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Comparison of Welfare Gains in the Armington, Krugman and Melitz Models

Insights from a Structural Gravity Approach

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Abstract

How large are the estimated gains from trade from a reduction in trade costs in the heterogeneous firms Melitz (M) model compared with the Armington (A) and Krugman (K) models? Surprisingly little is known beyond the one-sector model. This paper analyzes this question using a global trade model that contains ten regions and various numbers of sectors (1-10). Following Arkolakis et al. (2012), the analysis holds the local trade response constant across the model comparisons based on a structural gravity estimate. Various model features and scenarios are introduced that are important to real economies, almost none of which has been examined across the three market structures with a constant trade response. In response to global reductions in iceberg trade costs, in all the multi-sector models, the ranking of global welfare gains is Melitz > Krugman > Armington; and the Krugman model captures between 75 and 95 percent on the additional gains above the Armington model that are estimated by the Melitz model. However, for individual regions, there are numerous cases of reversed welfare rankings. i.e., Melitz < Krugman < Armington. For unilateral increases in tariffs, welfare gains are typically estimated with the Armington model, but welfare losses with monopolistic competition models. The paper constructs a multi-sector Feenstra ratio for the Dixit-Stiglitz variety externality and calculates changes in the terms-of-trade. These parameters provide economically intuitive explanations of the general pattern of results and exceptions. The paper concludes that gains from the reduction of trade costs for the world are: Melitz > Krugman > Armington. For individual regions, however, the welfare ranking of the Armington, Krugman and Melitz market structures is model, data, parameter and scenario dependent. The results highlight the need for data and structural considerations in policy analysis.

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Comparison of Welfare Gains in the Armington, Krugman and Melitz Models: Insights from a Structural Gravity Approach *

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1. Introduction

How large are the estimated gains from trade in the heterogeneous firms model of Melitz (2003) compared with the homogeneous firms, monopolistic competition model of Krugman (1980) and the perfectly competitive model of Armington (1969). This has been an important question since the publication of the Melitz (2003) paper. In their well-known paper, entitled "New Theories, Same Old Gains," Arkolakis, Costinot and Rodriguez-Clare (2012) showed that in their highly stylized one-sector model, [1] the welfare gains were identical. Key to their result was that they adjusted trade elasticities such that the trade response was the same across the Armington, Krugman and Melitz models consistent with a structural gravity estimate.

It is well known that the above result of Arkolakis *et al*. (2012) is fragile. Balistreri, Hillberry and Rutherford (2010) found that with a labor-leisure choice in the Arkolakis *et al*. (2012) one-sector model and a positive (negative) elasticity of labor supply with respect to the real wage, the Melitz model produced larger (smaller) welfare gains than the Armington model. [2] Arkolakis *et al*. (2012) showed analytically that if there is a unique aggregate intermediate good, the gains are larger in the monopolistic competition models. Further, they showed that multiple sectors break the welfare equivalence (with ambiguous impacts). Costinot and Rodriguez-Clare (2014) used numerical methods in multi-region, multi-sector models. Based on their results for the average for the world, they also found that the welfare gains are larger in the monopolistic competition models with a single aggregate intermediate good; there were, however, several exceptions for individual regions in their results. They also found that multiple sectors break the welfare equivalence. Melitz and Redding (2015) introduced a finite upper bound on the Pareto distribution of productivity in a model otherwise identical to the stylized model of Arkolakis *et al*. (2012). They showed that, compared with the Krugman model, there are larger welfare gains in the heterogeneous firms model from reductions in trade costs and smaller welfare losses from increases in trade costs. We summarize the known literature results regarding the relative welfare gains in table 1 and in more detail in section 2.2.

There is a need to further examine the sensitivity of the results. There are a wide range of modeling variations that have not been assessed for their relative welfare impacts. We develop numerous new results for the relative gains from trade in the Armington, Krugman and Melitz models. For a fair

[1] They assumed one sector, one factor of production; no labor-leisure choice; balanced trade in all regions; no initial tariffs, iceberg trade costs, no intermediates and a global change in iceberg trade costs.
[2] Balistreri *et al.*, (2010), however, did not hold the trade response constant between the Armington and Melitz models.

comparison, following Arkolakis et al. (2012), we hold the trade response in each scenario constant across the three market structures based on a structural gravity estimate. Like Costinot and Rodriguez-Clare (2014), our results are numerical. This allows us to assess not just the qualitative differences between the estimated gains from trade from the market structure, but also the quantitative differences. In particular, we answer the question of whether the Krugman model captures most of the gains from trade above the Armington model. That is, what is the relative importance of the variety externality in the Krugman model compared to the selection effect in the heterogeneous firms model in producing larger estimated gains above the perfectly competitive Armington model? We employ a ten-region model of global trade built on the GTAP 9 dataset. All of our exercises are comparative static without moving to autarchy.

To stay close to the earlier literature, we first replicate the Arkolakis *et al*. (2012) equivalence result from a global ten percent reduction in iceberg trade costs, in a one-sector model. We then progressively introduce real features of the data. We find that trade imbalances alone are insufficient to break the equivalence result of Arkolakis *et al*. (2012) in their one-sector model. We then introduce three features that break the welfare equivalence: (i) labor-leisure choice in a one-sector model;[3] (ii) intermediate demand in a single sector; and (iii) multiple (four) sectors with intermediate demand based on the data.[4] Next, we show that intermediate demand based on data as opposed to a single aggregate and a lower elasticity of substitution both make a significant difference in the comparative results across the models.[5] In table 5, we investigate variations in primary factor assumptions: single primary factor; three primary factors with and without a specific factor and labor-leisure choice.[6] Next, we expand our model

[3] In addition to Balistreri *et al.*, (2011), see also Adao, Arkolakis and Esposito (2017).

[4] Arkolakis, Costinot and Rodriguez-Clare (2012) first showed that both multiple sectors and tradable intermediates broke the welfare equivalence between monopolistic competition and the Armington model, but only tradable intermediates led to unambiguously larger welfare estimates.

[5] Costinot and Rodriguez-Clare (2014) incorporated intermediates in a multi-sector model, but they assumed an aggregate intermediate good. So all their sectors use intermediates in the same proportion in that model. Further, they did not test for sensitivity of the results to the elasticity of substitution for intermediates. We find that these assumptions have a strong impact: the former increases the relative gains of the monopolistic competition models and the latter reduces them.

[6] Costinot and Rodriguez-Clare (2014, 200-223) evaluated the impact two factors of production, but only in their autarchy exercises and with common cost shares across countries for the two factors. They report that there are virtually no Heckscher-Ohlin effects in their Armington model, but one could question how general that result is when factor cost shares are identical across all regions. Further, they do not report results in the monopolistic competition models with multiple primary factors of production; so we do not have comparable results for the Krugman or Melitz models.

Costinot and Rodriguez-Clare (2014, 231) indicate that we cannot generalize from autarchy exercises to trade policy exercises. In an Armington model, they find opposite results regarding the impact of multiple sectors between their autarchy exercise and a forty percent tariff increase. They conclude that "one should be careful when extrapolating from the autarky exercises …to richer comparative static exercises. Models that point towards larger to nine sectors and introduce both initial tariffs based on the data and also initial uniform tariffs that yield the same tariff revenue as in the data; this allows us to evaluate global free trade with and without initial uniform tariffs. [7] Finally, we use this model to investigate unilateral increases in tariffs by individual regions; then we typically obtain estimated welfare gains in the Armington model but welfare losses in the monopolistic competition models. Beyond the single sector model, with the exception the impact of multiple sectors and a single aggregate intermediate good, we are the first to solve for the relative welfare impacts of the Armington, Krugman and Melitz models in any of these model, data, parameter and scenarios variations.

We take advantage of the calibrated share form of CES technologies and preferences suggested by Rutherford (2002). We choose units such that initial prices are unity. Analogous to the "exact hat" approach of authors such as Dekle *et al*. (2008) and Costinot and Rodriguez-Clare (2014), [8] we recover the proportional changes in prices and quantities as the equilibrium solution to the numerical problem.

Our key results are the following.

If we consider the global welfare gains from the reduction in trade costs, in all model variants beyond the simple one-sector model without intermediates, we find that the Melitz structure produces larger welfare gains than the Krugman structure; and Krugman model produces larger welfare gains than the Armington model, hereafter, $M \succ K \succ A$. If we consider the estimate of the Melitz model for *the increase* in the global welfare gains above the Armington model, we find that the Krugman model produces between 75 and 95 percent of the increase in the welfare gains above the Armington model, depending on the model variant and data. This suggests that although the selection effect of the Melitz model adds to the welfare gains above the Krugman model, the variety effect of the Krugman model is quantitatively more important in explaining differences above the Armington model from global policy changes.

gains from trade liberalization from one counterfactual scenario may very well lead to smaller gains from trade liberalization for another." In this paper, all exercises are comparative static.

[7] Costinot and Rodriguez-Clare (2014, section 4.3) assumed uniform tariffs and zero initial tariffs when they assessed 40 percent tariff changes in the Melitz and Krugman models; so they did not evaluate global free trade. They assessed the impact of heterogeneous tariffs, but only in an Armington model without intermediates. Impacts in the Armington model, however, may be misleading for the effects in a Krugman or Melitz model. For example, in the cases of China and the United States in table 4 below that even the sign of the impact of a modeling variation in the Armington model may be opposite of the sign of the impact in the Krugman or Melitz models.

[8] The term "exact-hat" refers to the characterization of equilibrium impacts in proportional changes. That is, if $\hat{v}$ is the change in a variable denoted in the benchmark and counterfactual as v and v′, respectively, then $\hat{v}$ can be summarized as $\hat{v} = v'/v$. See Dekle, Eaton and Kortum (2008) for an earlier application of the exact hat methodology.

Regarding unilateral *increases* in tariffs without retaliation, we find welfare *gains* from terms-of-trade gains in the Armington model. But due to variety losses that typically dominate the terms-of-trade gains in monopolistic competition, we typically estimate welfare *losses* in the monopolistic competition models.

There are numerous cases for specific regions of a reversed welfare ranking than the welfare ranking for the average for the world, i.e., we have $M \prec K \prec A$ for one or more of our ten regions in many of our scenarios. These results show that for individual regions **the welfare ranking of the Armington, Krugman and Melitz market structures is model, data, parameter and scenario dependent.** We cannot conclude that one of these market structures will always produce larger or smaller welfare gains than another without additional restrictions on the model.

We develop two parameters that are crucial to understanding the reasons for the welfare impacts and, in particular, to understand reversed welfare rankings. These parameters are: (i) the percentage change in the terms-of-trade; and (ii) our multi-sector extension of the Feenstra ratio, which provides a measure of the variety impact on welfare. Without these parameters, interpreting the reasons for the welfare rankings sometimes involves a lot of educated guesswork. In *almost* all cases, when the Armington model provides more welfare gains than the monopolistic competition models, we find that our parameter shows larger terms-of-trade gains in the Armington model. Regarding Krugman versus Melitz, there are several cases where the Krugman model produces larger welfare gains than the Melitz model and the Feenstra ratio shows larger variety gains in the Krugman model. We interpret the larger welfare gains in these cases as due to larger expenditures in the Melitz model in sectors with smaller variety increases or fewer varieties in the Melitz model.

In section 2, we summarize the literature, with a focus in section 2.2 on what we know about the comparative welfare gains of the Armington, Krugman and Melitz models. In section 3, we discuss how we calibrate the trade response based on gravity models. We also describe the three alternate intermediate demand structures we model and our labor-leisure choice model. In section 4 we present our generalized Feenstra ratio to measure variety impacts and the terms-of-trade parameters; these parameters prove extremely useful explaining welfare results across market structures. We present the results of the simulations in section 5 and sensitivity to the gravity estimate and the estimate of the Dixit-Stiglitz elasticity in section 6. We conclude in section 7. In the two appendices we present the equations of the models and our development of our multi-sector, multi-region measure of variety impacts.

2. Literature Review

2.1 Rationales for the Gains from Trade

One of the oldest propositions in economics is that there are gains from international trade. Ricardo (1817) elucidated the principle of comparative advantage as the source of gains from international trade and Samuelson (1939) established it rigorously. Krueger (1974) and Bhagwati (1982) showed that in the presence of "rent-seeking" the gains from trade liberalization would be significantly larger than from specialization gains from comparative advantage.[9] Since 1979, numerous authors showed that under conditions of increasing returns to scale and imperfect competition, the gains from trade liberalization could be larger than under perfect competition for multiple reasons. The reasons included: (i) increased competition from international trade could lower markups, which would lead to rationalization gains as firms slide down their average cost curves, Krugman (1979); (ii) additional varieties in monopolistically competitive markets are a source of gains from trade, Krugman (1980); (iii) international trade could add additional varieties of intermediate inputs, Ethier (1982); (iv) foreign direct investment of multinationals could be a source of significant gains from trade in imperfectly competitive markets, especially in producer services markets, Markusen(1989; 2002), Markusen and Venables (1998); and Ethier and Markusen (1996). Beginning with Melitz (2003), many theoretical papers have emphasized the heterogeneous nature of firms in a monopolistic competition framework.[10] These models of heterogeneous firms provide a further rationale for the gains from international trade, as the endogenous decisions of firms to enter or exit could lead to an increase in output by the more efficient firms and an increase in the gains from trade. Following the Melitz (2003) paper, there has been a substantial increase in research in international economics based on firm level data sets. Several new stylized facts about international trade have been identified, including that only the most productive firms export and trade liberalization induces an intra-industry reallocation of resources that may provide an additional gain from trade.

2.2 Literature on Welfare Comparisons between Armington, Krugman and Melitz

In their influential paper, Arkolakis *et al*. (2012) construct a one-sector stylized version of the Armington, Krugman, and Melitz models. The surprising result they found in their simplest model was that the welfare impacts of reducing trade costs were equivalent across the three models. The simplifying assumptions of their simplest model include: it contains one sector per country; has one factor of production; does not contain intermediates; there is no labor-leisure choice; trade of each country is

[9] Bhagwati used the term "directly unproductive profit-seeking" activities.

[10] See, for example, Arkolakis *et al*. (2008) and Bernard, Redding and Schott (2007).

balanced and the reduction in trade costs is implemented as a global reduction in iceberg trade costs. Crucial to their result is the argument that given the wide acceptance of gravity models in international trade and the importance of the trade response to the welfare results, the structural parameters of the three models must be adjusted to yield trade responses consistent with gravity models. Estimation of the gravity model yields an estimate of the trade elasticity, which determines the trade response which, in turn, determines the welfare impact.

Balistreri, Hillberry and Rutherford (2010) were the first to point out that the Arkolakis *et al*. (2012) result in their highly stylized model was very fragile. Although they did not hold the trade response constant, they introduced a labor-leisure choice in an otherwise identical model to the stylized model of Arkolakis *et al*. (2012). They showed that, with a positive (negative) elasticity of labor supply, the Melitz model produces larger (smaller) welfare gains than the Armington model. They noted the equivalence in their model to a second sector. The intuition is that if there is a second non-tradable goods sector, then changes in trade costs can lead to changes in the measure of goods that can be produced, and models with perfect and monopolistic competition do not have the same welfare impacts. They noted that, in addition to multiple sectors, intermediates would break the equivalence in the welfare results. Arkolakis, Costinot and Rodriguez-Clare (2012) formally established that with intermediates, the monopolistic competition models unambiguously produce larger gains from trade liberalization than the perfect competition model; and there is non-equivalence of the welfare results with multiple sectors. Melitz and Redding (2015) show that the Arkolakis *et al*. (2012) equivalence result in their one sector model fails to hold if the Pareto distribution of productivity has a finite upper bound. Melitz and Redding find that the endogenous decisions of heterogeneous firms to enter and exit the market provide "an extra adjustment margin" that augments the gains from international trade compared to a Krugman style homogeneous firms model. In their model, there are larger welfare gains from reductions in trade costs and smaller welfare losses from increases in trade costs. The generality of the Melitz and Redding result, regarding the welfare dominance of the model with heterogeneous firms and a truncated Pareto distribution, has not yet been examined in models with more than one sector and other realistic features.

Costinot and Rodriguez-Clare (2014) use computer simulation models to investigate the relative welfare impacts of Armington, Krugman and Melitz models. They begin in their section 3 with autarky exercises, where they examine the impact of relaxing some of the simplifying assumptions of the one sector model of Arkolakis *et al*. (2012). With multiple sectors, but no intermediates and zero trade imbalances, they show that there are no selection effects in these autarky exercises, so the Melitz and Krugman model results are identical. In their 34 regions and 31 sectors numerical model, without intermediates, they find that the relationship between the monopolistic competition models and the

Armington model is ambiguous (Costinot and Rodriguez-Clare, 2014, 214-215).[11] They also evaluate a movement to autarchy with a single aggregate intermediate good without real data (where all sectors use intermediates in the same proportions). Regarding the average for the world and most regions, they find that $M \succ K \succ A$; but there are several exceptions to this pattern that are not discussed.

Costinot and Rodriguez-Clare (2014, table 4.3) also assess forty percent uniform tariff increases across market structures, rather than movements to autarky, in what they refer to as their richer comparative static exercises. Their models contain 10 regions and 16 sectors (with services always perfectly competitive), a single primary factor of production, zero trade balances and zero initial tariffs. In this model without intermediate goods, Costinot and Rodriguez-Clare find that aggregate losses of the uniform tariff tend to be larger in the Krugman model compared with Armington (with three regions being exceptions), i.e., $A \succ K$, but are slightly lower in the Melitz model compared with Krugman, i.e., $M \succ K$. They also consider a single aggregate intermediate good without real data shares (where all sectors use intermediates in the same proportions). With a single aggregate intermediate, the aggregate losses for the world are greatest in the Melitz model, next highest with Krugman and lowest with Armington, i.e., $M \prec K \prec A$; again there are exceptions to this ranking for four regions which are not explained.

Costinot and Rodriguez-Clare succeed in defining equilibrium conditions for a general equilibrium trade model with realistic features; but they have only numerically solved their model in the Melitz or Krugman framework for limited special cases. When they solve a version of this model for the Melitz and Krugman cases, however, they make the following simplifying assumptions: (i) there is an aggregate intermediate good where all sectors consume intermediate factors in the same proportion (see section 4.2.2 below for details); (ii) all tariffs are zero in the initial equilibrium; (iii) only a change in uniform tariffs is considered; (iv) all trade balances are zero; (v) there is a single factor of production; (vi) there are no sector specific factors; and (vii) there is no labor-leisure choice.

Costinot and Rodriguez-Clare subsequently assess the impact of allowing trade balances different from zero initially; heterogeneous tariff changes; and multiple factors of production. But they only analyze these assumptions in their Armington model. These evaluations in the Armington model are useful for understanding impacts in the Armington model, but do not generalize to the Krugman or Melitz models. As discussed in section 5.4, there are nine cases in the results in our table 4 below where the impact of a model assumption in the Armington model has an opposite impact in the Krugman or Melitz model, i.e., the sign of the impact is opposite. Clearly, knowledge of the impact of a modeling assumption

[11] See Costinot and Rodriguez-Clare (2014, 219-220). In all of their models, they assume that all services are perfectly competitive; then in their Krugman and Meltiz model, all other sectors are monopolistically competitive.

in the Armington model is insufficient to infer the impact of the same modeling assumption in the Krugman or Melitz models in general. Consequently, in our summary table of known comparative welfare results across the three market structures, we have rather limited results.

In summary, the structural gravity literature to date indicates that an aggregate intermediate good results in larger welfare estimates in the monopolistic competition models and multiple sectors break the welfare equivalence of the three market structures, but the welfare ranking of Melitz to Krugman varies with the model the region and the nature of the counterfactual experiment. As we explained in the footnotes of the Introduction section, the structural gravity literature to date has not tested the sensitivity of the results to a wide range of important model variations. That is, what are the relative welfare impacts of the Armington, Krugman or Melitz models with labor-leisure choice, heterogeneous tariff changes across sectors, intermediates with real data on intermediate factor proportions, the impact of CES demand for intermediates with an elasticity of substitution of intermediates less than one, multiple primary factors of production (or specific factors) with different factor intensities across regions, or tariff exercises with actual tariffs by region in the data. We also do not have results for the impacts of unilateral policy changes as opposed to global policy changes. We address all of these issues in this paper. In table 1, we summarize the literature results on comparing the three market structures.

