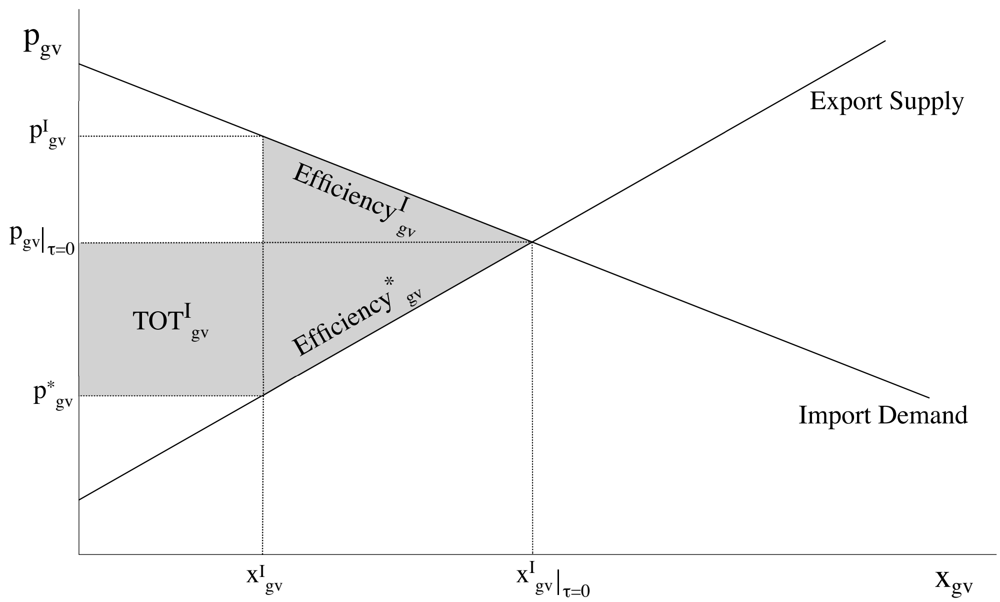
[9]As, $\frac{\partial log(p^*_{gv})}{\partial \tau^I_g}\Big|_{\tau^I_{gv}=0} = 0$, $\frac{\partial log(p^I_{gv})}{\partial \tau^I_g}\Big|_{\tau^I_{gv}=0} = 1$ and $\frac{\partial log(x^I_{gv})}{\partial log(p^I_{gv})} = \sigma^I_g$.

As we relax the small country assumption, the slope of the export supply curve begins to affect welfare. Define $\Lambda^I_{gv} \equiv \frac{\omega^I_{gv}(1+\bar{\omega}^I_{go}\sigma^I_g)}{(1+\bar{\omega}^I_{go})(1+\omega^I_{gv}\sigma^I_g)} \in [0,1]$, which measures the pass-through of the tariff for each exported variety's shipped price.[10] The full model then implies,

$$\frac{\partial W^I}{\partial \tau^I_{gv}} = -\tau^I_{gv} p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv}) + p^*_{gv} x^I_{gv} \Lambda^I_{gv}. \tag{7}$$

The following will consider a number of decompositions of this welfare function, which warrants some visualization of the problem. Figure 1 presents the welfare problem graphically. Application of the tariff τ^I_{gv} raises the price in country I to p^I_{gv}. The increase in price is strictly

Figure 1: Import Market for Variety v of Good g



less than the amount of the tariff since export supply is upward sloping and the exporter lowers the shipped price of its variety to p^*_{gv}. This generates efficiency losses for the importer and exporter. Explicitly, integrating the first term of Equation (7) will yield the negative

[10] At this point we can see where the analysis of Chen et al. (2014) introduces an unfounded assumption regarding pass-through of a tariff when export supply is upward sloping. Specifically, they assume $\Lambda^I = {\sigma_g}/{\omega_g+\sigma_g}$. In our model if we assumed as they do that export supply elasticities are homogenous, pass-through is $\Lambda^I = {\omega_g}/{1+\omega_g}$. While their assumption is convenient, it is unclear what model of export supply they have in mind, as it does not adhere to the export supply curves they estimate.

of the total deadweight losses to the importer (Efficiency^I_{gv}) and the exporter (Efficiency^*_{gv}). Integrating the second term of Equation (7) produces the total importer terms of trade gains (TOT^I_{gv}) and foreign efficiency losses. Empirically, we are interested in decomposing welfare and TRIs across these terms of trade and efficiency channels as well as their combined effects. Our model is by construction amenable to such decompositions. Next we will show how to calculate welfare and TRIs given the model.

3 Calculating Welfare and TRIs

The total change to importer welfare associated with moving from free trade to a positive tariff is acquired by integrating the partial derivative of the welfare function. Explicitly, we integrate Equation (1) from zero to the applied tariff τ^I_{gv} and add up the changes in welfare for each variety and good imported by I.

$$\begin{aligned}\Delta W^I &\equiv \sum_g \sum_v \int_0^{\tau^I_{gv}} \frac{\partial W^I}{\partial \tau^I_{gv}} \\ &= \sum_g \sum_v \left(- \int_0^{\tau^I_{gv}} p^*_{gv} x^I_{gv} \sigma^I_g (1 - \Lambda^I_{gv}) \tau d\tau + \int_0^{\tau^I_{gv}} p^*_{gv} x^I_{gv} \Lambda^I_{gv} d\tau \right).\end{aligned}$$

Since the welfare function is additively separable, we can evaluate these integrals variety by variety and decompose the efficiency and terms of trade effects. The solution to the aggregate change in importer welfare from all applied tariffs is thus,

$$\Delta W^I = -\frac{1}{2} \sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1 - \Lambda^I_{gv}) (\tau^I_{gv})^2 + \sum_g \sum_v p^*_{gv} x^I_{gv} \Lambda^I_{gv} \tau^I_{gv}. \tag{8}$$

To reiterate, welfare nests the canonical results from Feenstra (1995). This is evident as when $\Lambda = 0$ the change in welfare is only the efficiency losses to the importer from higher prices as tariffs increase. As Λ increases exporters pass-through more of the tariff to shipped prices, efficiency losses fall and terms of trade gains rise. Decomposing the welfare function across efficiency and terms of trade effects will lend insight into the channels through which tariffs are affecting importer welfare, and allow for comparisons to previous empirical studies.

Four key channels are evident from Figure 1; 1) Deadweight losses to the importer (Efficiency^I), 2) efficiency losses to the exporter (Efficiency^*), 3) global deadweight losses ($\text{AggEff}^I = \text{Efficiency}^I + \text{Efficiency}^*$) and 4) the total terms of trade distortion ($\text{AggTOT}^I = \text{TOT}^I + \text{Efficiency}^*$). From our model these regions are,

$$\Delta\text{Efficiency}^I = -\frac{1}{2}\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1 - \Lambda^I_{gv})^2 (\tau^I_{gv})^2 \tag{9}$$

$$\Delta\text{Efficiency}^* = -\frac{1}{2}\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1 - \Lambda^I_{gv})(\Lambda^I_{gv})(\tau^I_{gv})^2 \tag{10}$$

$$\Delta\text{AggEff}^I = -\frac{1}{2}\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1 - \Lambda^I_{gv})(\tau^I_{gv})^2 \tag{11}$$

$$\Delta\text{AggTOT}^I = \sum_g \sum_v p^*_{gv} x^I_{gv} \Lambda^I_{gv} \tau^I_{gv}. \tag{12}$$

In terms of evaluating trade policy, each of these measures is of individual interest. For those interested in assessing the economic efficiency for importers (i.e., the effects on domestic consumers) evaluating Efficiency^I is the key metric. Additionally, this deadweight loss measure is essentially the metric presented by the empirical literature as the costs of protectionism (c.f., Irwin (2010) and Kee et al. (2009)).

