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Quantifying Disruptive Trade Policies

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We present an innovative analytical framework that captures key mechanisms of international trade, and we demonstrate its usefulness as a tool for quantitative trade policy analysis. Our application relates to the tariff changes implemented by the United States in 2018 with subsequent retaliations by partner countries, particularly China. The framework is a multi-region multi-sector general equilibrium simulation model of the global economy. Our core contribution is to introduce a new trade structure that includes monopolistic competition among bilateral representative firms (BRF). We compare simulation results from the BRF structure to those from standard trade formulations of perfect and monopolistic competition. We find that the BRF structure leads to substantially larger trade and welfare changes induced by tariff shocks.

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1. Introduction

Academic arguments in favor of cooperative free trade are challenged by a wave of new protectionist measures. When major economies such as the United States pursue policies against economic integration and partner countries retaliate, economists are faced with the challenge of assessing the policy-induced impacts. This often involves quantitative analysis based on simulation models that complement theoretical considerations. The results of quantitative simulation models are sensitive to parametric and structural assumptions. Exploring this sensitivity helps inform and validate qualitative theoretical arguments.

In this paper we use a suite of simulation models of global trade to quantify the welfare impacts of the 2018 trade war between the US and its main trading partners. We offer results under three alternative structural assumptions about international trade that include a traditional model of perfect competition and two variants of monopolistic competition. Compared to perfect competition, adverse variety impacts under monopolistic competition significantly increase the

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welfare losses caused by tariffs. This is particularly true for our innovative structural trade representation that includes bilateral entry and exit of varieties (firms). We report structural sensitivities based on a diagnostic decomposition of both sectoral impacts as well as economy-wide welfare effects. Our approach allows for an intuitive and transparent explanation of the key economic drivers of policy impacts.

By introducing a computational environment characterized by monopolistic competition between bilateral representative firms (BRFs), we solve a number of challenges associated with the numerical application of contemporary trade theory. Our quantitative analysis of disruptive trade policies captures the distortionary effects of bilateral tariff shocks on varieties delivered at the bilateral level, as well as on spillover effects through trade diversion on varieties received by third countries. The established theoretical structure that might naturally be used to capture these effects is Melitz (2003), featuring a steady-state formulation of bilateral firm selection with ex ante entry and exit at the national level. This contrasts with Krugman (1980)'s formulation, which takes variety effects into account but not bilateral selection. According to Krugman, symmetric varieties enter the market at the level of a nation (or region), and a variety once offered to one market is offered to all markets.

While the Melitz formulation is theoretically appealing, its implementation in large-scale models based on empirical data is numerically challenging. For example, we have not been able to solve a disruptive trade policy shock for the Melitz-based model covering the 57 commodities of the GTAP10 database. Our experience with the computational limitations of implementing Melitz's theory in high-dimensional numerical models is shared by other applied trade economists using creative computational strategies. For example, faced with the inherent computational challenges, Bekkers and Francois (2018) use a set of endogenous supply and demand shifters such that an otherwise conventional Armington model mimics the Melitz responses. Their application includes what they term a *medium-size* model with 11 sectors. The Bekkers and Francois computational strategy is similar to the Balistreri and Rutherford (2013) decomposition strategy of iteratively recalibrating the Armington demand system. Balistreri and Rutherford have a total of nine sectors with only two Melitz sectors (in a subsequent application Balistreri, Böhringer, and Rutherford, 2018a, expand this to 13 sectors with four Melitz sectors).

As an alternative to a model based on Melitz (2003), the proposed BRF model captures the bilateral variety margin with very little computational effort compared to a standard Armington model. To explain the effects of diversity and productivity in the BRF structure compared to a fully fleshed Melitz structure, it is helpful to consider the Feenstra (2010) distinction between import-variety and export-variety gains from trade under monopolistic competition. Feenstra illustrates the Arkolakis, Costinot, and Rodríguez-Clare (2012) welfare equivalence result in a one-sector model by showing that the import-variety (love-of-variety) gains in Krugman are exactly equal to the export-variety (selection) gains in Melitz under equivalent trade elasticities. It is well known that with multiple sectors the Melitz formulation will generally feature both types of gains (Balistreri and Tarr, 2022a; Costinot and Rodríguez-Clare, 2014).

In our proposed BRF model, we capture import-variety gains while retaining Melitz's bilateral selection, so that gains from diversity preference are realized on a bilateral basis. In addition to the standard consumer-side variety effects familiar in theoretical models, diversity preference carries over to industrial productivity given the prominence of intermediate goods in trade. This feature follows from the pioneering intuition provided by Ethier (1982) and confirmed in contemporary application (e.g., Balistreri and Tarr, 2022a). In summary, the BRF formulation we propose does not explicitly replicate the Melitz theory but provides a computationally attractive alternative for large scale trade policy analysis that takes into account bilateral-trade adjustments, variety effects and subsequent productivity adjustments through the diversity of intermediate producers' goods.

For our applied analysis of trade policy, we use the tariff changes as of January 1, 2019, as a break point. Of course, political and other economic shocks have continued to unfold after this date. The Phase One Agreement between the US and China promised some relief from the trade war in 2020, but ultimately failed because China did not fulfill its commitment to significantly increase its imports from the US (Bown, 2022). Coincidentally, the global economy was shaken by the COVID pandemic. During the pandemic and the Biden US administration, the tariff changes were largely maintained (Bown, 2023). With the election and inauguration of Donald Trump for a second term as US president, trade disruptions increased dramatically in 2025. In light of escalating trade conflicts, we consider our methodological contributions in this paper to be even more relevant. Our comparative-static simulations with policy changes up to January 1, 2019 provide a suitable environment for examining the structural sensitivities of model-based analyses of disruptive trade policies.[1]

We use GTAP 11 data for model calibration.[2] The GTAP 11 data include regional

[1] Our primary goal of conducting structural sensitivity analysis determines the relatively limited scope of policy variations and our decision to adopt a comparative-static framework. There are likely important dynamic responses of firms to trade policy changes, for example in terms of the level and the geographical location of investments. We see various alternative approaches to modeling such dynamics. These, however, go beyond the scope of our analysis and objectives of this paper.

[2] The Global Trade Analysis Project (GTAP) is a research consortium initiated in 1992 to provide the trade policy analysis community with a global economic dataset that can be used for quantitative analysis of international policy. The GTAP project was founded by Thomas Hertel at Purdue University (see notably Hertel, 1997). The Center's staff economists are responsible for regular updates of the database (e.g. Aguiar et al., 2023). Software development within the GTAP project was significantly supported by researchers

input-output tables and bilateral trade flows with benchmark tariffs as of 2017. Our source for the tariff *changes* in 2018 from 2017 benchmark levels is Li (2018).[3] For countries that negotiated an exemption from the US steel tariffs (Brazil, Argentina, and South Korea) we apply a Voluntary Export Restraint (VER) equal to 15% ad valorem in the form of an export tax of the respective trade flows.[4] We perform counterfactual comparisons based on the 2018 tariff changes and VERs relative to the benchmark equilibrium provided by the 2017 GTAP accounts.

In our simulation analysis, we find that the escalation of US tariffs in 2018 and the subsequent retaliatory tariffs by trade partners are costly for both the US and the Chinese economies, while benefiting other regions (especially Europe) through trade diversion. These results are driven by the fact that beyond the US and China the 2018 policy changes are small relative to trade volumes.

Based on the BRF model variant, the US welfare costs of the 2018 trade war amount to $81.9 billion (or 0.62% of private consumption).[5] The welfare costs in the perfect-competition model variant are significantly less at $20.7 billion (or 0.16% of private consumption). We can place our quantitative welfare results for the US in the context of some of the sparse ex post econometric work that quantifies the 2018 trade disruption, specifically Fajgelbaum et al. (2020a,b). Fajgelbaum et al. (2020a) use a formulaic summation of the individual market impacts (changes in US import and export surplus plus new tariff revenues) based on observed trade responses. In their revision, Fajgelbaum et al. (2020b), they estimate the net welfare impact for the US at $24.8 billion (or 0.13% of GDP). It is important to note that the ex post econometric estimates of Fajgelbaum et al. (2020b) do not include welfare changes due to changes in the number of varieties. Taking this consideration into account, our comparative-static simulation analysis appears to reasonably align with the econometric evidence. We show larger welfare impacts in the BRF structure because there are substantial welfare and intermediate-input productivity changes related to lost varieties in the US market. Furthermore, our (equivalently parameterized) perfect-competition variant seems to underestimate the actual trade responses because it fails to account for extensive margin (entry and exit) changes. With equivalent price responsiveness captured by respective elasticities, we observe stronger trade diversion under the BRF structure.

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[3] The tariff data can be downloaded from https://www.card.iastate.edu/china/trade-war-data/. See Li (2018) for additional details.

[4] This gives us an approximation of the VER impacts. The important issue is that the rents associated with the VERs accrue to the export region not the US. Brazil and Argentina are part of the Mercosur region in the aggregate dataset used for our policy simulations. Given the relatively small value of steel imports from Mercosur we simply apply the VERs to the whole Mercosur region.

[5] As is customary in applied general-equilibrium analysis, welfare is measured using Hicksian equivalent variation in money-metric utility.

In addition to the econometric work of Fajgelbaum et al. (2020a,b) we can relate our findings to several computational studies that simulate the 2018 tariff escalations. First, is our earlier working paper (Balistreri, Böhringer, and Rutherford, 2018b), which considers the same scenarios, but is based on data for 2014 as the benchmark year (GTAP 10) with a different composition of US-China trade for model calibration. Under the BRF monopolistic-competition structure (Balistreri, Böhringer, and Rutherford, 2018b) find a 1.0% reduction in US welfare and a 1.7% reduction in China's welfare. By comparison, our welfare losses in the present analysis amount to 0.62% for the US and 1.23% for China. Li, Balistreri, and Zhang (2020) also use GTAP 10, but apply the perfect-competition canonical GTAPINGAMS model (Lanz and Rutherford, 2016). The tariffs used by Li, Balistreri, and Zhang differ slightly from ours, as they have been updated to post Phase One rates. Li, Balistreri, and Zhang (2020) report welfare reductions of 0.2% for the US and 1.7% for China.

Zheng et al. (2023) perform a comprehensive analysis of the US-China dispute using the GTAP 10 data and the GTAP model.[6] While Zheng et al. (2023) use GTAP 10 data in a static model, their analysis relies on a projection of the 2014 base-year data out to the policy window. Under a scenario that closely matches ours (their scenario 2a), Zheng et al. find a welfare reduction of 0.2% for the US and a welfare reduction of 0.6% for China.[7] With a recursive-dynamic extension of the GTAP model , Itakura (2020) and Walmsley and Minor (2020) find similar macroeconomic impacts.[8] Robinson and Thierfelder (2024) use the perfect-competition *Globe* model calibrated to GTAP 11 data to consider a set of hypothetical scenarios (not the observed tariff increases we use), and so the welfare results are not directly comparable to ours. Appendix B includes an extended literature review to complement our discussion of recent papers on the 2018 trade war. The review in the appendix covers contemporary arguments for cooperative trade and the evolution of theory-based quantitative policy analysis, which motivates the choice and design of our modeling framework.

The remainder of this paper is organized as follows. In section 2, we lay out the theory underlying our general equilibrium modeling framework. In section 3, we present our empirical data sources and provide a simple (partial equilibrium)

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[6] In addition to the global accounts (the GTAP data), the Global Trade Analysis Project maintains and supports a core perfect-competition Armington model (Hertel, 1997).

[7] As one might expect, Zheng et al. (2023) find small relative effects when they focus on the US-China Phase One agreement. The relative benefits of the Phase One tariff cuts measured by Zheng et al. where 0.02% for the US and 0.04% for China. This provides strong evidence that the Phase One agreement is an order of magnitude less important than the 2018 tariff escalation, and can be ignored in the broader context of the trade war.

[8] Itakura (2020) reports real GDP reductions of 0.4% and 1.1% for the US and China under the tariff scenario. Walmsley and Minor (2020) find initial US GDP reductions of 0.45% rising to 0.86% by 2030; and initial Chinese GDP reductions of 1.5% rising to 2.84%.

approximation of trade policy responses. In section 4 we discuss the quantitative general equilibrium impacts of the trade disruption with a comparison across the alternative structures. In section 5, we conclude.

2. Modeling framework

To examine the structural sensitivity of quantitative trade policy analysis, we develop a flexible modeling framework that encompasses three alternative representations of international trade:

ARM: **Armington** (1969) is based on perfectly competitive markets and constant returns to scale. Trade is in regionally differentiated goods (the so-called Armington assumption).

KRU: **Krugman** (1980) is based on imperfect competition, in which changes in the number of firms (varieties) influence aggregate productivity. Trade is in firm-level varieties. An important feature of the Krugman trade specification is that all varieties are sold in all regions.

BRF: **Bilateral Representative Firms** emphasizes the extensive margin of trade. Like Krugman, BRF incorporates a Dixit-Stiglitz variety effect related to firm-level varieties, but unlike Krugman, not all varieties (or firms) from a region are sold in (or supply to) every other region.

We are motivated to develop and explore the BRF structure for two reasons. First, Krugman's standard model is based on the restrictive assumption that entry and exit is at the level of a country or region. Second, we still face computational challenges applying mainstream bilateral-firm-selection theories (e.g., Melitz, 2003) in large-scale applications with many commodities. More specifically, the questionable feature of Krugman's structure is that isolated policy reforms affecting individual trade links have an unrealistically small or negligible impact on extensive-margin adjustments on that link. Therefore, the Krugman setting fails to reveal love-of-variety welfare impacts associated with bilateral shocks that do not significantly change global demand at the implied firm level. Rutherford and Tarr (2008) avoid this problem in their application of a single-country open-economy Krugman model, essentially applying the BRF structure to the external trade links of the open economy. Our analysis which builds on the previous working paper Balistreri, Böhringer, and Rutherford (2018b) is the first application of the BRF structure in a multi-region framework.

