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Taris and Welfare in New Trade Theory Models

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Tariffs and Welfare in New Trade Theory Models

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Abstract

Arkolakis, Costinot and Rodriguez-Clare (ACR, 2012) prove that, conditional on the change in openness, the welfare gains from foreign trade reforms are quantitatively identical across single-sector trade models with radically different micro-foundations. We generalize this result to domestic and multilateral trade reforms. And we extend it to cover revenue-generating import *tariffs*. This gives rise to a new type of welfare isomorphisms across models and liberalization scenarios and allows deriving a structurally identical optimal tariff formula. In contrast to the case of iceberg trade costs, welfare formulas based on tariff reforms are highly nonlinear and build on different types of trade elasticities and openness indices. Most importantly, the ACR iceberg formula *necessarily* underestimates the gains from trade. A stylized calibration of the model shows that the underestimation can be large.

JEL-Classification: F12, R12.

Keywords: Gravity Equation; Monopolistic Competition; Heterogeneous Firms; Armington Model; International Trade; Trade Policy; Gains from Trade

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1 Introduction

How large are the welfare gains from trade liberalization? And how do different trade-induced adjustment mechanisms shape the magnitude of these gains? Many authors have suggested that, through the expansion of available product variety to consumers (as stressed by Krugman (1980)), or through the weeding out of inefficient firms (as analyzed by Melitz (2003)), trade liberalization should yield larger welfare gains than when these mechanisms are not present (as in the perfect competition Armington trade model as used, e.g., by Anderson and van Wincoop, 2003). A recent paper by Arkolakis, Costinot and Rodriguez-Clare (2012, henceforth ACR) has forcefully challenged this view.

ACR derive a simple formula that relates welfare gains to the *change in observed openness* and to the elasticity of trade flows with respect to iceberg trade costs. Since exactly the same formula holds in the Melitz (2003), Krugman (1980) and Armington models, the novel mechanisms stressed in the more recent literature do not add additional welfare gains–conditional, of course, on identical changes in openness.[1] Moreover, the simple ACR formula allows for a very easy quantitative *ex post* evaluation of historical trade liberalization events. So, it appears that the careful micro-level perspective contained in new trade models "has not added much" to the gains from trade analysis.[2] Importantly, ACR's isomorphism is of limited interest for the purpose of *ex ante* analysis, where a key object of interest is the predicted change in openness resulting from some given tariff reform. Since that link does in general differ on the micro-foundation of the underlying trade model, welfare gains do differ.

In this paper, we extend the analysis of ACR to the presence of revenue-generating *ad valorem* tariffs. This is important, because tariffs obviously matter for political debates about the welfare effects of trade reform proposals such as in the context of Doha Round negotiations or related to bilateral trade agreements. Also, it is important to distinguish between multilateral liberalizations and unilateral ones. Unfortunately, the existence of tariff revenue considerably

[1]The equivalence result also obtains in the Eaton and Kortum (2002) Ricardian model as well as in the monopolistic competition trade model with variable markup (Arkolakis, Costinot and Rodriguez-Clare, 2010).

[2]Applying their formula to the US, ACR show that the gains from trade obtained from the class of models encompassed by their analysis, are quantitatively rather small (going from autarky to the status quo leads to welfare gains of 0.7 to1.4% of GDP). This quantitative result results from a very low measure of observed openness.

complicates the analysis of ACR. The welfare formula becomes highly non-linear in the sense that higher openness (based now on lower tariffs) has different effects on welfare depending on the level of openness and the level of the tariff in the initial equilibrium. Moreover, instead of the elasticity on iceberg trade costs, the elasticity on ad valorem tariffs shows up; these two numbers generally do not coincide. Nonetheless, it is possible to establish an isomorphism in the welfare formulas between the Melitz (2003), Krugman (1980), and Armington models, both for the cases of multilateral and unilateral trade liberalization, and in the presence of country asymmetries. Hence, ACR's claim that firm-level productivity heterogeneity and the associated selection effects do not generate additional welfare gains conditional on the change in openness beyond those predicted by simpler models holds more generally than previously established.

As a corollary to this analysis, we retrieve the formula for the optimal tariff in the three model environments. We show that the optimal tariff formulas are also isomorphic: Home's optimal tariff depends on Foreign's share of revenue generated from sales on its domestic market and on the elasticity of trade flows with respect to the ad valorem tariff. This is a novel and non-trivial observation. Simply applying the ACR isomorphism argument to the optimal tariffs results known from the literature (Gros, 1987) for the Krugman (1980) model, one would not be able to retrieve our result. The reason is that ACR's isomorphism results are derived under three macro-restrictions, the first of which (R1, balanced trade) of continues to apply but requires a different implementation in the presence of tariff revenue. This means that the logic of ACR's analysis does not go through without major modification. Nonetheless, the Krugman (1980) and the Melitz (2003) model are still isomorphic even if variation in openness stems from tariffs rather than iceberg trade costs.

Finally, imposing parameter restrictions that ensure model-isomorphisms, we compare welfare effects of trade liberalization as triggered by either a reduction in iceberg trade costs or ad valorem tariffs. Our analytical results establish that the welfare effects differ: tariff liberalization leads to higher welfare gains than lower iceberg trade costs. Calibration and simulation of the model shows that the difference between the two effects can be quantitatively substantial. Hence, for the purpose of ex post policy evaluation, it is of paramount importance to carefully consider the right type of underlying exogenous variation.

Our exercise is related to several strands of literature. First, of course, to the important paper by ACR.[3] Those authors already discuss two cases where their strong equivalence result–identical welfare effects independent of selection effects and endogenous entry–fails. In the presence of *multiple sectors*, some sectors have higher gains under monopolistic competition than under perfect competition, and other sectors have lower gains. The aggregate welfare effect is ambiguous (it depends on the sectoral weights). In the presence of *intermediate goods*, the gains from trade are always larger under monopolistic competition than under perfect competition. For other extensions (variable mark-ups and translog expenditure function with Pareto-distributed productivities), the strong equivalence holds. They also qualify their second main conclusion, namely that the share of expenditure on domestic goods and the trade elasticity jointly suffice for welfare analysis. They show that additional information is required in the case of multiple sectors (sectoral consumption shares and changes in sectoral employment)[4] and in case of intermediate goods (share of intermediate goods in variable and fixed production costs, share of intermediate goods in entry costs, and the elasticity of substitution σ separately from trade elasticity). However, they never touch the distinction between tariffs and iceberg trade costs.[5]

Second, there is a growing CGE literature that discusses the isomorphism discovered by ACR and the role of tariffs versus iceberg trade costs. That literature is simulation-based and does not offer any general analytical results. Balistreri, Hillberry, and Rutherford (2011) argue that "*[revenue-generating tariffs rather than iceberg trade costs] can generate differences in the Melitz formulation relative to a perfect competition model*" (p. 96). They do not, however, isolate the effect of considering revenue-generating tariffs rather than iceberg trade costs, as their

[3]Feenstra (2009) also discusses the welfare gains from trade in monopolistic competition trade models and discusses the (absence of) fundamental differences between the Krugman (1980) and the Melitz (2003) models. Chaney (2008) shows that the gravity equation derived from a Melitz-type model without free entry is structurally similar to the equation based on the Armington model as explained by Anderson and van Wincoop (2003).

[4]This point is related to Balistreri et al. (2010) who show that equivalence of Armington and Melitz breaks in the presence of a second sector (is this case, the second sector competing for labor is leisure). They, too, abstract from tariffs.