Allowing for export supply heterogeneity generates deadweight losses for the exporter. Evaluating Efficiency^* may not be of interest to truly protectionist policy makers, but for those evaluating a bargaining process between countries where importers internalize their distortions abroad from policy, this new metric should be valuable. Even more to this point, our ability to calculate the gains accrued by importers (AggTOT^I) at the cost of exporters should be of central importance to policy makers. Finally, while we are interested in aggregate (i.e., adding up welfare across all imported varieties and goods) welfare effects, the model is notably flexible enough to calculate each imported variety's contribution to efficiency and terms of trade in the economy.

With our welfare decompositions in hand, we now turn to TRIs. Generically, a TRI measures a uniform policy that is welfare equivalent to the vector of tariffs in the data. Put plainly, if an importer were to apply a uniform tariff across all goods and varieties how large would it have to be to yield the same welfare as the vector of applied tariffs which varies across goods and varieties. Since TRIs are theoretically founded, and calculated in welfare equivalence, they make cross country comparisons of trade restrictiveness possible. Here we take the intuition of TRIs a step further with our decompositions. We will ask such things as what is the uniform policy that leads to the same importer efficiency losses as applied tariffs. This will allow us to understand channels such as which countries' applied tariffs lead to the largest domestic distortions. That is to say, we will be able to evaluate and compare countries' trade policy in terms of domestic and foreign distortions (i.e., efficiency and terms of trade).

We begin by constructing TRIs for each of our decompositions. For example, we define the uniform tariff that yields to the same importer deadweight losses as applied tariffs, and denote it as $\text{TRI}_{\text{Efficiency}^I}$. Our decomposed TRIs are:

$$\begin{aligned}
TRI_{\text{Efficiency}^I} &= \left(\frac{\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv})^2 (\tau^I_{gv})^2}{\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv})^2}\right)^{\frac{1}{2}} \\
TRI_{\text{Efficiency}^*} &= \left(\frac{\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv})(\Lambda^I_{gv})(\tau^I_{gv})^2}{\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv})(\Lambda^I_{gv})}\right)^{\frac{1}{2}} \\
TRI_{\text{AggEff}^I} &= \left(\frac{\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv})(\tau^I_{gv})^2}{\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv})}\right)^{\frac{1}{2}} \\
TRI_{\text{AggTOT}^I} &= \frac{\sum_g \sum_v p^*_{gv} x^I_{gv} \Lambda^I_{gv} \tau^I_{gv}}{\sum_g \sum_v p^*_{gv} x^I_{gv} \Lambda^I_{gv}}.
\end{aligned}$$

As with our welfare calculations, depending on our perspective, each of these measures will shed light on where a country's policies are the most distortionary and restrictive. For instance, countries with high tariffs disproportionately in relatively elastically demanded industries will generate greater efficiency losses for the importer and yield large estimates of $\text{TRI}_{\text{Efficiency}^I}$. Conversely, high tariffs in inelastically supplied industries will increase $\text{TRI}_{\text{AggTOT}^I}$ as importers realize terms of trade gains.

Jointly, these decompositions interact through policy to yield the net TRI. Let $\Psi \equiv \frac{\sum_g \sum_v p^*_{gv} x^I_{gv} \Lambda^I_{gv}}{\sum_g \sum_v p^*_{gv} x^I_{gv} \sigma^I_g (1-\Lambda^I_{gv})}$, be our measure of the marginal aggregated terms of trade gains relative to efficiency losses from tariffs. Solving for the uniform tariff(s) that provides the same welfare for the importer (net of exporter deadweight losses) as the vector of applied tariffs yields,

$$TRI_{\text{Net}^I} = \Psi \pm \sqrt{\Psi^2 + (TRI_{\text{AggEff}^I})^2 - 2\Psi(TRI_{\text{AggTOT}^I})}\ . \qquad (13)$$

The first thing to notice is that the overall TRI takes on two values. With the introduction of upward sloping export supply curves (i.e., importer gains from terms of trade), welfare is no longer strictly decreasing with the tariff. This outcome is expected. Dakhlia and Temimi (2006) argue that with large countries (i.e., upward sloping export supply), the definition of the TRI should be modified to acknowledge importer terms of trade gains. In context, Anderson and Neary (1996) originally define the TRI against free trade (as we are doing here). No issues arise with this definition when export supply is perfectly elastic since welfare is monotonically decreasing with positive tariffs. As we see here, welfare is no longer monotonic, giving rise to multiple TRIs. Dakhlia and Temimi (2006) thus propose a modified TRI that measures deviations from optimal tariffs. We do not pursue that logic here, as our decompositions provide insight into the meaning of our multiple TRIs. We can see that adding the term under the radical, which we will denote as $\text{TRI}^{+}_{\text{Net}^I}$, measures the maximum distortion caused by the vector of tariffs. Conversely, subtracting this term, which we will denote as $\text{TRI}^{-}_{\text{Net}^I}$, yields the same welfare but measures the minimum of the distortions from applied tariffs to reach this welfare level.

Comparisons across the two measures have little meaning (i.e., one interpretation of Dakhlia and Temimi (2006)), but we will demonstrate that comparisons within the measures across countries is a valuable tool for quantifying trade restrictiveness and its channels for policy analysis. In a related theoretical application of new trade theory, Costinot and Rodríguez-Clare (2014) find multiple TRIs. They claim, "The non-uniqueness of the TRI reflects the importance of general equilibrium effects in gravity models," but do not expand on the finding. Here, we see that multiple TRIs arise as a consequence of importer terms of trade gains and provide insight into how importers are manipulating these gains with their policies.

4 Empirical Evaluation

Putting the analysis into motion requires estimates of import demand and export supply elasticities, trade flows and the universe of tariffs. The biggest challenge are reliable estimates of our elasticities for every traded good and country in the world. Here we have allowed for exporter heterogeneity in supply and assumed CES import demand. We thus borrow the structural estimator developed in Soderbery (2018), which yields consistent estimates of import demand and export supply elasticities for every HS4 product traded by every country. To be clear, the model requires importer-product specific import demand elasticities and importer-exporter-product specific export supply elasticities.[11] We combine these estimates with publicly available trade data from *ComTrade*. Finally, applied tariffs are importer by exporter by good specific and are extracted from a combination of *Trains*, the *International Customs Tariffs Bureau* and the WTO.[12] The intersection of our data leaves 182 countries trading 1087 HS4 products from 1990-2007.