Apart from the differences in trade specification the three model variants used for our structural sensitivity analysis share the logic of a generic multi-region multi-sector general equilibrium model (cf. Lanz and Rutherford, 2016). Decisions about the allocation of resources are decentralized, and the representation of behavior by consumers and firms follows the canonical assumptions of microeconomic optimization: (i) consumers maximize welfare through private consumption subject to a budget constraint; (ii) producers combine intermediate inputs and primary factors (several categories of labor, land, resources, and physical capital) at least cost subject to technological constraints. Preferences and technological constraints are described through nested constant-elasticity-of-substitution (CES) functions that capture demand and supply responses to changes in relative prices. By default, primary factors are treated as mobile across sectors within a region, while specific factors are tied to sectors in each region. We assume that a portion of capital payments in each industry that operates with increasing returns to scale is tied to the specific destination market (see our description below). Government demand, investment demand, and the balance of payment surplus are fixed at the base-year level.

In the following subsections we discuss the key differences in trade specification between our model variants and the canonical GTAPINGAMS model, which is documented in Lanz and Rutherford (2016). We focus on the BRF trade structure and then provide the specific restrictions implemented for the Krugman and Armington variations. Our exposition is targeted to the equations that appear in the respective model variants. We provide a more detailed derivation of the BRF structure in the context of a transparent single-sector multi-region trade model in Appendix C.

For the computer implementation of the numerical models, we use the high-level programming language GAMS (Generalized Algebraic Modeling System) whose notation closely follows standard matrix algebra (GAMS Development Corporation, 2013). The fundamental strength of GAMS lies in the ease with which mathematically defined models can be formulated. The system of equations which form our model is solved using PATH, a powerful algorithm for large-scale and complex non-linear problems (Dirkse and Ferris, 1995).

2.1 Monopolistic Competition with Bilateral Representative Firms (BRF)

Consider variety-adjusted supply of a *Dixit-Stiglitz* composite of goods $i \in \{\text{IRTS goods}\} \subset I$ from each source region $s \in R$ available for absorption in region $r \in R$. We denote composite supply in r as A_{ir} with firm-level component quantities of the representative bilateral variety as q_{isr}. The number of firms operating on each bilateral link is given by N_{isr}. With a constant elasticity of substitution of σ_i across firm varieties, we have the typical CES aggregation

$$A_{ir} = \psi_{ir} \left[\sum_s N_{isr} q_{isr}^{(\sigma_i - 1)/\sigma_i} \right]^{\sigma_i/(\sigma_i - 1)}, \tag{1}$$

where ψ_{ir} is a scale parameter. In the model formulation it is more convenient to represent the aggregation in terms of its dual price index, which embeds optimal choice,

$$P_{ir} = \left[\sum_{s} N_{isr} p_{isr}^{1-\sigma_i} \right]^{1/(1-\sigma_i)}, \tag{2}$$

where the p_{isr} are the landed-duty-paid prices faced in destination r. Equation (2) indicates the minimized cost of supplying one unit of the composite good i in region r as a function of the price vector.

Applying the envelope theorem to (2) we can derive the conditional demand for each firm-level variety:

$$q_{isr} = A_{ir} \left(\frac{P_{ir}}{p_{isr}} \right)^{\sigma_i}. \tag{3}$$

With a marginal cost (inclusive of transport payments) of c_{isr} a firm facing this demand will maximize profits by charging a gross price in the destination in accord with the standard markup formula:

$$p_{isr} = (1 + t_{isr}) \frac{c_{isr}}{1 - 1/\sigma_i}, \tag{4}$$

where we have introduced the policy instrument t_{isr} as an ad valorem tariff.

Free entry with increasing-returns firms indicates that all operating profits will be exhausted on fixed cost. That is, firms will enter to the point that the economic profits from creating a new variety are zero. We assume, consistent with the literature, that the input price of fixed cost payments is the same as for variable costs. Let $\mathtt{f}_{isr}$ be the fixed cost in terms of input quantity such that entry of a firm operating on the s to r trade link costs $\mathtt{f}_{isr} c_{isr}$. Setting this equal to net operating profits gives us the free-entry (zero-profit) condition:

$$c_{isr} \mathtt{f}_{isr} = \frac{p_{isr} q_{isr}}{\sigma (1 + t_{isr})}. \tag{5}$$

We now turn to the input market and technology. The bilateral variable c_{isr} can be thought of as the price of a composite input used by the increasing-returns firms for their fixed and variable costs. It is a composite because it embeds optimization over a set of primary-factor inputs, intermediate inputs, and bilateral transport margins. Let us assume a nested-CES constant-returns technology for producing the composite-input quantity x_{isr}. At the top level let us assume that a nested CES aggregate of all other inputs substitutes against a *bilateral specific factor* with fixed supply. Inclusion of this specific factor is critical to the convexity of the BRF formulation. Without a specific factor indexed bilaterally all firms would either enter or exit a given market resulting in *bang-bang* responses to price changes. With the bilateral specific factor, however, we have bilateral rents that adjust continuously to price changes, and firms will only abandon a given trade link if the price of the specific factor goes to zero. Let us represent the price of the bilateral specific factor as z_{isr}, the price of global transport services τ, and the price of a nested CES composite of all other industry inputs as w_{is}. Under decentralized optimization the price of the composite input is given by the unit-cost function

$$c_{isr} = \left[\alpha_{isr} \left(w_{is} + \gamma_{isr}\tau\right)^{1-\eta_{isr}} + \beta_{isr} z_{isr}^{1-\eta_{isr}}\right]^{1/(1-\eta_{isr})}. \tag{6}$$

In equation (6) we have parameters that represent the relative weights on mobile versus specific factors (α_{isr}, and β_{isr}) and the bilateral transport-margin coefficient (γ_{isr}). The substitution elasticity, η_{isr}, along with the assumed relative weight on the specific factor determines the continuous supply response of the bilateral composite input quantity, x_{isr}. This is discussed in the calibration subsection (Subsection 2.4).

We have market clearance in the bilateral composite input, where supply is given by x_{isr} and demand is given by each firm's use of the input for fixed and operating costs:

$$x_{isr} = N_{isr} \left(\mathtt{f}_{isr} + q_{isr}\right). \tag{7}$$

Equations (2) through (7) fully capture the assumed BRF structure and its intuitive underpinnings. We can greatly simplify the system in the computational model, however, by noting a few key results from theory.

First, note that we can show that firm-level output is a constant by substituting the optimal price from (4) into the zero-profit condition (5). Solving for the quantity we have:

$$q_{isr} = \mathtt{f}_{isr}(\sigma_i - 1).$$

The only margin of adjustment on a bilateral link is entry and exit, N_{isr}. Further, from equation (7), this indicates that proportional changes in input supply will be matched by proportional changes in the number of varieties. Using the popular "hat" notation we have

$$\hat{x}_{isr} = \hat{N}_{isr}.$$

Adding a bilateral calibration parameter λ_{isr} which captures observed trade data as well as the constant implied markup we can restate the price index in (2) directly as a function of the bilateral cost and the proportional change in varieties:

$$P_{ir} = \left[\sum_s \lambda_{isr}\hat{x}_{isr}[(1+t_{isr})c_{isr}]^{1-\sigma_i}\right]^{1/(1-\sigma_i)}.$$

Now directly deriving conditional composite-input demand we have

$$A_{ir}\frac{\partial P_{ir}}{\partial(1+t_{isr})c_{isr}} = A_{ir}\lambda_{isr}\hat{x}_{isr}\left(\frac{P_{ir}}{(1+t_{isr})c_{isr}}\right)^{\sigma_i}.$$

Inserting this on the right-hand side of equation (7) is problematic, however, because it causes a degeneracy.[9] To solve this we assume that only 90% of the variety effect is realized so $\hat{x}_{isr}$ is replaced in the system with

$$\tilde{x}_{isr} \equiv 0.9\hat{x}_{isr} + 0.1.$$

In that regard our BRF computational model gives an approximation. In a set of sensitivity runs in Section 4 we consider the impact of changing the proportion of realized variety impacts. The benefit of the approximation is that we can capture the BRF structure with no more computational overhead than a standard Armington model. To illustrate consider that the broader general equilibrium determines demand for the Dixit-Stiglitz composite in the importing region (denoted here as D_{ir}). Further, the general equilibrium determines the relevant input prices (w_{is}, z_{isr}, τ) in the source region. With these variables given, the BRF trade-equilibrium conditions in the model are as follows.

The BRF trade equilibrium:

$$A_{ir} = D_{ir} \tag{8}$$

$$P_{ir}^{\text{BRF}} = \left[\sum_s \lambda_{isr}\tilde{x}_{isr}[(1+t_{isr})c_{isr}]^{1-\sigma_i}\right]^{1/(1-\sigma_i)} \tag{9}$$

$$x_{isr}^{\text{BRF}} = A_{ir}\lambda_{isr}\tilde{x}_{isr}\left(\frac{P_{ir}^{\text{BRF}}}{(1+t_{isr})c_{isr}}\right)^{\sigma_i} \tag{10}$$

$$c_{isr} = \left[\alpha_{isr}\left(w_{is}+\gamma_{isr}\tau\right)^{1-\eta_{isr}} + \beta_{isr}z_{isr}^{1-\eta_{isr}}\right]^{1/(1-\eta_{isr})}. \tag{11}$$

These four equilibrium conditions correspond to the endogenous variables: P_{ir}^{BRF}, A_{ir}, c_{isr}, and x_{isr}^{BRF}. The constructed variety effect $\tilde{x}_{isr}$ is substituted directly into the conditions according to its definition.

2.2 A comparable Krugman structure

In contrast to the BRF trade equilibrium a standard Krugman model has entry of national varieties. A firm considers profits across all markets and weighs this against the fixed cost of entering. Once entered the firm supplies its variety to

[9] With the derived demand on the right-hand side of (7), we effectively have $x = \phi x/x^0$ or $1 = \phi/x^0$ where the key endogenous variable drops from the equilibrium condition.

all markets. The same features hold, however, where we have fixed markups and fixed output per firm. To capture the Krugman structure in a comparable model we simply need to replace the bilateral variety index with a country-specific index.

Let us assume that a Krugman firm's composite input is the upstream bilaterally-mobile input with price w_{is}. In this regard, the bilateral charges in terms of specific-factor rents and transport margins are simply additional costs taken as parameters by the firm. Where the firm markup and operating profits are attached to w_{is}. Let us denote total demand for the Krugman input y_{is}, where

$$y_{is} = \sum_r x_{isr} \frac{\partial c_{isr}}{\partial w_{is}}.$$

Following the same logic as in the model above we can use an index on this quantity, $\hat{y}_{is}$ to indicate the variety effects as they enter the Dixit-Stiglitz price index. Under the Krugman structure the equilibrium conditions are as follows.

The Krugman trade equilibrium:

$$A_{ir} = D_{ir} \tag{12}$$

$$P_{ir}^{\text{KRU}} = \left[\sum_s \lambda_{isr} \hat{y}_{is} [(1 + t_{isr}) c_{isr}]^{1-\sigma_i} \right]^{1/(1-\sigma_i)} \tag{13}$$

$$x_{isr}^{\text{KRU}} = A_{ir} \lambda_{isr} \hat{y}_{is} \left(\frac{P_{ir}^{\text{KRU}}}{(1 + t_{isr}) c_{isr}} \right)^{\sigma_i} \tag{14}$$

$$c_{isr} = \left[\alpha_{isr} \left(w_{is} + \gamma_{isr} \tau \right)^{1-\eta_{isr}} + \beta_{isr} z_{isr}^{1-\eta_{isr}} \right]^{1/(1-\eta_{isr})}. \tag{15}$$

As in the previous model, these four equilibrium conditions correspond to the endogenous variables: P_{ir}^{KRU}, A_{ir}, c_{isr}, and x_{isr}^{KRU}. There is no degeneration when we use $\hat{y}_{is}$ in the bilateral-input market clearance condition, so it is used directly as determined in the general equilibrium.

2.3 A comparable Armington structure

In the final structure we assume perfect competition. If we have perfect competition there are no markups over marginal cost and no variety impact from entry or exit. In this case we simply remove the variety index from the model.

The Armington trade equilibrium:

$$A_{ir} = D_{ir} \tag{16}$$

$$P_{ir}^{\text{ARM}} = \left[\sum_s \lambda_{isr} [(1 + t_{isr}) c_{isr}]^{1-\sigma_i} \right]^{1/(1-\sigma_i)} \tag{17}$$

$$x_{isr}^{\text{ARM}} = A_{ir} \lambda_{isr} \left(\frac{P_{ir}^{\text{ARM}}}{(1 + t_{isr}) c_{isr}} \right)^{\sigma_i} \tag{18}$$

$$c_{isr} = \left[\alpha_{isr} \left(w_{is} + \gamma_{isr} \tau \right)^{1-\eta_{isr}} + \beta_{isr} z_{isr}^{1-\eta_{isr}} \right]^{1/(1-\eta_{isr})}. \tag{19}$$

Again, these four equilibrium conditions correspond to the endogenous variables: P_{ir}^{ARM}, A_{ir}, c_{isr}, and x_{isr}^{ARM}.

2.4 Calibration

To ensure the consistency of our structural sensitivity analysis, the different model variants must be calibrated to identical economic data. Model calibration to the GTAP data with input-output and final demand transactions as well as bilateral trade flows follow directly from Lanz and Rutherford (2016). Balistreri and Rutherford (2013) and Balistreri and Tarr (2022a) provide details on calibrating monopolistic-competition trade models. Our structure, which leverages the theoretic result of fixed firm-level output under fixed markups, greatly simplifies the calibration procedure.

One can use the bilateral trade flows to calculate a set of CES Armington weights, λ_{isr}, that are consistent with the benchmark equilibrium (see Balistreri and Tarr, 2022a, Appendix A for details). If the variety indexes ($\tilde{x}_{isr}$ or y_{is}) in the benchmark equilibrium are set to one, the CES calibration is identical across the different structures. The firm-level variables do not need to be calibrated as they only affect the general equilibrium via the variety indexes.

Markups are fixed, so that shares of revenues allocated to fixed costs are fixed as well. As shown by Balistreri and Rutherford (2013) in their section on calibration, the product of the number of firms and the firm-level fixed cost must equal a fixed proportion of observed revenues for a given trade flow, so that the free choice of the number of initial firms (N_{isr}) directly indicates the benchmark-consistent level of firm-level fixed costs ($\mathtt{f}_{isr}$). Equivalently, any assumed or estimated value of $\mathtt{f}_{isr}$ must directly imply the benchmark-consistent number of initial firms. The only context in which the calibration of fixed costs might matter is a counterfactual experiment in which fixed costs are changed as a policy instrument (e.g., Balistreri, Hillberry, and Rutherford, 2011, change fixed costs in counterfactual experiments).