[5]In their footnote 33 ACR acknowledge a potential issue: "*To the extent that they act as cost-shifters, tariffs can be used, like any other variable trade costs, to obtain estimates of the trade elasticity using a gravity equation. By contrast, our main welfare formula would need to be modified to cover the case of tariffs. In particular, the results derived in Section II ignore changes in tariff revenues, which may affect real income both directly and indirectly (through the entry and exit of firms).*" In their analysis of tariff reform in Costa Rica, that also draws on a Melitz-Pareto model, Arkolakis et al. (2008) model trade reform as lower iceberg costs. They write "*One drawback of the model we present here is that we treat tariffs as transportation costs*".

framework also features multiple sectors and multiple factors. In a related paper, Balistreri and Markusen (2009) show that "*removing rent-generating tariffs have different effects in monopolistic competition versus Armington models, because optimal tariffs are different*". But, they abstract from firm-level heterogeneity. Balistreri and Rutherford (2012) argue that "*one can not consider [iceberg trade costs] equivalent to tariffs*" (p. 21). In a three-country, three-goods model, they show that in all settings – Armington, Krugman, and Melitz – any country unilaterally has an incentive to deviate from free trade and to impose an import tariff. Balistreri and Rutherford (2012) compare the effect of a 50% reduction in observed tariffs across an Armington and Melitz model. They find that the "*Melitz structure indicates larger average welfare gains*" (p. 38) and that "*[t]he strong equivalence result suggested by Arkolakis et al. (2008) and by Arkolakis et al. (forthcoming) are not supported in [the] empirical model*" (p. 38). They do not contrast the effects of tariff reform to reductions in iceberg trade costs.

The CGE literature relies on simulation. However, there is a third strand of research that provides analytical results on the contrast between iceberg trade costs and tariffs. Using a model with heterogeneous firms, Cole (2011a) illustrates that profit for an exporter is more elastic in response to tariffs than iceberg transport costs, which affects the entry/exit decision of firms. In a related paper, Cole (2011b) investigates the roles of different types of trade costs in a gravity equation of the type derived by Chaney (2008). He shows that the trade flow elasticity of tariffs is larger than that of iceberg trade costs. So, estimates derived from variables such as distance may underestimate the trade enhancing effects of tariff reform. More closely connected to our work, Schröder and Sørensen (2011) study a symmetric Melitz (2003) model and provide a welfare ranking of different *multilateral* trade policy instruments (unit and ad valorem tariffs with partial redistribution, variable iceberg trade costs, and fixed export costs). Different to us, they do not link their work to ACR and provide only a local characterization of welfare as a function of observed openness. Instead they focus on the role of redistribution in shaping the welfare ranking.

Finally, our paper also relates to literature on asymmetric Melitz (2003) models. The first such models were proposed by Falvey et al. (2006) and Demidova (2008). Unlike our paper, these authors assume the existence of an active linear outside sector which leads to factor price insensitivity. Pflüger and Russek (2011a,b) use these models to study the role of industrial policies and how they are shaped by cross-country endowment differences. These two-industry models allow for an elegant and tractable analysis, but they usually come with the cost of fixing factor prices. Another strand of literature studies small country versions of he Melitz (2003) model, also with the aim of simplifying the analysis of commercial policy options (Demidova and Rodriguez-Clare, 2009; Jung, 2012).

The remainder of the paper is structured as follows. Section 2 introduces the model setup, Section 3 derives our theoretical results. Section 4 provides a calibration and numerical analysis of the model to obtain a sense on the quantitative importance of our findings. Section 5 concludes.

2 Theoretical Framework

2.1 General Setup

We assume a world of two one-sector countries, Home and Foreign, indexed by $i \in \{H, F\}$, that may differ with respect to the size of their endowments.[6] Representative households in both countries have symmetric CES preferences (Dixit-Stiglitz) over differentiated varieties of final consumption goods,

$$U_i = \left(\int_{\omega \in \Omega_i} q[\omega]^{\rho} \, d\omega \right)^{1/\rho}, i \in \{H, F\}, \tag{1}$$

where Ω_i is the set of varieties available in country i, $q[\omega]$ is the quantity of variety ω consumed and $\sigma = 1/(1-\rho) > 1$ is the constant elasticity of substitution.[7] The price index dual to (1) is $P_i^{1-\sigma} = \int_{\omega \in \Omega_i} p[\omega]^{1-\sigma} \, d\omega$.

Labor is the only factor of production and is supplied inelastically at quantity L_i and price w_i. International trade is subject to frictions while intranational trade is frictionless. In all models considered, exporting from i to j involves iceberg trade costs τ_{ij}, where $\tau_{ii} = 1$. The key

[6] ACR allow for an arbitrary number of countries. One key insight in their analysis is that each country's welfare depends only on its own level of 'autarkiness', and not on the possibly complicated structure of the rest of the world. Therefore, restricting the analysis to two countries comes at little loss of generality. Moreover, we do not want to restrict attention to 'foreign' shocks (as ACR); to give meaning to this we need to fully close the model. This is easiest with just two countries.

[7] We use square brackets to denote functional relationships.

difference to ACR is that each country j may impose an *ad valorem tariff* $t_{ji} \geq 1$ on its imports from country i, where $t_{ii} = 1$. We assume that tariff revenue is redistributed lump sum.[8] As opposed to iceberg trade costs, a tariff distorts consumption decisions towards domestic goods but does not generate loss in transit. Finally, in all models, we impose that trade is balanced.[9]

2.2 Non-equivalence of total expenditure and total revenue

In the presence of tariffs, aggregate expenditure Y_i is given by

$$Y_i = \sum_{j \in \{H,F\}} t_{ij} X_{ji}, \tag{2}$$

where X_{ji} denotes the value of country i's imports from country j net of the tariff.

In the absence of tariffs, balanced trade, $X_{HF} = X_{FH}$, follows from representative agents in both countries being on their respective budget constraints. Then, total expenditure in country i, $Y_i = \sum_{j \in \{H,F\}} X_{ji}$, is equal to total revenues earned by firms in country i, $R_i = \sum_{j \in \{H,F\}} X_{ij}$. This equivalence, $Y_i = R_i$, constitutes the macro-level restriction R1 in ACR.

Consider now a situation with tariffs. As before, the value of exports has to be equal to the value of imports. The latter has to be calculated net of the tariff, such that $X_{HF} = X_{FH}$. The key difference is that balanced trade no longer implies that total expenditure of a country equals total revenues. In fact, we have

$$Y_i - R_i = (t_{ij} - 1) X_{ij} = (t_{ij} - 1) X_{ji} \geq 0,$$

where the equality only holds in the complete absence of tariffs.

We denote by

$$\lambda_{ij} \equiv \frac{t_{ji} X_{ij}}{Y_j},$$

the share of country j's total *expenditure* that is devoted to goods from country i. It is important

[8] Ossa (2011) assumes that tariff revenue is wasted; Schröder and Sörenson (2011) parameterize the degree of redistribution efficiency.

[9] Arkolakis et al. (2012) introduce three macro restrictions that have to hold across all models; we assume the same restrictions. However, their restriction R1 as stated formally in their paper fails to apply with revenue-generating tariffs.

to note that this share takes into account that consumers may pay a tariff on their imports. In a similar way, we denote by

$$\tilde{\lambda}_{ij} \equiv \frac{X_{ji}}{R_j},$$

the share of country j's *revenues* earned from selling to country i. In general, these two shares differ from each other and we have $\lambda_{ij} \geq \tilde{\lambda}_{ij}$. They coincide only in the absence of tariffs.

ACR express country j´s welfare as a function of its spending on domestic goods $\lambda_{jj} = X_{jj}/Y_j$. That share is referred to as the country's "autarkiness"; $1 - \lambda_{jj}$ would then be its openness. The simplicity of ACR's analysis very much hinges on the fact that λ_{jj} summarizes the country's stance relative to the rest of the world (consisting, potentially, of many countries). In the presence of tariffs, one must define two different versions of the "autarkiness" variable. Using balanced trade, we can rewrite λ_{jj} and $\tilde{\lambda}_{jj}$ as

$$\lambda_{jj} = \frac{1}{1 + t_{ji}X_{ij}/X_{jj}} \text{ and } \tilde{\lambda}_{jj} = \frac{1}{1 + X_{ij}/X_{jj}}. \tag{3}$$

Clearly, $\lambda_{jj} \leq \tilde{\lambda}_{jj}$, where the equality holds for $t_{ji} = 1$. To intuition is that a tariff drives a wedge between domestic expenditure for imports and export sales generated abroad. Balanced trade ties together export sales (net of the tariff), which, in turn, implies that income spent on imports is larger than export sales. Given that there is no tax on domestic goods, expenditure for domestic goods equals revenues earned on the domestic market. Combining these observations, we obtain the claim that $\lambda_{jj} \leq \tilde{\lambda}_{jj}$.