We are pursuing a classic quantitative treatment of importer welfare and TRIs through partial equilibrium product market reactions to tariffs with an incorporation of terms of trade effects. One alternative emerging in the literature are general equilibrium treatments of trade policy as in Ossa (2014). We prefer our methodology as it provides the ability to analyze a richer range of products and countries. Quantitative general equilibrium models incorporating terms of trade have strong requirements regarding domestic production data. Consequently, they are limited to databases such as WIOT or GTAP that only record data for a handful of industries and countries. Aggregation across products in an industry generally involves taking weighted averages of product level tariffs, which is one of they key critiques at the foundation of TRIs we are interested in analyzing. There are a number of trade-

[11] As is customary in trade given our data, we will define a variety as a unique exporter-product pair following Armington (1969). More specific in regard to this methodology, the key assumption is that demand (taste for variety – b^I_{gv}) and supply (productivity – η^I_{gv}) shocks are uncorrelated over time. We refer the reader to longer discussions in Soderbery (2018) regarding threats to identifying this quantitative supply and demand model. Additionally, Soderbery (2018) is somewhat loose when discussing applied tariffs in the estimator. The estimation of elasticities do take into account applied tariffs in the price data. Notably, the methodology by design addresses concerns such as those raised in Trefler (1993) regarding the endogeneity of tariffs.

[12] Many thanks to Robert Feenstra and John Romalis for the tariff data. They are the same utilized by Feenstra and Romalis (2014), which provides a detailed description in their Appendix B.

offs associated with adopting our methodology over general equilibrium alternatives. We roughly view these tradeoffs as a choice between complicated aggregate considerations (e.g., bilateral bargaining and welfare optimization) where general equilibrium analysis originates versus aggregating across heterogeneous microeconomic responses (e.g., TRIs and welfare quantification) where our methodology originates.[13]

Table 1 presents summary statistics for the largest importers in terms of GDP in 2006.[14] Higher GDP countries tend to be the biggest importers and exporters in the data. The US is the largest importer while China is the largest exporter in 2006. These large countries also tend to have the strongest importer market power, as indicated by high inverse export supply elasticities ω^I_{gv}. There is also a strong positive correlation between the median rate of pass-through and a country's imports relative to GDP. What these summary statistics do not fully capture is the variation in the amount of trade and elasticities across importer-exporter pairs and products.[15] Additionally, there is heterogeneity in the tariffs applied by importers. These dimensions of heterogeneity across importers, which depend on with whom and what goods are traded, are the motivation for compact aggregated statistics such as TRIs and

[13] One point of contention from our perspective is that these general equilibrium models hinge on estimates of import demand elasticities. For instance, Ossa (2014) applies Feenstra (1994)'s methodology to estimate demand elasticities. However, analyses of terms of trade in these models do not explicitly identify the role of export supply elasticities, even though Feenstra (1994)'s estimator imposes a particular form of export supply that may not be compatible with the general equilibrium modeling.

[14] We will focus on the top 14 countries for the sake of brevity. However, the full data will be available at web.ics.purdue.edu/~asoderbe.

[15] Comparing tariff pass-through rates to the literature illustrates how variation is masked by summary statistics. There are a handful of studies estimating pass-through at the industry level. Two examples that stand out are Feenstra (1989) and Irwin (2014). Feenstra (1989) finds a pass-through 0.57 Japanese trucks to the US in 1984. Here, we estimate a pass-through of 0.45 for HS 8427 (Motor Vehicles) from Japan to the US 1985. Irwin (2014) estimates pass-through of 0.4 Sugar in the 1930s. We find a distribution of pass-through rates for US sugar (HS 1702) that varies by exporter and year, with the 5th-95th between 0.4-0.77 and an average of 0.55. To our knowledge, the broadest estimates based on elasticities are from Broda et al. (2008). They estimate the same model, but under homogeneity (that is assuming $\omega^I_{gv} = \omega^I_g \ \forall \ v$. Using their assumptions and notation, pass-through is defined as $\xi_g = {}^1\!/_{1+\omega_g}$. Notice pass-through here is $1 - \Lambda^I_{gv} \equiv 1 - {}^{\omega^I_{gv}(1+\bar{\omega}^I_{go}\sigma^I_g)}\!/_{(1+\bar{\omega}^I_{go})(1+\omega^I_{gv}\sigma^I_g)}$. If we assume exporter homogeneity this reduces to $1 - \Lambda^I_{gv} = 1 - \Lambda^I_g = 1 - {}^{\omega^I_{gv}}\!/_{1+\bar{\omega}^I_{go}} = {}^1\!/_{1+\omega^I_g} = \xi_g$. Given their estimates, they suggest a typical pass-through rate of 0.40. Median pass-through for our entire sample is 0.59. The differences between the estimators is discussed in detail by Soderbery (2018), with the punchline being that ignoring heterogeneity when estimating supply and demand leads to systematically larger estimates of inverse export supply elasticities in trade data. Therefore, the systematically smaller pass-through rates in Broda et al. (2008) in comparison are a consequence of their systematically larger inverse export supply elasticity estimates.

aggregate welfare to evaluate trade and policy.

Table 1: Importer Characteristics in 2006

				Median Elasticities		
Country	GDP	Imports	Exports	Import Demand	Export Supply	Pass-through $(1-\Lambda)$
USA	13201.82	2622.06	1586.05	2.958	1.268	0.474
Japan	4340.13	732.28	1102.34	3.000	1.297	0.464
Germany	2906.68	1312.18	1772.61	3.030	1.276	0.467
China	2668.07	953.21	1902.92	2.898	1.302	0.459
UK	2345.01	760.11	579.16	2.989	0.906	0.576
France	2230.72	782.47	736.90	2.982	0.888	0.575
Italy	1844.75	612.35	689.93	3.018	0.862	0.583
Canada	1251.46	492.66	443.38	3.057	1.237	0.466
Spain	1223.99	443.41	293.75	2.842	0.645	0.623
Brazil	1067.96	125.64	139.39	2.851	0.779	0.614
Russia	986.94	177.31	229.06	2.981	0.869	0.587
India	906.27	182.74	154.01	2.997	0.790	0.617
Korea	888.02	460.65	461.17	2.791	0.508	0.670
Mexico	839.18	423.85	305.25	2.937	0.939	0.552
Australia	768.18	163.39	102.55	2.999	0.857	0.595
Netherlands	657.59	425.50	433.85	2.852	0.660	0.608
Turkey	402.71	172.95	114.27	2.847	0.481	0.697
Belgium	392.00	502.70	390.69	2.856	0.659	0.617
Sweden	384.93	175.98	202.45	2.843	0.719	0.583
Switzerland	379.76	247.29	287.35	2.852	0.723	0.585
Indonesia	364.46	63.82	139.16	2.813	0.518	0.675
Poland	338.73	186.51	124.85	2.849	0.686	0.594
Austria	322.44	196.15	186.48	2.846	0.700	0.581
Norway	310.96	93.70	100.15	2.823	0.740	0.580
Denmark	275.24	123.27	95.93	2.843	0.726	0.582

Notes: GDP is total gross domestic product reported by *CEPII*, Imports and Exports are reported by *ComTrade*, and all are in billions of US dollars from 2006. Elasticities are the median across all varieties, where Import Demand is the CES elasticity σ_g^I, Export Supply is the inverse export supply elasticity ω_{gv}^I, Pass-through to importer prices is one minus Λ_{gv}^I.