2.3 Applied Numerical literature on the welfare gains from trade liberalization

The early literature was based on constant returns to scale models, where the gains were based on comparative advantage and calculated from "Harberger triangles." The estimated gains from trade liberalization were sometimes characterized by the "Harberger constant," i.e., the gains were generally less than one percent of GDP from trade liberalization. Among others, de Melo and Tarr (1990) and Jensen and Tarr (2003) showed that, even in a perfect competition constant returns to scale model, if there were rents involved, the gains could be many multiples of the gains from the "Harberger triangles."

Regarding imperfect competition models with homogeneous firms, the path breaking article was by Harris (1984), who showed that the gains might be much larger if the behavioral interaction of oligopolists is altered by the trade policy. Harrison, Rutherford and Tarr (1997) estimated that the impact of rationalization gains (sliding down the average cost curve) were small in a quantity adjusting model of oligopoly. Rutherford and Tarr (2002) showed that in a fully dynamic model based on Paul Romer style endogenous growth with gains from variety, the gains from trade liberalization would be many multiples of the gains in a model with constant returns to scale. Markusen, Rutherford and Tarr (2005) and Rutherford and Tarr (2008) showed that introducing foreign direct investment in services with Dixit-Stiglitz endogenous productivity effects would substantially increase the welfare gains. Francois, Manchin and Martin (2013) have summarized many approaches to modeling market structure in CGE models and suggested ways that the alternate model structures could be tested.

Regarding heterogeneous firms, the first effort to numerically assess the welfare gains was by by Zhai (2008). His model was developed into an application to the Trans Pacific Partnership in Petri, Plummer and Zhai (2012). Unlike the Melitz model, however, neither Zhai's model, nor the model of Petri, Plummer and Zhai, allow entry or exit of firms, nor do these models allow uncertainly about the productivity (Zhai, 2008, pp. 7, 8). But their models do allow existing firms to enter new markets and that type of entry creates a new variety and a welfare gain. Since domestic firms face increased competition from foreign entry, some would be expected to exit. The model of Zhai, however, does not allow firm exit; consequently, the model exaggerates the variety externality. This explains why Petri, Plummer and Zhai obtain such large increases in the variety externality in their model. Recently other authors have adopted a computational setting for welfare analysis in frameworks with heterogeneous firms. The paper by Caliendo, Feenstra, Romalis and Taylor (2015) is a good example. Their approach is in the tradition of the exact hat approach.

Regarding papers that compare the welfare results across market structures, several papers have compared the welfare impacts in the Krugman and Armington structures. These include Balistreri, Rutherford and Tarr (2009), Rutherford and Tarr (2008) and Balistreri, Olekseyuk and Tarr (2017). These papers, however, did not hold the trade response constant. The first numerical model of real economies consistent with the full Melitz structure is Balistreri, Hillberry and Rutherford (2011). In their multi-region model they find that the welfare gains from tariff reductions are several times larger than with an Armington trade model. Jafari and Britz (2017) follow the model of Balistreri, Hillberry and Rutherford to assess the Transatlantic Trade and Investment Partnership (TTIP); they also find that the Melitz model produces considerably larger welfare gains than the Armington model. Neither Balistreri, Hillberry and Rutherford (2011) nor Jafari and Britz (2017), however, hold the trade response constant across the market structures.[12]

3. Trade Response Calibration, Intermediate Demand Structures and Labor-Leisure Choice

3.1 Calibration of the Trade Responses from a Structural Gravity Estimate

Our intent is to hold the trade responses constant in the Armington, Krugman and Melitz models based on a structural-gravity estimate. We take parameters based on econometric estimates for the Melitz model and adjust elasticities in the Krugman and Armington model so that the trade response is the same.

[12] Dixon, Jerie and Rimmer (2018) explain how to add Melitz equations to the GTAP general equilibrium modeling system. In their application, they develop a 10 region, 57 sector model with 56 Armington sectors and one Melitz sector to assess a unilateral tariff increase in the Melitz sector by the North American region.

To be precise, following Costinot and Rodriguez Clare, let λ_W indicate the share of global expenditures that are spent on goods that are produced in their respective home region:

$$\lambda_W \equiv \frac{\Sigma_r X_{rr}}{\Sigma_{r,s} X_{sr}},$$

where X_{sr} is the total value of country r's expenditures on goods from country s. If λ_W is the domestic trade share in the benchmark data and λ_W' is the domestic trade share in the in the counterfactual equilibrium, then $1-\lambda_W$ is the proportional change in the global trade share where $\hat{\lambda}_W$ is defined by:

$$\hat{\lambda}_W \equiv \frac{\lambda_W'}{\lambda_W}.$$

Note that in the special case of a movement to autarky, in the counterfactual, $\lambda_W' = 1$. Then $\hat{\lambda}_W = \dfrac{1}{\lambda_W}$ and the change in the trade response may be calculated from initial data and the trade elasticity without the need of a model. We adjust the Armington and Krugman elasticities to match the observed percentage increase in global trade intensity from the Melitz model. This gives us a fair comparison across structures where they are parameterized to generate an equivalent aggregate trade response.

The calculation of the trade response is nontrivial in a multi-sector model. Although the trade response is unique in a one sector model, in a multi-sector model there are trade responses in each sector. Further, depending on model assumptions, the trade elasticity may not be constant.[13] In this paper, we hold the aggregate trade response constant across the Armington, Krugman and Melitz models, which means that trade responses at the sector level are not necessarily constant across the models.

For the Pareto distribution shape parameter in the Melitz model, we choose the value 4.58 as the mean from the structural estimation of Balistreri, Hillberry and Rutherford (2011). Arkolakis *et al*. (2012) have shown that in the one sector Melitz model, the Pareto shape parameter is equal to the trade elasticity; in particular, the trade elasticity is independent of the Dixit-Stiglitz demand elasticity. The Dixit-Stiglitz elasticity remains relevant, however. In heterogeneous firms models with realistic features, it affects the value to consumers of additional varieties, and in the Krugman model it is central to the trade response as well. For the value of the Dixit-Stiglitz trade elasticity in the Melitz model, we take the value

[13] Melitz and Redding (2015) showed that the "existence of a single constant trade elasticity and its sufficiency property for welfare are highly sensitive to small departures from those Arkolakis, Costinot and Rodriguez-Clare parameter restrictions."

of 5.0 that Hillberry and Hummels (2014, p.1240) report as the median estimate from cross section and panel estimates.

Given these parameter values, for each scenario we calculate the trade response in the Melitz model and adjust elasticities in the Krugman and Armington models to obtain the same trade response. For the Krugman model, we adjust the Dixit-Stiglitz elasticities of substitution. In our nine-sector models, we have some CRTS sectors in our Krugman model; to get the same trade response, we also adjust the Armington elasticities for the CRTS sectors by the same multiple that we use for the adjustment of the Dixit-Stiglitz elasticities. The selection effect magnifies the trade response in the Melitz model, but this effect is absent in the Krugman model. To obtain the same trade response in the Krugman model as in the Melitz model, we must impose larger Dixit-Stiglitz elasticities. This means that the value of an additional variety will be greater in the Melitz model compared to the Krugman model.

Since the Krugman model has entry of firms, to hold the trade response constant, we find that we typically must choose the Armington elasticities of substitution to be larger than the Dixit-Stiglitz elasticities of our multi-sector Krugman models. In the Melitz model, the value of 4.58 for the shape parameter and 5.0 for the Dixit-Stiglitz elasticities are invariant across the scenarios. In the case of the Armington and Krugman models, the Armington and Dixit-Stiglitz elasticities vary with the scenario, and those values are in the tables of results.

In an effort to keep the love of variety effect constant in the Krugman and Melitz models, one might start with the Krugman model. That would require that we calibrate the Dixit-Stiglitz elasticities of substitution to be consistent with an estimate of the trade elasticity from a gravity model. Then we would attempt to impose those same Dixit-Stiglitz elasticities of substitution in the Melitz model. To hold the trade response in the Melitz model consistent with the gravity estimate, we would then attempt to adjust the Pareto shape parameter to achieve a trade response in the Melitz model consistent with the trade response in the Krugman model. The problem with this calibration strategy is that it requires a value of the Pareto shape parameter, a, very close to $\sigma - 1$, where σ is the Dixit-Stiglitz elasticity of substitution. At $a \leq \sigma - 1$ it is well known that the Melitz equilibrium is ill defined, as the productivity of the representative firm, and all the aggregates dependent on it, are unbounded. As a matter of computation, the Melitz models fail to solve reliability as the value of the Pareto shape parameter approaches $\sigma - 1$ from above. The economic intuition is that if the selection effect in the Melitz model is positive, then the entry effect in the Krugman model will have to be larger for both models to be consistent with the same trade response. To get larger entry effects in the Krugman model we need larger values of the Dixit-Stiglitz elasticity, which will give us lower gains for a single variety in the Krugman model (other things equal). Despite a variety being valued more highly in the Melitz model, our results show that it is possible for shifts in expenditure shares in multi-sector models to sometimes lead to larger variety gains in the Krugman model (a result explained by Feenstra, 1994).

3.2 Intermediate Demand Structures

We examine the impact of market structure with three intermediate demand structures: (i) Cobb-Douglas demand using the data on intermediate use in the input-output tables at the sector level; (ii) Cobb-Douglas demand with an aggregate intermediate which assumes that all sectors use intermediates in the same proportions; and (iii) CES demand for intermediates with elasticity of demand for intermediates of 0.5, using the data on intermediate use in the input-output tables at the sector level. Given that the structure is the same across regions, we suppress subscripts for the region in the equations of this section describing these intermediate use and demand structures.

3.2.1 Cobb-Douglas Demand with data on intermediate use.

Define:

P_{is} as the composite price of the i-th good in region s. This is the dual price variable that we define as the left-hand side variable in appendix B, equations 2a, 2b, and 2c. The definition depends on the three intermediate demand structures discussed below. P_{is} incorporates the technology and the optimization, and its depends on the Armington, Krugman or Melitz market structure.

Define x_{ij} as the intermediate inputs from sector i used in sector j (in region s);

$\theta_{ij} = P_i x_{ij} / \Sigma_i P_i x_{ij}$ = the share of intermediate expenditures of sector j on intermediates of sector i;

Total intermediates use of sector j are a Cobb-Douglas aggregate of its intermediates uses from the sectors.

$$Z_j = \Pi_i x_{ij}^{\theta_{ij}}$$

When we model intermediates as Cobb-Douglas, we also assume the production function in sector j is Cobb-Douglas; then output in sector j is:

$$Q_j = K_j^{\alpha_j} L_j^{\beta_j} R_j^{\gamma_j} Z_j^{1-\alpha_j-\beta_j-\gamma_j} \quad \text{where} \quad \alpha_j + \beta_j + \gamma_j < 1;\ \alpha_j \geq 0,\ \beta_j > 0,\ \gamma_j \geq 0,$$

where K_j, L_l and R_j are the primary factors capital, labor and a primary resource factor that is sector specific, respectively, used in sector j. We investigate the impact of primary factors by assuming variously that: (i) labor is the only primary factor; (ii) labor and capital are the only primary factors; and (iii) also, in some models, there is a sector specific factor along with capital and labor.

3.2.2 Cobb-Douglas Demand with an aggregate intermediate good.

Costinot and Rodriguez-Clare (2014) and Balistreri *et al*. (2011) employ a simplifying assumption regarding intermediate goods—they assume an aggregate intermediate good. Use of the aggregate good implies that, given an aggregate amount of intermediate purchases, factor proportions among intermediate goods are identical across sectors. For example, if autos and accounting services are two sectors in the model, the share of steel as an intermediate good is the same in the two sectors. To be more precise, define the following:

e_{jh} as expenditure by household h on consumption goods in sector j;

$A_j = \Sigma_h e_{jh} + \Sigma_i P_j x_{ji}$ as the total expenditure on goods in sector j for both consumption and intermediate use, where P_j and x_{ij} were defined above;

θ_j as the share of total expenditure on both intermediate and final goods that is spent on good j

$$\theta_j = A_j / \Sigma_i A_i \ .$$

Finally, define the aggregate good Z as a Cobb-Douglas aggregate good of all intermediate and final purchases:

$$Z = \Pi_i A_i^{\theta_i}$$

In this model, all firms use only the single composite commodity Z as its intermediates. That is, in all sectors, output is a Cobb-Douglas aggregate of labor, capital, the primary resource factor and the composite commodity Z:

$$Q_i = K_i^{\alpha_i} L_i^{\beta_i} R_i^{\gamma_i} Z^{1-\alpha_i-\beta_i-\gamma_i}$$

Note that intermediate use in the production function in sector i is not indexed by sector. It means that all firms allocate expenditure on intermediates from different sectors in the same proportions, not different intermediates based on the proportions in which they use the intermediates based on the data. Further, in this model, utility of consumers is a function of the composite commodity Z (which includes intermediates), rather than the final goods alone. We investigate the impact of these simplifying assumptions below.

3.2.3 CES Demand for Intermediates with actual data on intermediate use.

In this formulation, total intermediates are a CES aggregate of intermediate uses from the sectors:

$$Z_j = \left[\Sigma_i \theta_{ij} x_{ij}^{\rho_j} \right]^{\frac{1}{\rho_j}} \qquad \rho_j < 1$$

Where θ_{ij} *and* x_{ij} were defined in section 3.2.1. The production function is a CES aggregate of value-added and total intermediate demand:

$$Q_j = \left[\mu_{VA(j)} VA_j^{\rho_j} + \mu_{Z(j)} Z_j^{\rho_j} \right]^{\frac{1}{\rho_j}} \qquad \rho_j < 1$$

In our central formulation, we take the elasticity of substitution as $\sigma_j = \sigma = 0.5$ for all j. And value-added is a Cobb-Douglas aggregate of primary inputs:

$$VA_j = K_j^{\alpha_j} L_j^{\beta_j} R_j^{1-\alpha_j-\beta_j} \ ,$$

where the primary factors of production are defined above in section 3.2.1.

3.3 Labor-Leisure Choice

In our models with labor-leisure choice, we assume that utility in each region is a CES function of leisure and an aggregate of all goods and services consumption. Utility of goods and services consumption is a CES function of the various goods and services, so by two-stage budgeting, we may consider an aggregate non-leisure consumption good C, with a dual price P. Suppressing subscripts for the regions, we have that utility is:

$$U = \left[\mu^{1-\rho} \ell^{\rho} + (1-\mu)^{1-\rho} C^{\rho} \right]^{\frac{1}{\rho}} \qquad \rho < 1 \qquad \sigma = \frac{1}{1-\rho}$$

Where ℓ = leisure and C = consumption of the aggregate good/service.

Let E = the total time endowment of the consumer/worker; W = the wage rate; L = labor supply; and P = the price index of goods and services. The demand for leisure is:

$$\ell = \frac{\mu(WE+Y)}{W^{\sigma}k} \text{ where } k = \mu W^{1-\sigma} + (1-\mu)P^{1-\sigma} \text{ and}$$

the uncompensated elasticity of leisure demand with respect to the wage rate is:

$$\eta_{\ell} = \frac{\mu E * W}{W^{\sigma} \ell * k} - \frac{\mu(1-\sigma)W}{W^{\sigma}k} - \sigma$$

and the uncompensated elasticity of labor supply with respect to the wage rate is[14]:

$$\eta_L = \left[\frac{\ell}{\ell - E} \right] \eta_{\ell} = -\left[\frac{E}{L} - 1 \right] \eta_{\ell}$$

We evaluate the labor supply elasticity in the neighborhood of the initial equilibrium, where we choose units such that W = P = k = 1. Then we have:

[14] See Ballard (2000) for details of the derivation.

$$\eta_L = -\left[\frac{E}{L} - 1\right]\left[\left(\frac{E}{E+Y}\right) - \mu(1-\sigma) - \sigma\right]$$

In the special case of a single primary factor, zero trade balance and zero non-labor factor income, the elasticity of labor supply reduces to:

$$\eta_L = \left[\frac{E}{L} - 1\right](\sigma - 1)(1-\mu)\,.$$

Then the elasticity of labor supply is positive if an only if the elasticity of substitution exceeds unity.

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The compensated elasticity of leisure with respect to the real wage is:

$$\eta_\ell^* = \frac{\sigma W^{1+\sigma}}{k^{\frac{\sigma}{1+\sigma}}}\left[\mu W^{-2\sigma} k^{\frac{2\sigma-1}{1-\sigma}} - W^{-\sigma-1} k^{\frac{\sigma}{1-\sigma}}\right]$$

and the compensated elasticity of labor supply with respect to the real wage is:

$$\eta_L^* = -\left[\frac{E}{L} - 1\right]\eta_\ell^* = \left[\frac{E}{L} - 1\right]\sigma\left(1-\mu\right)$$

It is evident that the compensated elasticity of labor supply is always positive, where we have used our choice of units such that W= P = k = 1, to derive the right-hand side equality.

To calibrate our model, we need three parameters: σ, μ and E. The compensated and uncompensated elasticities of labor supply, both depend on three parameters: σ, μ and E, or E/L. Based on empirical estimates, we take the uncompensated and compensated elasticities of labor supply with respect to the real wages as: 0.2 and 0.7, respectively. In addition, given our choice of units, we have the relation that $\frac{E}{L} - 1 = \frac{\mu}{1-\mu}$ Then with our equations for the compensated and uncompensated elasticity of labor supply we have three equations in these three parameters.

4. A Multi-Sector Feenstra Ratio and Terms-of-Trade Parameter for Interpreting Welfare Results

In general, the monopolistic competition model can produce larger gains than the Armington model due to: (i) more varieties; (ii) lower markups over marginal costs that lead to rationalization gains; and (iii) with heterogeneous firms, an increase in average firm productivity from the selection effect. But in a multi-sector, multi-region model, there are also (iv) terms-of-trade effects that can impact differences in welfare results across regions and market structures. Since we assume, as in Krugman (1980), that the ratio of fixed to marginal costs for a firm is fixed with respect to the quantity, rationalization gains are ruled out as an explanation of our results. In order to help with the interpretation of the variety, selection and terms-of-trade effects, we have developed two parameters: a multi-sector version of the Feenstra ratio and the proportional change in the terms-of-trade.[15] We have found these parameters very insightful in explaining results and we report the values of both of these parameters for all scenarios, for all ten regions in this paper.

4.1 The Multi-sector Feenstra Ratio

Feenstra derived a measure we call the Feenstra ratio that precisely measures the welfare impact of the variety externality in a one-sector monopolistic competition model. We extend that measure to a multi-sector, multi-region Krugman or Melitz model. Details are in appendix A; here we provide the key results.

Despite the fact that all varieties are consumed everywhere in the Krugman model, Feenstra (1994; 2010) has shown that in a one-sector model, the welfare impact of a variety depends on its expenditure share. From Feenstra (2010, Theorem 2), the Feenstra ratio is:

$$F = \left[\frac{\lambda_{t-1}(I)}{\lambda_t(I)} \right]^{1/(\sigma-1)} = \frac{e(p_{t-1}, I_{t-1})}{e(p_t, I_t)} P^{SV}(p_t, p_{t-1}, q_t, q_{t-1}, I)$$

where e is the unit expenditure function, p_t and q_t are the vectors of prices and quantities in period t, I_t is the set of goods available in period t at prices p_t , I is the set of goods available in both periods t and t-1 and $P^{SV}(...)$ is the Sato-Vartia index that shows the ratio of the unit expenditure function in the two periods if the sets of available goods in the two periods are identical. Feenstra's theorem tells us that the proportional change in the unit expenditure function is the product of two terms that are: (i) a measure of the change in the prices charged by firms on goods common to the two periods (the Sato-Vartia index); and (ii) a ratio that is a measure of the value of the variety gain, the Feenstra ratio. The methodology requires distinguishing changes in the price charged by firms on goods available in both periods from the variety externality. Feenstra shows that $1-\lambda_t(I)$ is the expenditure on new goods relative to total expenditure in period t, so a larger number of new goods in period t will tend to lower $\lambda_t(I)$. A value of 1.01 for our Feenstra ratio means that the cost of a unit of utility declined by one percent due to new varieties.