We distinguish between two types of market structure: (i) monopolistic competition with free entry and (ii) perfect competition. The first situation is captured by a Melitz (2003) framework with asymmetries and Pareto-distributed firm-level productivities. As shown by Burstein and Vogel (2011), the Melitz-Pareto model collapses to the Krugman model when the associated gravity trade elasticities are constrained to be identical. In the remainder, for brevity, we refer to this model as to the M-model. The second case is the simple Armington model, referred to as the A-model. We start with a brief overview of equilibrium conditions for the M-model.

2.3 Equilibrium conditions in the Melitz-Pareto model

Firms compete monopolistically. After paying innovation costs $w_i f^e$ each draws its productivity level φ from a Pareto distributed c.d.f. $G[\varphi] = 1 - \varphi^{-\theta}$, where $\varphi > 1$.[10] The restriction $\theta > \sigma - 1$ guarantees the existence of a well-defined size distribution. Output is linear in φ. Additional to variable trade costs, a firm in country i has to pay fixed access costs $w_i f_{ij}$ to enter country j. We set $f_{ii} = f_{jj} = f^d$ and $f_{ij} = f_{ji} = f^x$. Under monopolistic competition with Dixit-Stiglitz preferences, firms charge a constant mark-up $1/\rho$ over marginal costs. The presence of export fixed costs and firm-level productivity heterogeneity induces selection into exporting. By affecting firm selection, trade liberalization (whether in the form of lower tariffs or lower iceberg costs) may have implication for macroeconomic outcomes such as welfare per capita. Burstein and Vogel (2011) show that when the Pareto shape dispersion parameter converges to its lower bound (i.e., if $\theta \to \sigma - 1$), the effect of fixed export costs is shut down and the Melitz (2003) model generates the same outcomes as the Krugman (1980) model.[11]

The first set of equilibrium conditions is made up of four *zero cutoff-profit conditions* (ZCPs). They determine the productivity φ^*_{ij} of those firms in country i which just break even by selling to market j :

$$r_{ij}\left[\varphi^*_{ij}\right] = \sigma w_i f_{ij}, \quad i \in \{H, F\}, \quad j \in \{H, F\}, \tag{4}$$

where $r_{ij}[\varphi] = Y_j P_j^{\sigma-1} t_{ji}^{-\sigma} \left(\frac{\rho}{\tau_{ij} w_i}\varphi\right)^{\sigma-1}$ is revenue of firm φ located in i earned from sales in country j. The price index P_i is given by

$$P_i^{1-\sigma} = \frac{\theta}{\theta - (\sigma - 1)} \sum_{j \in \{H,F\}} m_{ji} N_j \left(\frac{\rho \varphi^*_{ji}}{w_j \tau_{ji} t_{ij}}\right)^{\sigma-1}, \tag{5}$$

where N_j denotes the mass of domestic firms operating in j and $m_{ji} = \left(1 - G\left[\varphi^*_{ji}\right]\right) / \left(1 - G\left[\varphi^*_{jj}\right]\right) = \left(\varphi^*_{jj}/\varphi^*_{ji}\right)^{\theta}$ is the probability of exporting (the export participation rate).

The second set of conditions is made up of two *free entry conditions*, which make sure that

[10] In Felbermayr et al. (2012), we allow for countries to differ with respect to technology. In that paper, we show that endowment asymmetries and technology differences have isomorphic effects on optimal tariffs.

[11] Additionally, to ensure identical endogenous outcomes one requires $f^x = f^d$.

expected profits equalize the costs of innovation

$$\frac{\sigma-1}{\theta-(\sigma-1)}\left(\varphi_{ii}^{*}\right)^{-\theta}\sum_{j\in\{H,F\}}m_{ij}f_{ij}=f^{e},\;\; i\in\{H,F\}\,. \tag{6}$$

Finally, there are two *labor market clearing conditions*

$$N_i=\frac{\rho}{\theta f^{e}}L_i\left(\varphi_{ii}^{*}\right)^{-\theta},\;\; i\in\{H,F\}\,. \tag{7}$$

These conditions make up a system of eight equations in eight unknown endogenous variables $\{\varphi_{HH}^{*},\varphi_{FF}^{*},\varphi_{HF}^{*},\varphi_{FH}^{*},N_H,N_F,w_H,w_F\}$.

Finally, note that, in the M-model, we can express 'autarkiness' as $\lambda_{ii}^{M}=\left(1+t_{ij}m_{ij}f^{x}/f^{d}\right)^{-1}$, with $\tilde{\lambda}_{ii}^{M}$ resulting by simply replacing $t_{ij}=1$ in the expression for λ_{ii}^{M}.

2.4 Equilibrium conditions in the Armington model

As in Anderson and van Wincoop (2003) we assume that each of the two countries is exogenously specialized on a subset of varieties of similar measure normalized to unity. There are no fixed costs, technology is linear, firms are identical and operate under perfect competition. Under these circumstances, the utility function (1) simplifies to $U_i=\left(q_{ii}^{\rho}+q_{ji}^{\rho}\right)^{1/\rho}$.

The key equilibrium condition is the goods/labor market clearing condition

$$L_i=\sum_i \tau_{ij}q_{ij}, i\in\{H,F\}\,. \tag{8}$$

Optimal demand is given by

$$q_{ij}=Y_iP_i^{\sigma-1}\left(w_j\tau_{ji}t_{ij}\right)^{-\sigma}, \tag{9}$$

where the price index is $P_i^{1-\sigma}=\sum_j\left(\tau_{ji}t_{ij}w_j\right)^{1-\sigma}$. Total expenditure is defined as $Y_i=\sum_j t_{ij}X_{ji}=w_iL_i+\sum_j\left(t_{ij}-1\right)X_{ji}$, with export sales given by $X_{ij}=\tau_{ij}w_iq_{ij}$. Substituting into (8), one obtains two equations in the two endogenous variables $\{w_H,w_F\}$.

In the A-model, autarkiness is given by $\lambda_{ii}^{A}=\left[1+\left(\tau_{ji}t_{ij}w_j/w_i\right)^{1-\sigma}\right]^{-1}$ and $\tilde{\lambda}_{ii}^{A}=\left[1+t_{ij}^{-\sigma}\left(\tau_{ji}w_j/w_i\right)^{1-\sigma}\right]^{-1}$.

3 Welfare gains from trade reforms

This section presents analytical results on three distinct scenarios: (i) multilateral trade liberalization of tariffs and iceberg costs in a symmetric world, (ii) unilateral liberalization of tariffs and iceberg costs, (iii) multilateral liberalization in an asymmetric world. First, however, we offer a replication and generalization of ACR's results.

3.1 Replicating and generalizing ACR

To replicate ACR's findings, and to understand the role of tariff revenue in the welfare equation, we first abstract from tariffs, $t_{ij} = 1$. Consequently, $\lambda_{ii} = \tilde{\lambda}_{ii}$. Under this simplification, in the M-model, we can back out real per capita from the domestic entry condition as

$$W_i^M = \frac{w_i^M}{P_i^M} = \rho \left(\sigma f^d\right)^{1/(1-\sigma)} L_i^{1/(\sigma-1)} \varphi_{ii}^* \Longrightarrow \hat{W}_i^M = \hat{\varphi}_{ii}^* = -\hat{\lambda}_{ii}/\theta. \tag{10}$$

That is, welfare increases if the domestic productivity cut-off goes up, so that the marginal and average domestic firms are larger, more productive, and their average output cheaper. To replace $\hat{\varphi}_{ii}^*$ by an expression in $\hat{\lambda}_{ii}^M$, we totally differentiate the definition of λ_{ii}^M to obtain $\hat{\lambda}_{ii}^M = -(1-\lambda_{ii})\,\hat{m}_{ij}$. Not surprisingly, higher export participation lowers 'autarkiness'. Next, the change in export participation can be expressed as $\hat{m}_{ij} = \theta\left(\hat{\varphi}_{ii}^* - \hat{\varphi}_{ij}^*\right)$. Finally, the free entry condition relates domestic and export cutoff productivities such that $\hat{\varphi}_{ii}^* = -(1-\lambda_{ii})\,\hat{\varphi}_{ij}^*/\lambda_{ii}$. This allows us to rewrite welfare as a function of 'autarkiness' $\hat{W}_i^M = -\hat{\lambda}_{ii}/\theta$.