Table 2 begins our analysis of trade restrictiveness. For brevity and comparisons to the existing empirical literature we will continue focusing on trade in 2006.[16] To remind the

[16]To be clear, our calculations have been made considering all countries and years in the data. Additionally, standard errors presented are derived from an application of the delta method. The literature is notably vague regarding standard errors of TRIs and present "bootstrapped" standard errors. Bootstrapped standard errors are included in Table 2 and available upon request for other tables, but we believe they are misspecified. The delta method takes into account the standard errors of the elasticity estimates, while bootstrapping highlights the variation in elasticities across exporters. Full estimates will be available at web.ics.purdue.edu/~asoderbe and further derivations are available upon request.

Table 2: Trade Restrictiveness Indexes in 2006

Importer	Avg Tariff	$\text{TRI}_{\text{Canonical}}$	$\text{TRI}_{\text{Eff}^I}$	$\text{TRI}_{\text{AggEff}^I}$	$\text{TRI}_{\text{AggTOT}^I}$	$\text{TRI}^{-}_{\text{Net}^I}$	$\text{TRI}^{+}_{\text{Net}^I}$
USA	0.027	0.032	0.021	0.027	0.030	0.032	0.130
		(0.001)	(0.002)	(0.001)	(0.000)	(0.014)	(0.020)
		[0.025,0.041]	[0.014,0.044]	[0.019,0.046]	[0.025,0.036]	[0.024,0.044]	[0.069,0.464]
Japan	0.023	0.047	0.051	0.051	0.021	0.018	0.710
		(0.012)	(0.015)	(0.015)	(0.000)	(0.097)	(0.170)
		[0.037,0.058]	[0.039,0.062]	[0.040,0.061]	[0.016,0.027]	[0.013,0.024]	[0.589,0.815]
Germany	0.010	0.021	0.025	0.023	0.008	0.007	0.445
		(0.000)	(0.001)	(0.000)	(0.000)	(0.005)	(0.012)
		[0.016,0.026]	[0.016,0.031]	[0.016,0.030]	[0.007,0.010]	[0.006,0.009]	[0.222,0.625]
China	0.091	0.081	0.080	0.081	0.070	0.067	0.599
		(0.001)	(0.002)	(0.001)	(0.000)	(0.014)	(0.035)
		[0.074,0.089]	[0.071,0.090]	[0.072,0.091]	[0.064,0.075]	[0.062,0.072]	[0.541,0.686]
UK	0.011	0.011	0.020	0.021	0.011	0.008	0.123
		(0.000)	(0.004)	(0.002)	(0.000)	(0.023)	(0.034)
		[0.008,0.019]	[0.012,0.035]	[0.014,0.033]	[0.009,0.013]	[0.004,0.012]	[0.047,0.475]
France	0.010	0.024	0.021	0.023	0.009	0.008	0.433
		(0.000)	(0.001)	(0.000)	(0.000)	(0.008)	(0.022)
		[0.021,0.027]	[0.017,0.026]	[0.019,0.026]	[0.007,0.010]	[0.006,0.009]	[0.312,0.563]
Italy	0.010	0.022	0.019	0.021	0.008	0.007	0.401
		(0.000)	(0.001)	(0.000)	(0.000)	(0.009)	(0.025)
		[0.019,0.025]	[0.019,0.031]	[0.020,0.032]	[0.004,0.012]	[0.003,0.011]	[0.614,0.744]
Canada	0.033	0.033	0.032	0.034	0.013	0.011	0.607
		(0.001)	(0.005)	(0.003)	(0.000)	(0.045)	(0.124)
		[0.022,0.042]	[0.026,0.039]	[0.029,0.041]	[0.010,0.016]	[0.008,0.014]	[0.495,0.780]
Spain	0.010	0.018	0.022	0.023	0.008	0.007	0.459
		(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.004)
		[0.016,0.025]	[0.019,0.024]	[0.019,0.025]	[0.006,0.010]	[0.006,0.009]	[0.335,0.504]
Brazil	0.125	0.152	0.169	0.161	0.117	-0.040	0.196
		(0.008)	(0.013)	(0.01)	(0.001)	(0.164)	(0.163)
		[0.113,0.179]	[0.106,0.194]	[0.111,0.191]	[0.108,0.126]	[-0.127,0.099]	[0.147,0.285]
Russia	0.101	0.055	0.101	0.102	0.093	0.087	0.393
		(0.000)	(0.004)	(0.003)	(0.001)	(0.042)	(0.077)
		[0.052,0.063]	[0.094,0.106]	[0.095,0.106]	[0.088,0.098]	[0.080,0.096]	[0.333,0.481]
India	0.276	0.267	0.303	0.298	0.257	-0.164	0.311
		(0.002)	(0.014)	(0.014)	(0.001)	(0.240)	(0.155)
		[0.261,0.280]	[0.264,0.376]	[0.260,0.367]	[0.246,0.267]	[-0.231,-0.023]	[0.268,0.399]
Korea	0.074	0.032	0.148	0.136	0.058	0.005	0.344
		(0.001)	(0.002)	(0.001)	(0.000)	(0.014)	(0.015)
		[0.017,0.097]	[0.077,0.246]	[0.077,0.221]	[0.055,0.061]	[-0.064,0.046]	[0.244,0.457]
Mexico	0.100	0.055	0.055	0.053	0.037	0.009	0.091
		(0.005)	(0.005)	(0.004)	(0.000)	(0.207)	(0.207)
		[0.039,0.091]	[0.036,0.111]	[0.036,0.106]	[0.030,0.042]	[-0.011,0.026]	[0.037,0.530]

Notes: Avg Tariff is the simple average of all importer applied tariffs. $\text{TRI}_{\text{Canonical}}$ is calculated forcing pass-through to zero for all countries. Robust standard errors calculated using an application of the delta method are in parentheses. Bootstrapped confidence intervals are in brackets.

reader, $\text{TRI}^{-}_{\text{Net}^I}$ is the minimum uniform tariff that would yield the same overall welfare as applied tariffs. We thus interpret $\text{TRI}^{-}_{\text{Net}^I}$ as a measure of the efficacy of the tariffs applied by the importer. That is to say, a large $\text{TRI}^{-}_{\text{Net}^I}$ corresponds with an importer setting tariffs that target industries and exporters with relatively high rates of tariff pass-through so that terms of trade gains compared to efficiency losses are high. Notably, the strongest positive correlate with $\text{TRI}^{-}_{\text{Net}^I}$ is the change in importer welfare from its applied tariffs relative to total imports.