In a multi-sector, multi-region model, we define the Feenstra ratio for region s as:

[15] Quantifying an isolated selection effect in an open economy is nontrivial. Melitz (2003, p. 1721) notes that his aggregate productivity measure in an open economy could be less than his aggregate productivity measure in autarchy due to the output loss in transit of exports.

$$\bar{F}_s = \sum_i \theta_{is} F_{is}$$

where θ_{is} is the economy-wide expenditure share (absorption share) on goods or services of sector i in region s; and F_{is} is the Feenstra ratio for sector i in region s defined as:

$$F_{is} = \frac{PDS_{is}(0)}{PDS_{is}(1)} P_{is}^{SV}$$

where $PDS_{is}(t)$ is the Dixit-Stiglitz price index in sector i in region s, and P_{is}^{SV} is the Sato-Vartia index for sector i in region s. Given that the Sato-Vartia index remains an "ideal" index of firm level prices at the sub-sector level, and the Dixit-Stiglitz index is the unit cost of goods in sector i taking variety into account, our index F_{is} is precise at the sector level. If we have a one-sector model, our measure reduces to the ratio of Feenstra (2010). Given the existence of intermediates in our model, the aggregation across sectors is an approximation, but we have calculated and presented this aggregate variety measure for more than 40 scenarios in this paper, and the measure has consistently proved insightful and intuitive in explaining the welfare results.

4.2 Terms-of-trade Parameter

We define the terms-of-trade for region r as the weighted average of export prices divided by the weighted average of import prices:

$$TOT_r = \frac{\sum_i \exp_{ir} P_{ir}}{\sum_i \sum_{s \neq r} imp_{isr} P_{is}}$$

P_{ir} is the dual price which we defined in section 3.2; it is fully specified in appendix B, equations 2. As in section 3.1, define X_{isr} as the total value of country r's expenditures on good i from country s (excluding tariffs). The export weights are:

$$\exp_{ir} = \frac{\sum_{s \neq r} X_{irs}}{\sum_j \sum_{s \neq r} X_{jrs}}$$

The import weights are:

$$imp_{isr} = \frac{(1 + tar_{isr}) X_{isr}}{\sum_j \sum_{t \neq r} (1 + tar_{jtr}) X_{jtr}} \quad for \quad r \neq s$$

Where tar_{isr} is the tariff rate on imports from region s shipped to region r. Note that for exports, there is a unique weight associated with any good exported from a particular region; but the import weights imp_{isr} are bilateral by product.

5. Model Results

In order to clearly examine the impact of model assumptions and stay close to the results in the literature, we begin with single sector and four-sector models and examine a ten percent reduction in iceberg trade costs. For our tariff policy scenarios, we employ a more realistic nine-sector model. All our models contain ten regions and an untruncated Pareto distribution in the Melitz model. To be consistent with the literature, we rebalance the GTAP data so that all final demand is consumption demand. For our welfare results, we report Hicksian equivalent variation as a percent of the benchmark value of real consumption.

5.1 Welfare Equivalence in the Model with One Sector, One Factor and No Intermediates

We have two sets of simulations in table 2 with welfare equivalence between three market structures. First, we consider the simplest model of Arkolakis, Costinot and Rodriguez-Clare (2012), i.e., one-sector, one primary factor of production, no intermediate inputs, trade costs are iceberg, balanced trade, no labor-leisure choice, untruncated Pareto probability distributions of productivity. The counterfactual shock that we consider is a global uniform reduction in iceberg trade costs of ten percent. In column 2, we calculate the gains from trade using the formula of Arkolakis, Costinot and Rodriguez-Clare (2012). In columns 3-5, we calculate the welfare change from the reduction in trade costs using our model. To be consistent with the model of Arkolakis *et al. (2012)*, we rebalanced the data from the GTAP dataset such that all demand is final demand in table 2 (i.e., no intermediates), and there are zero trade balances in all regions of the model. Our simulations replicate the result of Arkolakis *et al.* (2012) that the alternative market structures generate identical welfare impacts. Further, the table shows that welfare can be derived from a very simple calculation based only on the domestic expenditure share trade response and the trade elasticity. These are precisely the points made by Arkolakis *et al. (2012)*.

In columns 6-8, we allow the initial trade balances based on the data. Note that the domestic expenditure shares λ_{rr} change as a result of the incorporation of the benchmark trade imbalances. In all the subsequent simulations in this paper, we assume trace imbalances based on the data and that the observed current-account imbalances are held fixed (in units of US consumption). Costinot and

Rodriguez-Clare (2014) explain how their welfare formula must be modified to incorporate benchmark trade imbalances and the ambiguity this creates in terms of setting up the counterfactual.[16] In our case, the numeraire is chosen to be the aggregate price index in the US, and so we simply hold the value of each region's current account fixed in these units. We find that in this class of one sector model, when rounded to a single decimal point of percentage change, we retain the welfare equivalence of the three market structures, i.e., the trade imbalances are not sufficient to separate the welfare results across the three market structures.

5.2 Breaking the Equivalence: Labor-Leisure Choice, Intermediate Goods and Multiple Sectors

In table 3, we introduce three model features that break the equivalence of the welfare results between the market structures: (i) labor-leisure choice; (ii) intermediates in a single sector (without labor-leisure choice); and (iii) multiple sectors with intermediates (without labor-leisure choice). In these scenarios we again consider a ten percent reduction in iceberg trade costs. We retain the single primary mobile factor assumption and allow trade imbalances in all scenarios based on the data. In our Krugman and Melitz multi-sector models in these scenarios, all the sectors are monopolistically competitive. The values of the elasticities in the Armington, Krugman and Melitz models to hold the trade response constant (based on a gravity estimate) are shown at the top of columns 1-9.

5.2.1 Labor-Leisure Choice (One Sector Model).

We add labor-leisure choice to the model in the previous set of simulations and present results in columns 1-3 of table 3. To facilitate comparison across the model structures, we continue to report Hicksian equivalent variation as a percent of consumption of goods and services in the benchmark equilibrium even in the models with labor-leisure choice.[17] We see that labor-leisure choice breaks the equivalence. For all regions, we have that $M \succ K \succ A$, i.e., the Krugman model produces larger welfare gains than the Armington model and the Melitz model produces slightly larger welfare gains than the Krugman model in all regions; in some cases (such as the OECD NEC and Australia-New Zealand), however, the difference between the Krugman and Melitz model results is only in the second decimal.

The larger gains in the monopolistic competition models are explained by the fact that the decline in trade costs increases real wages, which, with our positive elasticity of labor supply, makes more labor available for production. More labor available, leads to more varieties and an increase in welfare due to the Dixit-Stiglitz externality. Although they did not hold the trade response constant, this was the

[16] Their welfare formula and the data needed to calculate welfare becomes progressively more complex as they incorporate real features of the data.

[17] That is, we do not include the imputed value of leisure in the denominator.

argument of Balistreri *et al*. (2010). This intuition is verified by noting that all Feenstra ratios in columns 3 and 5 of table 3a exceed unity.

Regarding the larger gains in the Melitz model compared to the Krugman model, as explained in section 3.1, to calibrate to the common trade elasticity from gravity, we must select a higher value of the Dixit-Stiglitz elasticity in the Krugman model. This means that an additional variety is valued more highly in the Melitz model. Holding expenditure shares and the number of varieties constant, there will be larger gains from variety in the Melitz model. We see that the Feenstra ratio values are higher for all regions in the model other than the United States. For the United States, the expenditure shares (or fewer varieties in the Melitz model) induce a very slight reversal of the Feenstra ratio values. Since the terms-of-trade effects are the same in the Krugman and Melitz models, this suggests that selection effects in the Melitz model explain the larger welfare gains in the Melitz model.

5.2.2 Intermediates (One Sector).

The impact of adding intermediates in a single sector model is shown in columns 4-6 of table 3. To isolate the impact of intermediates, we hold labor supply fixed. We assume Cobb-Douglas production in the single primary factor (labor) and the single intermediate good.

In all regions of the model, we see that $M \succ K \succ A$. As shown by Feenstra ratios greater than one in all cases, the monopolistic competition models provide larger gains than Armington due to variety gains. The Melitz model provides additional gains relative to Krugman in these simulations. Given the larger Dixit-Stiglitz elasticity of substitution in the Krugman model, the value of a variety is greater in the Melitz model. Except for the United States, the Feenstra ratio is slightly larger in the case of the Melitz model (table 4a, columns 9 and 11); along with selection effects, this explains the larger gains from the reduction in trade costs in the Melitz model. This model departs in multiple ways from the model of Melitz and Redding (2015) in that it contains intermediates, a trade imbalance and untruncated Pareto distributions. Nonetheless our results in columns 1-6 of table 3 are consistent with the conclusion of Melitz and Redding (2015) that the heterogeneous model provides larger welfare gains than the Krugman model in these single sector models.

5.2.3 Multiple Sectors with Intermediates.

In columns 7-9 of table 3, we present results with four monopolistically competitive sectors, labor as a single primary factor of production and Cobb-Douglas demand for intermediates and labor (see section 4.2.1 for details of the intermediate demand structure). For the average welfare impact for the world and for seven of the ten regions, we again have the ranking $M \succ K \succ A$. Additional varieties contribute to larger welfare results and partly explain the larger net gains in the Krugman and Melitz models over Armington for most of the regions and the average for the world (see the Feenstra ratio values in table 3a). Again, given our calibration to a common trade response, an additional variety is valued more highly in the Melitz model; for six of our regions, the Feenstra ratio shows a larger welfare gain in the Melitz model than the Krugman model, which (along with possible gains from the selection effect) explains the larger gains in the Melitz model compared with the Krugman model.

With the introduction of multiple sectors, however, we have a reversal of the welfare ranking in the case of the Low Income region, i.e., we have $M \prec K \prec A$. The larger welfare gains for the Low Income region in the Armington model derive from larger terms-of-trade gains than in the monopolistic competition cases (columns 12, 13 and 15 of table 3a). So a smaller terms-of-trade gain in the monopolistic competition models outweighs their variety gains, leading to larger welfare gains in the Armington model for the Low Income region. This shows that the significant terms-of-trade effects that may be present in multiple sector, multiple region trade models, can dominate the variety and selection effects for some regions.

For three regions, we have the reversed welfare ranking of $M \prec K$: the Low Income region; Middle-Income region; and Australia-New Zealand (in the second decimal). Despite the fact that a variety is valued more highly in the Melitz model, in all three of these regions (and only these three regions), we see that the Feenstra ratio shows lower variety gains in the Melitz model. From the Feenstra ratio, we know that if expenditures are small on products that experience variety gains, the welfare impact of the variety gain will be reduced. In these three regions, the lower Feenstra ratios in the Melitz case show that, compared with the Krugman model, either expenditure shares shifted to sectors with fewer increases in varieties or there was a smaller increase in varieties in the Melitz model.

The fact that not all regions follow the pattern of the average for the world is consistent with the results of Costinot and Rodriguez-Clare (2014, table 4.3, p. 232). In their ten region model with 16 sectors and intermediates, they show reversed welfare rankings between Krugman and Armington in three of their regions (Eastern Europe, North America and Rest of World) and reversed welfare results for Krugman versus Melitz in the case of their Pacific Ocean region. They interpret the results for the average for the world based on the variety externality in the monopolistic competition models and the value of Dixit-Stiglitz elasticity for difference between Melitz and Krugman. They do not explain, however, the cases where they find reversed relative welfare rankings.[18] They do not use either expenditure shares

[18] In their ten region, sixteen sector model with intermediates, they conduct comparative static exercises of forty percent tariff increases. For seven of their regions and the average for the world, they find that the absolute value of the welfare losses is largest under Melitz and smallest under Armington. They explain that the larger losses in the Melitz case reflect the larger losses from a single variety in the Melitz case (and implicitly, consistent with their earlier interpretations, the losses are larger under Krugman than under Armington due to the loss of varieties). In their 34 region model, Costinot and Rodriguez-Clare (2014, table 4.1, p. 206) evaluate a movement to autarchy. They find that on average for the world: $M \succ K \succ A$. But they find four regions (Australia, Greece, Romania and the Russian Federation) with the reversed welfare ranking $M \prec K \prec A$.

across sectors nor terms-of-trade as part of their interpretation discussion. Our Feenstra ratio and terms of trade parameters, however, show that these are the keys to understanding reversed welfare rankings.

5.2.4 Relative Gains over Armington: Krugman compared to Melitz?

In all model variations in tables 3-6, for the average for the world, we find that $M \succ K \succ A$. Regarding the larger welfare gains of the monopolistic competition models, we ask how much of an additional welfare gain does the Melitz model provide over the Krugman model?

Let K_A = the ratio of the welfare gains in the Krugman model to the welfare gains in the Armington model; M_A = the ratio of the welfare gains in the Melitz model to the welfare gains in the Armington model. We define the Krugman model's share of the larger welfare gains in the Melitz model over the Armington as: $R_{K/M} = \left[\frac{K_A - 1}{M_A - 1}\right]$. For all scenarios in tables 3-6, we calculate and report this parameter in the text. To illustrate, consider the scenario with intermediate goods in a single sector model in table 3, columns 4-6. Regarding the average for the world, the Krugman (Melitz) model results in gains that are equal to 135 =3.8/2.8 (143 = 4.0/2.8) percent of the gains in the Armington model. Then the Krugman model provides an additional 35 percent of welfare gains over the Armington model and the Melitz model provides an additional 43 percent of welfare gains over the Armington model. Then, with intermediates in a single sector model, the Krugman model's share of the larger welfare gains in the Melitz model over the Armington model as: 35/43 = .82. In the case of labor-leisure choice in table 3, for the average for the world, the $R_{K/M}$ ratio is .87; and in the case of four-sectors in table 3, the ratio is .76. We conclude from this that, regarding the gains to the world, compared to a Melitz model, a Krugman model would capture the majority of the gains of the Melitz model above the Armington model.

5.3 Impact of Intermediate Demand based on Real Data and of a Lower Elasticity of Substitution for Intermediate Inputs

In this subsection, we assess the impact of intermediate demand with (a) real data on intermediate demand by sector; and (b) the elasticity of substitution for intermediates from different sectors.[19]

[19] As explained in section 3.2.2, the structural gravity literature to date has produced results for the relative welfare gains for Armington, Krugman or Melitz models only for the case of a single aggregate intermediate good with Cobb-Douglas demand, which ignores the data that different sectors use particular intermediates in different proportions. Costinot and Rodriguez-Clare (2014, p. 219) acknowledge that it would be better to use the data on the intermediate shares, but their algorithm was unable to find a solution with the actual data (in the monopolistic competition cases).

Costinot and Rodriguez-Clare (2014, table 4.1, p. 206) investigate the impact of using real data on intermediates in their Armington model with Cobb-Douglas demand. Those results are useful for understanding impacts in the

While holding the trade response constant across market structure models, we evaluate a ten percent reduction in iceberg trade costs in the Armington, Krugman and Melitz models for three structures of intermediate demand discussed in section 3.2: (i) a single aggregate intermediate good (columns 1-3); (ii) Cobb-Douglas demand for intermediates based on data on intermediate shares (columns 4-6); and (iii) CES demand for intermediates based on data on intermediate shares, with elasticity of substation equal to 0.5 (columns 7-9). To isolate the intermediate demand structure effect, in all models in this subsection 5.3, we assume four sectors that are all monopolistically competitive in the Krugman or Melitz cases, a single primary factor, zero tariffs, no labor-leisure choice, but we incorporate trade imbalances from the data. Table 4 shows several interesting results.

First, allowing intermediate demand to be disaggregated based on data increases the gains in the monopolistic competition models relative to the Armington model. With Cobb-Douglas demand for intermediates and a single aggregate intermediate good, equivalent variation in the Krugman (Melitz) model is 138 (147) percent of the equivalent variation in the Armington case; and these ratios rise to 155 (172) percent with intermediate shares based on data.

Second, the assumption of Cobb-Douglas demand for intermediates is very powerful. With the lower elasticity of substitution, the quantitative differences between the welfare gains in the perfect competition model and the monopolistic competition models is very significantly reduced. With CES demand and an elasticity of substitution for intermediates of 0.5, equivalent variation in the Krugman (Melitz) model falls to 107 (108) percent of the equivalent variation in the Armington case. With the lower elasticity of substitution, firms are less able to substitute goods from sectors whose Dixit-Stiglitz quality adjusted price falls the most; thus, the monopolistic competition models benefit less from the variety increases.

Third, focusing on the average for the world (and for seven of our ten regions), we have non-equivalence of the welfare results with $M \succ K \succ A$ in all three intermediate model structures. Similar to results in section 5.2.3, there are variety gains, verified by the Feenstra ratios in table 4a, that explain the larger gains in the monopolistic competition models on average. There are possible productivity gains in the Melitz model from the selection effect that would contribute to the larger welfare gains in the Melitz model. Since an additional variety is valued more highly in the Melitz model, for six of the seven regions (excluding the United States) where $M \succ K$, we can see from the Feenstra ratios that the variety impact is larger in the Melitz model for all three intermediate demand structures.

Armington model. But regarding the relative impacts of the Armington, Krugman and Melitz models, prior to this paper, the literature does not provide any results for the welfare impacts of an intermediate demand structure with real data in either the Cobb-Douglas case or for a lower elasticity of substitution.

Fourth, in multi-sector, multi-region models, terms-of-trade effects can result in reversed welfare rankings for some regions, with larger gains in the Armington model compared to either or both of the monopolistic competition models, i.e., we can have $A \succ K \text{ or } A \succ M$. For the Low Income region, we have $A \succ K \succ M$ with all three intermediate demand structures and for the Middle-Income region and Australia-New Zealand, in the case of the low elasticity of substitution of 0.5 we have $A \succ K \succ M$. Our terms-of-trade parameter reveals that, for these three regions, the change in the terms-of-trade is better in the Armington model than in both monopolistic competition models for all three intermediate demand structures. Although our Feenstra ratio parameter shows that these regions gain from variety, these results show that it is possible for a relatively better terms-of-trade impact in the Armington model to dominate the welfare ranking over the monopolistic competition models.

Fifth, a smaller variety gain that can contribute to a reversed ranking of $K \succ M$. For the three regions Lower-Income, Middle-Income and Australia-New Zealand, and the intermediate demand structures with real data, we have $K \succ M$. In the cases of these regions and intermediate demand structures, the Feenstra ratio shows a lower variety gain in the Melitz model than the Krugman model. Since an additional variety is valued more highly in the Melitz model due to the lower Dixit-Stiglitz elasticity, the larger Feenstra ratio in the Krugman model shows the importance of expenditure shares in these cases or possibly a smaller increase in varieties.

Sixth, regarding the relative quantitative importance of the Krugman or Melitz model over the Armington model, we see that, with these global changes, the Krugman model captures the majority of the differences in these cases. Using the results or the average welfare change for the world, the values of the parameter $R_{K/M}$ for the Krugman model's share of the larger welfare gains in the Melitz model over the Armington model are: .80 for Cobb-Douglas demand with a single aggregate intermediate; .76 for Cobb-Douglas demand with data on intermediate shares; and .87 for CES demand with data on intermediate shares.

Seventh, table 4 also provides concrete examples to the logical point that knowledge of the qualitative impact of a modeling assumption in the Armington model does not imply that the same modeling assumption will have the same qualitative impact in the Krugman or Melitz models. Consider the impact of a Cobb-Douglas intermediate structure with real data compared to Cobb-Douglas demand with an aggregate intermediate good. There are nine cases in table 4 where the sign of the impact in the Armington model has the opposite sign of the impact in either the Krugman or Melitz model.[20] Take China in particular. If we compare the estimated welfare gains for China using the Armington model (shown in table 4, columns 1 and 4), we see that they are smaller with the real data (3.5% – 3.6% < 0).

[20] See the cases of Canada, China, Japan, Low Income and Middle Income.

But with the Krugman model, the welfare change for China of using real data is positive (9.7% - 7.8% > 0).