There are two other aspects of the calibration process that we would like to emphasize. Firstly, the elasticity of substitution in the sectors that are potentially modeled as monopolistically competitive. We adopt $\sigma_i = 3.8$ for all monopolistically competitive sectors following the plant-level estimates of Bernard et al. (2003).[10] We adopt the same value for the respective sectors in the Armington formulation. As a matter of gravity analysis, Arkolakis, Costinot, and Rodríguez-Clare (2012) show analytically that trade responses will be the same under Armington and Krugman models for equivalent values of σ. Their restrictive assumptions do not hold for our general equilibrium setting, yet we use the value of σ_i as a common reference value for the elasticity of substitution across varieties.[11]

The second aspect of calibration that should be emphasized has to do with our specific-factors formulation and the benchmark local supply elasticity. The supply of each bilateral specific factor is fixed. Changes in the supply of the composite input, x_{isr}, will involve changes in mobile inputs. One can solve for a closed-form expression of the local supply elasticity as a function of the value share of the specific factor and the elasticity of substitution, η_{isr} (see Balistreri, Jensen, and Tarr, 2015, Appendix G). In each industry, we assume that specific-factor payments are equal to 5% of gross output and these payments are shared bilaterally in proportion to each market served, including the domestic market.[12] Taking into account benchmark taxes and trade margins, we obtain the value share of specific factor payments as β_{isr} (choosing units such that all prices equal one at the benchmark). The formula for the local supply elasticity (μ_{isr}) is given by (see Balistreri, Jensen, and Tarr, 2015, Appendix G):

$$\mu_{isr} = \eta_{isr} \frac{1 - \beta_{isr}}{\beta_{isr}}. \tag{20}$$

Given β_{isr} and an assumed common value of $\mu = \mu_{isr}$ we invert (20) to calibrate the appropriate η_{isr}. We use the same values across all three model variations for potentially monopolistically competitive sectors. In the central case, we assume $\mu = 1$ and investigate, in Section 4, how results react to a reduction or an increase of this value.

[10] We use the standard elasticity of substitution provided in the GTAP database for those sectors that are perfectly competitive across the model variations. Using the common Bernard et al. (2003) estimate for the BRF and Krugman models ensures sizable variety effects that are directly controlled through a single parameter. In Section 4, we carry out a sensitivity analysis in which we alternatively assume $\sigma_i = 2.5$ and $\sigma_i = 5$.

[11] Balistreri and Tarr (2022b) take a different approach for models where the equivalence proposed by Arkolakis, Costinot, and Rodríguez-Clare (2012) does not hold. Balistreri and Tarr adjust the σ used in their Armington structure such that it induces an *average* trade response which is equivalent to the *average* trade response calculated from their monopolistic-competition model for a given policy scenario. Thus, they base their model comparison on the average trade response and not the structural parameter σ.

[12] In the event that total capital payments cannot cover 5% of gross output, we assign all capital to be sector specific.

3. Data

Beyond structural assumptions on causal relationships (i.e., model logic), a quantitative impact assessment of disruptive trade policies requires empirical data. To simulate the impacts of tariff shocks introduced by trade wars we need globally consistent data that characterize technologies, preferences, and endowments at the country level, as well as a set of price response parameters (elasticities). Our primary data source is the recently released GTAP version 11 database (Aguiar et al., 2023). GTAP 11 features detailed national accounts on production and consumption (input-output tables) together with bilateral trade flows, initial tariff rates and export taxes for the base-year 2017 across 65 goods matched to sectors and 141 countries as well as 19 composite regions. In addition to the social accounts, the GTAP database provides empirically estimated elasticities that determine the responses of economic agents to policy-induced price changes.

The GTAP data can be organized and aggregated using the GTAPINGAMS routines (Lanz and Rutherford, 2016). We maintain a detailed set of commodities in order to capture the effects of trade policy reforms, which can vary depending on initial cost shares (as provided by the input-output data), the ease of input substitution (as reflected by sector-specific elasticities), and sector-specific regulations (here, changes in tariff rates). We aggregate a few of the 65 commodities in GTAP 11 to be consistent with the 57 commodities provided in the previous GTAP version 10, because the 2018 tariff changes (Li, 2018) were set for the GTAP 10 commodities. We focus on key regions of interest and therefore aggregate to the nine regions listed in Table 1.[13] Table 1 also lists the primary factors of production, where as described in Section 2 some capital is designated for bilateral specific factors. The set of 57 commodities in our aggregation is listed in Table 2. The sectors that are potentially treated as monopolistically competitive under the Krugman and BRF structures—food processing, manufacturing, and business services sectors—appear in bold face.

We perform some preliminary diagnostics to illustrate the quantitative significance of the trade war in the context of real data. Figures 1 and 2 provide a concise presentation of the scale of US-China trade, the scale of the added tariff distortions, and the scale of elasticity-driven first-guess trade responses. In these figures we calculate changes in trade using a commodity-specific partial-

[13] Our regional aggregation is driven by our desire to capture the welfare impacts of key countries and regions while limiting the overall number of regions to facilitate a concise reporting of simulation results. The selected regions cover the tariff changes among the US, China, and exporters of steel to the US. South Korea is included because of its importance for steel exports to the US and its large trade volumes with both the US and China. Canada and Mexico are included because of their integration with the US. The regional aggregates for the EU and Mercosur constitute important trading partner for the US and China. The remaining countries and regions in the GTAP 11 database are grouped together in two larger composite regions, i.e., the Rest of OECD and the Rest of the World.

Table 1. Regions and primary factors

Regions		Factors	
GTAPINGAMS Identifier	Definition	GTAPINGAMS Identifier	Definition
EUR	EU-27 plus	LAB	Unskilled labor
USA	U.S.A	TEC	Technicians and Professionals
CHN	China		
CAN	Canada	CLK	Clerks
MEX	Mexico	MGR	Managers and Officials
MRC	Mercosur		
KOR	S. Korea	SRV	Service workers
OEC	Rest of OECD		
ROW	Rest of World	CAP	Capital
		LND	Land
		RES	Resource

equilibrium model of trade among the regions. We use linear supply and demand functions calibrated to consistent supply and demand elasticities and benchmark transactions for 2017. In our graphical exposition, we deliberately use the same scale for each figure to provide a stark comparison across goods and the relative bilateral trade volumes. We are aware that this makes much of the figure difficult to read and therefore provide the full underlying data in Appendix A. Commodities with more than $1 billion of benchmark trade are represented in the figures, with the full set of benchmark and partial equilibrium trade flows and landed-duty-paid prices reported in Appendix A (Tables A.1 and A.2). The three-letter identifiers are mapped to descriptions in Table 2. The purpose of our partial equilibrium analysis is to provide a point of comparison for the more elaborate general-equilibrium analysis and to identify those relevant sectors that are heavily impacted by the tariff war.

We focus on the US and China because their tariff escalations are substantial and quantitatively dominate tariff changes related to the steel and aluminum dispute between the US and other trade partners. In Figures 1 and 2 the black point with its adjacent commodity label indicates the benchmark trade volume along the horizontal axis and the gross-of-tariff (landed-duty-paid) benchmark import price on the vertical axis, with the net-of-tariff prices normalized to one. The connected red point indicates the partial-equilibrium gross-of-tariff price and trade response to the 2018 tariff escalation.[14]

The most important import sector for the US is electronic equipment (`eeq`). US imports from China of `eeq` in 2017 are reported to be valued at $200.6 billion with an initial tariff rate of less than 1%. This is represented in Figure 1 by the black

[14] For example, benchmark US imports of Machinery and equipment nec (`ome`) are $30.4 billion at an initial tariff rate of 1.0% and a landed-duty-paid price of 1.04. The 2018 tariff policy raises the tariff rate to 22.1%, resulting in a partial equilibrium reduction of imports by $6.3B.

Table 2. Commodities (sectors/industries)

GTAPINGAMS Identifier	Definition	GTAPINGAMS Identifier	Definition
pdr	Paddy rice	**lum**	Wood products
wht	Wheat	**ppp**	Paper products, publishing
gro	Cereal grains nec	**oil**	Petroleum, coal products
v_f	Vegetables, fruit, nuts	**crp**	Chemical, rubber and plastic products
osd	Oil seeds	**nmm**	Mineral products nec
c_b	Sugar cane, sugar beet	**i_s**	Ferrous metals
pfb	Plant-based fibers	**nfm**	Metals nec
ocr	Crops nec	**fmp**	Metal products
ctl	Cattle,sheep,goats,horses	**mvh**	Motor vehicles and parts
oap	Animal products nec	**otn**	Transport equipment nec
rmk	Raw milk	**eeq**	Electronic equipment
wol	Wool, silk-worm cocoons	**ome**	Machinery and equipment nec
frs	Forestry	**omf**	Manufactures nec
fsh	Fishing	ele	Electricity
col	Coal	gdt	Gas manufacture, distribution
cru	Crude oil	wtr	Water
gas	Natural gas	cns	Construction
omn	Minerals nec	trd	Trade
cmt	Meat: cattle, sheep, goats, horse	otp	Transport nec
omt	Meat products nec	wtp	Sea transport
vol	Vegetable oils and fats	atp	Air transport
mil	Dairy products	**cmn**	Communication
pcr	Processed rice	**ofi**	Financial services nec
sgr	Sugar	**isr**	Insurance
ofd	Food products nec	**obs**	Business services nec
b_t	Beverages and tobacco products	ros	Recreation and other services
tex	Textiles	osg	Public administration, defense, health, education
wap	Wearing apparel	dwe	Dwellings
lea	Leather products		

Notes: Monopolistically competitive sectors appear in **bold** face. “nec” indicates not elsewhere classified.

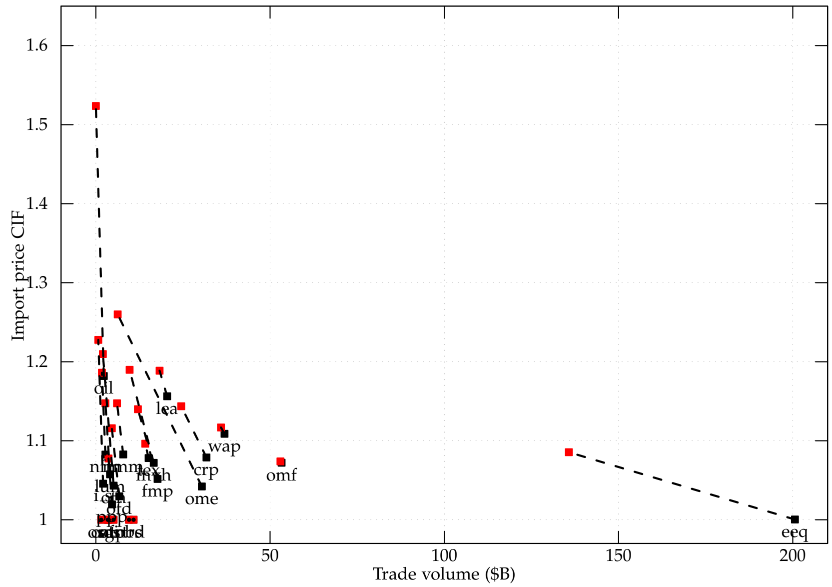

Figure 1. US imports from China: benchmark trade, tariffs, and implied partial equilibrium responses

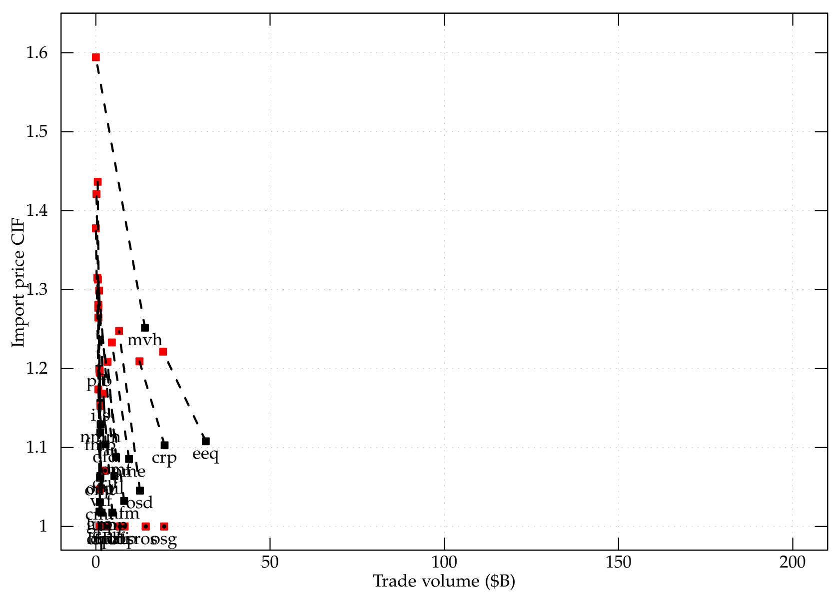

Figure 2. Chinese imports from the US: benchmark trade, tariffs, and implied partial equilibrium responses

square in the lower right corner of the figure. The 2018 US trade-war tariff on `eeq` increased to 9.2%. With the assumed elasticities, this translates to a partial equilibrium increase in the delivered price to 1.085 and a reduction in `eeq` imports from China to $135.7 billion. Indicated by the red point in the figure connected to the black `eeq` point as the benchmark. Other goods imported from China that have substantial benchmark trade include machinery and equipment (`ome`), other manufactures (`omf`), wearing apparel (`wap`), chemical, rubber, and plastic products (`crp`), and leather products (`lea`).

In Figure 2 we consider trade in the other direction, i.e. Chinese imports from the US. In the 2017 base-year as our benchmark, the trade volumes are much lower and the tariffs are higher on China's imports from the US. US export of Chemical, rubber, and plastic products (`crp`) are a good example, with benchmark tariffs of 6.5% on Chinese imports valued at $19.7 billion. These tariffs increase to 16.7% under the 2018 retaliatory tariffs. As a partial equilibrium response China's imports from the US fall to $12.5 billion. The most important commodities among other US exports to China include electronic equipment (`eeq`) at $31.6 billion, chemical, rubber, plastic products (`crp`) at $19.7 billion, and oil seeds (`osd` in the form of soybeans) at $12.6 billion.