We see considerable variation across countries in $\text{TRI}^{-}_{\text{Net}^{I}}$. Our estimates highlight differences across even seemingly similar countries in how policies target terms of trade. Comparing our TRIs between the US and Japan is a useful example. These countries are both large importers and WTO members with similar average tariffs. Our estimate of $\text{TRI}^{-}_{\text{Net}^{I}}$ for the US is nearly double that for Japan. This suggests Japan's tariffs tend to target exporters and goods that generate large efficiency losses and relatively small terms of trade gains. The story is precisely the opposite for the US. This pattern is confirmed by decompositions of the effects of tariffs on efficiency ($\text{TRI}_{\text{Eff}^{I}}$) with the effects on terms of trade ($\text{TRI}_{\text{AggTOT}^{I}}$) across the two countries. We see that US tariffs generate large terms of trade gains relative to efficiency losses.

Conversely, $\text{TRI}^{+}_{\text{Net}^{I}}$ can be thought of as a measure of the inefficient use of tariffs by the importer. A high $\text{TRI}^{+}_{\text{Net}^{I}}$ corresponds with tariffs leading to large efficiency losses relative to terms of trade gains. We can see these differences clearly by contrasting the US and Canada. The US has a relatively low $\text{TRI}^{+}_{\text{Net}^{I}}$ while Canada has one of the largest estimates. The implication is that the US applies tariffs that target inelastically exported varieties (i.e., terms of trade gains), while Canada applies tariffs targeting elastically supplied varieties. Consequently our new TRIs quickly explain the large welfare gains to the US from its policies in comparison to the small welfare effects of tariffs in Canada. The following will present our full welfare estimates, and document that US tariffs increase welfare by 1.33% of its total imports, while Canadian tariffs only increase welfare by 0.59% of its imports in 2006. In light of this discussion, labeling these overall indexes as trade restrictiveness should be done with care – a more appropriate characterization is in terms of the overall distortions to the import market caused by tariffs.

A more classic analogy equating trade restrictiveness and TRIs lies in $\text{TRI}_{\text{Eff}^{I}}$. This index simply measures the size of the deadweight losses to consumers in the importing country due to its tariffs. It is therefore the most appropriate comparison to the canonical measure ($\text{TRI}_{Canonical}$) from the empirical literature where we force pass-through of the tariff to be zero (c.f., Feenstra (1995) and Kee et al. (2009)). By ignoring terms of trade effects, we see a strong correlation between all of the efficiency measures.

These efficiency measures closely follow the simple average of applied tariffs. There are however some important departures between the canonical TRI and our efficiency TRIs. For the US, the canonical measure overstates the restrictiveness of applied tariffs in terms of their distortion to welfare. This is a result of the relatively high degree of tariff pass-through to shipped prices for exporters to the US (see Table 1). The aggregate efficiency $\text{TRI}_{\text{AggEff}^I}$ highlights this for US policy, as it is higher than the importer efficiency index, suggesting exporter deadweight losses are relatively high as a result of US tariffs. Our measures thus present a clear way to observe whether exporters or importers bear a relatively larger portion of the burden tariffs in terms of deadweight losses.

Additionally, the terms of trade index $\text{TRI}_{\text{AggTOT}^I}$ in the US is larger than the efficiency indexes, which shows how US policy extracts welfare at the expense of exporters. Conversely, the canonical TRI understates restrictiveness when importers' policies are relatively inefficient (i.e., terms of trade gains are achieved with large corresponding deadweight losses). India's policies highlight this point most clearly. Specifically, our indexes suggest Indian tariffs are the most inefficiently applied as they lead to substantial deadweight losses to both India and its trading partners with relatively small corresponding terms of trade gains. Explicitly, our measure of effectiveness $\text{TRI}^{-}_{overall}$ is the lowest of all importers and $\text{TRI}_{\text{AggEff}^I}$ is high relative to $\text{TRI}_{\text{AggTOT}^I}$ in India.

The patterns of the data embodied by TRIs are echoed by our welfare estimates. Table 3 presents welfare across our importers. Unambiguously, the canonical welfare estimates overstate the efficiency losses induced by tariffs. Without terms of trade gains, these estimates suggest welfare is decreasing substantially for all importers from applied tariffs. Our model tells a different story. While tariffs generate efficiency losses to the importer, we see that for all but two countries tariffs yield greater welfare through terms of trade gains. The net effect for importers effectively applying tariffs to generate terms of trade gains is generally around a positive 1-3% of the total value of imports welfare gain (e.g., US, China, Russia). Relating these estimates back to our TRIs in Table 2, these countries also generate the largest $\text{TRI}^{-}_{\text{Net}^I}$.

While most importers capitalize on terms of trade gains with their tariffs, Brazil and India

Table 3: The Effect of Applied Tariffs on Welfare in 2006

		$\frac{\Delta\text{Importer Welfare}}{\text{Imports}}$		Decomposing Importer Welfare			
Importer	Imports	Canonical	ΔW^I	ΔAggEff^I	ΔEfficiency^I	ΔEfficiency*	ΔAggTOT^I
USA	2622.06	−0.54%	1.33%	−0.22%	−0.11%	−0.11%	1.55%
		(0.02%)	(0.05%)	(0.05%)	(0.04%)	(0.02%)	(0.02%)
Japan	732.28	−0.46%	0.96%	−0.20%	−0.11%	−0.09%	1.16%
		(0.24%)	(0.13%)	(0.13%)	(0.07%)	(0.06%)	(0.02%)
Germany	1312.18	−0.12%	0.38%	−0.06%	−0.04%	−0.02%	0.44%
		(0.00%)	(0.01%)	(0.01%)	(0.01%)	(0.00%)	(0.01%)
China	953.21	−1.27%	3.31%	−0.54%	−0.30%	−0.24%	3.86%
		(0.03%)	(0.06%)	(0.06%)	(0.05%)	(0.02%)	(0.03%)
UK	760.11	−0.78%	0.37%	−0.15%	−0.13%	−0.03%	0.52%
		(0.01%)	(0.30%)	(0.30%)	(0.02%)	(0.30%)	(0.01%)
France	782.47	−0.11%	0.34%	−0.05%	−0.03%	−0.02%	0.39%
		(0.00%)	(0.01%)	(0.01%)	(0.00%)	(0.00%)	(0.01%)
Italy	612.35	−0.10%	0.30%	−0.05%	−0.03%	−0.02%	0.35%
		(0.00%)	(0.01%)	(0.01%)	(0.00%)	(0.00%)	(0.00%)
Canada	492.66	−0.32%	0.59%	−0.10%	−0.06%	−0.05%	0.69%
		(0.02%)	(0.08%)	(0.08%)	(0.02%)	(0.07%)	(0.01%)
Spain	443.41	−0.09%	0.30%	−0.05%	−0.03%	−0.02%	0.35%
		(0.00%)	(0.01%)	(0.01%)	(0.01%)	(0.00%)	(0.00%)
Brazil	125.64	−8.13%	−1.99%	−6.62%	−6.06%	−0.56%	4.64%
		(0.65%)	(0.55%)	(0.55%)	(0.43%)	(0.15%)	(0.07%)
Russia	177.31	−7.29%	3.18%	−0.97%	−0.61%	−0.36%	4.15%
		(0.15%)	(2.22%)	(2.22%)	(0.06%)	(2.22%)	(0.08%)
India	182.74	−138.06%	−12.61%	−21.92%	−19.27%	−2.65%	9.31%
		(6.91%)	(45.67%)	(45.67%)	(5.51%)	(45.25%)	(0.50%)
Korea	460.65	−2.50%	0.17%	−1.99%	−1.81%	−0.18%	2.16%
		(0.04%)	(0.05%)	(0.05%)	(0.06%)	(0.02%)	(0.01%)
Mexico	423.85	−2.67%	0.48%	−1.57%	−1.22%	−0.34%	2.04%
		(0.52%)	(0.43%)	(0.43%)	(0.30%)	(0.31%)	(0.06%)