5.4 Multiple Primary Factors, Sector Specific Factors and Labor-Leisure Choice

Heretofore, we have assumed a single primary factor of production. In this section, we investigate the impact of allowing primary factors of production to include labor, capital and a resource factor which may be sector specific. Demand for primary factors is Cobb-Douglas. We also consider a case with labor-leisure choice, using the structure explained in section 3.3. All scenarios assume: four monopolistically competitive sectors; CES demand for intermediates based on the data on intermediate shares by sector, and an elasticity of substitution equal to 0.5; initial trade imbalances; and initial tariffs. We take primary factor share intensities from the GTAP data. We simulate a global ten percent reduction in iceberg trade costs.

For the Armington, Krugman and Melitz market structures, we produce estimates for the welfare gains with a single primary factor in columns 1-3 and with three primary factors columns 4-6. Holding market structure constant, at a single decimal point of percentage welfare change, we see no change for the average for the world and almost no change for any of the ten regions. This extends the Costinot and Rodriguez-Clare result, of very little impact of multiple factors of production, to the Krugman and Melitz models. Our models in this section and the model of Costinot and Rodriguez-Clare incorporate differences in factor intensities across counties. We believe, however, that further research is warranted into the question of whether differences in factor endowments are adequately incorporated before we conclude that Heckscher-Ohlin forces are unimportant.

The results without labor-leisure choice (columns 1-9) show the same pattern as in table 4. That is, regarding the welfare impacts, we have $M \succ K \succ A$ for seven of the ten regions and for the average for the world. For the regions Australia-New Zealand, Low Income and Middle Income, we have that $A \succ K \succ M$. The additional factors of production do not change the qualitative result.

One quantitative difference, however, is that we find larger welfare gains in table 5. Comparing columns 1-3 of table 5 with columns 7-9 of table 4, the only difference is the presence of initial tariffs in table 5. The initial tariffs imply there is less trade than is optimal for the world, so the reduction of iceberg trade costs leads to larger gains from a second-best effect.

Labor-leisure choice, however, does reverse the qualitative result for Australia-New Zealand and the Low Income regions regarding the ranking of Armington compared to the monopolistic competition models. Without labor-leisure choice, these regions obtain larger estimated gain in the Armington model, but prefer the outcomes of the monopolistic competition models with labor-leisure choice. This result is consistent with the earlier result we saw in table 3, where with labor-leisure choice the availability of more resources led to more varieties and more gains in the monopolistic competition models.

The values of our parameter $R_{K/M}$ for the Krugman model's share of the larger welfare gains in the Melitz model over the Armington model in the four sets of scenarios are: .83; .83; .83; .82. Again, we observe that, for these global changes in iceberg costs, the selection effect contributes to additional welfare gains, but the variety impact of the Krugman model is quantitatively more important than the selection effect of the Melitz model.

5.5. Tariff and Iceberg Trade Costs Reduction in a Nine-sector, Ten Region Model

In this subsection, we compare the welfare effects in the Armington, Krugman and Melitz models of global free trade in a more realistic model structure. We incorporate initial tariffs based on the data for the first time, and, as in the models of tables 3-5, we have initial trade imbalances. We expand our models to nine-sectors, four of which are always modeled as perfectly competitive Armington sectors, and five of which are modeled as monopolistically competitive when we evaluate the Krugman and Melitz models.[21] All versions of these models contain Cobb-Douglas demand for three primary factors of production: labor, capital and a resource factor. We allow some of the resource factor to be sector specific factor in all of these models. We assume CES demand for intermediates based on the data on intermediate shares by sector with an elasticity of substitution equal to 0.5. We also evaluate the impact of uniform tariffs and labor-leisure choice. For sensitivity purposes with the earlier simulations, we evaluate and compare a reduction in iceberg trade costs in this model. We continue to hold the trade response constant across the three market structures.

5.5.1 Global Free Trade in Tariffs

We evaluate a movement to global free trade in three model variants: (i) initial tariffs based on the data; (ii) initial uniform tariffs in each country where the uniform tariff rate equalizes the revenue for initial tariffs based on the data; and (iii) initial tariffs based on the data with labor-leisure choice. Focusing first on the results for the average for the world, in all three model variants we again have the ranking of welfare results as $M \succ K \succ A$.

When we start with initial uniform tariffs and move to global free trade, we see that the gains in the Armington model drop to very small gains—to about .05% of consumption from .24% of consumption with initial tariffs based on the data. The lower gains with uniform tariffs in the Armington

[21] We aggregate the 57 sectors of the GTAP database into the following sectors (the first four of which are always perfectly competitive sectors in this subsection): (i) agriculture; (ii) natural resources extraction; (iii) utilities; (iv) all other services, not included elsewhere; (v) food; (vi) textiles; (vii) refined resource products; (viii) other manufacturing, not elsewhere classified; and (ix) business services.

model are explained by the property that the Harberger triangles of distortion costs of the tariff increase with the square of the tariff. Since the Harberger distortion costs of the tariffs are smaller with uniform tariffs, the gains in the monopolistic competition models are proportionately much larger than the Armington model, rising to 406 (467) percent of the gains in the Armington model in the Krugman (Melitz) model.

The values of our parameter $R_{K/M}$ for the relative importance of the Krugman model to the Melitz model are: (i) .95 for initial tariffs based on data; (ii) .83 for initial uniform tariffs; and (iii) .90 for initial tariffs with labor-leisure choice. Again, we observe that the variety impact of the Krugman model is quantitatively more important than the selection effect of the Melitz model, in this case for global changes in tariffs.

Turning to individual regions, we see that in the Armington model, the Low Income and Middle-Income regions experience a welfare loss from global free trade (columns 7, 10 and 13). Our terms-of-trade parameter shows that these are the regions that experience the strongest terms-of-trade loss due to global free trade.[22] In the Armington model, the terms-of-trade loss dominates the efficiency gains for these regions.

In the case of China (with global free trade and initial non-uniform tariffs), we have a welfare ranking reversal compared with the aggregate, i.e., we have $A \succ K \succ M$. This occurs both with and without labor-leisure choice (see table 6, columns 7-9, and columns 13-15). The reasons are very interesting. First, unlike the usual case when Armington produces larger welfare gains than the monopolistic competition models, our terms-of-trade parameter shows that there is a more favorable change in the terms-of-trade in the monopolistic competition models. Thus, the larger welfare gains in the Armington model cannot be explained by the terms-of-trade. Our Feenstra ratio parameter for China in these cases, however, shows that there is a loss of the Dixit-Stiglitz variety externality in the monopolistic competition models. In our previous models, all sectors were monopolistically competitive and all our estimated Feenstra ratios were all greater than one.[23] In this model, however, we have perfectly competitive sectors as well as monopolistically competitive sectors, and it is possible for regions to shift expenditures away from monopolistically competitive sectors toward perfectly competitive sectors. Any such shift would entail a loss of the variety externality. Our Feenstra ratio shows that when the model has perfectly competitive sectors as well as monopolistically competitive sectors, it is possible to experience a

[22] The Mexico-Peru-Chile region also experiences a small loss from global free trade in the Armington model without labor-leisure choice, and has a small negative terms-of-trade loss in these cases.

[23] Although we do not observe it in any of simulations, it is an open question whether in a multi-region monopolistic competition model a region could shift expenditures toward sectors that experience a variety loss, resulting a net loss of the variety externality.

welfare loss due to a reduction of the Dixit-Stiglitz variety externality. To augment the intuition for this interpretation, we note that value-added in monopolistically competitive sectors in China declines in these scenarios, both in absolute amounts and in percentage terms relative to the Armington sectors in these models.[24]

Then why does Krugman provide more welfare gains than Melitz in the case of China in these model variants? We observe that the terms-of-trade parameter for China has the same value in the Krugman and Melitz cases (columns 13 and 15; and columns 23 and 25 in table 6a). And the Feenstra ratio is larger by .002 in the Melitz case (column 14 versus 16 and column 24 versus 26 in table 6a). Then the ranking $K \succ M$ cannot be explained by either by the terms-of-trade effect or by the variety externality. Given the possibilities for differences in these models, that leaves only a larger productivity gain in the Krugman model compared with the Melitz model as a possible explanation. Melitz (2003) noted the possibility of a reduction in the productivity of the economy after a reduction in trade costs due to the selection effect, and our China case may be an example. But the model in Melitz (2003) is a one-sector monopolistically competitive model. Here we have multiple sectors and we include some perfectly competitive sectors. The intersectoral shift in resources would also entail some productivity gain from the more efficient intersectoral allocation of resources, and the intersectoral shifts are not identical across the models.

5.5.2 Iceberg Trade Cost Reduction in the Nine-Sector Model

For sensitivity, we compare the impact of a ten percent reduction in iceberg trade costs in the four-sector models (columns 7-9 of table 5) with the nine-sector models (columns 1-3 of table 6). The only differences between the models in these scenarios is: (i) the number of sectors; and (ii) in our nine-sector models, we assume four of the sectors are perfectly competitive, even when we allow five sectors to be monopolistically competitive. We retain the welfare ranking for the average for the world that $M \succ K \succ A$. The main difference in the results is that, while results for the Armington model are the same in the four and nine-sector models, the welfare gains in the monopolistic competition models are smaller in the nine-sector model. The intuition is that a smaller share of the economy is monopolistically competitive in the nine-sector models, so the variety gains are smaller. Inspection of the Feenstra ratios verifies the smaller variety gains. Comparable results and interpretations apply when we allow labor-leisure choice, i.e., compare columns 4-6 of table 6, with columns 10-12 of table 5. The values of the

[24] In the case of labor-leisure choice, in our Krugman model, we find that value-added in the CRTS sectors increases by 0.2% while value-added in the IRTS sectors falls by 0.1%. In the Melitz model, value added in the CRTS sectors falls by 0.4%, but value-added in the Melitz sectors of the model falls by 1.3%. Without labor-leisure choice, value-added declines in both CRTS and IRTS sectors, but the percentage decline is larger in absolute value in the IRTS cases.

parameter $R_{K/M}$ for the relative importance of the Krugman model to the Melitz model in our iceberg cost reduction scenarios are: .88 without labor-leisure choice and .87 with labor-leisure choice.

However, the welfare ranking of for the Low Income region switches depending on the number of sectors. For the Low Income region, compare columns 1-3 table 6, where we have $M \succ K \succ A$, with columns 7-9 of table 5, where in the four sector model we have $A \succ K \sim M$. The only difference is the number of sectors in the model. We see that for the Low Income region, in the nine-sector model there are larger terms-of-trade gains in the monopolistic competition models; we had the opposite terms-of-trade ranking in the four-sector model. This shows that in multi-sector, multi-region models, how the data are aggregated can impact the qualitative ranking of the welfare gains.

6. Sensitivity of the Welfare Results to the Trade Response and to Unilateral versus Global Policy Scenarios

Given the acknowledged importance of the trade response, in this section we examine the sensitivity of the results to a change in the trade response. We also examine a unilateral increase in tariffs to forty percent by each of our ten regions (in ten separate simulations). As one of our most realistic models, we examine sensitivity in our nine-sector, ten-region model with three primary factors of production, labor-leisure choice and actual tariffs and trade imbalances based on the data in the benchmark equilibrium.

6.1 Sensitivity to the Trade Response

We continue to determine the trade response in the Melitz model and adjust the Dixit-Stiglitz elasticities in the Krugman model and Armington elasticities to match the trade response. The key parameters that impact the trade elasticity in the Melitz model are the Pareto shape parameter and the Dixit-Stiglitz elasticity. We conduct sensitivity on these two parameters separately.

For the high and low values of the Pareto shape parameter, we take plus and minus two standard deviations from the mean of the preferred probability distribution estimated by Balistreri *et al*. (2011), while we hold the Dixit-Stiglitz elasticity of substitution constant at our central value of 5.0. Regarding sensitivity to the Dixit-Stiglitz elasticity, for a solution to the Melitz model, we must have $a > \sigma - 1$, where a is the Pareto shape parameter and σ is the Dixit-Stiglitz elasticity. Given our central value of 4.58 for the Pareto shape parameter and 5.0 for the Dixit-Stiglitz elasticity, we take plus and minus 0.5 for the Dixit-Stiglitz elasticity in our sensitivity analysis for σ. Our results for sensitivity to the Pareto shape parameter are in table 7A and for the Dixit-Stiglitz elasticity in table 7B. The values of the Pareto shape parameter in the Melitz model, Dixit-Stiglitz elasticities in the Krugman model and Armington elasticities are shown in the first two rows of table 7A and table 7B. The percent change in the trade response due to a movement to global free trade is shown in the third row of table 7A and 7B. The results with central trade response are the same as in table 6, columns 13-15.

We see that a larger trade response leads to larger welfare gains for the world, but the differences from the estimates of the central elasticities are not large. Further, we do not see any cases of a sign change in the welfare impacts: those regions that lose with the central trade response, lose with the high and low trade responses. In the case of China, its losses increase in the Melitz model with a high trade response.

6.2 Impact of a Unilateral Increase of Tariffs to Forty Percent

For a unilateral change in tariffs, in the absence of retaliation from trade partners, there are terms-of-trade effects that lead to gains from the imposition of tariffs up to the optimal tariff for the region. In all of our previous policy scenarios, we have imposed a simultaneous change of the policy on a global basis. In a movement to global free trade, however, the terms of trade effects of tariffs could be positive or negative for any particular region (our results in section 5.6 are an example). In this subsection, we investigate the ranking of the impacts across the three market structures of the unilateral imposition of a forty percent uniform tariff by each region of our model, starting from initial tariffs in the data. These results illustrate two points: (i) with unilateral tariff increases, it is possible to have positive estimated welfare gains in the Armington model and negative estimated welfare gains in the monopolistic competition models. In fact, opposite signs are our typical result; and (ii) for losses from trade policy changes, it is possible for the absolute value of the losses to be larger in the Melitz model than the Krugman model.

For each of our ten regions we simulate a unilateral increase in tariffs to 40 percent and compare results for the three market structures, were we adjust elasticities in the Krugman and Armington models to match the trade response of the Melitz model. The results of the 30 simulations are presented in table 8, where we only present the results for the region that is imposing the increase it its tariffs to a uniform 40 percent. In the Armington model, we see that all countries gain from the unilateral imposition of a 40 percent uniform tariff. Both a theoretical derivation[25] and our numerical simulations are consistent with

[25] Intuition into the value of the optimal tariff in a multi-region Armington model can be obtained from the following. Given product differentiation at the level of the region in the Armington model, to achieve marginal revenue equal to marginal costs, a representative region's optimal export tax for good i in destination region r is $t_{ir}^{*} = \left[\varepsilon_{ir} / (\varepsilon_{ir} - 1)\right] - 1$ where ε_{ir} is the elasticity of demand for exports of the representative country of good i in destination region r. It has been shown by Harrison, Rutherford and Tarr (1997a, appendix C) that $\varepsilon_{ir} = \sigma_{ir}^{mm} - \lambda_{ir}^{\sigma_{ir}^{mm}} k$, where σ_{ir}^{mm} is country r's elasticity of substitution for imports of good i from different import regions, λ_{ir} is the representative country's share of the market of good i in region r and k is a positive constant. The optimal export tax is then: $t_{ir}^{*} = \left[(\sigma_{ir}^{mm} - \lambda_{ir}^{\sigma_{ir}^{mm}} k) \Big/ (\sigma_{ir}^{mm} - \lambda_{ir}^{\sigma_{ir}^{mm}} k - 1) \right] - 1$. When the market share is small or σ_{ir}^{mm} is

the optimal tariff for these countries in the range of about 25 percent. Although the countries experience a welfare loss by further increasing the tariff above 25 percent, the gains from increasing tariffs from initial levels to the optimal level dominate the losses for the increase above the optimal level to 40 percent.

The welfare results in the models with monopolistically competitive sectors are strikingly different—seven of the ten regions have the opposite sign for the welfare impact as in the Armington model. Except for the Unites States, Australia-New Zealand and the Middle-Income regions, the other seven regions lose from the imposition of 40 percent uniform tariffs. The intuition is that even small increases in tariffs typically result in a loss of varieties and a welfare loss from the loss of the Dixit-Stiglitz externality. And for these seven regions, the losses are larger in absolute value in the Melitz model compared with the Krugman model. The Feenstra ratios in table 8 show there is a welfare loss due to the loss of varieties in all of these seven regions, and the variety loss is larger in the Melitz model than in the Krugman model.

In the cases of the United States and the Middle-Income region, the Feenstra ratios show that they experience a loss of welfare from the variety loss, but the terms of trade gain dominates the welfare loss from the loss of varieties. The interesting case to explain is the Australia-New Zealand region in the model with Krugman sectors; we observe a gain in welfare from the varieties (Feenstra ratio larger than 100%), despite the increase in tariffs. Feenstra has explained that it is not the number of varieties alone that is important to the variety externality, but also the expenditure share. We have four perfectly competitive sectors in our model; a shift in expenditures toward the monopolistically competitive sectors would increase the value of varieties; a higher expenditure share can offset the loss in the number of varieties. To provide support for our result regarding the Feenstra ratio in the Krugman model, we calculate the change in value added for the Australia-New Zealand region; we find a 5.7 percent decline in the value-added of the perfectly competitive sectors and a 1.6 percent increase in the value added of the monopolistically competitive sectors.

7. Conclusion

We have produced numerous new results for the relative welfare impacts of the Armington, Krugman and Melitz models for a substantially expanded range of modeling features that have not

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large, then the optimal tax may be approximated by $t_{ir}^{*} \approx \left[\sigma_{ir}^{mm} / (\sigma_{ir}^{mm} - 1)\right] - 1 = \left[\sigma^{mm} / (\sigma^{mm} - 1)\right] - 1 = (5/4) - 1 = .25$, where we have employed our assumption of a value of 5.0 for the central value of the Armington elasticity of substitution for all sectors and regions. The optimal export tax will increase with the market share. From Lerner symmetry, this market power can be exploited by an import tariff.

previously been examined in the literature. Since our results are numerical, we quantify the relative importance of the three market structures.

In response to global changes in trade costs, in all of our multi-sector models, we find that the ranking of global welfare gains is $M \succ K \succ A$. While the Melitz model produces more welfare gains than the Krugman model in response to global changes in trade costs, we find that the Krugman model captures the majority of the increase in the gains above the Armington model. Regarding individual regions, however, we find several cases of reversed welfare rankings. i.e., $M \prec K \prec A$. With unilateral increases in tariffs, we typically find that the Armington model produces gains, while the monopolistic competition models produce losses. We develop two parameters for each scenario (the terms-of-trade and the Feenstra ratio) which are crucial for understanding the reasons for the relative welfare rankings. When the welfare gains are larger in the Armington model, it is usually because we find that the terms-of-trade effects for that region are greater in the Armington model. In those cases where the Krugman model produces larger welfare gains than the Melitz model, we usually find that the variety externality is greater in the Krugman model, reflecting a shift in expenditure shares toward sectors with smaller variety gains or less of a variety increase in the Melitz model. If the models with monopolistic competition sectors also contain some perfectly competitive sectors, the Feenstra ratio identifies cases where there is a variety loss from global free trade due to expenditure shifts to the perfectly competitive sectors or a loss of varieties. We conclude that for individual regions, the welfare ranking of the Armington, Krugman and Melitz market structures is model, data, scenario and parameter dependent.

References

Adao, Rodrigo, Costas Arkolakis and Federico Esposito (2017), "Endogenous Labor Supply and the Gains from International Trade," 2017 Meeting Papers 1044, Society for Economic Dynamics. Available at: https://ideas.repec.org/p/red/sed017/1044.html.

Arkolakis, Costas, Arnaud Costinot and Andres Rodriguez-Clare (2012), "New Trade Models, Same Old Gains?" *American Economic Review*, 102(1), 94–130.

Armington, Paul (1969), "A Theory of Demand for Products Distinguished by Place of Production," *International Monetary Fund Staff Papers*, Vol. 16(1), 159-178.

Balistreri, Edward J., Russell H. Hillberry and Thomas F. Rutherford (2011), "Structural Estimation and Solution of International Trade Models with Heterogeneous Firms," *Journal of International Economics*, Vol. 83(2), 95-108.

Balistreri, Edward J., Russell H. Hillberry and Thomas F. Rutherford (2010), "Trade and Welfare: Does Industrial Organization Matter," *Economics Letters*, 109(2), 85–87.