The partial equilibrium illustrations in Figures 1 and 2 are useful for first-round insights into how scheduled tariff changes translate into economic impacts driven by the magnitude of the tariff changes, the base-year trade flows, and trade elasticities. In subsequent analysis, we refine these estimates based on more comprehensive and sophisticated general equilibrium models.[15]

We make one final comment on our use of the GTAP 11 data with its 2017 base year. Most other computational studies of the 2018 trade war, including our earlier working paper (Balistreri, Böhringer, and Rutherford, 2018b), use 2014 as the base year. The changes in trade patterns between 2014 and 2017 are, however, important - e.g., US imports from China in the `eeq` category increased significantly during that period.[16] The shift in the composition of trade is important for our welfare analysis, as US tariffs on `eeq` increased less sharply than on many of the goods with larger trade volumes in 2014. Applying the same structure and tariff increases to the 2014 base year resulted in a 1.0% reduction in US welfare (Balistreri, Böhringer, and Rutherford, 2018b), which is substantially higher than our central result in the current analysis (a 0.6% welfare reduction). In summary, the use of a base year that is consistent with policy shocks is important for an appropriate impact assessment.

[15] Similar figures in Section 4 include general equilibrium responses together with the partial equilibrium responses as a comparison.

[16] A comparison of the Figures 1 and 2 with the figures in Balistreri, Böhringer, and Rutherford (2018b) shows that `eeq` imports from China increased by about $40 B between 2014 and 2017, and other machinery and equipment (`ome`) imports declined by more than $40B.

4. Results

Our modeling framework permits us to investigate the outcome of policy shocks for three alternative structural assumptions, which figure prominently in applied trade analysis. As our central setting, we refer to the BRF model variant, which combines theoretical innovations in the area of bilateral firm-level product differentiation with imperfect competition.

Table 3 reports the region-specific welfare impacts on private households (measured as Hicksian equivalent variation) across the three model structures.[17] Figure 3 provides a graphical exposition of welfare impacts. Across trade structures, the largest impacts occur for the BRF trade specification. Across regions, economic losses from the trade war are concentrated on the US and China, as we might expect. The steel and aluminum tariffs affect a relatively small share of global trade, while the tariffs between the US and China represent significant distortions for their bilateral trade flows. Our BRF simulations suggest trade war costs for the US on the order of $81.9 billion annually. Although these are sizable costs in dollars, its share of aggregate US consumption (0.6%) is not large. If we were to distribute costs evenly among the approximately 130 million US households, the annual economic loss would amount to about $620 per household.

Figure 4 reports the gross output changes for US sectors across the three model structures. Figures 5 and 6 focus on the ten sectors with the largest percentage losses and the ten sectors with the largest percentage gains. In the lower panel of Figures 5 and 6, we also report the losses and gains in dollars to indicate their importance in the broader economy.[18] The general pattern is that the BRF model generates larger output responses, while the Krugman and Armington models generate similar output changes. There are a few exceptions, however. In particular, the Krugman and Armington models indicate larger output responses in some agricultural sectors: the oil seed (primarily soybeans), plant-based fiber (primarily cotton), and forestry products. These sectors are modeled as constant-returns sectors across all three model variants. Under the BRF structure we have larger trade responses in the increasing-returns sectors, but the resource reallocation means slightly muted responses in the shrinking constant-returns sectors.

The Krugman model indicates sectoral responses similar to the Armington structure despite the fact that welfare impacts are larger in the Krugman model (especially at the global level) due to global variety losses. Regardless of the trade structure, it is clear that the Chinese retaliatory tariffs are hitting specific export-dependent US agricultural sectors hard. Real revenues from oil seed production are falling by between $5.8B (11.5%) and $6.5B (12.9%) across the model structures.

[17] Global losses are reported as the summation of regional changes.

[18] The change in gross output in dollars is calculated as the change in the sectoral revenue divided by the true-cost-of-living index for the US household. Thus, the dollar amounts shown represent real revenue changes evaluated in household consumption units.

Table 3. Welfare impacts across model structures

	Benchmark GDP ($B)	Benchmark Consumption ($B)	Equivalent Variation ($B)			Equivalent Variation (%)		
			BRF	Krugman	Armington	BRF	Krugman	Armington
USA U.S.A	19,480	13,314	-81.9	-23.5	-20.7	-0.62	-0.18	-0.16
EUR EU-27 plus	18,708	10,582	40.6	9.9	8.5	0.38	0.09	0.08
ROW Rest of World	15,989	9,648	23.5	4.5	4.0	0.24	0.05	0.04
CHN China	12,652	5,071	-62.5	-22.7	-16.9	-1.23	-0.45	-0.33
OEC Rest of OECD	7,324	4,085	16.5	3.9	3.9	0.40	0.10	0.09
MRC Mercosur	2,810	1,832	5.8	1.9	2.4	0.32	0.11	0.13
CAN Canada	1,649	967	1.8	0.2	0.7	0.19	0.02	0.07
KOR S. Korea	1,624	751	9.0	2.4	2.2	1.19	0.32	0.29
MEX Mexico	1,159	754	2.8	0.6	0.6	0.37	0.07	0.09
Global	81,395	47,003	-44.3	-22.9	-15.3	-0.09	-0.05	-0.03

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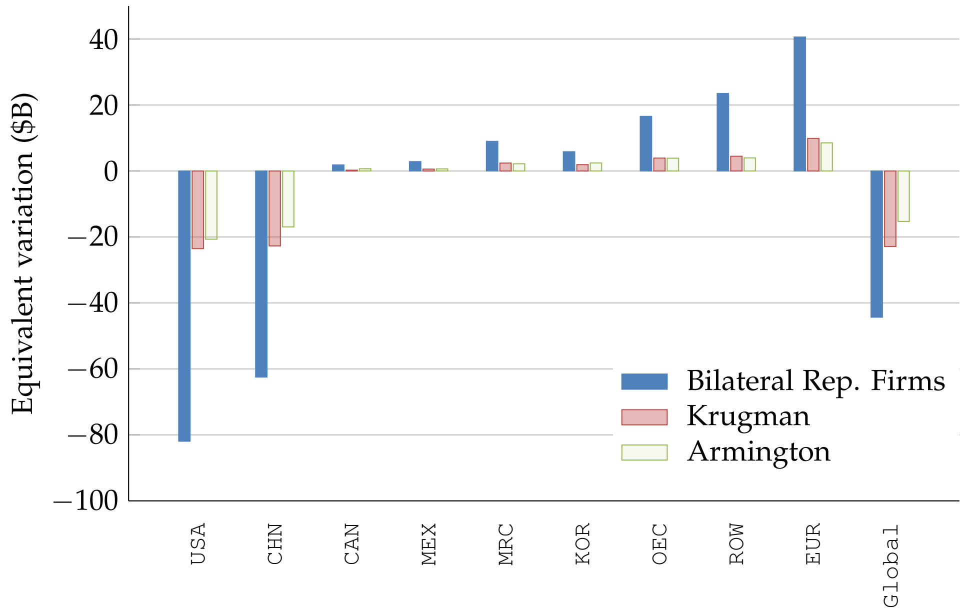

Figure 3. Welfare impacts

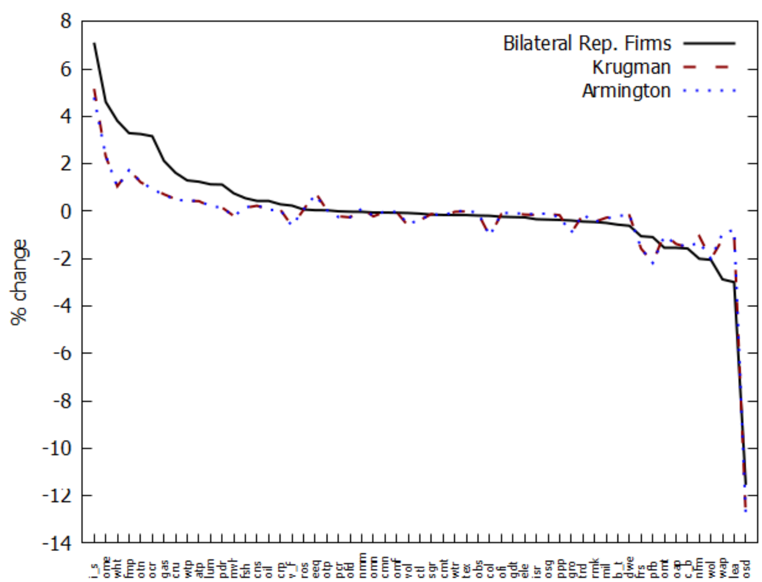

Figure 4. US sectoral impacts across models

Figure 6 focuses on the ten sectors with the greatest percentage increases in gross output. We observe increases in import-competing industries like ferrous metals (iron and steel) as well as machinery and equipment. There are some agriculture sectors that are expanding, such as wheat and crops nec, as they take over factors of those crops (mainly soybeans) that are exported to China. The most important expanding sectors, in terms of value, are again machinery and equipment, as well as ferrous metals. Output for the machinery and equipment sector is growing by between \$9.8B (2.3%) and \$19.5B (4.6%). Here, the differences of impacts between the market structures is quite pronounced: For the BRF variant, the expansion of the machinery and equipment sector which produces with increasing returns to scale is twice as high as in the other variants.

Table 4 provides the decomposition of GDP into expenditure and income components. Nominal values are divided by the true-cost-of-living index (as established by the representative agent's unit expenditure function in each region). Each record is thus measured in household consumption units. The reported change in consumption expenditure then represents the Hicksian equivalent variation in private income (welfare). It is important to note that the changes in the other expenditure accounts (investment (I), government (G), and exports less imports ($X - M$)) represent price changes, because the model is closed by holding these expenditures fixed (in their own prices). Recall that for the sake of complexity reduction and our focus on the role of alternative trade specifications, we adopt simple closure rules: investment, government, and the trade balances are fixed in real quantity terms.[19] That is a -0.3% change in government expenditures reflects a -0.3% change in the price of the government's Leontief unit expenditure function relative to the price index associated with consumption (the true-cost-of-living index)—it does not reflect a change in the quantity of any government expenditures.

The second panel of Table 4 breaks down income to accommodate a standard functional incidence analysis. We see moderate percentage losses for capital and the labor categories (in the 0.6% range which is consistent with the percent equivalent variation in income), but larger losses for landowners (6.7%). This substantial reduction in land income, again, reflects the concentration of foreign retaliation on agricultural goods.[20] There are, on the other hand, sizable gains in tariff rev-

[19] For trade closure in a multi-region model of the global economy, a real commodity unit (or a linearly homogeneous index of commodity units) must be established to indicate the balance of payment ($M_r - X_r$), which across all regions must net out to zero. To dissipate the impacts of choosing a particular good from a particular region as numeraire good, which might generate anomalous terms-of-trade effects, we choose an index over all goods consumed. Technically, the price index that establishes the fixed balance of payment is constructed as the weighted average of benchmark household-consumption prices throughout the world.

[20] With persistence, the decrease in land income can have a large capitalized value im-