The corresponding relation for the A-model is found from the optimal quantity sold domestically $q_{ii} = Y_i P_i^{\sigma-1} w_i^{-\sigma}$, with $Y_i = w_i L_i$ substituted:

$$W_i^A = \frac{w_i^A}{P_i^A} = L_i^{1/(\sigma-1)} q_{ii}^{1/(1-\sigma)} \Longrightarrow \hat{W}_i^A = \frac{1}{1-\sigma}\hat{q}_{ii}. \tag{11}$$

So, forcing the representative household to consume more of the domestic variety depresses its utility. Note that the welfare equations W_i^M and W_i^A already reveal telling parallel structures. In the M-model, the domestic productivity cutoff φ_{ii}^* is a sufficient statistic for welfare; in the A-model the quantity of domestic output consumed locally q_{ii} plays the same role. Also, in the reduced form expressions shown in (10) and (11), population size plays an isomorphic role for the level of welfare.

Now, in the Armington model, one can show that $\hat{q}_{ii} = \hat{\lambda}_{ii}$, i.e., the change of country $i's$ degree of 'autarkiness' is directly proportional to the change in the quantity of the domestic good demanded in country i.

Lemma 1 ***(ACR generalized)*** *In the absence of tariffs* ($t_{ij} = 1$)*, welfare changes according to*

$$\hat{W}_i = -\frac{1}{\varepsilon}\hat{\lambda}_{ii}, \tag{12}$$

where $\varepsilon = \theta$ *in the Melitz model and* $\varepsilon = \sigma - 1$ *in the Krugman as well as in the Armington models.*

Proof. In the text and Appendix. ■

Integrating, we can write the formula in Lemma 1 as $W_i(\lambda_{ii}) = W_i(1)\lambda_{ii}^{-1/\varepsilon}$, where $W_i(1)$ is the level of autarky welfare (the constant of integration). The formula is identical to ACR's, but our analysis is more general than theirs: we have made no assumptions on the origin of exogenous shocks and whether, when they effect trade costs, they are unilateral or multilateral. In their original derivations, ACR relate domestic welfare changes in a country to unilateral iceberg trade cost or foreign market size shocks. The formula is helpful for the *ex post* welfare evaluation of trade reform scenarios which can be carried out with information on the change in 'autarkiness' and the trade elasticity ε only. Econometrically, that elasticity is independent of the exact microfoundation of the estimated gravity model. However, it has different economic interpretation. If the underlying structural model is the Armington model, then ε corresponds the elasticity of substitution across varieties, therefore controlling to what extent foreign varieties complement domestic ones giving rise to consumption gains from trade. In the Krugman (1980) model, ε plays the same role, but it also governs the degree of love for variety and, hence, the gains from the availability of new varieties. Finally, in the Melitz (2003) model with Pareto distributed productivity, ε is inversely related to the degree of productivity dispersion which, in turn, determines the distribution of prices. So, for the quantitative welfare implications of trade reform, conditional on the degree of autarkiness, the microfoundations do not matter.

3.2 The role of tariff revenue

In the case of tariff reform, the analysis is more complicated for the following reasons. First, the change of a tariff affects λ_{ii} not only through adjustments in equilibrium cutoffs or quantities, but also directly. In the M-model, therefore, we need to derive the impact of a change in the tariff on the domestic entry cutoff, which then allows writing change in λ as a function of the change in the domestic entry cutoff. Second, the welfare equations used in Section 3.1 are not suitable when one considers tariff reforms because they ignore tariff income. Tariff revenue is redistributed to consumers in a lump-sum fashion and has to be taken into account when computing real per capita income. It is convenient to work with the indirect utility function. Using optimal demand and the zero cutoff profit conditions, we obtain

$$W_i^M = (\sigma - 1)\left(\frac{\theta}{\theta - (\sigma - 1)}\sum_j m_{ji} N_j \left(\frac{f_{ji}}{\tau_{ji}}\varphi_{ji}^*\right)^\rho\right)^{\frac{1}{\rho}}.$$

In changes, we have

$$\begin{aligned}\hat{W}_i^M &= \rho^{-1}\left(\lambda_{ii}\left(\rho\hat{\varphi}_{ii}^* + \hat{N}_i\right) + (1-\lambda_{ii})\left(\rho\hat{\varphi}_{ji}^* + \hat{N}_j + \hat{m}_{ji}\right)\right) \\ &= -\frac{\theta-\rho}{\rho}\left(\lambda_{ii}\hat{\varphi}_{ii}^* + (1-\lambda_{ii})\,\hat{\varphi}_{ji}^*\right), \end{aligned} \tag{13}$$

where the second equation follows from labor market clearing, $\hat{N}_j = -\theta\hat{\varphi}_{jj}^*$. We therefore have to write the change in the import cutoff $\hat{\varphi}_{ji}^*$ as a function of the change in the domestic entry cutoff $\hat{\varphi}_{ii}^*$.

For the A-model, welfare in changes is given by

$$\hat{W}_i^A = \lambda_{ii}\hat{q}_{ii} + (1-\lambda_{ii})\,\hat{q}_{ji}. \tag{14}$$

Comparing expressions (13) and (14), constants apart, we find again that productivity cutoffs in the M-model and consumed quantities in the A-model play similar roles in determining welfare. However, in contrast to the expressions (10) and (11), reducing the left-hand-sides to a single endogenous variable (φ_{ii}^*, q_{ii}) is much more involved as the restrictions tying those variables to imports are complicated by the presence of tariffs.

3.3 Symmetric countries

In the presence of symmetric countries, the welfare analysis is simple because there are no wage differences across countries. An important limitation is, however, that we have to restrict ourselves to *multilateral* liberalization in order to maintain symmetry of countries. Under these circumstances, one can show the following result.

Lemma 2 ***(Multilateral tariff reform and symmetry.)*** *With symmetric countries, multilateral liberalization of tariffs leads to exactly the same relationship between welfare and 'autarkiness' across the Melitz, Krugman and Armington models*

$$\hat{W} = -\frac{1}{\rho}\frac{t-1}{t}\tilde{\lambda}\hat{\lambda}. \tag{15}$$

Proof. M-model: The relative zero cutoff profit conditions relate the change in the cutoffs to the change in tariffs: $\hat{\varphi}^x - \hat{\varphi}^d = \hat{t}/\rho$. Using the free entry condition, we can write the change in the domestic cutoff as a function of the change in the tariff: $\hat{\varphi}^d = -(1-\tilde{\lambda})\hat{t}/\rho$. Substituting out $\hat{t}$ from the differenced definition of $\hat{\lambda}$ we obtain $\hat{\lambda} = -(1-\lambda)(\theta-\rho)\hat{\varphi}^d/(1-\tilde{\lambda})$. With symmetric countries, the import cutoff productivity level equals the export cutoff productivity level. Exploiting this observation and using the free entry condition, we can rewrite welfare as $\hat{W} = (\theta-\rho)(t-1)\lambda\hat{\varphi}^d/\rho$. Putting things together yields the result stated in the Lemma.
A-model: The degree of autarkiness changes according to $\hat{\lambda} = (1-\lambda)(\sigma-1)\hat{t}$. Market clearing implies $\left(1-\tilde{\lambda}\right)\hat{q}^m = -\tilde{\lambda}\hat{q}^x$ and relative demand $\hat{q}^x - \hat{q}^d = -\sigma\hat{t}$. Inserting these observations into the welfare function $\hat{W} = \lambda\hat{q}^d + (1-\lambda)\hat{q}^x$ and recognizing that $\left(\tilde{\lambda}/\lambda\right)(1-\lambda)/\left(1-\tilde{\lambda}\right) = t$, the observation in the Lemma follows. ■

Compared to the case of iceberg trade costs (12), *ex post* quantification of tariff reform is more complicated. First, one cannot simply integrate the expression to obtain levels, since the level of tariffs figures prominently in the derivation of the welfare effects. Similarly (and related), the level of autarkiness matters for the elasticity as well. Second, it is not the trade flow elasticity (θ in the case of the Melitz (2003) model or $\sigma-1$ in the case of Krugman (1980)) that governs the welfare-openness link, but the demand elasticity ρ. That elasticity is the same with or without selection effects, so equation (15) is isomorphic across the Melitz and the Krugman worlds.