Notes: Imports are in billions of US $ in 2006. All welfare measures are relative to total imports. Canonical welfare is calculated forcing pass-through to zero for all countries. Robust standard errors calculated using an application of the delta method are in parentheses.

do not. We can conclude from our estimates that these countries inefficiently apply large tariffs to industries with elastic demand and low pass-through. This strategy does produce large terms of trade gains, but these gains are dwarfed by even larger efficiency losses. This observation also highlights a key inefficiency of the canonical model. Since every distortion is captured by importer efficiency losses in these models they drastically overstate importer efficiency losses. Specifically, canonical estimates overstate efficiency losses to importers by a factor of five, on average. For example, the canonical model estimates a welfare loss of 138%

(or $252.3 billion) to India from its applied tariffs. Our estimates also suggest significant welfare losses to India, but accounting for terms of trade gains yield a more realistic 12.6% welfare loss. Generally, for countries that appear to be targeting terms of trade with their policies, this discrepancy between the canonical estimates of importer efficiency losses can be upward of ten fold (e.g., Russia). The data and our estimates thus suggest an important role for terms of trade when estimating importer welfare.

Lastly, it is worth briefly discussing the precision of these estimates. The statistics presented by Tables 2 and 3 are country level aggregates that combine many heterogenous market estimates. Each of these estimates may contain error, and even these errors vary at the importer-exporter-product level. We estimate standard errors for TRIs and welfare using a customized delta method in order to combine the contribution of the standard errors for each of our elasticity estimates.[17] For the most part, welfare and TRIs at the country level appear precisely estimated. Additionally, we find the departures quite sensible. A notable, albeit intuitive, example is India. India tends to apply large tariffs inefficiently (i.e., against relatively elastic imports) as embodied by our TRI estimates. This state of policy and trade creates knife edge cases that exacerbate abnormally large standard error estimates in their import demand and export supply elasticities as we aggregate. As such, even standard error estimates here provide insight into the structure and distribution of tariffs applied by importers.

4.1 Application: China's WTO Accession

Here we use our estimates for more detailed analysis of a specific importer's policies. China's WTO accession in 2001 was a particularly interesting rearranging of trade policy by a country emerging as a leader in international trade. We will show how to use the robust decompositions of our model to dissect China's trade policy changes. Table 4 begins by decomposing China's welfare five years before and after 2001.

In 1996, China was a relatively large importer of foreign goods at nearly $240 billion. Their policies at the time were some of the most protectionist in the world with an average

[17] Derivations are available upon request.

tariff around 30%. Their tariffs were relatively effectively applied as we see a large TRI^{-}_{Net}, and generated significant terms of trade gains ($35B or 15% of import value) with relatively small efficiency losses ($8.6B or 4% of import value). In the aggregate, Chinese policies in 1996 yielded a welfare gain of nearly $20B (8% of import value). The most striking difference comes from comparing the canonical results (i.e., where all export supply is assumed to be perfectly elastic) to our estimates. Since Chinese tariffs are relatively large and distortionary and canonical estimates load all of the effects on importer efficiency losses, the empirical literature would estimate nearly $40B (16% of import value) of deadweight loss to China form its tariffs in 1996. Interestingly, even though the estimated deadweight loss from the canonical method is nearly five times larger than from our model, our TRIs are almost identical.

Table 4: Chinese Welfare and Restrictiveness Before and After WTO Accession

		Welfare ($Bill)				Trade Restrictiveness			
Year	Imports	Efficiency^I	AggTOT^I	Total	Canonical	Avg Tar	$\text{TRI}_{\text{Eff}^I}$	$\text{TRI}^{-}_{\text{Net}}$	$\text{TRI}_{\text{Canon}}$
1996	237.134	−8.613	35.401	19.663	−38.124	0.216	0.295	0.194	0.297
		(1.317)	(3.147)	(3.571)	(1.106)		(0.054)	(0.175)	(0.005)
2006	953.212	−2.883	36.775	31.585	−12.130	0.077	0.080	0.067	0.081
		(0.470)	(0.253)	(0.603)	(0.256)		(0.000)	(0.014)	(0.001)

Notes: Imports are in Billions of US $, Avg Tar are the simple average of tariffs. Robust standard errors calculated using an application of the delta method are in parentheses.

A related discussion exists in Anderson and Neary (2003). There they argue that differences in elasticity estimates have a relatively small effect on TRI calculations, but model specification has a more significant impact.[18] Here we are using the same elasticities for each calculation – the canonical case simply forces all export supply elasticities to zero.

[18]From pg. 645 of Anderson and Neary (2003), "Of course, all our estimates of the TRI and the MTRI are dependent on the model used to calculate them. Anderson (1998) reports that results are not very sensitive to elasticity values, a finding that applies here as well since the same data and model are used. The insensitivity result is consistent with the folklore of CGE modeling elasticities do not matter much but specification of the model does matter. (For an illustration in the TRI context, see O'Rourke (1997).) It would be useful to have estimates based on different CGE models to understand better the effects of differences in specification. Despite these caveats, the case seems to be made that the standard measures are likely to be very seriously misleading in practice."

We confirm that model specification does in fact have a significant impact on our welfare calculations. However, a valuable feature of our model is it seems to nest the canonical restrictiveness measure from our decompositions. In essence, canonical estimates focus solely on the relative importance of importer efficiency losses from tariffs. This channel is readily documented by our model through $\text{TRI}_{\text{Efficiency}^I}$

China's post WTO accession trade in 2006 is handily different from 1996. On average, tariffs were cut by two thirds, and imports nearly quadruple. The growth in imports along with tariff cuts could lead to an ambiguous effect on the scale of the welfare effects from tariffs. We see that even though imports rose, declining tariffs dominate the efficiency losses, which fall from \$8.6B (4% of import value) to \$2.9B (0.3% of import value). Conversely, the terms of trade effects are dominated by the scale of imports. While they rise in levels from \$35.4B to \$36.7B, they fall in percent of import value from 15% to 4%. Total welfare gains in China from tariffs nearly double in levels, but fall in percent of import value from 8% to 3%. As we should expect, the TRIs derived from efficiency losses to China fall. As we have noted, the information contained in $\text{TRI}^{-}_{\text{Net}}$ is more intricate than simply trade restrictiveness. We conclude from the decline in $\text{TRI}^{-}_{\text{Net}}$ that Chinese policy is less predatory post WTO accession. The confines of the WTO have been shown to hinder the ability of member countries to take advantage of terms of trade gains through tariffs, which supports this result.[19]

Comparing a particular period of trade policy for a particular importer provides a setting to further decompose the effects of policy. Our model also allows for rich analysis of the effects of an importer's policy on its trading partners. By introducing terms of trade effects and heterogeneity across exporters, our model generates significant variation in the impact of policy changes on exporting countries ignored by canonical estimates. Table 5 presents the impact of China's WTO accession on its main trade partners.