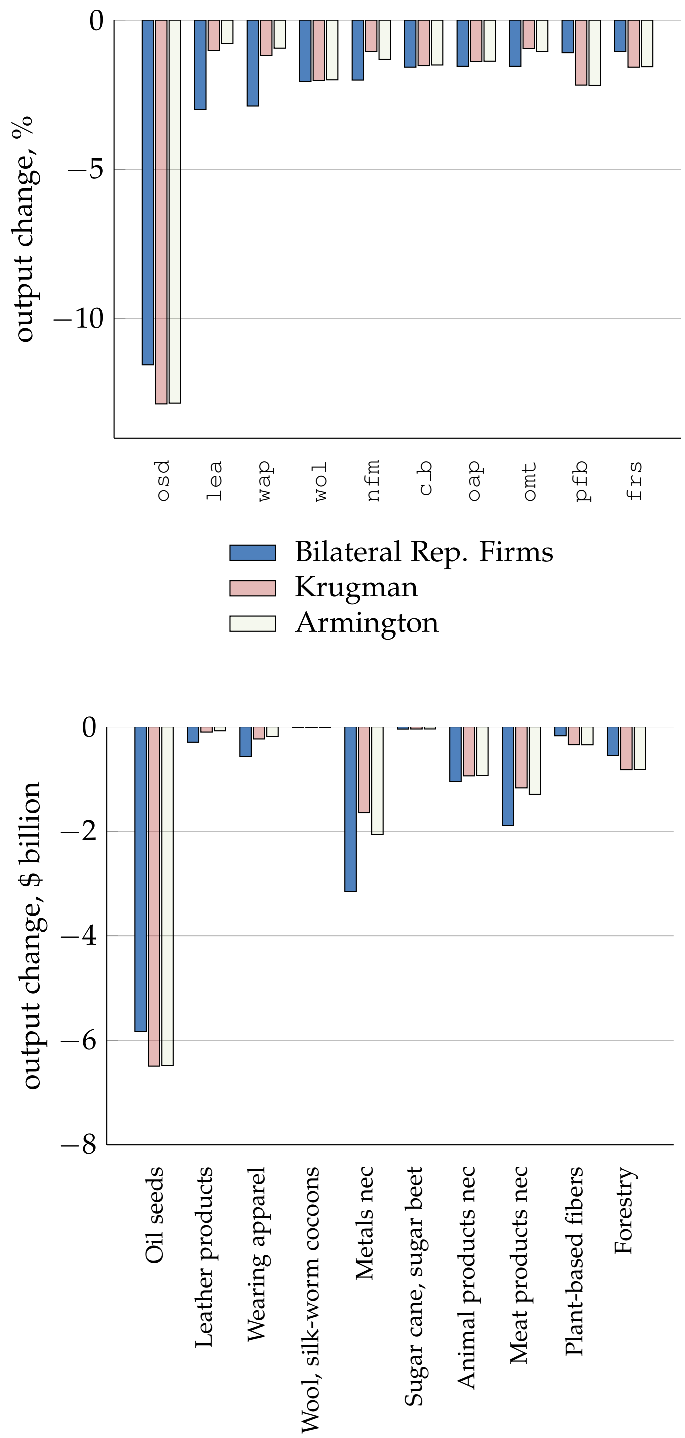

Figure 5. US Sectoral impacts: losers

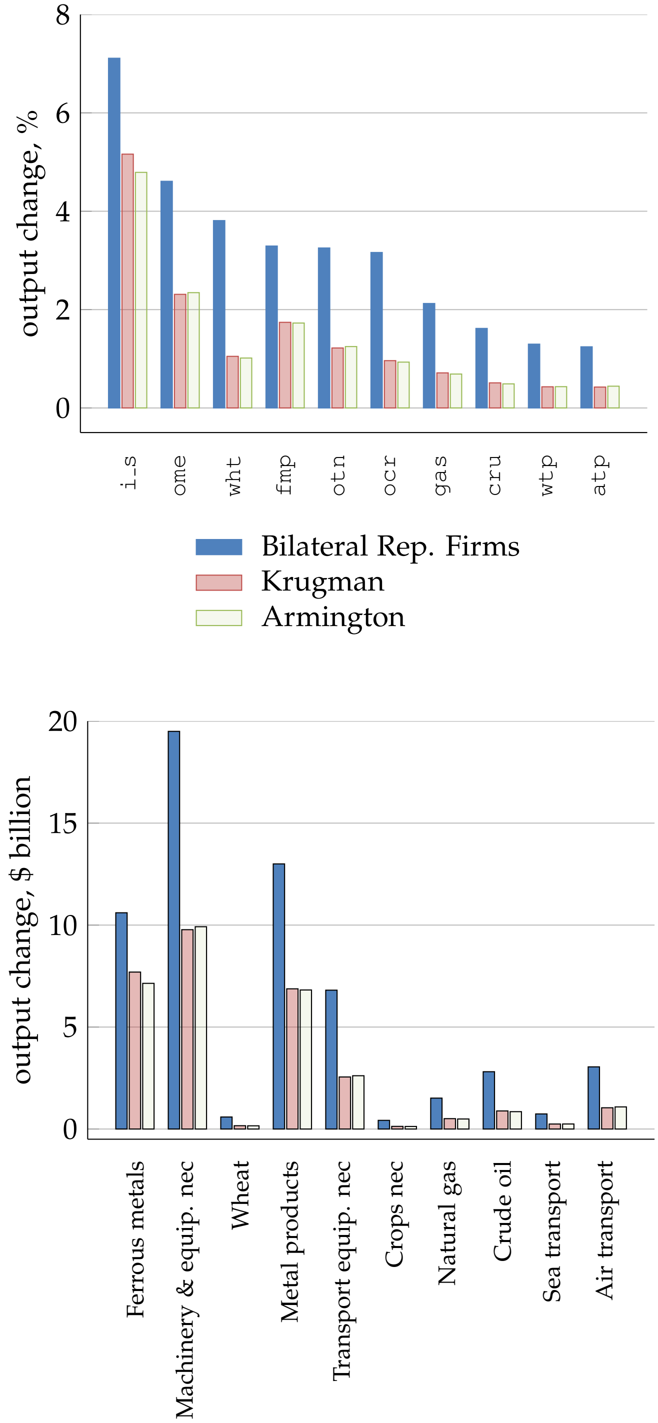

Figure 6. US sectoral impacts: winners

enues on the income side. The third panel of Table 4 decomposes real income by sectors. These sectoral income accounts capture value added by sector, but also include all sector-specific tax revenues or payments such as tariffs, output taxes and subsidies, or taxes and subsidies on intermediate inputs and final demands. The consumption, investment, and government accounts are included at the bottom of panel three, because some of the tax revenues are directly associated with final demand transactions and are not associated with a specific sector.

Table 4. US real GDP impacts decomposed

	Benchmark ($B)	Change ($B)	Change (%)
Expenditures:			
Consumption	13,314	-81.9	-0.6
Investment	4,043	67.5	1.7
Government	2,746	-8.2	-0.3
Net Exports (X-M)	-622	-8.8	1.4
Total	19,480	-31.5	-0.2
Income by recipient:			
`LAB` Unskilled Labor	1,493	-11.2	-0.7
`TEC` Technicians and Professionals	868	-5.4	-0.6
`CLK` Clerks	1,118	-7.2	-0.6
`MGR` Managers and Officials	4,187	-27.1	-0.6
`SRV` Services workers	564	-3.1	-0.5
`CAP` Capital	6,466	-43.0	-0.7
`LND` Land	42	-2.8	-6.7
`RES` Resource	81	1.2	1.5
Specific factors	826	47.1	5.7
Direct factor tax	1,990	-12.3	-0.6
Output tax revenue	1,220	-2.4	-0.2
Indirect tax (domestic)	374	-2.3	-0.6
Tariff revenue	212	39.2	18.5
Export tax revenue	36	-2.3	-6.3
Total	19,480	-31.5	-0.2
Income by sector:			
`obs` Business services	3,925	-0.5	0.0
`osg` Public administration, defense, health, education	3,597	-24.2	-0.7
`trd` Trade	2,055	-14.4	-0.7
`dwe` Dwellings	1,377	-9.7	-0.7
`ros` Recreation and other services	1,212	-2.4	-0.2
`cns` Construction	881	-5.2	-0.6
`ofi` Financial services	852	0.7	0.1

(Continued...)

pacting farm values.

Table 4. US real GDP impacts decomposed (...Continued)

	Benchmark ($B)	Change ($B)	Change (%)
cmn Communication	767	0.4	0.1
isr Insurance	506	0.8	0.2
omf Manufactures	453	-1.9	-0.4
crp Chemical, rubber, plastic products	429	1.7	0.4
eeq Electronic equipment	368	11.3	3.1
otp Transport nec	341	-1.9	-0.5
ele Electricity	245	-1.6	-0.7
fmp Metal products	175	3.0	1.7
ome Machinery and equipment	171	5.4	3.1
mvh Motor vehicles and parts	148	-0.1	-0.1
omn Minerals	138	-1.1	-0.8
ofd Food products	127	0.6	0.5
atp Air transport	121	1.0	0.8
cru Crude Oil	111	1.6	1.5
ppp Paper products, publishing	108	-0.3	-0.3
b_t Beverages and tobacco prod	104	-0.7	-0.6
wtr Water	101	-1.0	-0.9
otn Transport equipment	100	1.6	1.6
nmm Mineral products	52	0.2	0.5
gas Natural gas	47	1.0	2.1
i_s Ferrous metals	45	6.6	14.5
v_f Vegetables, fruit, nuts	43	-0.2	-0.4
nfm Metals	42	0.7	1.8
oil Petroleum, coal products	35	1.1	3.2
frs Forestry	33	-0.5	-1.5
lum Wood products	30	0.4	1.3
cmt Meat: cattle,sheep,goats,horse	30	0.2	0.8
col Coal	29	-0.4	-1.3
gdt Gas manufacture, distribution	29	-0.2	-0.6
osd Oil seeds	28	-3.7	-13.1
oap Animal products	28	-0.8	-2.7
mil Dairy products	26	0.2	0.6
ctl Cattle,sheep,goats,horses	24	-0.3	-1.2
tex Textiles	23	0.2	0.9
omt Meat products	22	0.1	0.4
wap Wearing apparel	20	-0.1	-0.6
gro Cereal grains	19	-0.3	-1.8
wtp Sea transport	18	0.1	0.7
ocr Crops	12	0.3	2.6
sgr Sugar	10	0.0	0.4
lea Leather products	9	0.4	4.6

(Continued...)

Table 4. US real GDP impacts decomposed (...Continued)

	Benchmark ($B)	Change ($B)	Change (%)
`vol` Vegetable oils and fats	9	0.2	2.2
`rmk` Raw milk	8	-0.2	-2.1
`fsh` Fishing	6	0.0	0.0
`pfb` Plant-based fibers	6	-0.1	-2.4
`wht` Wheat	6	0.2	2.8
`c_b` Sugar cane, sugar beet	2	-0.0	-1.7
`pdr` Paddy rice	1	0.0	0.0
`pcr` Processed rice	1	0.0	2.0
`wol` Wool, silk-worm cocoons	0	0.0	-5.1
Consumption	282	-1.8	-0.6
Investment	-46	2.4	-5.2
Government	136	-0.4	-0.3
Total	19,480	-31.5	-0.2

Table 5 reports the weighted-average Dixit-Stiglitz variety impacts for the monopolistically competitive sectors. The statistic reported is the percentage change in a multi-sector Feenstra ratio as developed by Balistreri and Tarr (2022b).[21] The single-good Feenstra ratio is calculated for each of the monopolistically competitive sectors, and then averaged based on initial absorption (consumption plus intermediate use) shares. A key feature of the bilateral representative firms structure is that the number of firms can vary across trade partners. While US tariffs may induce *exit* of Chinese firms exporting to the US (resulting in adverse variety impacts on the US), the US tariffs may induce *entry* of Chinese firms exporting to Europe and Mexico, for example, resulting in variety gains for Europe and Mexico. The BRF specification intensifies trade diversion along the extensive margin of trade while the bilateral extensive margin is not represented in the standard Krugman structure. Under the Krugman structure, varieties are only indexed by the exporting region. If the US tariffs induce exit of Chinese varieties this impact is felt by all of China's trade partners. Table 5 shows that the 2018 trade disruptions induce varieties losses for almost all regions of the world (with small gains in the EU and Rest-of-World regions) under the Krugman structure: For example, Mexico benefits from the bilateral dispute between the US and China through trade diversion along the intensive margin, but suffers from an overall loss of varieties. In contrast, the bilateral representative firms model indicates variety gains for Mexico and all other regions except China, US, and Canada.

[21] In his Theorem 2, Feenstra (2010) provides a theoretical justification for his measure in a single-good model. The Feenstra ratio indicates the portion of the change in the region-specific composite price index that is due purely to changes in the number of varieties.

Table 5. Variety impacts across model structures

	Weighted average % change in Feenstra ratio	
	Bilat. Rep. Firm	Krugman
USA U.S.A	-0.078	-0.015
EUR EU-27 plus	0.019	0.002
ROW Rest of World	0.020	0.001
CHN China	-0.047	-0.020
OEC Rest of OECD	0.018	-0.002
MRC Mercosur	0.025	-0.021
CAN Canada	-0.015	-0.053
KOR S. Korea	0.027	-0.004
MEX Mexico	0.063	-0.016

The bilateral variety changes and stronger trade diversion effects under the BRF structure have important implications for third country impacts of the largely US-China conflict. Note, for example, in Table 3 that the EU's welfare increases by $40.6B under the BRF structure, but only $9.9B under the Krugman structure, reflecting the ability of the EU in the BRF structure to gain substantial benefits from extensive-margin trade with both China and the US. These effects are substantially muted under the Krugman structure, because extensive-margin adjustments only operate at the national level in the Krugman model. The same pattern prevails in all third countries. On average, the positive welfare impacts on third countries (not the US or China) under the Krugman structure are only 23% of the BRF welfare gains.

Figure 7 indicates benchmark trade and trade responses to tariff shocks for US imports of Electronic Equipment (eeq) from China. The information is presented similar to that in Figures 1 and 2, but now our comparison is based on general equilibrium rather than solely partial equilibrium simulations. In Figure 7 vertical shifts correspond to changes in protection and endogenous price responses, and horizontal shifts characterize associated quantity adjustments (through interaction of supply and demand). The line that connects the benchmark point, labeled (eeq), with the BRF model outcome indicates the central general equilibrium response. The line from the BRF point moving to the left connects to the partial equilibrium outcome (the same response shown in Figure 1). This line indicates the difference between the partial equilibrium and BRF general equilibrium responses. We see that taking general equilibrium effects into account is important, as the trade volume falls by much less ($-20B) in general equilibrium compared to the partial equilibirum ($-65B). The US price for electronic equipment increases less in general equilibrium than in partial equilibrium. This reflects less tariff pass-through as the net price of Chinese eeq falls. In general, we observe less pass-through in the general equilibrium models. While we calibrated the partial and general equilibrium models to the same local value of the supply elasticity, in

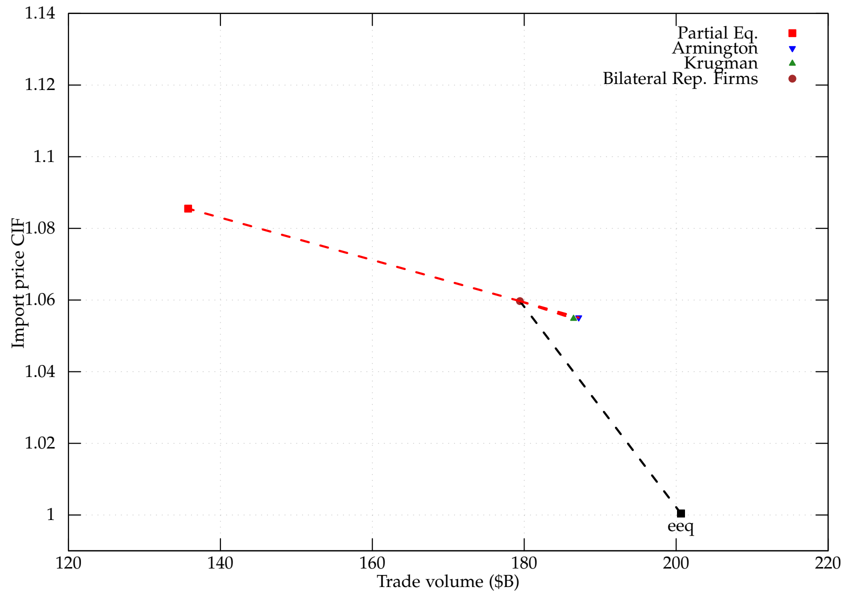

Figure 7. US Electronic Equipment (eeq) imports from China: benchmark trade, tariffs, and alternative model responses

the general equilibrium models the supply response operates on bilateral provision (as described in Section 2.4). In contrast, the supply response in the simplified partial-equilibrium trade model operates on total regional supply to all markets. This implies a small(er) overall price reduction when demand falls on an isolated set of bilateral trade links.

In Figure 7 the lines moving to the right of the BRF result connect to the Armington and Krugman results, showing the differences in the trade responses across our three different structural trade assumptions. The BRF model shows larger trade responses based on the bilateral-exit margin. It is striking how similar the responses are from the Armington and Krugman models, even though we have larger global welfare impacts in the Krugman model. This reveals that in a multi-sector model, variety impacts play an important role even for similar trade responses (see Balistreri and Tarr, 2022b, for a detailed analysis of this finding). The Krugman trade response is slightly larger than under Armington, but because Chinese electronic equipment firms only exit based on changes in global demand for their products, the largely bilateral trade war does not lead to a trade response that is as pronounced as under the BRF structure.