Evaluated at the zero-tariff, $t = 1$, we have $\hat{W} = 0$. The intuition is that a negligibly small positive tariff only transfers income from one country to the other without any distortionary effects. Note that, in the M-model, as $t \to 1$ and $\tau \to 1$, 'autarkiness' converges to $\underline{\lambda}^M \geq 1/2$ even in the case of symmetry. This is due to the presence of fixed market access costs. In the A-model, by symmetry, we have $\underline{\lambda}^A = 1/2$. However, if $f^x = f^d$ in the Melitz model, or $\beta = \sigma - 1$, we have $\underline{\lambda}^M = \underline{\lambda}^A = 1/2$. We are now ready to state the following Proposition:

Proposition 1 ***(Multilateral trade liberalization with symmetric countries.)*** *In two-country Armington, Krugman, or Melitz models, with identical technologies and endowments, conditional on openness, gains from trade due to lower tariffs are always weakly superior to gains from lower iceberg trade costs.*

Proof. Denote by $W^t(\lambda)$ the welfare level as a function of the tariff with $\tau = 1$, and by $W^\tau(\lambda)$ the welfare level as a function of iceberg costs with $t = 1$. Notice that (i) $W^t(1) = W^\tau(1)$, (ii) $W^t(\underline{\lambda}) = W^\tau(\underline{\lambda})$, (iii) $W^t(\lambda)$ is a decreasing, concave function of λ, (iv) $W^\tau(\lambda)$ is a decreasing, convex function of λ. We prove concavity of $W^t(\lambda)$ in the Appendix for the M-model. The claim follows directly from these four observations. ■

Figure 1: Gains from trade: multilateral trade liberalization

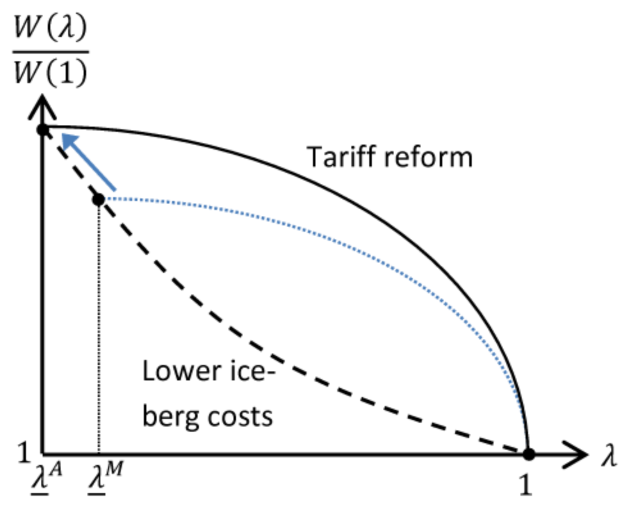


Figure 1 illustrates how welfare changes with λ. The dashed convex curve corresponds to the $W^{\tau}(\lambda)$.[12] The solid concave curve corresponds to $W^{t}(\lambda)$ under the additional assumption that $f^x = f^d$ (so, $\underline{\lambda}^M = \underline{\lambda}^A = 1/2$).[13] Regardless of whether τ or t is adjusted–the 'free' trade or the autarky equilibria always deliver identical levels of welfare.[14] Across both scenarios, 'autarkiness' λ increases in trade costs, and welfare falls in 'autarkiness'. We know that, at $t = 1$, the marginal effect of a tariff reform is zero; so, at $\underline{\lambda}^A$, we must have $W'(\lambda) = 0$. In contrast, welfare changes from lower iceberg costs are never zero.[15] If $f^x > f^d$, the 'free' trade levels of autarkiness differ across the A and the M model. Still, it must be true that $W^t(\underline{\lambda}^M) = W^{\tau}(\underline{\lambda}^M)$. At that point, the slope of $W^t(\underline{\lambda})$ is zero, while it is strictly negative for $W^{\tau}(\underline{\lambda})$. So, conditional on openness, the Krugman and Armington models feature higher levels of welfare.

3.4 Asymmetric countries

With asymmetric countries, we can no longer fix the wage rate, which complicates the analysis. Fortunately, one can express the wage as a function of the domestic entry cutoff, or analogously, by the domestic consumption quantity and proceed as in the previous subsection. For that purpose, we solve the log-linearized system of equilibrium conditions, allowing for differences in country sizes L_H and L_F as well as in tariffs t_H and t_F. Taking endogenous wage adjustments into account, we first consider unilateral trade liberalization ($\hat{t}_H \neq 0$, $\hat{t}_F = 0$) and then revisit multilateral liberalization with asymmetric countries ($\hat{t} \equiv \hat{t}_H = \hat{t}_F$).

3.4.1 Unilateral tariff reform

Lemma 3 ***(Welfare with unilateral tariff reforms.)*** *In two-country Armington, Krugman and Melitz models, with asymmetric endowments, unilateral tariff reform of country H affects*

[12] Convexity is an immediate consequence of the ACR formula displayed in Lemma 1.

[13] This is the case in the Krugman (1980) model.

[14] Note that, despite perfect symmetry, 'free' trade does not imply that $\lambda = 1/2$ because there are fixed market access costs. So the lowest level of 'autarkiness' is given by $\underline{\lambda} > 1/2$.

[15] Using concepts from the geometrical inspection of gains from trade, illustrated e.g., in Bhagwati, Panagariya and Srinivasan (1998), iceberg costs generate 'rectangular' welfare losses, while tariffs produce 'triangular' dead weight efficiency losses ("Harberger triangles"). The latter rely on infra-marginal effects, while the former do not. This observation suggests that our result as highlighted in Figure 1 applies to a broader class of models than generalizations of the Krugman (1980) setup.

welfare in H and F according to

$$\hat{W}_H = \frac{1}{\rho}\frac{t_H - 1}{t_H}\frac{1/\left(t_H - 1\right) - \left(\zeta - 1\right)\tilde{\lambda}_{FF}}{1 - \tilde{\lambda}_{HH} + \left(\zeta - 1\right)\tilde{\lambda}_{FF}}\tilde{\lambda}_{HH}\hat{\lambda}_{HH}, \tag{16}$$

$$\hat{W}_F = -\frac{1}{\varepsilon}\hat{\lambda}_{FF} \tag{17}$$

where $\zeta > 1$ is the gravity elasticity of trade with respect to an ad valorem tariff, structurally given by

$$\zeta = \begin{cases} \frac{\theta}{\rho} & \text{in the Melitz (2003) model} \\ \sigma & \text{in the Krugman (1980) and Armington models} \end{cases},$$

and $\tilde{\lambda}_{ii}$ is country i's, $i \in \{H, F\}$ share of revenues earned domestically.

Proof. In the Appendix. ■

Equation (16) bears resemblance to equation (15), which was derived under the assumption of symmetry. The relevant gravity elasticity ζ is different from the one discussed by ACR: not surprisingly, what matters for welfare in the context of tariff reform, is not the elasticity of trade flows with respect to iceberg trade costs ε but the elasticity with respect to ad valorem tariffs ζ. Additionally, the welfare change depends on the level of the tariff t_H and on the level of $\tilde{\lambda}_{HH}$, the relevant 'autarkiness' measure. Besides ζ, welfare also depends separately on ρ. Most importantly, however, the sign of the welfare change is no longer unambiguously negative. The reason, of course, lies in the fact that, from $H's$ perspective, their exists a strictly positive optimal tariff. In particular, the sign of $\hat{W}_H$ depends on t_H. In contrast, for Foreign (which, by assumption, does not impose a tariff), the welfare formula is given by the ACR equation. This establishes that the ACR formula also encompasses *foreign* tariff changes.

Based on (16), one can retrieve a formula relating openness and the optimal tariff. For a tariff close enough to zero, we are sure that $\hat{W}_H/\hat{\lambda}_{HH} > 0$. For large tariffs, in contrast, we have $\hat{W}_H/\hat{\lambda}_{HH} < 0$. By continuity, there exists an optimal tariff that satisfies the first order condition $\hat{W}_H/\hat{\lambda}_{HH} = 0$.

Lemma 4 ***(Optimal tariff.)*** *In a two-country world, the optimal tariff of Home is given by*

$$t_H^* = \left[\tilde{\lambda}_{FF}\left(\zeta - 1\right)\right]^{-1} + 1, \tag{18}$$

where $\zeta > 1$ is the elasticity of trade with respect to an ad valorem tariff, with $\zeta = \theta/\rho$ in the Melitz (2003) model and $\zeta = \sigma$ in the Krugman (1980) and Armington models and $\tilde{\lambda}_{FF}$ is Foreign's share of revenues earned domestically.