Balistreri, Edward J. and Thomas F. Rutherford (2013), "Computing general equilibrium theories of monopolistic competition and heterogeneous firms,"' in *Handbook of Computable General Equilibrium Modeling* Vol. 1, Peter B. Dixon and Dale W. Jorgenson eds., Amsterdam, North Holland, Elsevier, Chapter 23, 1513–1570.

Balistreri, Edward J., Thomas F. Rutherford and David G. Tarr (2009), "Modeling Services Liberalization: The Case of Kenya," *Economic Modeling*, Vol. 26 (3), May, 668-679.

Balistreri, Edward J., Zoryana Olekseyuk and David G. Tarr (2017), "Privatization and the Unusual Case of Belarusian Accession to the WTO," *The World Economy*, Vol. 40, 2564-2591.

Balistreri, Edward J., David G. Tarr and Hidemichi Yonezawa (2015), "Deep Integration in Eastern and Southern Africa: What are the Stakes?" *Journal of African Economies*. Article first published online July 28, 2015, doi:10.1093/jae/ejv012

Ballard, Charles (2000), "How Many Hours are in a Simulated Day? The Effects of Time Endowment on the Results of Tax-Policy Simulation Models." Available at: https://pdfs.semanticscholar.org/59b3/4cbb9cc1c02f2c0735dec3e3bcb9ad632507.pdf

Bernard, A.B., S. J. Redding, and P. Schott (2007), "Comparative Advantage and Heterogeneous Firms," *Review of Economic Studies*, 74(1), 31–66.

Bhagwati, Jagdish (1082), "Directly Unproductive Profit-Seeking Activities," *Journal of Political Economy*, Vol. 90, No. 5, 988-1002.

Caliendo, Lorenzo, Robert C. Feenstra, John Romalis and Alan M. Taylor (2015), "Tariff Reductions, Entry and Welfare: Theory and evidence for the last two decades," Working Paper 21768, National Bureau of Economic Research, December.

Chaney, T. (2008), "Distorted Gravity: The Intensive and Extensive Margins of International Trade," *The American Economic Review*, Vol. 98(4), 1707-1721.

Costinot, Arnaud and Andres Rodriguez-Clare (2014), "Trade Theory with Numbers: Quantifying the Consequences of Globalization," in *Handbook of International Economics,* Elhanan Helpman, Kenneth Rogoff and Gita Gopinath (eds.), Vol. 4, 197-262, Amsterdam: Elsevier.

Costinot, Arnaud and Andres Rodriguez-Clare (2013), "Online Appendix to Trade Theory with Numbers: Quantifying the Consequences of Globalization," March. Available at: https://economics.mit.edu/files/9215

Dekle, Robert, Jonathan Eaton and Samuel Kortum (2008), "Global Rebalancing with Gravity: Measuring the Burden of Adjustment," *IMF Staff Papers*, Vol. 55(3), 511-540.

Devarajan, Shantayanan and Sherman Robinson (2013), "Contribution of Computable General Equilibrium Modeling to Policy Formulation in Developing Countries," in *Handbook of Computable General Equilibrium Modeling*," Peter Dixon and Dale Jorgenson (eds.), Vol. I, chapter 5, 277-301, Elsevier.

Dixon, Peter, Michael Jerie and Maureen Rimmer (2018), *Trade Theory in Computable General Equilibrium Models: Armington, Krugman and Melitz*, Singapore: Springer.

Eaton, Jonathan and Samuel Kortum (2002), "Technology, Geography and Trade," *Econometrica*, Vol. 70(5), 1741-1779.

Ethier, Wilfred (1982), "National and International Returns to Scale in the Modem Theory of International Trade," *American Economic Review*, Vol. 72(2):389-405.

Ethier, Wilfred and James R. Markusen, (1996), "Multinationals, Technical Diffusion, and Trade," *Journal of International Economics*, Vol. 41, 1-28.

Feenstra, Robert C. (2010), "Measuring the Gains from Trade Under Monopolistic Competition," C*anadian Journal of Economics*," Vol. 43(1), 1-28.

Feenstra, Robert C. (1994), "New Product Varieties and the Measurement of International Prices," *American Economic Review*, Vol. 84, 157-177.

Francois, Joseph, M. Manchin and Will Martin (2013), "Market Structure in CGE Models of International Trade," in Peter Dixon and Dale Jorgenson (eds.), *Handbook of Computable General Equilibrium Models*, Amsterdam: North Holland, Elsevier.

Harris, Richard, 1984. "Applied General Equilibrium Analysis of Small Open Economies with Scale Economies and Imperfect Competition," *American Economic Review*, Vol. 74(5), pages 1016-32.

Harrison, Glenn W., Thomas F. Rutherford and David G. Tarr (1997), "Quantifying the Uruguay Round," *Economic Journal*, Vol. 107, No. 444, September, 1405-1430.

Harrison, Glenn W., Thomas F. Rutherford and David G. Tarr (1997a), "Trade Policy Options for Chile: A Quantitative Evaluation," World Bank Working Paper No. 1783. Available at: http://documents.worldbank.org/curated/en/538631468015839517/pdf/WP1783.pdf,

Hillberry, Russell and David Hummels (2013), "Trade Elasticity Parameters for a Computable General Equilibrium Model," in *Handbook of Computable General Equilibrium Modeling, Vol. 1B*, Peter B. Dixon and Dale W. Jorgenson (eds.), Amsterdam: Elsevier.

Jafari, Yaghoob and Wolfgang Britz (2017), "Modelling Heterogeneous Firms and Non-Tariff Measures in Free Trade Agreements Using Computable General Equilibrium," *Economic Modelling*, https://doi.org/10.1016/j.econmod.2018.04.004, in press.

Jensen, Jesper, Thomas F. Rutherford and David G. Tarr (2010), "Modeling Services Liberalization: The Case of Tanzania," *Journal of Economic Integration*, Vol. 25 (4), December, 644-675. http://dx.doi.org/10.11130/jei.2010.25.4.644

Jensen, Jesper and David G. Tarr (2003), "Trade, Exchange Rate and Energy Pricing Reform in Iran: Potentially Large Efficiency Effects and Gains to the Poor," *Review of Development Economics*, Vol. 7, Number 4, November, 543-562.

Krueger, Anne O. (1974), "The Political Economy of the Rent-Seeking Society," *American Economic Review*, Vol. 3, 291-303.

Krugman, Paul (1979), "Increasing Returns, Monopolistic Competition and International Trade," *Journal of International Economics*, 9(4), 469–479.

Krugman, Paul. (1980), "Scale Economies, Product Differentiation, and the Pattern of Trade," *The American Economic Review*, 70(5), 950–959.

Markusen, James R. (1989), "Trade in Producer Services and in Other Specialized Intermediate Inputs," *American Economic Review*, Vol. 79, 85-95.

Markusen, James R. (2002), *Multinational Firms and the Theory of International Trade*, Cambridge, MA.: MIT Press.

Markusen, James R., Thomas F. Rutherford and David G. Tarr (2005), "Trade and Direct Investment in Producer Services and the Domestic Market for Expertise," *Canadian Journal of Economics*, Vol 38 (3), 758-777.

Markusen, James R. and Anthony Venables (1998), "Multinational Firms and the New Trade Theory," *Journal of International Economics* Vol. 46, 183-204.

Melitz, Marc J. (2003): "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, Vol. 71(6), 1695–1725

Melitz. Marc J. and Stephen J. Redding (2015), "New Trade Models, New Welfare Implications," *American Economic Review*, Vol. 105(3), 1105-1146.

Melo, Jaime de, and David G. Tarr (1990), "Welfare Costs of US Quotas in Textiles, Steel and Autos," *Review of Economics and Statistics*, August, 489-497.

Petri, Peter A., Michael G. Plummer, and Fan Zhai (2012), "Trans-Pacific Partnership and Asia-Pacific Integration: A Quantitative Assessment," Washington, DC: Peterson Institute of International Economics.

Ricardo, David (1817), On the Principles of Political Economy and Taxation. Available at: http://www.econlib.org/library/Ricardo/ricP.html.

Rutherford, Thomas F. (2002), "Lecture Notes on Constant Elasticity Functions." Avaiable at: http://www.gamsworld.org/mpsge/debreu/ces.pdf

Rutherford, Thomas F. and David G. Tarr (2002), "Trade Liberalization, product variety and growth in a small open economy: a quantitative assessment," *Journal of International Economics*, Vol. 56 (2), March, 247-272.

Rutherford, Thomas F. and David G. Tarr (2008), "Poverty Effects of Russia's WTO Accession: modeling 'real households' with endogenous productivity effects," *Journal of International Economics*, Vol 75 (1), pp 131-150.

Samuelson, Paul A. (1939), "The Gains from International Trade," *Canadian Journal of Economics*, Vol. 5(2), 195–205.

Sato, Kazuo (1976), "The Ideal Log-Change Index Number," *The Review of Economics and Statistics*, Vol. 58(2), 223-228.

Vartia, Y.O. (1976), "Ideal log-change index numbers," *Scandinavian Journal of Statistics*, Vol. 3, 121–6

Zhai, Fan (2008), "Armington Meets Melitz: Introducing Firm Heterogeneity in a Global CGE Model of Trade," Journal *of Economic Integration*, Vol. 23(3). September, 575-604.

Table 1: Literature Results of the Ranking of the Armington, Krugman and Melitz Models Welfare Gains from the Reduction in Trade Costs

Model Assumptions and Methodology	Ranking of Welfare Gains	
	Key: A = Armington; K = Krugman; M = Melitz*	
1. Analytic Solutions		
One Sector, No Intermediates, One Factor, Zero Trade Balance, Iceberg Trade costs	**A=K=M**	Arkolakis, Costinot and Rodriguez-Clare (2012)
with Labor-Leisure choice and positive elasticity of labor supply**	$\boxed{M \succ A}$	Balistreri, Hillberry and Rutherford (2010)
with upper bound on the Pareto Probablity Distribution of Productivity	$\boxed{M \succ K}$	Melitz and Redding (2015)
2. Computer Simulations, Autarky Exercises, Numerical Point Estimates without parameter sensitivity* **		
33 Regions, 31 Sectors with One Primaty Factor, Zero Trade Balance, Iceberg Trade Costs		
Muliple sectors, no intermediates	$A \succ K \sim M$	Costinot and Rodriguez-Clare (2014, table 4.1)
multiple sectors, one aggregate intermediate good	$\boxed{M \succ K \succ A}$	Costinot and Rodriguez-Clare (2014, table 4.1)
3. Computer Simulations, Comparative Static Exercises, Numerical Point Estimates without parameter sensitivity		
10 regions, 16 sectors, Zero Initial Tariffs, Zero Trade Balances, uniform tariffs, one Primary Factor		
Losses from imposing a Global Uniform 40% Tariff in a 10 Region, 16 Sector Model* **		
Multiple sectors, no intermediates	$\boxed{K \succ M \succ A}$	Costinot and Rodriguez-Clare (2014, table 4.3)
multiple sectors, one aggregate intermediate good	$\boxed{M \succ K \succ A}$	Costinot and Rodriguez-Clare (2014, table 4.3)

*If and only if the Melitz model produces welfare gains preferred to (larger than) the Krugman model, then we write: $M \succ K$ and similarly for other rankings. We write $K \sim M$ for the same welfare gains.

**Computer simulations: If the elasticity of labor supply to the traded goods sector is negative (zero), the estimated welfare gain under Melitz is less than (equal to) Armington.

***We report the Costinot and Rodriguez-Clare (2014, p. 204) results based on their average for the world, although their results for individual regions in their model differ in several cases. We also rank the models based on their definition that the "gains" from international trade as the absolute value of the real income change associated with the increase in trade costs...

Table 2: Equivalence of Welfare Results Across Market Structures in the Simplest One Sector Model, with and without balanced trade*

Impacts of Global Ten Percent Reduction in Iceberg Trade Costs

Full Model Results are Hicksian Equivalent Variation as a Percent of Consumption

	1	2	3	4	5	6	7	8	9
	domestic		Zero Trade Balance for all Countries			Data Based Trade Balances for all Countries			domestic
	trade	Arkolakis et al.	Full Model Calculations			Full Model Calculations			trade
	share	formula***	Armington	Krugman	Melitz	Armington	Krugman	Melitz	share
Region	λ_{rr}	**ε = 4.58****	σ(D,M) = 5.58**	σ = 5.58**	σ=5.0; a=4.58**	σ(D,M) = 5.58**	σ = 5.58**	σ=5.0; a=4.58**	λ_{rr}
Australia-New Zealand	77.2%	3.0%	3.0%	3.0%	3.0%	3.1%	3.1%	3.1%	77.8%
Canada	70.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	70.1%
China	72.1%	3.7%	3.7%	3.7%	3.7%	4.0%	4.0%	4.0%	72.8%
Japan	83.0%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	83.0%
Mexico-Chile-Peru	67.0%	4.6%	4.6%	4.6%	4.6%	4.8%	4.8%	4.8%	67.3%
Low Income NEC	55.5%	6.4%	6.4%	6.4%	6.4%	5.8%	5.8%	5.8%	54.4%
Middle Income NEC	75.6%	3.2%	3.2%	3.2%	3.2%	3.3%	3.3%	3.3%	76.4%
OECD NEC	81.4%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	81.6%
Philippines	62.9%	5.1%	5.1%	5.1%	5.1%	4.6%	4.6%	4.6%	61.2%
United States	84.6%	1.9%	1.9%	1.9%	1.9%	1.7%	1.7%	1.7%	82.9%
average for the World	79.0%		2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	

* Model with One Sector, One Factor, No Intermediates, No Labor-Leisure Choice, Untruncated Pareto distribution of productivity.

** ε is the elasticity of demand for imports with respect to variable trade costs, taken from gravity (here the absolute value of the gravity estimate is used); σ(D, M) is the Armington elasticity of substitution between imports and domestic goods; σ is the Dixit-Stiglitz elasticity of substitution between varieties in a sector; and "a" is the shape parameter in the Pareto distribution..

*** Arkolakis *et al*. (2012) derive the proportional change in welfare in this simple model with zero trade balances as: $W = \lambda_{jj}^{-1/\varepsilon}$ where $\hat{\lambda}_{jj} \equiv \lambda'_{jj}/\lambda_{jj}$, and λ_{jj} and λ'_{jj} are country j's shares of global expenditure on home goods in the initial and counterfactual equilibria, respectively (ε = the absolute value of the elasticity of demand for imports with respect to variable trade costs from gravity). Since this is a decline in trade costs, $\lambda_{jj}^{-1/\varepsilon} > 1$, and the percentage gains from trade using the Arkolakis *et al*. (2012) formula are 100*G_j where: $G_j = \lambda_{jj}^{-1/\varepsilon} - 1$.

Source: Authors' calculations.

Table 3: Breaking the Equivalence: Labor-Leisure Choice, Intermediates and Multiple Sectors

Impacts of Global Ten Percent Reduction in Iceberg Trade Costs

Results are Hicksian Equivalent Variation as a Percent of Consumption

All scenarios include trade imbalances, but have zero tariffs and a single primary factor

	1	2	3	4	5	6	7	8	9
	Labor-Leisure Choice			Cobb-Douglas Demand for Intermediates					
	Single Sector-No intermediates			Single Sector			Four Sectors		
	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz
Region	σ(D,M) = 5.58*	σ = 5.58*	σ=5.0; a=4.58*	σ(D,M) = 5.58*	σ = 5.58*	σ=5.0; a=4.58*	σ(D,M) = 6.12*	σ = 5.64*	σ=5.0; a=4.58*
Australia-New Zealand	3.1%	3.23%	3.26%	3.2%	4.2%	4.4%	3.59%	3.71%	3.66%
Canada	4.1%	4.32%	4.36%	4.1%	5.1%	5.3%	4.2%	6.3%	6.9%
China	4.0%	4.19%	4.23%	3.9%	6.7%	7.5%	3.5%	9.8%	12.5%
Japan	2.1%	2.25%	2.27%	2.3%	2.9%	3.1%	2.1%	4.3%	4.9%
Mexico-Chile-Peru	4.8%	5.02%	5.07%	4.7%	5.9%	6.1%	4.9%	6.4%	6.8%
Low Income NEC	5.7%	6.10%	6.15%	5.7%	7.4%	7.7%	6.5%	5.8%	5.5%
Middle Income NEC	3.3%	3.49%	3.52%	3.4%	4.4%	4.6%	3.7%	3.7%	3.6%
OECD NEC	2.3%	2.42%	2.44%	2.4%	3.2%	3.4%	2.3%	3.8%	4.2%
Philippines	4.6%	4.91%	4.95%	4.7%	5.9%	6.1%	4.8%	7.2%	7.8%
United States	1.7%	1.85%	1.86%	1.9%	2.3%	2.4%	1.9%	2.8%	3.0%
average for the World	2.69%	2.85%	2.87%	2.79%	3.76%	3.98%	2.80%	4.34%	4.83%

* σ(D,M) is the Armington elasticity of substitution between imports and domestic goods; σ is the Dixit-Stiglitz elasticity of substitution between varieties in a sector; and "a" is the shape parameter in the Pareto distribution.

Source: Authors' estimates.

Table 3a: Parameters for Table 3--the Feenstra ratio and Proportional Changes in the Terms-of-trade (TOT).*

	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16
	Labor-Leisure Choice					Cobb-Douglas Demand for Intermediates					Cobb-Douglas Demand for Intermediates				
	Single Sector-No intermediates					Single Sector					Four Sectors				
	Armington	Krugman		Melitz		Armington	Krugman		Melitz		Armington	Krugman		Melitz	
Region	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra
Australia-New Zealand	1.004	1.004	1.030	1.004	1.031	1.005	1.005	1.019	1.005	1.020	1.021	1.013	1.016	1.013	1.014
Canada	1.007	1.008	1.040	1.007	1.042	1.003	1.004	1.025	1.004	1.027	1.009	1.020	1.029	1.021	1.037
China	1.008	1.009	1.037	1.009	1.039	1.003	1.006	1.020	1.007	1.024	0.993	1.003	1.030	1.004	1.042
Japan	0.996	0.996	1.023	0.996	1.023	0.999	0.998	1.015	0.998	1.015	0.990	0.999	1.021	0.999	1.026
Mexico-Chile-Peru	1.011	1.012	1.044	1.012	1.046	1.007	1.009	1.028	1.008	1.030	1.012	1.013	1.030	1.012	1.033
Low Income NEC	1.007	1.009	1.059	1.009	1.061	0.998	1.001	1.037	1.001	1.039	1.016	1.009	1.028	1.009	1.025
Middle Income NEC	1.006	1.006	1.032	1.006	1.033	1.005	1.006	1.020	1.005	1.021	1.014	1.003	1.018	1.002	1.013
OECD NEC	0.996	0.996	1.025	0.996	1.025	0.998	0.997	1.015	0.997	1.016	0.993	0.997	1.018	0.997	1.020
Philippines	1.001	1.002	1.051	1.002	1.051	0.996	0.997	1.033	0.997	1.034	0.997	1.006	1.037	1.006	1.042
United States	0.983	0.983	1.023	0.983	1.022	0.987	0.984	1.015	0.985	1.014	0.987	0.986	1.017	0.987	1.017
average for the World															

*See section 5 for a definition of these parameters. We present the inverse of the Feenstra ratio, so an increase is a decline in the cost of a unit of utility due to variety increases. In the Armington model, the Feenstra ration = 1 in all cases, so is not presented.