Figures 9 and 8 provide the same analysis of trade responses as Figure 7 for goods with more than $1B in benchmark shipments (except US imports of eeq which is outside the scale of the graph). The full set of results are reported in Tables A.1 and A.2. For many of the trade-important goods imported by the US, we see a pattern where the largest trade response occurs under the BRF structure.

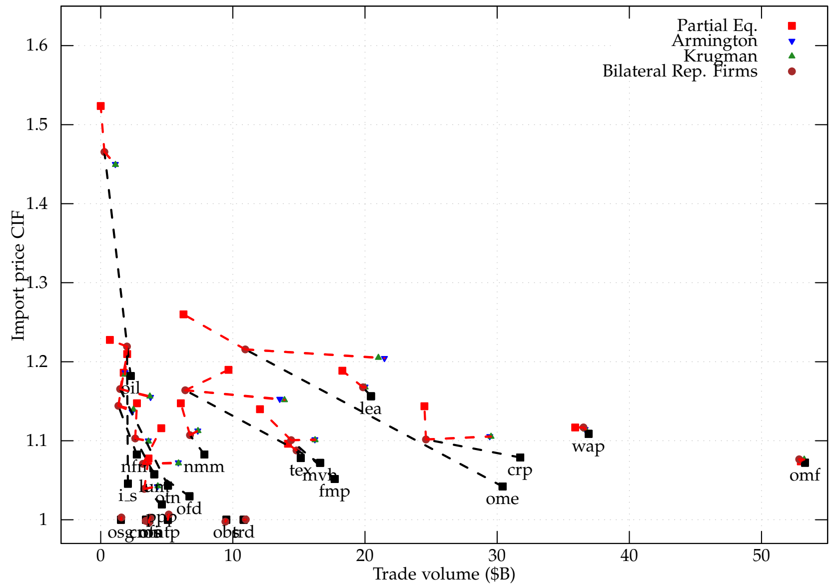

Figure 8. Chinese imports from the US: benchmark trade, tariffs, and alternative model responses

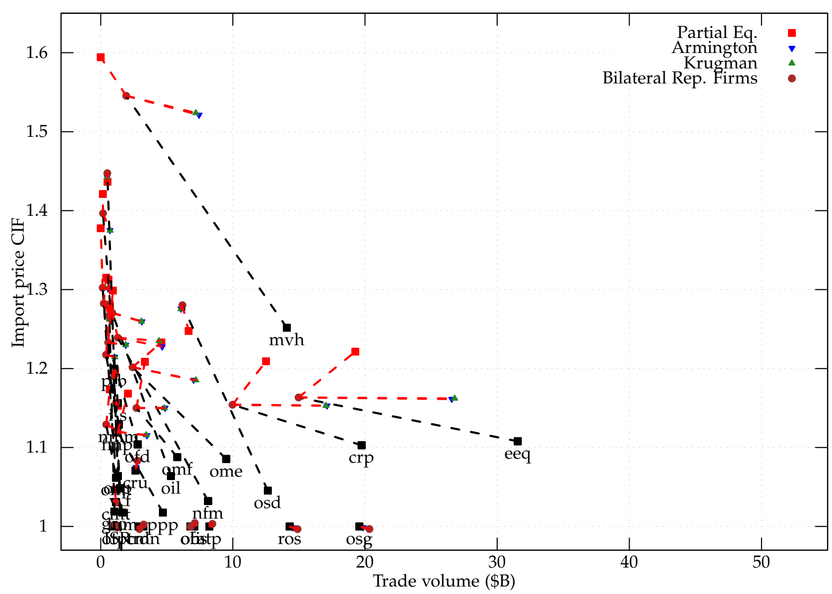

Figure 9. US imports from China (except eeq): benchmark trade, tariffs, and alternative model responses

Table 6. Piecemeal parametric sensitivity of the BRF model

	Parameter Setting			Global Welfare Change ($B)		
	Lower	Central	Upper	Lower	Central	Upper
Firm-variety substitution	2.5	3.8	5.0	-49.4	-44.3	-42.6
Supply elasticity	0.8	1.0	1.5	-46.4	-44.3	-41.4
Variety Approximation	0.85	0.90	0.95	-39.9	-44.3	-51.0

The Armington and Krugman models understate the trade response relative to a model with bilateral entry or selection. For Chinese imports, we see again that the partial equilibrium model understates the trade response and overstates the price pass-through relative to the BRF general equilibrium model. For example, in Section 3 we mention that the increase in Chinese tariffs on US `crp` reduced trade from $19.7B in the benchmark to $12.5B based on the partial equilibrium response. We now see that, under the BRF structure, Chinese imports of `crp` from the US are reduced to $10.0B. Regarding the differences in trade responses across the three general equilibrium modeling variants, a more general insight is that import responses are substantially higher in the bilateral representative firms environment relative to either the Armington or Krugman environments, although the models are calibrated to the same local response parameters.

The BRF structure is critically dependent on a number of key parameters. While our primary purpose is to conduct a *structural* sensitivity analysis across different structural trade specifications, it is also useful to investigate how sensitive BRF responses are to key parameters. First, it is well understood that variety impacts under monopolistic competition are directly impacted by the elasticity of substitution. Second, we have introduced sector-specific factors. Supply responses by industries then depend on the specific-factor shares and the elasticity of substitution between the specific and mobile factors as captured by the local supply elasticity. Third, our reduced-form solution method only captures a portion of the potential variety impacts. To examine the sensitivity of our central case BRF welfare results to these three important parametric choices, we conduct piecemeal changes. The results are summarized in Table 6. Global welfare changes are reported in billions of dollars representing the summation of Hicksian equivalent variation for the representative agents across all regions. Our intention is not only to quantify the sensitivity to unknown parameters, but also to confirm the qualitative responses that should follow from the theoretical model logic.

In the first row of Table 6 we consider the decrease and increase of the elasticity of substitution for firm-level varieties in the sectors that operate under monopolistic competition. As the elasticity increases, the value of a new variety falls. As expected, we see that a reduction of the firm-level elasticity of substitution increases the global welfare losses from the trade war. Conversely, increasing the elasticity reduces the global losses as there is a less pronounced love-of-variety effect at higher substitution elasticities.

In the second row of Table 6, we alter the supply elasticity in sectors with monopolistic competition. As discussed in Section 2, we assume a local supply elasticity for x_{isr} (the default is one) which determines the elasticity of substitution η_{isr} conditional on the value share of specific factors in sector i. Changes in supply elasticities have opposite welfare effects. With rising tariffs trade declines more sharply, but at the same time we have more trade diversion. The latter effect dominates in our policy scenario, where the dominant tariff increases are between the US and China. Global welfare losses are reduced as we increase the supply elasticity, because production can be more easily reallocated worldwide.

In the final row of Table 6, we consider the effects of our reduced-form solution method. As explained in Section 2, our parsimonious implementation of the BRF structure requires an approximation such that only a fraction of the variety change is realized. In the central case, we assume that this fraction is 90%. As expected, global welfare losses fall (increase) when we lower (raise) this value This again highlights the importance of variety effects for the welfare analysis of trade policy.

5. Conclusion

The applied analysis of trade policy based on numerical simulation models has gained importance under a new wave of protectionist measures, recently prominently undertaken by the United States. Quantitative assessments of policy impacts are sensitive to the choice of parametric data as well as structural assumptions. We illustrate the importance of structural trade assumptions in a welfare analysis of the 2018 trade war. The literature on alternative trade specifications (see our review in Appendix B) indicates larger welfare impacts in applied models that include monopolistic competition and bilateral selection of firms. This contrasts with stylized single-sector theoretical models in which there is equivalence between models with different structures. Due to computational complexity there are, however, limited applications of large-scale models that include both monopolistic competition and firm selection à la Melitz (2003). We present an innovative structure that retains bilateral representative firms (BRF) while adding little complexity to the computational environment, making it feasible to conduct policy-relevant large-scale simulations with many sectors and regions.

In our illustrative scenario analysis, which focuses on the 2018 US-China trade war, we contrast the BRF model with: (i) the widely adopted Armington approach of regional product differentiation in competitive markets and (ii) the Krugman perspective of monopolistic competition in national firms. We show that firm selection is a key mechanism by which the trade equilibrium adjusts to regulatory changes. We find that the disruptive trade policies, restricting free trade largely through new tariffs, come at non-negligible welfare cost for the global economy. The US tariffs have not brought economic gains to the US, but, in conjunction with retaliatory measures by trading partners, have caused substantial export losses.

Overall, the trade war can hardly be justified within the modeling framework for assessment that we propose.

Our new trade specification with bilateral representative firms provides an appealing framework for applied trade policy analysis but important limitations remain. These primarily relate to parametric uncertainty such as the choice of the elasticity of substitution among firm-level varieties which determines the love-of-variety effect. To operationalize the model we also introduce bilateral specific factors, the calibration of which represents an empirical challenge with potentially large implications for the quantitative simulation results. Regarding the limitations in structural logic, we implement the BRF specification in a static setting. Extending the BRF logic to a dynamic environment where firms engage in investment and specific factors are malleable is an important future challenge.

Nevertheless, we consider our present BRF specification which combines monopolistic competition with bilateral firm entry and variety selections to be an important innovation for trade policy analysis, not least because it has proven to be computationally manageable in large-scale applications.

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Appendix A.

Table A.1. US imports from China

	Benchmark		BRF		KRU		ARM		Partial Eq.	
Good	$B	Price	$B	Price	$B	Price	$B	Price	$B	Price
eeq	200.626	1.000	179.431	1.060	186.495	1.055	187.170	1.055	135.747	1.085
omf	53.291	1.072	52.850	1.076	53.230	1.076	53.106	1.075	52.973	1.074
wap	36.917	1.109	36.530	1.117	36.695	1.114	36.652	1.115	35.900	1.117
crp	31.750	1.079	24.610	1.102	29.533	1.105	29.436	1.106	24.492	1.144
ome	30.408	1.042	10.940	1.216	21.010	1.205	21.473	1.204	6.266	1.260
lea	20.452	1.156	19.852	1.168	20.014	1.168	19.997	1.168	18.284	1.189
fmp	17.703	1.052	14.410	1.101	16.221	1.101	16.204	1.102	12.053	1.140
mvh	16.603	1.072	6.401	1.164	13.908	1.152	13.549	1.153	9.674	1.190
tex	15.133	1.078	14.814	1.088	14.929	1.087	14.904	1.087	14.172	1.096
trd	10.818	1.000	10.981	1.000	10.904	0.999	10.866	1.001	10.818	1.000
obs	9.509	1.000	9.439	0.998	9.491	0.999	9.486	1.000	9.509	1.000
nmm	7.840	1.083	6.758	1.107	7.360	1.112	7.345	1.113	6.060	1.147
ofd	6.723	1.030	3.197	1.071	5.887	1.072	5.873	1.072	4.583	1.116
otn	5.095	1.043	1.471	1.165	3.724	1.156	3.775	1.155	2.005	1.210
atp	5.081	1.000	5.151	1.007	5.114	1.002	5.095	1.003	5.081	1.000
ppp	4.624	1.019	3.300	1.039	4.327	1.043	4.291	1.042	3.623	1.078
lum	4.053	1.057	2.614	1.103	3.615	1.099	3.599	1.100	2.744	1.147
ros	3.676	1.000	3.753	1.003	3.710	1.001	3.693	1.002	3.676	1.000
ofi	3.668	1.000	3.652	0.996	3.664	0.998	3.662	0.999	3.668	1.000
cmn	3.426	1.000	3.408	0.999	3.422	1.000	3.421	1.000	3.426	1.000
nfm	2.733	1.083	1.338	1.144	2.478	1.140	2.375	1.137	1.739	1.186
oil	2.270	1.182	0.283	1.465	1.119	1.449	1.110	1.450	0.000	1.524
i_s	2.059	1.046	1.992	1.219	1.834	1.184	1.853	1.186	0.698	1.228
osg	1.536	1.000	1.569	1.003	1.552	1.000	1.545	1.001	1.536	1.000
ISR	0.489	1.000	0.487	0.996	0.488	0.998	0.488	0.999	0.489	1.000
wtp	0.401	1.000	0.406	1.007	0.404	1.002	0.402	1.003	0.401	1.000
v_f	0.391	1.011	0.279	1.116	0.276	1.113	0.274	1.115	0.320	1.110
ocr	0.263	1.016	0.202	1.072	0.195	1.068	0.193	1.069	0.224	1.062
OMN	0.239	1.146	0.203	1.271	0.203	1.262	0.203	1.262	0.218	1.257
otp	0.234	1.000	0.239	1.006	0.236	1.002	0.235	1.003	0.234	1.000
oap	0.214	1.005	0.175	1.095	0.173	1.093	0.173	1.095	0.190	1.090
cns	0.170	1.000	0.173	1.007	0.172	1.002	0.171	1.003	0.170	1.000
cmt	0.117	1.000	0.043	1.048	0.098	1.048	0.098	1.049	0.073	1.100
vol	0.107	1.012	0.049	1.049	0.093	1.048	0.094	1.049	0.079	1.082
b_t	0.092	1.054	0.088	1.059	0.090	1.065	0.089	1.065	0.082	1.086
cru	0.025	1.375	0.009	1.536	0.009	1.520	0.009	1.520	0.012	1.512
frs	0.024	0.998	0.018	1.064	0.018	1.059	0.018	1.060	0.021	1.057
omt	0.019	1.026	0.007	1.072	0.017	1.072	0.016	1.073	0.013	1.121
osd	0.018	0.956	0.011	1.068	0.010	1.065	0.010	1.066	0.014	1.051
ele	0.009	1.000	0.006	1.072	0.006	1.067	0.006	1.068	0.007	1.064
fsh	0.007	1.003	0.006	1.076	0.006	1.077	0.006	1.078	0.007	1.078
sgr	0.006	1.245	0.003	1.257	0.005	1.264	0.005	1.265	0.004	1.320
gdt	0.004	1.000	0.002	1.111	0.003	1.102	0.003	1.103	0.003	1.097
pcr	0.003	1.058	0.001	1.105	0.003	1.104	0.003	1.105	0.002	1.158
wtr	0.002	1.000	0.002	1.003	0.002	1.000	0.002	1.001	0.002	1.000
mil	0.001	1.106	0.001	1.103	0.001	1.105	0.001	1.105	0.001	1.111
gro	0.001	1.002	0.001	1.107	0.001	1.105	0.001	1.107	0.001	1.102
pdr	0.000	0.953	0.000	0.996	0.000	0.995	0.000	0.997	0.000	0.993
wol	0.000	1.000	0.000	1.107	0.000	1.103	0.000	1.104	0.000	1.099
ctl	0.000	1.000	0.000	1.035	0.000	1.034	0.000	1.035	0.000	1.032
rmk	0.000	1.015	0.000	1.018	0.000	1.017	0.000	1.018	0.000	1.015
wht	0.000	1.000	0.000	1.103	0.000	1.102	0.000	1.103	0.000	1.098
col	0.000	1.159	0.000	1.291	0.000	1.282	0.000	1.282	0.000	1.275
pfb	0.000	1.000	0.000	1.109	0.000	1.105	0.000	1.107	0.000	1.100
c_b	0.000	0.958	0.000	1.059	0.000	1.056	0.000	1.058	0.000	1.053