Proof. The optimal tariff satisfies $\hat{W}_H/\hat{t}_H = 0$. Since all variation in λ_{HH} is due to variation in t_H, the requirement is equivalent to $\hat{W}_H/\hat{\lambda}_{HH} = 0$. The optimal tariff formula then follows directly from equation (16). ■

Note that the optimal tariff formula (18) is mathematically the same regardless of whether selection effects are present or not. For the Krugman (1980) case, it has been derived by Gros (1987); for the Melitz (2003) model by Felbermayr, Jung and Larch (2011). These papers have not revealed the fundamental isomorphism of the optimal tariff formula across the Armington, Krugman and Melitz models and have not identified the crucial elasticity ζ as the elasticity from an empirical gravity model on the *ad valorem* tariff. However, the latter paper already contains the observation that the Melitz (2003) trade cost elasticity θ does not suffice to determine the optimal tariff. Also, the country's share of spending on domestic varieties over total expenditure is not the relevant openness statistic; rather it is the trade partner's spending on its domestic varieties relative to total foreign *revenue* (not expenditure), $\tilde{\lambda}_{FF}$. As the tariff elasticity of trade flows, the $\tilde{\lambda}_{FF}$ statistic is much less readily available obtainable from standard data sources.

The isomorphism of the optimal tariff formula is surprising, since it implies that, conditional on $\tilde{\lambda}_{FF}$, the different externalities present in the different models yield exactly the same corrective import tax. The Armington and Krugman models feature terms-of-trade externalities and mark-up distortions, the Melitz model adds an additional entry distortion; see Demidova and Rodriguez-Clare (2009).

Note that (18) collapses to

$$t_H^* = \frac{1}{\zeta - 1} + 1 > 0 \tag{19}$$

when H is a small country, i.e., when $\tilde{\lambda}_{FF} = 1$. Then, the rationale for optimal tariffs cannot lie in the presence of terms-of-trade effects. For example, $t_H^* = (1/\rho)\left[\rho\theta/(\theta - \rho)\right]$ in the small-economy Melitz model studied by Demidova and Rodriguez-Clare (2009). In that setup, the tariff corrects for a markup distortion $(1/\rho)$ and an entry distortion $\rho\theta/(\theta - \rho)$. The former but not the latter arises also in the Krugman (1980) model, which is characterized by letting

$\theta \to \rho/(1-\rho)$. Then, the optimal tariff formula further simplifies to $t_H^* = 1/\rho$, which is just equal to the markup in the monopolistic competition model with CES preferences. The same optimal tariff applies in the Armington model; however, for a different reason. There, since each country produces a distinct variety, firms have jointly market power, even if the share of foreign spending falling on their variety $\left(1-\tilde{\lambda}_{HH}\right)$ goes to zero.

Although (18) is the first order condition associated to (16), it is fundamentally different in that the left-hand-side, t_H^*, is crucial in determining $\tilde{\lambda}_{FF}$. The equation therefore identifies merely a *correlation* between two endogenous variables. Equation (16), in contrast, has a *causal* interpretation: higher tariffs affect openness, and this changes the level of welfare. Nonetheless equation (18) can be useful in assessing how much multinational tariff reforms (through WTO rounds) restrict individual countries. With low tariffs, one does not make a quantitative large error by setting $\tilde{\lambda}_{FF} = \lambda_{FF}$. Additionally assuming a symmetric distribution of endowments and technologies across the world, it is easy to see that with λ_{FF} around 0.2 and a standard choice of σ around 1.4, t_H^* is in the neighborhood of 140%. The equation also shows that higher foreign openness (caused by determinants other than Home's tariffs) creates incentives to increase the tariff that Home imposes.

Proposition 2 ***(Unilateral trade liberalization.)*** *In the two-country Armington, Krugman and Melitz models, with identical technologies and endowments, conditional on openness, welfare gains from unilateral trade liberalization due to lower tariffs are always weakly superior to welfare gains from lower iceberg trade costs.*

Proof. Let $W_H^t(\lambda_{HH})$ denote the level of welfare attainable through variation in tariffs t, and $W_H^\tau(\lambda_{HH})$ the level of welfare attainable through variation in iceberg trade costs τ. Let $\underline{\tilde{\alpha}}$ the level of autarkiness that obtains if both $t=1$ and $\tau=1$ (but $f^x/f^d > 1$). Clearly, in that cases, $W_H^t(\underline{\lambda}_{HH}) = W_H^\tau(\underline{\lambda}_{HH}) = W_H(\underline{\lambda}_{HH})$. Similarly, of trade frictions are prohibitive, i.e., under autarky, $W_H^t(1) = W_H^\tau(1) = W_H(1)$. Equation (12) and ACR show that if welfare variation is due to changes in τ (and $t=1$), $W_H^\tau(\lambda_{HH}) = W_H(1)(\lambda_{HH})^{-1/\varepsilon}$, where $\varepsilon = \theta$ in the Melitz and $\varepsilon = \sigma - 1$ in the Armington or Krugman models. Clearly, $W_H^f > W_H^\tau(\lambda_{HH}) > W_H^a$ for all $\lambda_{HH} \in (0,1)$, since $W_H^{\tau\prime}(\lambda_{HH}) < 0$ for all λ_{HH}, where the superscripts f and a refer to free trade and autarky, respectively. Moreover, $W_H(\lambda_{HH})$ is concave if $\varepsilon > 1$ (which is true empirically). If trade liberalization is due to lower tariffs, there is no closed form solution for the level of welfare. However, due to the existence of an optimal tariff, welfare as a function of $t, W_H^t(\lambda_{HH})$ achieves a maximum at some well-defined interior $\lambda_{HH} \in (0,1)$. Since free trade and autarky always yield identical welfare levels, it must be true that $W_H^t(\lambda_{HH}) \geq W_H^\tau(\lambda_{HH})$, with strict inequality if $\lambda_{HH} \in (0,1)$. ■

Figure 2: Gains from trade: unilateral trade liberalization

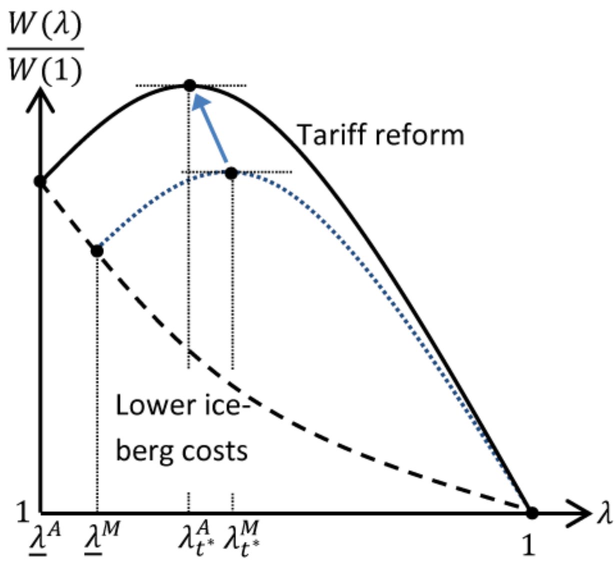


Figure 2 illustrates how welfare changes with λ in the liberalizing country (Home). The convex curve belongs to the $W^\tau-$schedule; the hump-shaped concave locus describes the effects of lower tariffs on Home welfare W^t. As in Figure 1, the picture shows what happens when f^x/f^d converges to unity, so that $\underline{\lambda}^M$ converges to $\underline{\lambda}^A$. Incidentally, the convex locus also depicts the evolution of welfare of the non-reforming other country (Foreign).

3.4.2 Multilateral trade liberalization.

In a final scenario, we consider the welfare effects of a multilateral tariff reform in the context of a setup with two countries of different size. This captures the essence of multiple rounds of tariff reductions orchestrated by the GATT/WTO, where $t_i = t, i \in \{H, F\}$ ensures that each country's tariff concession is met with a matching concession of the trading partner. As in the other cases, there exist isomorphisms between the Armington, Krugman (1980) and Melitz (2003) models.