Source: Authors estimates

Table 4: Impacts of Intermediate Modeling Structure with Four-sectors with a Global Ten Percent Reduction in Iceberg Trade Costs*

Results are Hicksian Equivalent Variation as a Percent of Consumption

		1	2	3	4	5	6	7	8	9
	domestic trade share	Cobb-Douglas Demand Single Composite Intermediate			Cobb-Douglas Demand for Intermediates ; real data			Elasticity of Substition for Intermediates = 0.5; real data		
		Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz
Region	λ_{rr}	σ(D,M) = 5.86*	σ = 5.59*	σ=5.0; a=4.58*	σ(D,M) = 6.13*	σ = 5.65*	=5.0; a=4.58	σ(D,M) = 5.96*	σ = 5.61*	σ=5.0; a=4.58*
Australia-New Zealand	89.3%	3.5%	3.7%	3.7%	3.6%	3.71%	3.66%	3.6%	2.9%	2.8%
Canada	84.4%	4.3%	5.3%	5.5%	4.2%	6.3%	6.9%	4.2%	4.5%	4.6%
China	91.1%	3.6%	7.8%	9.1%	3.5%	9.7%	12.5%	3.4%	4.9%	5.2%
Japan	91.6%	2.1%	3.4%	3.6%	2.1%	4.3%	4.9%	2.0%	2.8%	3.0%
Mexico-Chile-Peru	82.9%	4.8%	6.0%	6.2%	4.9%	6.4%	6.8%	4.8%	5.0%	5.0%
Low Income NEC	76.9%	6.3%	6.2%	6.1%	6.5%	5.8%	5.5%	6.5%	4.7%	4.4%
Middle Income NEC	88.3%	3.6%	3.8%	3.9%	3.7%	3.7%	3.6%	3.6%	2.9%	2.7%
OECD NEC	91.4%	2.3%	3.3%	3.6%	2.3%	3.8%	4.2%	2.3%	2.7%	2.7%
Philippines	79.2%	4.7%	6.5%	6.8%	4.8%	7.2%	7.8%	4.7%	5.3%	5.4%
United States	90.6%	1.9%	2.4%	2.5%	1.9%	2.8%	3.0%	1.9%	2.0%	2.1%
average for the World	90.0%	2.77%	3.83%	4.09%	2.80%	4.34%	4.83%	2.75%	2.93%	2.96%

*All scenarios with four IRTS sectors and trade imbalances included; but single primary factor and zero tariffs.

Source: Authors' calculations.

Table 4a: --the Feenstra ratio and Proportional Changes in the Terms-of-trade*

	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16
	Cobb-Douglas Intermediate Single Composite Intermediate					Cobb-Douglas Demand for Intermediates real data					Elasticity of Substition for Intermediates = 0.5 real data				
	Armington	Krugman		Melitz		Armington	Krugman		Melitz		Armington	Krugman		Melitz	
Region	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra
Australia-New Zealand	1.0186	1.0110	1.0160	1.0112	1.0157	1.0209	1.0129	1.0159	1.0134	1.0139	1.0220	1.0113	1.0134	1.0112	1.0119
Canada	1.0103	1.0117	1.0251	1.0116	1.0272	1.0091	1.0199	1.0290	1.0207	1.0366	1.0108	1.0160	1.0236	1.0160	1.0270
China	0.9940	1.0020	1.0242	1.0024	1.0307	0.9928	1.0025	1.0303	1.0036	1.0424	0.9925	1.0000	1.0195	1.0000	1.0229
Japan	0.9927	0.9984	1.0166	0.9981	1.0188	0.9897	0.9991	1.0209	0.9986	1.0265	0.9892	0.9990	1.0160	0.9989	1.0191
Mexico-Chile-Peru	1.0117	1.0122	1.0279	1.0120	1.0302	1.0120	1.0126	1.0304	1.0123	1.0329	1.0129	1.0120	1.0256	1.0117	1.0266
Low Income NEC	1.0141	1.0089	1.0297	1.0090	1.0297	1.0163	1.0092	1.0275	1.0092	1.0255	1.0181	1.0081	1.0240	1.0078	1.0230
Middle Income NEC	1.0125	1.0047	1.0179	1.0046	1.0163	1.0144	1.0030	1.0176	1.0025	1.0134	1.0149	1.0039	1.0147	1.0037	1.0116
OECD NEC	0.9937	0.9967	1.0159	0.9967	1.0172	0.9931	0.9968	1.0181	0.9968	1.0204	0.9925	0.9976	1.0143	0.9978	1.0155
Philippines	0.9971	1.0049	1.0342	1.0049	1.0382	0.9973	1.0056	1.0372	1.0056	1.0424	0.9982	1.0046	1.0309	1.0047	1.0339
United States	0.9871	0.9865	1.0151	0.9867	1.0148	0.9869	0.9865	1.0172	0.9866	1.0174	0.9866	0.9875	1.0141	0.9879	1.0140
average for the World															

*See section 5 for a definition of these parameters. In the Armington model, the Feenstra ration = 1 in all cases.

Source: Authors estimates

Table 5: Impacts of Global Ten Percent Reduction in Iceberg Trade Costs with Multiple Primary Factors, Sector-Specific Factors and Labor-Leisure Choice

Results are Hicksian Equivalent Variation as a Percent of Consumption

All scenarios with four IRTS sectors; trade imbalances and initial tariffs incorporated; intermediates with CES demand**

	1	2	3	4	5	6	7	8	9	10	11	12
	Labor as the single factor			Three mobile factors			Three mobile factors			Three mobile factors		
	Sector Specific Factor: No			Sector Specific Factor: No			Sector Specific Factor: Yes			Sector Specific Factor: Yes		
	Labor-Leisure Choice: No			Labor-Leisure Choice: No			Labor-Leisure Choice: No			Labor-Leisure Choice: Yes		
	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz
Region	σ(D,M) = 5.98*	σ = 5.60*	σ=5.0; a=4.58*	σ(D,M) = 5.97*	σ = 5.60*	σ=5.0; a=4.58*	σ = 5.81*	σ = 5.59*	σ=5.0; a=4.58*	σ = 5.81*	σ = 5.59*	σ=5.0; a=4.58*
Australia-New Zealand	3.8%	3.4%	3.3%	3.8%	3.4%	3.3%	3.8%	3.6%	3.5%	3.74%	3.87%	3.88%
Canada	4.4%	5.1%	5.3%	4.4%	5.1%	5.3%	4.3%	5.0%	5.2%	4.3%	5.5%	5.7%
China	4.0%	6.5%	7.2%	4.0%	6.5%	7.1%	3.9%	6.1%	6.5%	3.9%	6.7%	7.4%
Japan	2.2%	3.4%	3.7%	2.2%	3.4%	3.6%	2.2%	3.2%	3.4%	2.2%	3.4%	3.7%
Mexico-Chile-Peru	5.0%	5.5%	5.7%	5.0%	5.5%	5.6%	5.0%	5.4%	5.5%	4.9%	5.7%	5.9%
Low Income NEC	7.9%	6.7%	6.5%	7.9%	6.7%	6.5%	7.8%	7.4%	7.4%	7.8%	8.0%	8.1%
Middle Income NEC	4.3%	3.8%	3.6%	4.3%	3.8%	3.6%	4.2%	4.0%	3.9%	4.2%	4.2%	4.2%
OECD NEC	2.5%	3.2%	3.4%	2.5%	3.2%	3.4%	2.5%	3.0%	3.1%	2.5%	3.3%	3.4%
Philippines	5.0%	6.1%	6.3%	5.0%	6.0%	6.3%	5.0%	5.8%	6.0%	5.0%	6.2%	6.5%
United States	2.0%	2.3%	2.4%	2.0%	2.3%	2.4%	1.9%	2.3%	2.3%	2.0%	2.5%	2.6%
average for the World	3.08%	3.63%	3.74%	3.07%	3.62%	3.73%	3.03%	3.53%	3.63%	3.03%	3.82%	3.99%

* σ(D,M) is the Armington elasticity of substitution between imports and domestic goods; σ is the Dixit-Stiglitz elasticity of substitution between varieties in a sector; "a" is the shape parameter in the Pareto distribution.
**CES demand for intermediates with elasticity of substitution = 0.5.
Source: Authors' estimates.

Table 5a: the Feenstra ratio and Proportional Changes in the Terms-of-trade*

	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Labor as the Single Factor					Three Mobile Factors					Three Mobile Factors					Three Mobile Factors				
	Sector Specific Factor: No					Sector Specific Factor: No					Sector Specific Factor: Yes					Sector Specific Factor: Yes				
	Labor-Leisure Choice: No					Labor-Leisure Choice: No					Labor-Leisure Choice: No					Labor-Leisure Choice: Yes				
	Armington	Krugman		Melitz		Armington	Krugman		Melitz		Armington	Krugman		Melitz		Armington	Krugman		Melitz	
Region	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra
Australia-New Zealand	1.022	1.011	1.013	1.011	1.012	1.022	1.011	1.013	1.011	1.012	1.023	1.014	1.014	1.014	1.013	1.022	1.014	1.015	1.014	1.015
Canada	1.011	1.016	1.024	1.016	1.027	1.011	1.016	1.024	1.016	1.027	1.011	1.015	1.023	1.015	1.026	1.011	1.015	1.025	1.015	1.029
China	0.992	1.000	1.019	1.000	1.023	0.992	1.000	1.019	1.000	1.023	0.992	0.998	1.018	0.998	1.021	0.992	0.998	1.020	0.998	1.024
Japan	0.988	0.998	1.016	0.998	1.019	0.988	0.998	1.016	0.998	1.019	0.989	0.997	1.015	0.996	1.018	0.989	0.996	1.016	0.996	1.019
Mexico-Chile-Peru	1.013	1.012	1.025	1.012	1.027	1.013	1.012	1.025	1.012	1.026	1.013	1.013	1.025	1.012	1.026	1.013	1.013	1.026	1.012	1.028
Low Income NEC	1.020	1.010	1.024	1.010	1.025	1.020	1.010	1.024	1.010	1.025	1.021	1.017	1.027	1.017	1.029	1.020	1.018	1.029	1.018	1.032
Middle Income NEC	1.016	1.005	1.014	1.005	1.012	1.016	1.005	1.014	1.005	1.012	1.016	1.008	1.015	1.008	1.014	1.016	1.008	1.016	1.008	1.015
OECD NEC	0.992	0.997	1.014	0.998	1.015	0.992	0.997	1.014	0.998	1.015	0.992	0.996	1.014	0.996	1.015	0.992	0.995	1.015	0.995	1.016
Philippines	0.998	1.005	1.031	1.005	1.034	0.998	1.005	1.031	1.005	1.034	0.998	1.003	1.030	1.003	1.032	0.998	1.003	1.032	1.003	1.035
United States	0.986	0.987	1.014	0.987	1.014	0.986	0.987	1.014	0.987	1.014	0.986	0.986	1.014	0.986	1.013	0.986	0.986	1.015	0.986	1.015
average for the World																				

*See section 5 for a definition of these parameters. In the Armington model, the Feenstra ration = 1 in all cases.
Source: Authors estimates

Table 6: Impact of Global Free Trade, Uniform Tariffs and Iceberg Cost Reduction in a More Realistic Nine-Sector Model.

All scenarios with: 4 CRTS and 5 IRTS sectors; Ten Regions; initial tariffs and trade imbalances; three factors of production where part of the third factor is sector specific; and intermediates with CES demand and elasticity of substitution = 0.5.

Results are Hicksian equivalent variation as a percent of consumption.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	10% reduction in iceberg costs			10% reduction in iceberg costs			Global Free Trade			Global Free Trade			Global Free Trade		
							Uniform Tariff: No			Uniform tariff: Yes			Uniform Tariff: No		
	Labor-Leisure Choice: No			Labor-Leisure Choice: Yes			Labor-Leisure Choice: No			Labor-Leisure Choice: No			Labor-Leisure Choice: Yes		
	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz
Region	σ(D,M) = 6.03*	σ = 5.55*	σ=5.0; a=4.58*	σ(D,M) = 6.04*	σ = 5.55*	σ=5.0; a=4.58*	σ = 8.00*	σ = 5.81*	σ=5.0; a=4.58*	σ = 6.88*	σ = 5.88*	σ=5.0; a=4.58*	σ = 8.03*	σ = 5.83*	σ=5.0; a=4.58*
Australia-New Zealand	3.3%	2.8%	2.9%	3.3%	2.9%	3.0%	0.6%	0.8%	0.9%	0.2%	0.1%	0.1%	0.6%	0.9%	1.0%
Canada	4.2%	4.8%	4.9%	4.2%	5.0%	5.1%	0.2%	0.4%	0.5%	0.1%	0.3%	0.3%	0.2%	0.5%	0.6%
China	4.0%	4.8%	4.6%	4.0%	5.2%	5.2%	0.3%	-1.4%	-2.4%	0.0%	0.5%	0.4%	0.3%	-1.2%	-2.2%
Japan	2.3%	3.0%	3.2%	2.3%	3.1%	3.3%	0.4%	1.2%	1.5%	0.1%	0.3%	0.4%	0.4%	1.3%	1.6%
Mexico-Chile-Peru	4.7%	4.9%	4.9%	4.6%	5.0%	5.1%	-0.1%	0.0%	0.0%	0.2%	0.3%	0.3%	-0.1%	0.0%	0.1%
Low Income NEC	7.1%	10.4%	11.0%	7.1%	11.6%	12.7%	-0.2%	0.1%	0.2%	-0.1%	1.4%	2.4%	-0.2%	0.6%	0.9%
Middle Income NEC	3.7%	3.7%	3.7%	3.7%	3.7%	3.8%	-0.2%	0.0%	0.1%	-0.2%	-0.1%	-0.1%	-0.2%	0.0%	0.2%
OECD NEC	2.6%	3.0%	3.1%	2.6%	3.2%	3.3%	0.4%	1.1%	1.2%	0.1%	0.4%	0.4%	0.4%	1.2%	1.4%
Philippines	5.2%	6.2%	6.4%	5.2%	6.3%	6.6%	0.1%	0.5%	0.7%	0.3%	0.6%	0.7%	0.1%	0.5%	0.7%
United States	2.0%	2.2%	2.2%	2.1%	2.3%	2.4%	0.4%	0.4%	0.5%	0.1%	0.1%	0.1%	0.4%	0.4%	0.5%
average for the World	2.96%	3.31%	3.36%	2.96%	3.47%	3.55%	0.24%	0.40%	0.41%	0.05%	0.22%	0.25%	0.24%	0.48%	0.51%

* See table 3 for definitions of elasticities. **Source: Authors' estimates**

Table 6a: the Feenstra ratio and Proportional Changes in the Terms-of-trade*

	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	10% Reduction in Iceberg Costs					10% Reduction in Iceberg Costs					Global Free Trade					Global Free Trade					Global Free Trade				
											Uniform Tariff: No					Uniform Tariff: Yes					Uniform Tariff: No				
	Labor-Leisure Choice: No					Labor-Leisure Choice: Yes					Labor-Leisure Choice: No					Labor-Leisure Choice: No					Labor-Leisure Choice: Yes				
	Armington	Krugman		Melitz		Armington	Krugman		Melitz		Armington	Krugman		Melitz		Armington	Krugman		Melitz		Armington	Krugman		Melitz	
Region	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra	TOT	TOT	Feenstra	TOT	Feenstra
Australia-New Zealand	1.014	1.008	1.010	1.007	1.012	1.015	1.010	1.010	1.009	1.013	1.015	1.020	1.000	1.020	1.002	1.007	1.007	1.000	1.006	1.000	1.016	1.021	1.000	1.021	1.002
Canada	1.006	1.014	1.019	1.014	1.022	1.006	1.015	1.020	1.015	1.023	0.999	1.000	1.001	1.000	1.001	1.003	1.004	1.001	1.003	1.001	0.999	1.000	1.001	1.000	1.001
China	0.997	1.001	1.010	1.001	1.011	0.996	1.000	1.012	1.000	1.013	1.003	1.011	0.993	1.011	0.995	0.998	0.999	1.001	0.999	1.001	1.003	1.010	0.994	1.010	0.996
Japan	0.998	1.007	1.010	1.008	1.011	0.998	1.006	1.010	1.007	1.012	1.011	1.023	1.002	1.025	1.004	1.005	1.006	1.001	1.006	1.001	1.010	1.022	1.003	1.024	1.005
Mexico-Chile-Peru	1.009	1.017	1.018	1.017	1.023	1.009	1.018	1.019	1.017	1.024	0.995	0.995	0.999	0.995	1.000	1.005	1.005	1.000	1.005	1.001	0.995	0.995	1.000	0.995	1.000
Low Income NEC	1.011	1.044	1.021	1.045	1.050	1.012	1.050	1.023	1.053	1.058	0.977	0.983	1.000	0.978	1.008	0.986	1.017	0.995	1.027	1.021	0.977	0.987	1.001	0.984	1.014
Middle Income NEC	1.005	1.002	1.013	1.001	1.013	1.006	1.003	1.014	1.002	1.014	0.985	0.979	1.001	0.978	1.000	0.991	0.991	1.000	0.991	1.000	0.985	0.979	1.001	0.979	1.000
OECD NEC	0.998	0.997	1.010	0.997	1.010	0.998	0.996	1.011	0.996	1.011	1.003	1.005	1.003	1.006	1.003	1.005	1.004	1.001	1.003	1.001	1.003	1.005	1.003	1.006	1.003
Philippines	1.002	1.019	1.023	1.019	1.031	1.002	1.018	1.024	1.019	1.032	0.996	0.996	1.002	0.997	1.002	1.006	1.010	1.001	1.010	1.003	0.996	0.996	1.002	0.997	1.002
United States	0.991	0.983	1.011	0.984	1.010	0.990	0.983	1.012	0.983	1.010	1.016	1.010	1.000	1.010	1.000	1.006	1.003	1.000	1.002	1.000	1.016	1.010	1.000	1.009	1.000

*See section 5 for a definition of these parameters. In the Armington model, the Feenstra ration = 1 in all cases.
Source: Authors estimates

Table 7: Sensitivity of the Global Free Trade Welfare Results to a Common Change in the Trade Response*

All results in the Model with Nine-Sectors, Three Primary Factors with Labor-Leisure Choice and Trade Imbalances. Results are Hicksian Equivalent Variation as a Percent of Consumption

7A: Change in the Pareto Shape Parameter**

	Low trade response			Central trade response			High trade response		
	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz
Pareto shape parameter (a)			4.13			4.58			5.03
Armington or Dixit-Stiglitz elasticity	7.53	5.2	5	8.03	5.83	5	8.51	6.38	5
change in global trade share	1.82%	1.82%	1.82%	1.99%	1.99%	1.99%	2.15%	2.15%	2.15%
Region									
Australia-New Zealand	0.5%	0.9%	1.0%	0.6%	0.9%	1.0%	0.6%	0.9%	1.1%
Canada	0.2%	0.5%	0.5%	0.2%	0.5%	0.6%	0.2%	0.4%	0.6%
China	0.3%	-1.6%	-1.9%	0.3%	-1.2%	-2.2%	0.3%	-0.9%	-2.4%
Japan	0.4%	1.4%	1.5%	0.4%	1.3%	1.6%	0.5%	1.3%	1.7%
Mexico-Chile-Peru	-0.06%	0.0%	0.0%	-0.05%	0.0%	0.1%	-0.05%	0.0%	0.1%
Low Income NEC	-0.2%	0.9%	0.9%	-0.2%	0.6%	0.9%	-0.1%	0.5%	0.8%
Middle Income NEC	-0.2%	0.1%	0.1%	-0.2%	0.0%	0.2%	-0.2%	0.0%	0.2%
OECD NEC	0.4%	1.3%	1.3%	0.4%	1.2%	1.4%	0.5%	1.2%	1.4%
Philippines	0.1%	0.6%	0.7%	0.1%	0.5%	0.7%	0.1%	0.4%	0.7%
United States	0.4%	0.4%	0.4%	0.4%	0.4%	0.5%	0.4%	0.4%	0.5%
average for the World	0.224%	0.477%	0.484%	0.242%	0.478%	0.505%	0.260%	0.482%	0.526%

*****The trade response is the change in the global trade share, defined above as $1-\lambda_W$. It is calculated in the Melitz model; then the Dixit-Stiglitz and Armington elasticities are adjusted in the Krugman and Armington models such that the trade responses are equal in the three market structures.
******For the high and low value of the Pareto shape parameter, we take plus and minus two standard deviations from the mean of the preferred distribution estimated by Balistreri et al. (2011).