As Table 4 documented, China's tariffs before WTO accession were large and relatively distortionary. Unlike the canonical model, which has no clear predictions regarding exporter

[19]This is very much in line with Soderbery (2018), which, using the same data, shows that while WTO importers' tariffs do respond to terms of trade motives they are less responsive after accession, thus reinforcing the findings of Bagwell and Staiger (2011).

Table 5: The Effects of Chinese Tariffs on Exporter Welfare

China Imports: 1996							
Exporter	Exports	Efficiency*	Efficiency* (% of Exports)	TOT*	TOT* (% of Exports)	Avg Tariff	TRI_{Eff*}
JPN	65.340	−1.756	−2.69%	−10.680	−16.34%	0.293	0.298
USA	26.278	−0.731	−2.78%	−3.287	−12.51%	0.289	0.305
KOR	23.829	−0.911	−3.82%	−4.084	−17.14%	0.295	0.336
DEU	16.103	−0.267	−1.66%	−2.337	−14.52%	0.296	0.247
ITA	7.248	−0.120	−1.65%	−1.038	−14.32%	0.308	0.241
RUS	5.222	−0.052	−1.00%	−0.280	−5.37%	0.208	0.165
FRA	3.653	−0.077	−2.11%	−0.437	−11.96%	0.297	0.256
GBR	3.590	−0.097	−2.69%	−0.511	−14.24%	0.283	0.307
AUS	3.002	−0.034	−1.15%	−0.233	−7.76%	0.272	0.184
IDN	2.497	−0.044	−1.75%	−0.194	−7.79%	0.301	0.159
CAN	2.078	−0.036	−1.73%	−0.176	−8.48%	0.262	0.223
SWE	1.732	−0.038	−2.22%	−0.224	−12.94%	0.256	0.247
CHE	1.731	−0.031	−1.77%	−0.257	−14.85%	0.275	0.245
NLD	1.700	−0.034	−2.00%	−0.198	−11.65%	0.266	0.245
BRA	1.126	−0.460	−40.87%	−0.482	−42.81%	0.249	1.047
IND	0.922	−0.012	−1.32%	−0.056	−6.12%	0.275	0.196
ESP	0.858	−0.020	−2.32%	−0.118	−13.70%	0.293	0.280
AUT	0.510	−0.007	−1.46%	−0.068	−13.26%	0.266	0.216
MEX	0.278	−0.004	−1.47%	−0.015	−5.35%	0.265	0.257
NOR	0.181	−0.003	−1.44%	−0.026	−14.17%	0.243	0.219
Total	237.134	−7.126	−3.00%	−24.713	−10.42%	0.216	0.303
China Imports: 2006							
Exporter	Exports	Efficiency*	Efficiency* (% of Exports)	TOT*	TOT* (% of Exports)	Avg Tariff	TRI_{Eff*}
JPN	261.678	−0.547	−0.21%	−12.006	−4.59%	0.096	0.083
KOR	158.047	−0.341	−0.22%	−6.514	−4.12%	0.096	0.082
USA	108.473	−0.340	−0.31%	−4.153	−3.83%	0.094	0.098
DEU	75.830	−0.199	−0.26%	−3.703	−4.88%	0.096	0.095
AUS	18.905	−0.069	−0.37%	−0.492	−2.60%	0.091	0.099
ITA	17.479	−0.041	−0.24%	−0.851	−4.87%	0.099	0.088
FRA	16.062	−0.035	−0.22%	−0.599	−3.73%	0.097	0.085
RUS	13.709	−0.006	−0.05%	−0.094	−0.69%	0.071	0.024
GBR	12.181	−0.028	−0.23%	−0.476	−3.91%	0.091	0.086
IDN	11.071	−0.052	−0.47%	−0.370	−3.34%	0.095	0.100
BRA	10.312	−0.019	−0.19%	−0.147	−1.42%	0.084	0.058
CAN	10.181	−0.011	−0.11%	−0.195	−1.91%	0.087	0.057
IND	9.241	−0.064	−0.69%	−0.309	−3.34%	0.091	0.141
CHE	9.012	−0.028	−0.32%	−0.511	−5.67%	0.091	0.102
BEL	7.562	−0.016	−0.21%	−0.255	−3.38%	0.083	0.077
NLD	6.950	−0.013	−0.18%	−0.269	−3.87%	0.089	0.070
SWE	5.966	−0.016	−0.26%	−0.260	−4.36%	0.087	0.090
ESP	5.425	−0.011	−0.20%	−0.163	−3.00%	0.095	0.076
MEX	3.602	−0.008	−0.21%	−0.099	−2.76%	0.083	0.091
AUT	3.210	−0.009	−0.30%	−0.160	−4.99%	0.089	0.099
NOR	1.246	−0.002	−0.12%	−0.041	−3.29%	0.079	0.052
Total	953.212	−2.307	−0.24%	−31.710	−3.33%	0.077	0.082

Notes: Exports, exporter efficiency losses (Efficiency*), and exporter terms of trade losses (TOT*) are in billions of US $. For the sake of space, standard errors are available at web.ics.purdue.edu/~asoderbe.

welfare from tariffs, our model precisely calculates the deadweight losses to exporters from Chinese tariffs (Efficiency*). Exporter losses vary across country as their mix of products and export supply elasticities are heterogeneous. The country most impacted by Chinese tariffs in 1996, as a percent of total exports, was Brazil. Brazilian was the 15^{th} largest exporter to China in 1996, shipping about $1B of goods. The mix of tariffs it faced resulted in 80% of this value in efficiency plus terms of trade losses. Conversely, Russia, the 6^{th} largest exporter, was most favorably taxed by China, losing only 6% of its export value relative to free trade. These differences are clearly reflected by the TRI faced by exporters. The uniform tariff that would lead to the same efficiency losses as applied tariffs was over 100% for Brazil, and only 16.5% for Russia.

Notably, WTO members tended to face the most restrictive tariffs in 1996, as their TRIs were generally large and tended to be above the average tariff they face. This apparent discrimination by Chinese policy potentially motivates the push for China to join the WTO. After joining the WTO, Chinese tariffs fall rapidly with heterogeneous effects across its trade partners. Efficiency and terms of trade losses to exporters fall across the board, with the most significant decreases being accrued by WTO members. Interestingly, even though Russia was not a WTO member at the time (and therefore not subject to MFN tariffs), China appears to have restructured tariffs favorably for them as well, as their deadweight losses fall to under one percent of exports. Uncovering these rich patterns of how an importer's policy differentially impacts exporters hinges on our model's ability to capture terms of trade effects and exporter heterogeneity. Overall, deadweight (efficiency plus terms of trade) losses for all exporters to China fell from 13.42% of total exports ($31.83 billion) in 1996 to only 3.57% ($34.02 billion) in 2006.