Lemma 5 ***(Welfare with multilateral tariff reforms, asymmetric countries.)*** *In the asymmetric two-country Armington, Krugman and Melitz models, with asymmetric endowments, multilateral tariff reform affects welfare of country i as follows*

$$\hat{W}_i = \frac{1 - 2\,(t-1)\,(\zeta - 1)\,\tilde{\lambda}_{jj} - t\frac{\tilde{\lambda}_{jj}}{\tilde{\lambda}_{ii}}\,\tilde{\lambda}_{ii}}{1 - \tilde{\lambda}_{ii} + (2\zeta - 1)\,\tilde{\lambda}_{jj}} \frac{1}{\rho}\frac{1}{t}\hat{\lambda}_{ii}, i \in \{H, F\}\,, \tag{20}$$

while a multilateral reduction of iceberg-type trade costs results in

$$\hat{W}_i = -\frac{1}{\varepsilon}\hat{\lambda}_{ii}.$$

Proof. In the Appendix. ∎

Despite country size asymmetries, multilateral reduction of iceberg costs increases welfare according to the ACR formula. This generalization of the ACR result has not been noted before. However, in the case of multilateral tariff reform, the welfare formula is more involved. In particular, the elasticity $\hat{W}_i/\hat{\lambda}_{ii}$ need not be negative. This implies that, as with unilateral tariff changes, for some country, welfare gains from multilateral tariff reform are attainable.

Lemma 6 ***(Optimal multilateral tariffs, asymmetric countries.)*** *In the asymmetric two-country Armington, Krugman and Melitz models, with asymmetric endowments, country i wishes to set the following tariff*

$$t_i^* = \frac{1 + 2\,(\zeta - 1)\,\tilde{\lambda}_{jj}}{1 + 2\,(\zeta - 1)\,\tilde{\lambda}_{ii}} \frac{\tilde{\lambda}_{ii}}{\tilde{\lambda}_{jj}}. \tag{21}$$

If $L_i > L_j$, *then* $t_i^* > 1$, *if* $L_i < L_F$, *then* $t_i^* < 1$, *and if* $L_i = L_j$, $t_i = t_j = 1$.

Proof. The optimal tariff satisfies $\hat{W}_i/\hat{t} = 0$. Since all variation in λ_{ii} is due to variation in t, the requirement is equivalent to $\hat{W}_i/\hat{\lambda}_{ii} = 0$. The optimal tariff formula then follows directly from equation (20). ∎

When the world labor endowment is distributed unequally across countries, the larger country wishes to set a positive tariff to maximize welfare, while the smaller country prefers a negative tariff, i.e., an import subsidy. If subsidies are ruled out, the small country sets a zero tariff. In the context of country size asymmetries, countries have very different preferred policies when negotiating multilateral tariff liberalization rounds .

Now, we are finally ready to state the following proposition:

Proposition 3 ***(Multilateral trade liberalization, asymmetries.)*** *In a two-country world with Home the relatively larger country, and identical technologies, conditional on openness, multilateral tariff liberalization (i) leads to larger welfare gains relative to autarky than lower iceberg costs; (ii) the smaller country gains by more than the larger one, (iii) both countries have similar gains when iceberg costs fall.*

Proof. In the text. ■

Figure 3: Gains from trade: multilateral trade liberalization, Home large

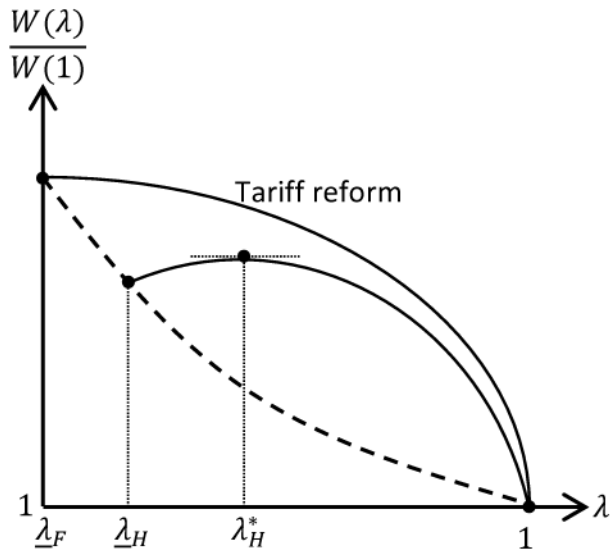


Figure 3 illustrates the situation of multilateral tariff reform against the case of lower iceberg trade costs, which is again shown by the convex curve. We assume that $f^x = f^d$, and so $\underline{\lambda}^A_{ii} = \underline{\lambda}^M_{ii} = \underline{\lambda}_i$. Since we consider asymmetric countries, we need to distinguish the welfare loci for the large (Home) and the small (Foreign) country. The large country has an incentive to set positive tariff, i.e., its welfare is maximized before its degree of 'autarkiness' hits the lowest possible level. The small country would want to subsidize imports, and therefore sees its welfare increase monotonically as its 'autarkiness' falls.

4 Numerical quantification of the gains from trade

4.1 Calibration

In this section, we implement the models discussed analytically above by means of a numerical exercise. The aim is to gain a sense on the possible bias size when welfare calculations are entirely based on viewing trade barriers as non-revenue generating but resource-consuming iceberg trade costs. Since our theoretical frameworks are fairly stylized, we do not aim at a realistic calibration of the world economy; the rich CGE literature is better equipped for this purpose (see Balistreri and Rutherford (2012) for a survey). Rather, we model a world of only two countries. In our baseline exercise, where we study multilateral trade cost and tariff reductions, we even assume symmetry, but assume asymmetry whenever necessary for our argument. The objective of this section is not to analyze a realistic world trade reform scenario, but merely to quantify the importance of our theoretical results.

We calibrate the model toward the US economy as around the year 2000; Table 1 summarizes our strategy. We start by assigning values to the elasticity of substitution σ and the Pareto shape parameter θ. Drawing on the estimates reported in Bernard, Eaton, Kortum, and Jensen (2003), we set $\theta = 3.3.$ and $\sigma = 3.8$. When we are interested in nesting the Melitz, Krugman, and Armington models, we choose $\sigma = \beta + 1 = 4.3$. Under that restriction, the Melitz model collapses to the Krugman model. And all models display the same optimal tariff conditional on $\tilde{\lambda_{FF}}$.

Moreover, for the year of 2000, we observe an average most favored nation tariff factor of 1.016 as evidenced in the World Bank's WITS data base, and a startup failure rate as reported by Bartelsman et al. (2004). Next, we want the model to replicate two key statistics of he US economy, namely the export participation rate and the import penetration rate, as observed in 2000. Following Bernard, Jensen, Redding, and Schott (2007), the former is 17.2% while the latter is 23.4%. These choices imply an iceberg trade cost factor of 1.37, relative market access costs $\left(f^x/f^d\right)$ of 1.75 and relative innovation costs $\left(f^e/f^d\right)$ of 5.49. These implied values compare well to the literature, where Demidova (2008) finds $f^x/f^d = 1.8$ and Obstfeld and

Rogoff (2001) report $\tau = 1.3$.[16]

Table 1: Calibration

Parameter	Value	Source
Constants and parameters from the empirical literature		
Elasticity of substitution (σ)	3.8	Bernard et al.(2003)
Pareto shape parameter (θ)	3.3	Bernard et al.(2003)
Failure rate ($G(\varphi^*)$)	0.170	Bartelsmann et al. (2004)
Observed/targeted data, around 1970		
Average tariff factor (t)	1.060	World Bank WITS data base
Export participation rate (m^x)	0.104	Bernard et al.(1995)
Import penetration rate ($1-\lambda$)	0.060	Lu and Ng(2012)
Observed/targeted data, at 2000		
Average tariff factor (t)	1.016	World Bank WITS data base
Export participation rate (m^x)	0.172	Bernard et al.(2007)
Import penetration rate ($1-\lambda$)	0.234	OECD (2005)
Implied parameters, 1970		
Iceberg trade cost factor (τ)	2.23	
Relative market access costs (f^x/f^d)	0.58	
Relative innovation costs $\left(f^e/f^d\right)$	5.49	
Implied parameters, 2000		
Iceberg trade cost factor (τ)	1.37	
Relative market access costs (f^x/f^d)	1.75	
Relative innovation costs $\left(f^e/f^d\right)$	5.49	