7B. Change in the Dixit-Stiglitz Elasticity of Substitution

	High trade response			Central trade response			Low trade response		
	Armington	Krugman	Melitz	Armington	Krugman	Melitz	Armington	Krugman	Melitz
Pareto shape parameter (a)			4.58			4.58			4.58
Armington or Dixit-Stiglitz elasticity	8.25	6.08	4.5	8.03	5.83	5	7.86	5.63	5.5
change in global trade share	2.06%	2.06%	2.06%	1.99%	1.99%	1.99%	1.93%	1.93%	1.93%
Region									
Australia-New Zealand	0.6%	0.9%	1.2%	0.6%	0.9%	1.0%	0.6%	0.9%	0.9%
Canada	0.2%	0.5%	0.7%	0.2%	0.5%	0.6%	0.2%	0.5%	0.5%
China	0.3%	-1.0%	-3.8%	0.3%	-1.2%	-2.2%	0.3%	-1.3%	-1.4%
Japan	0.4%	1.3%	1.9%	0.4%	1.3%	1.6%	0.4%	1.4%	1.4%
Mexico-Chile-Peru	-0.05%	0.0%	0.1%	-0.05%	0.0%	0.1%	-0.06%	0.0%	0.0%
Low Income NEC	-0.2%	0.6%	0.2%	-0.2%	0.6%	0.9%	-0.2%	0.7%	0.7%
Middle Income NEC	-0.2%	0.0%	0.4%	-0.2%	0.0%	0.2%	-0.2%	0.0%	0.1%
OECD NEC	0.4%	1.2%	1.6%	0.4%	1.2%	1.4%	0.4%	1.2%	1.2%
Philippines	0.1%	0.5%	1.0%	0.1%	0.5%	0.7%	0.1%	0.5%	0.5%
United States	0.4%	0.4%	0.6%	0.4%	0.4%	0.5%	0.4%	0.4%	0.4%
average for the World	0.251%	0.479%	0.510%	0.242%	0.478%	0.505%	0.236%	0.477%	0.481%

Source: Authors' Estimates

Table 8: Impact of a *Unilateral* Increase in the Tariff Rates to a Uniform Forty Percent, Starting from Initial Tariffs.

All results are for the region raising the tariffs*

Model is the Nine Sector, Three Factor Model with Labor-Leisure Choice and Trade Imbalances

	Hicksian Equivalent Variation as a percent of consumption				Terms of Trade Changes				Feenstra ratios	
Region	**Armington**	**Krugman**	**Melitz**		**Armington**	**Krugman**	**Melitz**		**Krugman**	**Melitz**
Australia-New Zealand	0.34%	1.03%	1.03%		113.4%	114.4%	114.9%		100.2%	99.7%
Canada	0.80%	-0.71%	-1.01%		116.5%	114.5%	114.6%		99.4%	98.3%
China	0.91%	-4.12%	-4.72%		116.2%	113.5%	113.3%		98.6%	98.3%
Japan	0.41%	-1.52%	-1.79%		115.5%	113.6%	113.6%		99.2%	98.9%
Mexico-Chile-Peru	1.17%	-0.46%	-0.74%		115.7%	112.5%	112.8%		99.6%	98.2%
Low Income NEC	0.16%	-0.21%	-0.33%		111.6%	110.7%	111.0%		99.9%	98.6%
Middle Income NEC	0.82%	0.61%	0.55%		114.8%	114.7%	114.9%		99.9%	99.6%
OECD NEC	0.66%	-0.79%	-1.03%		117.4%	116.3%	116.3%		99.4%	99.3%
Philippines	0.86%	-1.97%	-2.30%		119.6%	114.9%	115.3%		99.0%	97.6%
United States	1.88%	0.51%	0.40%		125.8%	124.1%	124.1%		99.4%	99.3%

*Ten separate simulations for each of the three market structures, with only the results for the region raising the tariffs shown.

Source: Authors' estimates.

Table 9: Benchmark Tariff Rates, by Product and Region of the Model

	Exports From:									
	Australia-New Zealand	Canada	China	Japan	Mexico-Peru-Chile	Low Income nec	Middle Income nec	OECD nec	Philippines	USA
Imports into*:										
Australia-New Zealand										
Agriculture	**NA**	0.78%	15.61%	10.06%	5.79%	9.31%	4.04%	11.73%	0.11%	0.62%
Food	**NA**	15.34%	6.22%	31.80%	15.18%	16.83%	11.89%	39.24%	0.91%	3.78%
Natural Resources	**NA**	0.00%	0.02%	0.01%	2.08%	1.64%	1.93%	0.16%	2.93%	0.02%
Manufactured Goods	**NA**	0.44%	4.08%	0.27%	4.47%	6.52%	4.88%	1.48%	0.96%	0.08%
Refined Resource Products	**NA**	0.33%	1.31%	0.64%	2.42%	5.98%	3.70%	1.50%	0.53%	0.20%
Textiles and Apparel	**NA**	6.48%	4.56%	5.33%	6.04%	13.44%	6.37%	3.39%	2.23%	3.26%
Canada										
Agriculture	0.15%	**NA**	4.20%	9.93%	0.39%	8.33%	12.32%	6.36%	3.16%	0.00%
Food	0.99%	**NA**	8.57%	40.55%	5.74%	16.04%	16.56%	21.26%	23.02%	1.69%
Natural Resources		**NA**	0.37%	0.07%	0.02%	0.06%	1.91%	0.10%	2.97%	
Manufactured Goods	2.11%	**NA**	2.97%	0.03%	0.05%	9.25%	5.10%	1.53%	4.00%	
Refined Resource Products	1.21%	**NA**	2.48%	1.21%	0.08%	8.42%	3.88%	0.89%	4.05%	
Textiles and Apparel	5.52%	**NA**	7.34%	9.87%	0.47%	16.92%	11.50%	7.69%	8.52%	0.00%
China										
Agriculture	0.78%	1.58%	**NA**	14.79%	9.20%	15.39%	8.47%	43.69%	1.10%	1.00%
Food	1.84%	4.36%	**NA**	11.38%	14.25%	15.60%	13.35%	18.56%	3.18%	2.83%
Natural Resources	0.08%	0.07%	**NA**	1.36%	4.42%	11.27%	1.40%	2.49%	0.01%	0.29%
Manufactured Goods	2.18%	0.92%	**NA**	0.03%	3.14%	11.30%	5.94%	1.75%	1.16%	0.85%
Refined Resource Products	3.55%	1.75%	**NA**	0.36%	5.43%	12.89%	6.86%	2.97%	0.48%	2.17%
Textiles and Apparel	7.85%	13.82%	**NA**	10.08%	10.09%	17.21%	14.53%	9.90%	1.57%	11.52%
Japan										
Agriculture	0.31%	0.78%	3.05%	**NA**	0.04%	7.75%	12.91%	5.88%	1.42%	2.72%
Food	1.84%	6.59%	5.12%	**NA**	7.74%	14.77%	15.01%	25.13%	3.32%	3.47%
Natural Resources	0.31%	0.15%	2.57%	**NA**	0.74%	8.29%	2.00%	6.73%	1.71%	0.36%
Manufactured Goods	14.34%	2.86%	6.85%	**NA**	2.54%	13.42%	7.60%	3.76%	1.99%	1.00%
Refined Resource Products	1.60%	1.90%	5.26%	**NA**	2.96%	8.09%	5.31%	3.52%	2.00%	1.96%
Textiles and Apparel	4.26%	3.76%	7.85%	**NA**	3.44%	12.23%	7.90%	6.59%	0.17%	5.72%
Mexio-Peru-Chile										
Agriculture	0.11%	0.00%	3.36%	1.02%	**NA**	9.41%	4.93%	3.33%	7.02%	0.07%
Food	0.50%	5.91%	3.36%	16.72%	**NA**	14.07%	6.80%	6.07%	4.19%	0.35%
Natural Resources			0.06%	0.02%	**NA**	1.83%	0.87%	0.09%	2.97%	
Manufactured Goods	6.06%	0.00%	7.63%	0.00%	**NA**	6.35%	2.60%	0.33%	2.63%	
Refined Resource Products	0.36%		0.40%	0.49%	**NA**	7.43%	2.12%	0.17%	3.64%	0.06%
Textiles and Apparel	5.60%	0.00%	5.68%	5.18%	**NA**	9.90%	3.10%	0.51%	2.04%	0.00%
Low Income Countries, nec										
Agriculture	0.01%	0.11%	5.50%	0.62%	12.79%	**NA**	5.79%	1.94%	6.72%	1.91%
Food	0.22%	1.84%	2.85%	2.79%	6.46%	**NA**	4.56%	2.09%	2.60%	1.63%
Natural Resources	0.00%	0.00%	0.73%	0.00%	1.96%	**NA**	0.61%	0.09%	0.86%	0.00%
Manufactured Goods	1.05%	0.43%	7.17%	0.08%	4.99%	**NA**	2.90%	0.27%	2.26%	0.22%
Refined Resource Products	0.81%	0.02%	0.75%	0.35%	2.72%	**NA**	2.24%	0.09%	1.27%	0.02%
Textiles and Apparel	0.15%	0.24%	6.38%	0.32%	25.52%	**NA**	13.09%	0.13%	6.59%	9.67%
Middle Income Countries, nec										
Agriculture	0.18%	0.66%	2.90%	2.79%	4.53%	7.30%	**NA**	12.18%	7.49%	0.78%
Food	0.51%	8.58%	9.69%	10.42%	3.85%	13.44%	**NA**	11.33%	9.60%	2.30%
Natural Resources	0.00%	0.00%	0.05%	0.01%	0.87%	1.98%	**NA**	0.55%	0.26%	0.07%
Manufactured Goods	1.67%	0.92%	2.29%	0.02%	4.11%	8.71%	**NA**	0.76%	1.20%	0.36%
Refined Resource Products	0.83%	0.58%	3.44%	0.59%	2.34%	7.55%	**NA**	0.76%	1.43%	0.84%
Textiles and Apparel	4.70%	13.00%	4.07%	2.71%	13.24%	15.11%	**NA**	4.51%	4.74%	8.82%
OECD, nec										
Agriculture	1.25%	1.46%	9.01%	4.05%	1.01%	13.60%	7.91%	**NA**	6.66%	4.15%
Food	3.18%	22.40%	10.03%	22.47%	7.34%	21.03%	15.52%	**NA**	7.85%	2.55%
Natural Resources	0.16%	0.01%	0.77%	3.30%	0.27%	5.82%	5.49%	**NA**	1.27%	0.11%
Manufactured Goods	8.02%	1.75%	7.54%	0.13%	1.80%	9.52%	6.38%	**NA**	2.80%	0.73%
Refined Resource Products	1.72%	0.84%	4.48%	1.01%	0.85%	9.99%	5.48%	**NA**	1.83%	1.33%
Textiles and Apparel	5.50%	8.97%	7.35%	12.01%	2.37%	15.22%	7.69%	**NA**	4.39%	7.37%
Philippines										
Agriculture	0.00%	0.03%	0.00%	8.23%	10.75%	39.10%	12.13%	22.00%	**NA**	0.80%
Food	0.50%	6.09%	4.66%	5.99%	6.28%	25.03%	10.68%	10.28%	**NA**	3.18%
Natural Resources	0.00%	0.22%		0.04%	9.83%	8.46%	2.82%	0.58%	**NA**	0.01%
Manufactured Goods	0.19%	0.17%	0.13%	0.04%	2.67%	8.50%	2.83%	0.24%	**NA**	0.22%
Refined Resource Products	0.29%	3.51%	0.30%	0.07%	7.95%	8.48%	2.20%	0.85%	**NA**	0.22%
Textiles and Apparel	3.40%	15.01%		1.50%	24.42%	11.81%	10.69%	7.52%	**NA**	12.74%
USA										
Agriculture	0.00%	0.95%	3.21%	8.09%	0.82%	5.63%	4.87%	81.83%	3.84%	**NA**
Food	0.61%	16.83%	8.31%	35.49%	0.92%	15.67%	13.99%	18.87%	5.97%	**NA**
Natural Resources	0.00%		0.50%	0.14%	0.05%	5.08%	1.55%	0.26%	2.19%	**NA**
Manufactured Goods	1.31%		5.27%	0.14%	0.14%	9.11%	4.51%	1.77%	2.45%	**NA**
Refined Resource Products	0.19%		4.83%	1.07%	0.09%	8.91%	4.98%	2.02%	4.66%	**NA**
Textiles and Apparel	3.77%		6.24%	12.72%	0.27%	14.44%	5.60%	6.82%	6.43%	**NA**

*A blank cell means a zero tariff rate. Three sectors are not reported in the table: business services, utilities and other services. Tariffs on business services and other services are zero. With the exception of five cases, tariffs on utilities are zero, so are not reported. The only three above 0.04% are: 0.84% (0.17%) on imports from Low Income countries into China (Middle-Income countries); and 0.28 percent on imports from Middle-Income countries into OECD, nec.

Source: GTAP 9 dataset.

Table 10: Value Added by Region and Sector in the Benchmark Data

(In billions of US dollars)

Sector	Sector Classification	Australia-New Zealand	Canada	China	Japan	Mexico-Peru-Chile	Low Income nec	Middle Income nec	OECD nec	Philippines	USA
		Region									
aggregate CRTS		**880**	**1005**	**3377**	**3297**	**842**	**442**	**9527**	**9421**	**123**	**8984**
aggregate IRTS		**571**	**664**	**3640**	**2414**	**676**	**214**	**5653**	**9687**	**93**	**6247**
Agriculture	CRTS	35	20	541	50	50	93	1153	316	24	148
Business Services	IRTS	420	402	1335	1352	310	106	2761	5037	38	3776
Utilities	CRTS	29	38	110	103	20	15	391	397	5	299
Food	IRTS	34	40	177	154	79	36	582	612	15	283
Natural Resources	CRTS	127	108	384	18	99	107	2159	287	10	273
Other Manufactuing	IRTS	54	107	958	481	137	19	901	1969	23	1158
Other Services	CRTS	689	839	2342	3125	672	226	5824	8421	84	8264
Refined Resource Products	IRTS	57	107	933	405	130	35	1177	1803	13	930
Textiles and Apparel	IRTS	5	8	236	21	19	17	234	267	4	100

Source: GTAP 9 dataset.

Appendix A: Measurement of the Variety Impact in a Multi-Sector Model—A Multi-Sector Feenstra Ratio

Feenstra (2010, equation 4) derived his index for the welfare impact of the variety externality in a one-sector monopolistic competition model. In this note, we extend that measure to a multi-sector, multi-region Krugman or Melitz model. We begin with a review of the key theorems. Since Feenstra's theorem depends on the Sato-Vartia index, we start with the Sato-Vartia index and then summarize Feenstra's theorem. We then generalize the Sato-Vartia index and the Feenstra ratio to our multi-sector, multi-region model.

The Sato-Vartia Theorem

Define the log change price and quantity indices between time 0 and 1 as:

$$\ln P = \sum_{i=1}^{n} w_i \ln \frac{p_{i1}}{p_{i0}} \tag{1}$$

$$\ln Q = \sum_{i=1}^{n} w_i \ln \frac{q_{i1}}{q_{i0}} \tag{2}$$

Where $\left(p_{it}, q_{it}\right)$ are the prices and quantities of i^{th} good in time t and w_i is its non-negative weight in the indices such that $\sum_{i=1}^{n} w_i = 1$. The expenditure index E is given by

$$E = \frac{\sum_{i=1}^{n} p_{i1} q_{i1}}{\sum_{i=1}^{n} p_{i0} q_{i0}} \ . \tag{3}$$

These indices are defined as "ideal" log change indices, if we can find weights w_i (which are identical for both the price and quantity indices) that result in

$$PQ \equiv E \ .^{26} \tag{4}$$

For many years finding the weights that would yield an ideal log change index eluded researchers, and the literature produced indices with weights that were approximations to the ideal index. The problem was solved in 1976. Vartia (1976) produced two weighting formulas, known as Vartia I and Vartia II, both of

[26] If $PQ \equiv E$ with different weights in the price and quantity indices, the indices are said to be dual to each other and they satisfy the weak factor reversal test. If the weights are identical in the price and quantity indices, they are said to satisfy the strong factor reversal test and they are ideal. See Sato (1976).
.

which yield ideal log change indices. Sato (1976) independently discovered the Vartia I index. Moreover, Sato showed that if the utility function is homothetic, then his price and quantity indices are dual to the CES direct and indirect utility function. Given homothetic preferences, he shows that solving the partial differential equation of the log change quantity index, yields the CES direct utility function.

The solution for the weights is the following. Define $st_i = \frac{p_{it} q_{it}}{\sum_{k=1}^{n} p_{kt} q_{kt}}$ as the expenditure share of good i at time t, t = 0,1. Then the weights of the Vartia I or the Sato-Vartia index are:

$$w_i = \frac{\dfrac{s1_i - s0_i}{\ln(s1_i) - \ln(s0_i)}}{\sum_{k=1}^{n} \left[\dfrac{s1_k - s0_k}{\ln(s1_k) - \ln(s0_k)} \right]} \quad . \tag{5}$$

Rewriting equation (1), the Sato-Vartia price index may be written as:

$$P^{SV} = \prod_{i=1}^{n} \left[\frac{p_{i1}}{p_{i0}} \right]^{w_i} \tag{6}$$

The Sato-Vartia Index at the Sector Level

We must extend the Sato-Vartia index to our model with multiple sectors and multiple regions. Importantly, Sato (1976, footnote 11) notes that while the formula (6) applies for an economy-wide index where each good i is a unique good, the index would remain an ideal sub-index for subgroups where i is a sector composed of multiple goods. That is, this log-change formula can be applied to the sub-groups to yield ideal sub-indices. We employ this ideal sub-group property to obtain Sato-Vartia indices at the sector level.

Notation. Using 0 and 1 to denote the value of a variable in the benchmark and counterfactual equilibrium, respectively, define:

(i) $s0_{irs}$ and $s1_{irs}$ as the expenditure shares in the benchmark and counterfactual equilibria, respectively, for all varieties of goods in sector i shipped from region r into region s;

(ii) $pf0_{irs}$ and $pf1_{irs}$ as the gross price (including tariffs) of a firm's variety of good i shipped form region r to region s;

(iii) $qf0_{irs}$ and $qf1_{irs}$ as the quantity of a firm's variety of good i shipped from region r to region s;

(iv) $N0_{irs}$ and $N1_{irs}$ the number of firms (varieties) in sector i that are shipped from region r to region s.

In the Krugman model, all varieties in a given sector have the same price and are shipped to all destinations, so we could drop the destination index. In the Melitz model, however, the measure of the number of firms is bilateral, and firm level prices and quantities in (ii) and (iii) above are for the representative firm as defined by Melitz (2003). Bilateral expenditure shares are given by the product of the gross price of the representative firm times its quantity times the number of firms, i.e.,

$$s0_{irs} = \frac{pf0_{irs} * qf0_{irs} * N0_{irs}}{\sum_t pf0_{its} * qf0_{its} * N0_{its}}$$

$$s1_{irs} = \frac{pf1_{irs} * qf1_{irs} * N1_{irs}}{\sum_t pf1_{its} * qf1_{its} * N1_{its}}$$

Given the expenditure shares, the Sato-Vartia weights for our sub-indices are:

$$w_{irs} = \frac{\dfrac{s1_{irs} - s0_{irs}}{\ln(s1_{irs}) - \ln(s0_{irs})}}{\sum_t \left[\dfrac{s1_{its} - s0_{its}}{\ln(s1_{its}) - \ln(s0_{its})} \right]}$$

Our matrix of bilateral trade data at the country level does not contain any zeros. That is, we have $st_{irs} > 0$, for all *i, r, s* and *t*. Since we track expenditures based on sales of the average firm, we have $w_{irs} > 0$ for all *i, r, s,* d, and we do not need an exception for zero expenditures. [27]

We have $\sum_t w_{its} = 1$.

Analogous to the Sato-Vartia index in a single sector model, we define a Sato-Vartia index for the sector i in region s of the change in prices charged by the firm. Our ideal price index for the change in the prices charged by firms for the goods available in both periods is:

$$P_{is}^{SV} = \prod_r \left[\frac{pf_{irs}}{pf0_{irs}} \right]^{w_{irs}} \tag{7}$$

[27] In Feenstra's approach, he allowed for the possibility of some good to be sold in only one of the periods by defining the Sato-Vartia index over the set $I = I_{t-1} \bigcap I_t$ where I_t is the set of goods with expenditures in period t; so I is the set of goods with expenditures in both periods. If there were no exports to some destinations for some good i, in either the benchmark or counterfactual scenario, noting that $\lim_{s1_{irs} \to 0^+} w_{irs} = 0$ and similarly for $s0_{irs}$, we could define the weight as zero if the share is zero in either the benchmark of counterfactual. Then if a new variety appears (or an old variety disappears) in the counterfactual equilibrium, this variety would not impact our Sato-Vartia index.