Table A.2. China imports from US

	Benchmark		BRF		KRU		ARM		Partial Eq.	
Good	$B	Price	$B	Price	$B	Price	$B	Price	$B	Price
eeq	31.557	1.108	14.972	1.163	26.788	1.162	26.562	1.161	19.262	1.221
crp	19.741	1.103	9.972	1.154	17.042	1.153	17.123	1.153	12.509	1.209
osg	19.573	1.000	20.333	0.997	19.829	0.999	19.860	0.999	19.573	1.000
ros	14.299	1.000	14.898	0.997	14.518	0.998	14.547	0.999	14.299	1.000
mvh	14.086	1.252	1.926	1.545	7.202	1.524	7.444	1.521	0.000	1.594
osd	12.644	1.045	6.184	1.280	6.071	1.275	6.079	1.276	6.655	1.248
ome	9.499	1.085	2.406	1.202	7.206	1.185	7.030	1.185	4.590	1.233
atp	8.224	1.000	8.449	1.003	8.280	1.002	8.302	1.002	8.224	1.000
nfm	8.125	1.032	1.299	1.239	4.410	1.235	4.656	1.228	0.696	1.281
obs	7.072	1.000	7.122	1.004	7.085	1.000	7.089	1.001	7.072	1.000
ofi	6.788	1.000	6.817	1.000	6.795	0.999	6.800	1.000	6.788	1.000
omf	5.791	1.088	2.706	1.150	4.820	1.150	4.870	1.150	3.346	1.209
oil	5.317	1.064	0.877	1.270	3.088	1.260	3.117	1.260	0.588	1.313
ppp	4.709	1.018	1.294	1.120	3.449	1.116	3.498	1.115	2.061	1.168
cmn	3.240	1.000	3.253	1.002	3.242	1.000	3.244	1.001	3.240	1.000
trd	2.857	1.000	2.932	0.997	2.879	0.999	2.887	0.999	2.857	1.000
ofd	2.800	1.104	0.569	1.233	1.891	1.230	1.900	1.230	0.922	1.299
cru	2.635	1.071	2.785	1.083	2.691	1.075	2.691	1.075	2.635	1.071
lum	1.654	1.018	0.423	1.129	1.200	1.122	1.209	1.122	0.690	1.174
OMN	1.604	0.954	1.176	1.157	1.155	1.154	1.155	1.155	1.302	1.153
v_f	1.463	1.048	0.959	1.195	0.950	1.191	0.952	1.192	1.078	1.198
nmm	1.375	1.129	0.403	1.217	1.060	1.215	1.064	1.215	0.691	1.277
oap	1.297	1.064	1.028	1.191	1.021	1.188	1.022	1.188	1.090	1.195
i_s	1.291	1.156	0.177	1.397	0.715	1.375	0.698	1.375	0.167	1.421
ISR	1.265	1.000	1.269	0.999	1.266	0.999	1.267	1.000	1.265	1.000
fmp	1.253	1.119	0.229	1.282	0.810	1.267	0.809	1.267	0.420	1.315
omt	1.168	1.062	0.149	1.302	0.569	1.302	0.579	1.301	0.000	1.378
cmt	1.162	1.031	1.146	1.030	1.151	1.033	1.152	1.033	1.094	1.047
otp	1.057	1.000	1.088	1.002	1.065	1.001	1.069	1.001	1.057	1.000
gro	1.042	1.019	0.655	1.267	0.653	1.263	0.654	1.263	0.716	1.264
pfb	1.021	1.200	0.502	1.447	0.492	1.442	0.493	1.442	0.518	1.436
tex	0.969	1.089	0.304	1.170	0.763	1.165	0.769	1.165	0.515	1.223
wtp	0.915	1.000	0.937	1.004	0.920	1.002	0.922	1.002	0.915	1.000
lea	0.612	1.102	0.205	1.179	0.484	1.179	0.489	1.179	0.324	1.238
frs	0.610	0.984	0.487	1.045	0.471	1.043	0.471	1.044	0.512	1.048
ocr	0.607	1.068	0.262	1.257	0.258	1.251	0.258	1.252	0.257	1.257
b_t	0.487	1.072	0.065	1.297	0.251	1.292	0.254	1.291	0.000	1.357
col	0.479	1.263	0.142	1.569	0.140	1.558	0.140	1.558	0.134	1.561
gas	0.477	1.065	0.514	1.081	0.489	1.070	0.488	1.070	0.477	1.065
mil	0.477	1.072	0.084	1.232	0.295	1.230	0.298	1.230	0.102	1.294
wht	0.369	1.010	0.074	1.251	0.073	1.246	0.073	1.246	0.000	1.245
otn	0.313	1.082	0.066	1.215	0.220	1.202	0.216	1.202	0.120	1.258
fsh	0.258	1.067	0.254	1.081	0.253	1.077	0.254	1.077	0.255	1.075
wap	0.138	1.139	0.017	1.336	0.075	1.337	0.077	1.337	0.039	1.355
gdt	0.131	1.008	0.137	1.011	0.131	1.013	0.131	1.013	0.128	1.014
cns	0.095	1.000	0.098	1.004	0.096	1.002	0.096	1.002	0.095	1.000
vol	0.082	1.100	0.017	1.232	0.057	1.227	0.056	1.228	0.023	1.307
wtr	0.040	1.000	0.042	1.001	0.041	1.001	0.041	1.001	0.040	1.000
ele	0.031	1.000	0.033	0.999	0.032	0.999	0.032	0.999	0.031	1.000
sgr	0.018	1.065	0.005	1.167	0.013	1.164	0.013	1.164	0.008	1.215
ctl	0.017	1.005	0.018	1.001	0.018	0.999	0.018	0.999	0.017	1.005
wol	0.016	1.376	0.003	1.613	0.002	1.604	0.002	1.603	0.000	1.597
pcr	0.005	1.002	0.005	1.007	0.005	1.011	0.005	1.012	0.004	1.026
rmk	0.000	1.003	0.000	1.004	0.000	1.001	0.000	1.001	0.000	1.003
c_b	0.000	0.999	0.000	1.197	0.000	1.197	0.000	1.197	0.000	1.216

Appendix B. Extended Literature Review

There are gains from international trade. Few things are more agreed upon by economists. From the original statement of comparative advantage (Ricardo, 1817) to the formal neoclassical general equilibrium (Samuelson, 1939, 1962; Kemp, 1962) to advanced models of industrial organization (Melitz, 2003) the intuition is clear and compelling. Equally clear, however, is the fact that the gains will not be distributed equally among countries that engage in trade (Ray, 1977), and the fact that some agents may lose from trade even if their country gains on average (Stolper and Samuelson, 1941). Furthermore, we know that the distribution of the gains can be manipulated by countries acting strategically (Johnson, 1953), or through the rent-seeking activities of special interest groups (Grossman and Helpman, 1994).

With a broad consensus on the potential benefits from international trade, the global community established a set of institutions, most notably the World Trade Organization (WTO) as governed by the General Agreement on Tariffs and Trade (GATT), to provide guidance towards a cooperative global trading system (Bagwell and Staiger, 1999).[22] The primary goal of the WTO is to promote free trade through a set of multilateral rules and dispute settlement procedures. These discourage countries from implementing trade distortions motivated either by strategic *beggar-thy-neighbor* incentives or by their interest in placating rent-seeking special-interest groups. Bagwell and Staiger (1999) argue that the GATT's reciprocity and nondiscrimination rules assist governments in their implementation of globally sound trade policy when they face politically powerful constituents interested in distorting trade to capture rents.[23]

More recently, however, the global trading system seems to be entering a new order of disruptive unilateral policies. As the prime protagonist of protectionism, the United States is currently pursuing trade policies that put little weight on global efficiency and overall gains from trade. Starting with the Republican administration in 2017 the US has wielded unilateral tariff instruments to stem import surges under its safeguard and national security (section 201 and 232) authority and as a punishment for alleged intellectual property violations by the Chinese (section 301 tariffs). Disputes over intellectual property violations would have naturally fell under the dispute settlement procedures at the WTO, but the

[22] The WTO started operations on January 1, 1995 as an implementation and enforcement mechanism for the General Agreement on Tariffs and Trade (GATT), which was created in 1947 as a framework for organizing post-war international trading rules.

[23] The WTO has six key objectives: (1) to set and enforce rules for international trade, (2) to provide a forum for negotiating and monitoring further trade liberalization, (3) to resolve trade disputes, (4) to increase the transparency of decision-making processes, (5) to cooperate with other major international economic institutions involved in global economic management, and (6) to help developing countries benefit fully from the global trading system.

US acted unilaterally. In fact, over the last decade the US has expressed contempt for the WTO's principles and procedures. The 2018 US tariffs were met with quick retaliation. For a complete and up-to-date overview of the US-China trade war see Bown (2023). The subsequent US administrations have continued, and now significantly escalated, these protectionist actions. Against this backdrop trade economists are engaged in quantifying the impacts of disruptive trade policies.

The international trade structure that dominates this type of computational (applied) trade policy analysis is based on the Armington (1969) assumption of differentiated regional goods within a constant-returns-to-scale (CRTS) perfect competition setting. The proposition to differentiate products by country of origin has several empirical advantages, but it has been criticized for its inconsistency with micro-level observations and questionable counterfactual implications. The Armington assumption provides a tractable solution to various problems associated with the standard neoclassical (Heckscher-Ohlin) perspective of trade in homogeneous goods (Whalley, 1985): (i) it accommodates the empirical observation that a country imports and exports the same good (so-called cross-hauling); (ii) it avoids over-specialization implicit to trade in homogeneous goods; and (iii) it is consistent with trade in geographically differentiated products (gravity). While the Armington assumption provides a convenient lens to view trade data, it may introduce terms-of-trade effects which dominate the welfare results of policy changes. Even in the absence of market power by individual firms, the Armington assumption of product heterogeneity provides implicit market power for the policy authority in a perfectly competitive market context, which is the higher the larger are the trade flows and the smaller are the demand elasticities for the traded goods by trading partners (de Melo and Robinson, 1989; Balistreri and Markusen, 2009).

Balistreri and Rutherford (2013) discuss the inherent tensions between standard Armington (CRTS) models and more advanced computational approaches incorporating modern trade theory based on firm-level product differentiation and imperfect competition (Krugman, 1980; Melitz, 2003). Krugman (1979, 1980) uses firm-level product differentiation in a monopolistic-competition framework to illustrate that there are gains from trade even in the absence of comparative advantage. The Krugman (1980) model illustrates that additional varieties are a key source of the gains from trade under a standard constant-elasticity-of-substitution demand system. Ethier (1982) further expands the notion of variety gains to intermediate inputs, where new varieties, available through trade, increase the productivity of domestic firms. Foreign direct investment and the theory of multinationals are an additional source of gains, especially in producer services that are not easily traded (Markusen, 1989, 2002; Markusen and Venables, 1998; Ethier and Markusen, 1996). Markusen, Rutherford, and Tarr (2005) show that introducing foreign direct investment in services with endogenous variety effects and specialized *home-office* inputs substantially increase the gains.[24]

The theory of international trade moved forward again with Melitz (2003), who introduced the competitive selections of heterogeneous firms in a monopolistic competition model with fixed cost associated with supplying external markets. In the Melitz model trade induces a reallocation of within-industry resources away from low-productivity firms toward high-productivity firms. There is compelling empirical support for both the basic structure of heterogeneous firms (Bartelsman and Doms, 2000; Bernard and Jensen, 1999) and the endogenous reallocation toward more productive firms (Aw, Chen, and Roberts, 2001; Trefler, 2004). A key feature of the Melitz (2003) model is that there will be a unique number of varieties on each bilateral link, because trade policy affects selection. This is in contrast to models based on Krugman (1980) where once a variety is produced (a firm enters the market) that variety is consumed in every market. In the structure we introduce we have selection in the form of entry on each bilateral link, but we maintain the more simplified Krugman structure. We maintain convexity in the trade equilibrium by replacing the Melitz steady-state structure with specific-factor payments by the bilateral firms.

Most of the conventional computational studies adopting the Armington-CRTS framework (i.e. ignoring innovations of monopolistic competition) focus on changes in rent generating tariffs triggered by trade policy reforms. The studies often report seemingly small welfare gains associated with trade liberalization, generally in the range of less than one percent. There is reason to suspect that the early studies understate the gains from trade. It is recognized that Armington models imply high optimal tariffs (Brown, 1987; Balistreri and Markusen, 2009). Balistreri and Markusen (2009) argue that the Armington structure misallocates market power over varieties away from firms and toward the discretion of the policy authority. The monopolistic competition structure properly allocates market power over varieties to firms and thus results in lower optimal tariffs. Another source of potential bias in trade modeling is the fact that many trade distortions do not generate tariff revenues for the importing country. An important example are the voluntary export restraints (VERs) that South Korea imposed to avoid the 2018 US steel and aluminum (Section 232) tariffs.[25] In general, non-tariff barriers to trade are important and substantially increase the welfare impacts. For example, de Melo and Tarr (1990) and Jensen and Tarr (2003) use standard perfect competition models to show substantial gains from trade liberalization when the rents

[24] We do not incorporate foreign direct investment in the version of the model used in this paper, but using a similar monopolistic-competition model Balistreri and Olekseyuk (2025) incorporate that extension.