4.2 Application: A Renegotiation of the NAFTA

President Trump has vowed to renegotiate the NAFTA. While the details of this renegotiation are murky, our model provides us with a lightweight tool to examine some hypothetical restructuring of tariffs between the US, Canada and Mexico. As a first step, we consider the (unlikely) situation where the US backs out of NAFTA by applying MFN tariffs to Canada and Mexico with no retaliation by these countries. That is to say, the US increases tariffs against its neighbors and Canada and Mexico maintain zero tariffs on US exports. Next, we consider the (more likely) situation where all North American countries back out of the NAFTA if the US backs out by reverting to MFN tariffs for each good they trade.

We can calculate the counterfactual changes in trade flows and welfare in each country by simulating the effects implied by our model given our estimated import demand and export supply elasticities. Table 6 presents these counterfactual scenarios. Comparing our estimates using actual data (Baseline) to the first scenario where the US raises tariffs agains Canada and Mexico (US Only), we see that the value of US imports from Canada and Mexico only modestly decreases by around 2%. This is for two reasons. First, reverting to MFN tariffs by the US implies increasing tariffs from zero to only around 3% on average. Second, the US has relatively strong importer market power, as the median export supply elasticity in the US is relatively large and pass-through of the tariff relatively weak (Table 1). These characteristics explain why the distortion to US imports from increasing North American tariffs is mild. A related result is that US efficiency losses from this increase in tariffs is modest at around $0.45 billion. However, US terms of trade gains increase substantially by around $7 billion, as raising tariffs on its North American trade partners allows the US to capitalize on its importer market power. Ultimately, the US can realize welfare gains from unilaterally increasing tariffs against Canada and Mexico.

Table 6: Welfare Effects of Renegotiating the NAFTA

			Δ Importer Welfare ($Bill)				Δ Exporter Welfare ($Bill)		
Scenario		Imports	Efficiency^I	AggTOT^I	Total	Exports	Welfare$^*_{CAN}$	Welfare$^*_{MEX}$	Welfare$^*_{US}$
Baseline	Canada	305.941	0.000	0.000	0.000	305.941	·	0	0
	Mexico	253.967	0.000	0.000	0.000	253.967	0	·	0
	US	626.763	0.000	0.000	0.000	626.763	0	0	·
US Only	Canada	305.941	0.000	0.000	0.000	305.941	·	0	0
	Mexico	253.967	0.000	0.000	0.000	253.967	0	·	0
	US	611.852	−0.449	7.162	6.407	611.852	-4.246	-3.527	·
All N.A.	Canada	297.611	−0.171	4.949	4.572	297.611	·	0	-5.154
	Mexico	219.881	−5.491	18.084	10.713	219.881	0	·	-19.964
	US	611.852	−0.449	7.162	6.407	611.852	-4.246	-3.527	·

Notes: Imports and Exports are from the other North American countries in billions of US $. Baseline is calculated using actual data in 2006 where welfare Importer Welfare are the welfare effects from tariffs (i.e., importer efficiency and importer terms of trade gains). Exporter Welfare are the welfare effects of importer tariffs on the exporter. For instance, Welfare$^*_{CAN}$ are the welfare losses to Canadian exporters due to tariffs by the corresponding importer. *US only* is the counterfactual where the US exits the NAFTA and applies MFN tariffs, while *All N.A.* indicates all North American countries exit the NAFTA and apply MFN tariffs when the US is involved.

The right-hand pane of Table 6 presents total exports by each North American country to the other North American countries. Here we see the complement of the effect on imports. The increase in US tariffs has a fairly symmetric impact on both Canadian and Mexican exports, with each falling by around 2%. Additionally, we can calculate the welfare losses to Mexican and Canadian exporters from the increased US tariffs. We estimate these losses to be around \$4 billion for each country. These losses are significant as the terms of trade gains realized by the US are borne by the exporter as welfare loss.

Next, we examine the effects of Canada and Mexico responding to US tariff increasing by applying their MFN tariffs to US imports. The strongest effects are seen in Mexico. There US exports fall by around 5%, and US welfare from exports to Mexico falls by around \$20 billion. This is driven by relatively large increases in tariffs by Mexico – from zero to around 15% on average. Mexican consumers bear substantial efficiency losses of around \$5.5 billion. These efficiency losses are however offset by an increase in Mexican terms of trade gains, as Mexico capitalizes on market power over US imports. The net effect on US welfare in the final counterfactual where all NAFTA countries raise tariffs is a welfare loss of \$18.5 billion (\$6.4 billion in importer gains from higher tariffs and \$25 billion loss to US exporters from higher retaliatory tariffs). These results highlight the potential pitfalls of unilateral tariff policy aimed at increasing welfare through terms of trade gains. If we expect protectionist responses from partner countries, the welfare gains from tariffs (as seen in Table 3) may be quickly overtaken by exporter welfare losses as in this counterfactual scenario for the US.[20]

One caveat to this analysis is the time frame of our welfare effects. Given the estimation, welfare in this model should be thought of as *yearly* short-medium run gains and losses. They do not account for any long run adjustments by import markets to rising prices and falling quantities of imports that could lead to additional welfare losses for the importer. For instance, the US imports significant quantities of goods used as intermediates in production from Canada and Mexico. Increasing prices of these imported goods may lead to long-run welfare losses in downstream US industries not captured by our model. Additionally, the efficiency losses to Mexican consumers may very well be most impactful on US producers in Mexico importing intermediates from their US parent.

Lastly, we should also admit the possibility that in the long-run export supply and import demand elasticities may be lower than our estimates (c.f., Ruhl (2008), Kehoe et al. (2015) and Leibovici and Waugh (2016)). The former drives terms of trade gains to importers, and

[20]We view the spirit of these results as the impetus of the theoretical literature pioneered by Grossman and Helpman (1994) and propagated by Bagwell and Staiger (1999). The estimates here should thus be thought of as a comprehensive set of indexes and welfare measures that quantify the unilateral pressures of terms of trade and efficiency channels resulting from trade policy.

the latter dictates importer efficiency losses. Our estimates of short run terms of trade gains may decline (if long run export supply is more elastic) while efficiency losses may grow (if long run import demand is more elastic) in the long run. Ultimately, we expect these caveats would only serve to further aggregate welfare losses to the US if the NAFTA is abandoned and member countries retaliate. Thus, we view our estimates, which accumulate each year, as a lower bound to US losses from abandoning the NAFTA.

5 Conclusion

Applying a quantitative model that accounts for importer market power and exporter heterogeneity highlighted the importance of terms of trade when evaluating import tariffs. We demonstrated that the current empirical literature overstates importer losses from tariffs and restrictiveness as it ignores the gains to importers from manipulating terms of trade. Broadly, we showed that acknowledging importer terms of trade motives when setting tariffs has significant implications for welfare and TRI estimates in the data.

Finally, through an application of China's WTO accession we further documented the benefits of our methodology. We were able to explicitly measure the effects of China's sweeping tariff reductions on importer and exporter welfare. Additionally, we showed how our model can be used to identify the efficacy of import tariffs through various TRIs. Ultimately, the rich detail provided by our methodology should be a valuable tool for practitioners and policy makers alike.

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