Feenstra's Theorem

In his one-sector model, Feenstra shows that there is a ratio $\left[\frac{\lambda_{t-1}(I)}{\lambda_t(I)}\right]^{1/(\sigma-1)}$ that precisely measures the value of the Dixit-Stiglitz variety externality. In particular, Feenstra (2010, Theorem 4) shows that:

$$\frac{e(p_t, I_t)}{e(p_{t-1}, I_{t-1})} = P^{SV}(p_t, p_{t-1}, q_t, q_{t-1}, I)\left[\frac{\lambda_t(I)}{\lambda_{t-1}(I)}\right]^{1/(\sigma-1)} \tag{8}$$

where e is the unit expenditure function and $P^{SV}(...)$ is the Sato-Vartia price index, σ is the elasticity of substitution between varieties, I_t is the set of goods available in period t and $I = I_{t-1} \bigcap I_t$ is the set of goods available in both periods . Intuitively, since the Sato-Vartia index is based on prices charged by firms, it does not account for the Dixit-Stiglitz variety externality. Feenstra's theorem tells us that the proportional change in the unit expenditure function is the product of two terms that are: (i) a measure of the change in the prices charged by firms on goods common to the two periods (the Sato-Vartia index); and (ii) a ratio that is a measure of the value of the variety gain, the Feenstra ratio. The methodology requires distinguishing changes in the price charged by firms on goods available in both periods from the variety externality.

The Multi-Sector Feenstra Ratio

For what follows, it is convenient to rewrite equation 8 as:

$$F = \left[\frac{\lambda_{t-1}(I)}{\lambda_t(I)}\right]^{1/(\sigma-1)} = \frac{e(p_{t-1}, I_{t-1})}{e(p_t, I_t)} P^{SV}(p_t, p_{t-1}, q_t, q_{t-1}, I) \tag{9}$$

where we call the left hand side the Feenstra ratio.

Feenstra Ratio at the Sector Level. Define $PDS_{is}(1)$ and $PDS_{is}(0)$ as the Dixit-Stiglitz price index in the sector i in region s, in the counterfactual and benchmark equilibrium, respectively. We use these unit cost indices to adjust for the variety externality at the sector level in a manner analogous to the Feenstra theorem. That is, we define the Feenstra ratio at the sector level as:

$$F_{is} = \frac{PDS_{is}(0)}{PDS_{is}(1)} P_{is}^{SV} \tag{10}$$

where in equation 10 we use our ideal sector level Sato-Vartia index in region s. Since the Dixit-Stiglitz price index is the unit cost function for goods in sector i taking variety into account, and the Sato-Vartia index is the ideal index for the prices charged by firms, we believe we have an ideal measure of the variety impacts at the sector level. In particular, in a one-sector model our measure is the measure of Feenstra in equation 8, i.e., we have that $F_{is} = F$ if the number of sectors equals 1.

Multi-Sector Feenstra Ratio. For an ideal aggregate measure of the variety impacts across sectors, independent of the price impacts,[28] we would have to account for the differential variety impacts that accrue in terms of their use as both intermediates and final goods. This, in turn, depends on the production technology for intermediates and utility across different goods. We take the simplest tact and calculate a weighted average of the sector-level variety impacts. That is, we define:

$$\bar{F}_s = \sum_i \theta_i F_{is} \tag{11}$$

where θ_i is the economy-wide expenditure share (absorption share) on goods or services in sector i. Our aggregate measure is an approximation to an ideal multi-sector measure of the variety impacts; but we have calculated and presented this aggregate variety measure for more than 40 scenarios in this paper, and the measure has proved useful and intuitive in explaining the welfare results.

[28] Sato (1976) notes that if the utility function is multi-level CES, then it is possible to aggregate from the sub-indices to get an ideal aggregate index.

Appendix B: Equations of the Model

1 Notation:

Sets:
Regions are indexed by $r \in R$ or $s \in R$. Goods and services are indexed by $i \in I$ or $j \in I$, with subsets $k \in K \subseteq I$ for Krugman treatments, and $m \in M \subseteq I$ for Melitz treatments. Factors are indexed by $f \in F$, with the subset $\tilde{F} \subseteq F$ indicating a sector-specific factor.

Variables:

D_r Full consumption index[1]

Y_{ir} Output index[2]

A_{ir} Supply index[3]

e_r Unit-expenditure index (true-cost-of-living index)

c_{ir} Price of domestic output (marginal cost)

P_{ir} Price of goods and services

w_{fr} Price of factors

$\tilde{w}_{fir}$ Price of sector-specific factors

M_{ir} Number of entered firms ($\forall i \in K \cup M$)

p_{krs} Gross firm-level price (Krugman firms)

q_{krs} Firm-level quantity (Krugman firms)

N_{mrs} Number of operating Melitz firms

$\tilde{p}_{krs}$ Gross firm-level price (Melitz representative firms)

$\tilde{q}_{krs}$ Firm-level quantity (Melitz representative firms)

$\tilde{\varphi}_{krs}$ Firm-level productivity (Melitz representative firms)

[1]In the model variation where we have an aggregate intermediate good this real quantity is gross of intermediates inputs. Consumption includes all final demand: household consumption and investment, and government spending.

[2]Under monopolistic competition treatments Y_{ir} indicates the composite (of value added and intermediate) input that firms in industry i use for real fixed and variables costs.

[3]Under an Armington treatment this is the Armington aggregate, and under monopolistic competition this is the Dixit-Stiglitz aggregate.

RA_r Nominal Income

Instruments:

τ_{irs} Iceberg trade cost factor

t_{irs} Tariff

Parameters:

$d0_r$ Benchmark value of full consumption[1]

$y0_{ir}$ Benchmark value of gross output of sector i

$a0_{ir}$ Benchmark value of domestic and imported supply of good i

α_{jir} Benchmark share of intermediate input j in gross output for sector i

β_{fir} Benchmark share of factor f in value added for sector i

μ_r Benchmark share of leisure in full consumption

θ_{ir} Benchmark share of i in total consumption of goods and services[1]

σ Elasticity of substitution between Armington, Krugman, or Melitz varieties

λ^A Preference weight in Armington aggregation of varieties

λ^K Preference weight in Krugman aggregation of varieties

λ^M Preference weight in Melitz aggregation of varieties

σ^L Elasticity of substitution between leisure and consumption of goods and services

σ^M Elasticity of substitution between intermediate inputs and value added

f^K_{kr} Fixed cost associated with a Krugman firm

f^M_{mrs} Fixed cost associated with operation of a Melitz firm on the r to s trade link

f^E_{mr} Sunk cost associated with entry of a Melitz firm

a Pareto shape parameter

b Pareto lower support

δ Annual probability of firm death

$\bar{F}_{fr}$ Endowment of mobile factor f

$\overline{SF}_{fir}$ Endowment of factor f specific to industry i

$\overline{BOP}_r$ Benchmark capital account surplus

2 Model Equations

2.1 Representing the basic technologies and preferences using duality

With the option to include a labor-leisure choice the unit expenditure function is given by

$$e_r = \left[\mu_r w_{Lr}^{1-\sigma^L} + (1-\mu_r) \left(\prod_i P_{ir}^{\theta_{ir}} \right)^{1-\sigma^L} \right]^{1/(1-\sigma^L)} . \tag{1}$$

If $\mu_r = 0$ labor supply is inelastically supplied, and preferences over goods and services indicated by the Cobb-Douglas nest alone.

The production function is given by one of the following alternative equations depending on the assumed treatment of intermediates. We always assume that value added inputs combine in a Cobb-Douglas nest, but there are different treatments of intermediates. If we assume intermediates entering the top-level nest with an elasticity of substitution $\sigma^M \neq 1$ we have

$$c_{ir} = \left[\sum_j \alpha_{jir} P_{jr}^{1-\sigma^M} + (1 - \sum_j \alpha_{jir}) \left(\prod_{f \notin \tilde{F}} (w_{fr})^{\beta_{fir}} \prod_{f \in \tilde{F}} (\tilde{w}_{fir})^{\beta_{fir}} \right)^{1-\sigma^M} \right]^{1/(1-\sigma^M)} . \tag{2a}$$

If $\sigma^M = 1$ the production function is fully Cobb-Douglas:

$$c_{ir} = \prod_j (P_{jr})^{\alpha_{jir}} \prod_{f \notin \tilde{F}} (w_{fr})^{(1-\sum_j \alpha_{jir})\beta_{fir}} \prod_{f \in \tilde{F}} (\tilde{w}_{fir})^{(1-\sum_j \alpha_{jir})\beta_{fir}}; \tag{2b}$$

and if we adopt the single-composite intermediate treatment the price of intermediates is the unit expenditure index:

$$c_{ir} = e_r^{\sum_j \alpha_{jir}} \prod_{f \notin \tilde{F}} (w_{fr})^{(1-\sum_j \alpha_{jir})\beta_{fir}} \prod_{f \in \tilde{F}} (\tilde{w}_{fir})^{(1-\sum_j \alpha_{jir})\beta_{fir}}. \tag{2c}$$

In the case that we do not have intermediates the α share parameters in the above equations would be zero.

The next set of equations indicate the good or service supply price, which is a composite of domestic and imported goods. For the Armington structure we have a simple CES aggregation of regional varieties:

$$P_{is} = \left[\sum_r \lambda_{irs}^A [(1+t_{irs})\tau_{irs} c_{ir}]^{1-\sigma} \right]^{1/(1-\sigma)} . \tag{3a}$$

If we assume monopolistic competition the supply prices are indicated by the Dixit-Stiglitz aggregation of either Krugman firm-level varieties,

$$P_{ks} = \left[\sum_r \lambda^K_{krs} M_{kr} p^{1-\sigma}_{krs} \right]^{1/(1-\sigma)} ; \tag{3b}$$

or Melitz representative-firm varieties,

$$P_{ms} = \left[\sum_r \lambda^M_{mrs} N_{mrs} \tilde{p}^{1-\sigma}_{mrs} \right]^{1/(1-\sigma)} . \tag{3c}$$

2.2 Market clearance

Equations 1 through 3 indicate a dual representation of technologies and utility. We proceed with the general equilibrium market-clearance conditions prior to establishing the bilateral equilibrium conditions that are specific to the monopolistically competitive Krugman and Melitz firms. First we establish the market clearance conditions for goods and services available for domestic use. These goods trade at the price P_{ir}, and are potentially used in consumption and production. Supply is simply the quantity $a0_{ir} A_{ir}$ and demand is derived by applying Shephard's Lemma to the established dual consumption and production technologies. The market clearance conditions are given by

$$a0_{ir} A_{ir} = d0_r D_r \frac{\partial e_r}{\partial P_{ir}} + \sum_j y0_{jr} Y_{jr} \frac{\partial c_{jr}}{\partial P_{ir}}. \tag{4}$$

where e_r and c_{jr} indicate the unit-cost (unit-expenditure) functions indicated in (1) and (2).

Now let us establish the market clearance conditions for output which has c_{ir} as the associated price. Under the Armington structure output is exported directly and so market clearance is given by

$$y0_{ir} Y_{ir} = \sum_s \tau_{irs} a0_{is} A_{is} \frac{\partial P_{is}}{\partial [(1 + t_{irs}) \tau_{irs} c_{ir}]}, \tag{5a}$$

where the price index P_{is} is given by unit cost function defined in (3a) above. For the monopolistic competition formulations the market clearance conditions must account for the various uses of output as it is allocated to fixed and variable costs. Under Krugman we have

$$y0_{kr} Y_{kr} = M_{kr} \left(f^K_{kr} + \sum_s q_{krs} \right); \tag{5b}$$

and under Melitz we have

$$y0_{mr} Y_{mr} = \delta f^E_{mr} M_{mr} + \sum_s N_{mrs} \left(f^M_{mrs} + \frac{\tilde{q}_{mrs}}{\tilde{\varphi}_{mrs}} \right). \tag{5c}$$

We proceed by specifying the market clearance conditions for primary factors. For sector-specific factors ($f \in \tilde{F}$) the rents are indicated by the following market clearance condition:

$$\overline{SF}_{fir} = y0_{ir} Y_{ir} \frac{\partial c_{jr}}{\partial \tilde{w}_{fir}}. \tag{6}$$

For mobile factors ($f \notin \tilde{F}$), that are not labor, we have to account for demand across the different sectors, and for labor we have to account for leisure demand:

$$\bar{F}_{fr} = \sum_i y0_{ir} Y_{ir} \frac{\partial c_{jr}}{\partial w_{fr}} + d0_r D_r \frac{\partial e_r}{\partial w_{fr}}. \tag{7}$$

Leisure demand is given by the final term on the right-hand side, and this is not zero only if the factor is labor and we have chosen an elastic-labor-supply structure.

Normally the quantity associated with the consumption activity $d0_r D_r$ would be fully exhausted in final demand, but under our treatment of a single-composite intermediate input some of this quantity is used in production. Market clearance for the consumption good is given by

$$d0_r D_r = \frac{RA_r}{e_r} + \sum_j y0_{jr} Y_{jr} \frac{\partial c_{jr}}{\partial e_r}. \tag{8}$$

Notice that changes in the first term on the right-hand side indicate changes in money-metric utility (Equivalent Variation). Also note that the second term drops out in all cases except when we assume a single-composite intermediate input, because e_r only enters production if we have equation (2c).

2.3 Krugman specific equations

Consistent with the Dixit-Stiglitz aggregation bilateral demand for a variety produced by a small firm shipping from r to s is given by

$$q_{krs} = \lambda^K_{krs} a0_{ks} A_{ks} \left(\frac{P_{ks}}{p_{krs}} \right)^{\sigma}. \tag{9}$$

Faced with this demand the small firm maximizes profit by setting the gross price according the standard markup:

$$p_{krs} = \frac{(1 + t_{krs}) \tau_{krs} c_{kr}}{1 - 1/\sigma}. \tag{10}$$

Accumulated profits earned across all markets will just cover fixed costs, which indicates the free entry condition:

$$\sum_s \frac{p_{krs} q_{krs}}{\sigma(1 + t_{krs})} = f^K_{kr} c_{kr}. \tag{11}$$

Associated with this equilibrium condition is M_{kr} the number of entered firms in region r.

2.4 Melitz specific equations

The Melitz model is slightly more complex because there is both entry and selection. We proceed along the same path as the Krugman formulation, but we note that the equilibrium is defined on a representative variety (firm) for each trade link. Demand for the representative variety is

$$\tilde{q}_{mrs} = \lambda^M_{mrs} a0_{ms} A_{ms} \left(\frac{P_{ms}}{\tilde{p}_{mrs}}\right)^{\sigma}. \tag{12}$$

Optimal pricing is given by

$$\tilde{p}_{mrs} = \frac{(1+t_{mrs})\tau_{mrs} c_{mr}}{\tilde{\varphi}_{mrs}(1-1/\sigma)}. \tag{13}$$

We now need a condition that indicates selection into each bilateral market. The marginal firm will be earning zero profits, and Melitz shows how the revenues of the marginal and average firms are related using the distribution of productivity draws. With a Pareto distribution (with shape parameter a) the zero-cutoff profit condition specified on the representative firm's profit is given by

$$\frac{\tilde{p}_{mrs}\tilde{q}_{mrs}}{(1+t_{mrs})} \frac{a+1-\sigma}{a\sigma} = f^M_{mrs} c_{mr}. \tag{14}$$

We still need a zero profit condition that determines how many firms enter (take a productivity draw). A potential entrant has positive expected profits from potentially multiple markets. Equilibrium requires these expected profits just equal the annualized sunk cost associated with establishing a variety. With δ as the rate of firm death we have the following free-entry condition:

$$\sum_s \frac{N_{mrs}}{M_{mr}} \frac{\tilde{p}_{mrs}\tilde{q}_{mrs}(\sigma-1)}{(1+t_{mrs})a\sigma} = \delta f^E_{mr} c_{mr}. \tag{15}$$

Finally, we must establish the productivity of the representative firm, which depends on the density of operating to entered firms and the parameters of the distribution:

$$\tilde{\varphi}_{mrs} = b \left(\frac{N_{mrs}}{M_{mr}}\right)^{-1/a} \left(\frac{a+1-\sigma}{a}\right)^{1/(1-\sigma)}. \tag{16}$$

2.5 Income balance

The final task is to establish income balance, where the nominal expenditures of the representative agent must equal the value of factor endowments, any tariff revenue, plus the capital account surplus. The model is based on real quantities (it is linearly homogeneous in prices), and thus the transfer associated with the capital account must be specified in terms of a real unit. We use the aggregate consumption commodity for the United States as the transfer commodity. Of course, the sum across all regional capital account surpluses is zero (there is no global surplus or deficit), so there is no net impact on equation (8). The regional budget is given by

$$
\begin{aligned}
RA_r = &\sum_{f \notin \tilde{F}} w_{fr} \bar{F}_{fr} \\
&+ \sum_{f \in \tilde{F}} \sum_i \tilde{w}_{fr} \overline{SF}_{fir} \\
&+ \sum_{i \notin K \cup M} t_{isr} c_{is} a0_{ir} A_{ir} \frac{\partial P_{ir}}{\partial [(1 + t_{irs}) \tau_{irs} c_{ir}]} \\
&+ \sum_k t_{ksr} M_{ks} p_{ksr} q_{ksr} / (1 + t_{ksr}) \\
&+ \sum_m t_{msr} N_{ksr} \tilde{p}_{msr} \tilde{q}_{msr} / (1 + t_{msr}) \\
&+ e_{\text{usa}} \overline{BOP}_r.
\end{aligned}
\tag{17}
$$

3 Computation

The plain algebraic formulation of the model presented above hides a few details that facilitate an efficient computational model. The model is solved as a Mixed Complementarity Problem (MCP) within the General Algebraic Modeling System (GAMS) software using the Mathematical Programming System for General Equilibrium (MPSGE) as a subsystem.[4] The base Armington model, formulated using MPSGE, is augmented with the Krugman and Melitz modules as outlined in the decomposition methods suggested by Balistreri and Rutherford (2013).

An MCP takes advantage of *variational-inequality* (or sometimes *complementary-slack*) equilibrium conditions whereby positive variables (prices and activity indexes) are associate with specific inequality constraints. For example, the market clearance condition (4) is actually computed using the following variational-inequality condition:

$$
\begin{aligned}
a0_{ir} A_{ir} - \left(d0_r D_r \frac{\partial e_r}{\partial P_{ir}} + \sum_j y0_{jr} Y_{jr} \frac{\partial c_{jr}}{\partial P_{ir}} \right) &\geq 0; \\
P_{ir} &\geq 0; \text{and} \\
P_{ir} \left[a0_{ir} A_{ir} - \left(d0_r D_r \frac{\partial e_r}{\partial P_{ir}} + \sum_j y0_{jr} Y_{jr} \frac{\partial c_{jr}}{\partial P_{ir}} \right) \right] &= 0.
\end{aligned}
\tag{18}
$$

In words we would say supply is greater than or equal to demand and if the associated price is positive supply equals demand. If supply is greater than demand the associated price

[4]GAMS Development Corporation. General Algebraic Modeling System (GAMS) Release 24.9.1. Washington, DC, USA, 2017. MPSGE is a subsystem written by Thomas F. Rutherford (Rutherford, 1999) that automatically generates and checks consistency of the nonlinear constant-returns system.

in that market must be zero. Competitive production activities have a similar structure—marginal cost may exceed price for slack activities. While in this application the CES technologies and preferences keep the equilibrium away from *corners*, the MCP formulation is computationally efficient and extensible to equilibrium problems that include non-scarce commodities and slack activities.

One additional note on computation is that we take advantage of the *calibrated-share* form of the CES technologies and preferences as suggested by Rutherford (2002). We choose units such that the central prices are one in the benchmark, and the activity indexes are naturally one. This yields an equilibrium problem that is naturally well scaled for computation (the central variables are unity in the known equilibrium). One may relate our scaling strategy to the "exact-hat" methods popular with other authors (Dekle et al., 2008; and Costinot and Rodríguez-Clare, 2014). Like those methods we directly recover the proportional changes in prices and quantity indexes as the equilibrium solution to the numeric problem.