[25] Allowing a trade partner to collect the rents associated with a trade distortion, through a VER, is a good way to avoid retaliation; but it is also a good way to *lose* a trade war. Optimal tariffs rely on a collection of the tariff revenues!

associated with the distortion are surrendered.[26]

With the rise of the new trade theories, there is a growing number of computational studies that include imperfect competition. Harris (1984) considers the gains associated with behavioral responses by oligopolistic firms engaged in international trade. Adopting an oligopolistic model setting Harrison, Rutherford, and Tarr (1997) report small gains associated with increased firm size (reduced average cost). Rutherford and Tarr (2002) use an endogenous-growth model with variety gains to show that the welfare impacts can be many times larger than in a standard constant-returns perfect competition model. Markusen, Rutherford, and Tarr (2005) and Rutherford and Tarr (2008) introduce FDI in services with variety effects which generates substantially larger welfare impacts.

More recently, the Melitz (2003) theory has inspired a new generation of computational approaches to quantitative trade-policy analysis. Zhai (2008) introduces the first calibrated computational model that includes competitive selection of heterogeneous firms. This model is extended and applied in an analysis of the Trans-Pacific Partnership by Petri, Plummer, and Zhai (2012). The model, while including selection, does not include endogenous entry so the mass of potential firms is held fixed. Balistreri, Hillberry, and Rutherford (2011) implement a model with the full Melitz theory applied to the manufacturing sector. They find that, relative to an otherwise equivalent Armington model, the Melitz model generates welfare impacts that are on average four times larger. Balistreri and Rutherford (2013) provide a more comprehensive guide to applying monopolistic competition theories, including the Melitz structure, in computational models that are calibrated to data.[27] Other important computational applications of the new theories include Dixon, Jerie, and Rimmer (2016) and their comprehensive book on the topic: Dixon, Jerie, and Rimmer (2018). Costinot and Rodríguez-Clare (2014) draw a closer link between the theory and traditional computational methods by quantify the welfare impacts of globalization in a large-scale model that extends the simple gravity-based welfare calculations put forward by Arkolakis, Costinot, and Rodríguez-Clare (2012). In a similar computational setting Caliendo et al. (2015) consider the welfare impacts of tariff liberalization over the period from 1990 to 2010. Our analysis is in the tradition of bringing contemporary trade theory into a theory-with-numbers empirical environment.

[26] Regulations which increase trade costs, without retaining rents, produce "efficiency cost rectangles" and are more likely to lower welfare of both parties. Regulations such as VERs (and tariffs) which increase trade costs while transferring rents to one or the other party may improve outcomes for one country at the expense of the other.

[27] Although not directly related to trade policy, we have applied the Melitz structure in analysis of climate policy, carbon leakage, and carbon-content tariffs (Balistreri, Böhringer, and Rutherford, 2018a; Balistreri and Rutherford, 2012). In the context of policies that affect the competitive position of firms on world markets (i.e., sub-global emissions regulation) outcomes are shown to be especially sensitive to the assumed trade structure.

Appendix C. Detailed derivation of a Bilateral Representative Firms (BRF) model

This appendix provides a more detailed presentation of the Bilateral Representative Firms (BRF) theory in the context of a one-sector general-equilibrium model. This parallels the one-sector environment in the original Krugman (1980) formulation, as well as the stylized one-sector models explored by Arkolakis, Costinot, and Rodríguez-Clare (2012). Our application in this paper, as outlined in Section 2, includes many sectors and a more complex production structure with intermediate inputs, tariff instruments, and transportation margins. These extensions are necessary for our application, but are perhaps a distraction from the core theoretic innovation. The one-sector environment without trade costs facilitates a more transparent presentation of the core details of the theory. The extension is a modest revision of the Krugman model to include bilateral specific factors and a bilateral entry margin. In a standard Krugman model there is one mobile factor and entry is at the national level.

We begin with region-s utility (U_s) given by a Constant-Elasticity-of-Substitution (CES) aggregation of a mass of N_{rs} different symmetric varieties sourced from region-r with quantity q_{rs}:

$$U_s = \left(\sum_r N_{rs} {q_{rs}}^{\rho} \right)^{1/\rho} . \tag{C.1}$$

We point out that N_{rs} indicates the number of varieties that arrive in region s from region r. This is different than in a standard Krugman model where all varieties produced in r are consumed in all destinations s because entry operates at the level of a region in a standard Krugman formulation.

Let us denote income in region s as $\mathcal{I}_s$ and the price of a good from r landed in s as p_{rs}. The budget constraint is thus

$$\mathcal{I}_s = \sum_r N_{rs} p_{rs} q_{rs}. \tag{C.2}$$

The consumer in region s maximizes utility subject to this constraint. It is often more convinient to work with the dual expenditure minimization problem. One can show that the value function of the expenditure minimization problem is given by the following *expenditure* function:

$$\begin{aligned} e_s(U_s, \boldsymbol{p}) &= U_s \left(\sum_r N_{rs} {p_{rs}}^{1-\sigma} \right)^{1/(1-\sigma)} \\ &= U_s P_s(\boldsymbol{p}), \end{aligned} \tag{C.3}$$

where $\sigma = 1/(1-\rho)$, and we introduce the true-cost-of-living price index $P_s(\boldsymbol{p})$:

$$P_s(\boldsymbol{p}) = \left(\sum_r N_{rs} {p_{rs}}^{1-\sigma} \right)^{1/(1-\sigma)} . \tag{C.4}$$

In addition to a set of other useful duality properties this price index provides a convenient measure of region-s welfare as real income:[28]

$$U_s = \frac{\mathcal{I}_s}{P_s(\boldsymbol{p})}. \tag{C.5}$$

With the expenditure function (C.3) specified we can derive compensated demand for an individual variety i by the envelope theorem, where we note that N_{rs} is not a parameter but the mass of firms indexed by i from region r servicing market s. Compensated demand is

$$\begin{aligned} h_{irs}(U_s, \boldsymbol{p}) &= \frac{\partial e_s(U_s, \boldsymbol{p})}{p_{irs}} \\ &= U_s \left(\frac{P_s(\boldsymbol{p})}{p_{irs}} \right)^{\sigma}, \end{aligned} \tag{C.6}$$

and leveraging duality uncompensated demand is

$$q_{irs}(\mathcal{I}_s, \boldsymbol{p}) = \frac{\mathcal{I}_s}{P_s(\boldsymbol{p})} \left(\frac{P_s(\boldsymbol{p})}{p_{irs}} \right)^{\sigma}. \tag{C.7}$$

We now consider the firm's profit maximization problem given that they have a monopoly in their variety. First, however, we make a critical large-group monopolistic competition assumption. Firms are assumed small enough relative to the market that their decisions cannot affect the aggregate price index (Dixit and Stiglitz, 1977). That is, we assume that for an individual firm i they perceive

$$\frac{\partial P_s(\boldsymbol{p})}{\partial p_{irs}} = 0.$$

Inverse demand as a function of the quantity is thus given by

$$p_{irs} = P_s{}^{\rho} \left(\frac{\mathcal{I}_s}{q_{irs}} \right)^{1/\sigma}, \tag{C.8}$$

where P_s is taken as a parameter by the firm. Firm revenue is

$$q_{irs} p_{irs} = P_s{}^{\rho} \mathcal{I}_s{}^{1/\sigma} q_{irs}{}^{1-1/\sigma}; \tag{C.9}$$

and taking the derivative with respect to q_{irs}

$$\text{marginal revenue} = (1 - 1/\sigma) p_{irs}. \tag{C.10}$$

We now consider the firm's technology. Let us assume that firms use a single input with market price c_{rs}. Note that this input is specific to firms in region r supplying to market s. This is a departure from the standard Krugman formulation, where the input price would be the same for all firms in region r. We

[28] For an extended discussion on this and the appropriate cardinalization that yields money-metric indirect utility see Balistreri and Tarr (2022a).

adopt the standard internal-economies technology for firms (where f_{rs} is the input requirement for covering fixed costs):

$$\begin{aligned}\text{Total Cost} &= c_{rs}\left(f_{rs} + q_{irs}\right)\\ \text{Average Cost} &= c_{rs}\left(f_{rs}/q_{irs} + 1\right)\\ \text{Marginal Cost} &= c_{rs}\end{aligned}$$

Profit maximization indicates marginal revenue equal to marginal cost. This indicates the mark-up pricing condition common to CES large-group monopolistic competition models:

$$p_{irs} = p_{rs} = \frac{c_{rs}}{1 - 1/\sigma}, \tag{C.11}$$

where the first equality is indicated by our symmetry assumption. Using the markup equation we can also calculate the operating profits of each firm in the short-run (given sunk fixed costs). Denote operating profits of a firm from r servicing market s as π_{rs}. Operating profits are revenues less operating costs, but operating costs are revenues times $(1 - 1/\sigma)$ from the markup formula. We have

$$\begin{aligned}\pi_{rs} &= p_{rs}q_{rs} - p_{rs}q_{rs}(1 - 1/\sigma)\\ \pi_{rs} &= \frac{p_{rs}q_{rs}}{\sigma}.\end{aligned} \tag{C.12}$$

Free entry ensures that operating profits just cover the fixed cost payments such that long-run profits are zero. That is,

$$c_{rs}f_{rs} = \frac{p_{rs}q_{rs}}{\sigma}. \tag{C.13}$$

Using the free-entry condition we now show that firm output is actually a constant in this, and in more elaborate environments, as long as the input price for fixed costs is the same as the input price for operating costs. In this class of models firm output is invariant to demand or supply shocks. The only response is in the number of operating firms (N_{rs}). Substituting the optimal markup into the free-entry condition we have

$$c_{rs}f_{rs} = \frac{c_{rs}q_{rs}}{(1 - 1/\sigma)\sigma}.$$

On the left-hand side we have the price of fixed-cost inputs (c_{rs}) and on the right-hand side we have the price of operating-cost inputs (c_{rs}). Given that these are the same the expression reduces to

$$q_{rs} = f_{rs}(\sigma - 1). \tag{C.14}$$

The fixed cost and σ are parameters, so the output quantity of each firm is fixed. In Section 2 above we take advantage of this feature in computation, because we know that the proportional changes in varieties equals proportional change in input demand.

Input demand across all firms from r servicing market s (denoted x_{rs}) is given by the total input use in both fixed and operating activities:

$$x_{rs} = N_{rs}\left(f_{rs} + q_{rs}\right). \tag{C.15}$$

Input supply is given by a competitive sector. The input to monopolistically competitive firms is a composite of a mobile input (labor) and a bilateral specific factor. Let us denote the price of labor in region r as w_r and the rental return on the specific factors as z_{rs}. We have a constant-returns technology for the sector producing the composite input. The price of the composite input will equal its minimized unit cost (marginal-cost pricing). Under a CES technology we have

$$c_{rs} = \left[\alpha {w_r}^{1-\eta} + \beta {z_{rs}}^{1-\eta}\right]^{1/(1-\eta)}. \tag{C.16}$$

Given this technology, demand or endowment shocks will induce a response as labor reallocates across the bilaterally indexed composite input activities.

Conditional demand for the primary inputs can be derived by applying the envelope theorem. Let us have an endowment of labor $\bar{L}_r$. The market clearance condition for labor is thus given by

$$\begin{aligned} \bar{L}_r &= \sum_s x_{rs} \frac{\partial c_{rs}}{\partial w_r} \\ &= \sum_s \alpha x_{rs} \left[\frac{\left(\alpha {w_r}^{1-\eta} + \beta {z_{rs}}^{1-\eta}\right)^{1/(1-\eta)}}{w_r}\right]^{\eta}. \end{aligned} \tag{C.17}$$

The same procedure is used to derive the market clearance for the bilateral specific factors

$$\bar{\mathcal{Z}}_{rs} = \beta x_{rs} \left[\frac{\left(\alpha {w_r}^{1-\eta} + \beta {z_{rs}}^{1-\eta}\right)^{1/(1-\eta)}}{z_{rs}}\right]^{\eta}. \tag{C.18}$$

The final general-equilibrium condition requires income balance. That is income will equal the value of endowments in each region:

$$\mathcal{I}_r = w_r \bar{L}_r + \sum_s z_{rs} \bar{\mathcal{Z}}_{rs}. \tag{C.19}$$

We proceed by producing a table that includes the full set of variable and conditions that represent the general equilibrium as a square system. We only have equality conditions, but we follow the Mathiesen-Rutherford (see Rutherford, 1995) mixed-complementarity-problem tradition of logically associating equilibrium conditions with associated nonnegative endogenous variables. The presentation is verbose for transparency. With R regions the system includes $4R + 6R^2$ equations with as many associated variables. The system is only defined in relative prices, however, so one price is designated as numeraire and the associated market-clearance condition is removed by Walras' Law.

Table C.1. One-sector General Equilibrium with Bilateral Representative Firms

Description	Equilibrium Condition	Associated Variable
Zero unit-profits Dixit-Stiglitz aggregation	$P_s = \left(\sum_r N_{rs} {p_{rs}}^{1-\sigma}\right)^{1/(1-\sigma)}$	U_s
Firm-level profit maximization	$p_{rs} = \frac{c_{rs}}{1-1/\sigma}$	q_{rs}
Free entry	$c_{rs} f_{rs} = \frac{p_{rs} q_{rs}}{\sigma}$	N_{rs}
Zero unit-profits composite-input production	$c_{rs} = \left[\alpha {w_r}^{1-\eta} + \beta {z_{rs}}^{1-\eta}\right]^{1/(1-\eta)}$	x_{rs}
Market-clearance utility	$U_s = \frac{\mathcal{I}_s}{P_s}$	P_s
Market-clearance firm-output	$q_{rs} = U_s \left[\frac{\left(\sum_k N_{ks} {p_{ks}}^{1-\sigma}\right)^{1/(1-\sigma)}}{p_{rs}}\right]^{\sigma}$	p_{rs}
Market-clearance composite input	$x_{rs} = N_{rs} \left(f_{rs} + q_{rs}\right)$	c_{rs}
Market-clearance labor	$\bar{L}_r = \sum_s \alpha x_{rs} \left[\frac{\left(\alpha {w_r}^{1-\eta} + \beta {z_{rs}}^{1-\eta}\right)^{1/(1-\eta)}}{w_r}\right]^{\eta}$	w_r
Market-clearance specific factors	$\bar{\mathcal{Z}}_{rs} = \beta x_{rs} \left[\frac{\left(\alpha {w_r}^{1-\eta} + \beta {z_{rs}}^{1-\eta}\right)^{1/(1-\eta)}}{z_{rs}}\right]^{\eta}$	z_{rs}
Income balance	$\mathcal{I}_r = w_r \bar{L}_r + \sum_s z_{rs} \bar{\mathcal{Z}}_{rs}$	$\mathcal{I}_r$