We also calibrate the model to observed data from the 1970s. Then, the average US most favored nation import tariff was standing at 6.0%, the export participation rate was 10.4% (in 1976; Bernard et al., 1995). The import penetration rate was 6% in the year of 1970. While the tariff was about four times higher in the 70s than in the year 2000, and the import penetration rate about four times lower, the export penetration rate was only about 7 percentage points lower. This has important implication for the model parameters implied by these moments. Iceberg trade costs are 123% in 1970 relative to 37% in 2000 (replicating the fairly low 1970 import penetration rate), but *relative* market entry costs are below unity (so that the model replicates the observed export participation rate). Note, however, that this is perfectly com-

[16]The implied parametrization of market access costs is found by solving $\lambda = \left[1 + tm^x \left(f^x/f^d\right)\right]^{-1}$ for f^x/f^d. The implied value for τ is found by solving $m^x = t^{-\frac{\theta}{\rho}} \tau^{-\theta} \left(f^x/f^d\right)^{-\frac{\theta}{\sigma-1}}$ for τ. The implied value for f^e/f^d follows from the free entry condition

$$\frac{\sigma-1}{\theta-(\sigma-1)} p^{in} \left[1 + \frac{f^x}{f^d} \left(\tau \left(\frac{f^x}{f^d}\right)^{\frac{1}{\sigma-1}}\right)^{-\theta}\right] = \frac{f^e}{f^d}.$$

patible with falling *absolute* fixed costs of market access costs.[17] A rising ratio f^x/f^d implies increased protection of domestic firms. Relative innovation costs f^e/f^d have been held fixed at the 2000 level, but the implied failure rate $G(\varphi^*)$ has been recalibrated.

4.2 Multilateral liberalization in a symmetric world

Our first scenario is a multilateral liberalization of tariffs or iceberg trade costs in a symmetric world. We compare three cases. In each, we compare equilibria anchored in observed historical openness levels with hypothetical 'free' trade or autarky equilibria. Crucially, in each comparison, we replicate observed openness levels either by choosing an appropriate value for the ad valorem tariff rate t or for the iceberg trade cost τ. Table 2 provides results.

Table 2: Multilateral liberalization in a symmetric world

	τ	t	λ	W	ΔW
(A) 'Free' trade versus 2000					
(A0)	1.00	1.00	0.53	0.218	
(A1)	1.37	1.00	0.76	0.195	11.79%
(A2)	1.00	1.35	0.76	0.209	4.31%
(B) 1970 versus Autarky					
(B0)			1.00	0.180	
(B1)	2.23	1.00	0.94	0.183	1.89%
(B2)	1.00	2.14	0.94	0.189	5.45%
(C) 2000 versus Autarky					
(C0)			1.00	0.180	
(C1)	1.41	1.00	0.76	0.194	7.99%
(C2)	1.00	1.39	0.76	0.208	15.62%
(D) 2000 versus 1970					
(D0)	1.37	1.02	0.76	0.195	
(D1)	2.20	1.02	0.94	0.183	6.56%
(D2)	1.00	1.59	0.94	0.187	4.28%

Notes: Welfare gains relative to year (A) 2000, (B) Autarky, (C) Autarky, (D) 1970).

Scenario (A) compares 'free' trade with the status observed as of year 2000. 'Free' trade refers to a situation where all variable trade costs are zero; λ, the share of expenditure allocated to domestic goods, is still different from 0.50 (but very close to it, 0.53) due to fixed market access

[17] Felbermayr and Prat (2011) show that, since the 1970s, domestic market access costs have fallen faster than other fixed costs categories in most OECD countries. This is consistent with our calibration finding. Felbermayr and Jung (2011b).

costs.[18] The level of welfare in this situation is 0.218, see (A0).[19] In line (A1) we reproduce the observed level of openness (more correctly: autarkiness) as of 2000, $\lambda = 0.76$, by adjusting iceberg trade costs to $\tau = 1.37$ but keeping tariffs to zero (i.e., $t = 1$). Relative to the year 2000 status, 'free' trade would feature a level of welfare higher by 11.79%. In contrast, line (A2) adjusts tariffs to $t = 1.35$ to achieve the same level of factual openness. The associated welfare gain from moving to 'free' trade is much smaller now, $\Delta W = 4.31\%$. Hence, when taking 'free' trade as the (unobserved) counterfactual, the welfare loss gap from less than free trade depends very strongly on the nature of trade frictions. Linking variation in openness to variation in iceberg costs alone can lead to substantial biases – in the case of the 'free trade versus restricted trade' scenario, welfare losses from iceberg costs are substantially bigger than those from tariffs.

Scenarios (B) and (C) take the autarky equilibrium as the starting point and contrast it with observed equilibria calibrated towards the 1970 or 2000 levels of openness. Again, the exercises differentiate between two polar cases: one where the factual levels of openness are generated by adjustment of iceberg trade costs, and one where they are generated by adjustment of tariffs. Lines (B1) and (B2) shows that the observed openness as of 1970 (6%) can be replicated by either setting $\tau = 2.23, t = 1.00$, or by setting $\tau = 1.00, t = 2.14$ (i.e., an ad valorem tariff of 114%). However, the welfare gains relative to autarky are very different: Adjustment of trade costs leads to gains from trade of 1.89% while adjustment of tariffs generates almost three times higher gains equal to 5.45%. Targeting the openness level of 2000 (24%) delivers a very similar picture. Then, adjustment of trade costs leads to a 7.99% improvement in welfare while adjustment of tariffs generates gains about twice as high (15.62%). Note that Arkolakis et al. (2012) undertake a similar "autarky versus status quo" comparison but focus on τ only. Our simple numerical results suggest that this focus can significantly understate the gains from trade.

Finally, scenario (D) compares the two factual historical situations of 1970 and 2000. Unlike in scenarios (A)-(C) before, *both* the 1970 as well as the 2000 equilibrium replicate the observed openness measures. Line (D0) refers to the equilibrium as of 2000. Line (D1) increases tariffs from the observed 2000 level (1.6%) to the observed 1970 level (6.0%), and adjusts the unobserved

[18] For this reason we use quotation marks when referring to 'free' trade.

[19] Note that the absolute level of W is meaningless.

iceberg trade costs such that the 1970 openness level results. Relative to 1970, this results in year 2000 welfare lying 6.56% higher. If, instead, iceberg costs are driven to their minimum and tariffs are (counterfactually) adjusted such that the observed 1970 openness is again replicated, the welfare differential is only 4.28%. As before, the welfare calculations depend substantially on the type of trade cost adjustment assumed when calibrating the model towards some observed change in openness.

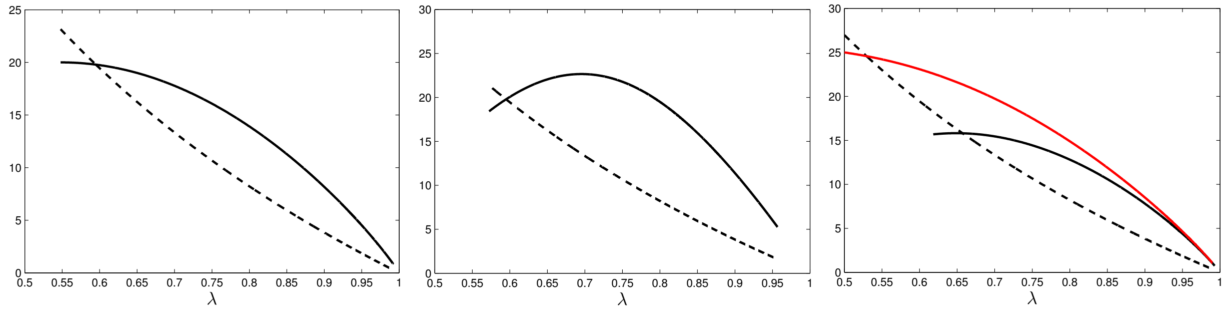
Figure 4 generalizes the insights obtained from Table 2 by looking at gains from trade (relative to the autarky case) over a more extended range of 'autarkiness' measures λ. The diagrams vary one policy parameter (τ or t at a time, keeping the other fixed at 1.06.). Diagram (a) confirms our theoretical insight derived earlier that the gains from trade are a concave function of λ when taking the underlying variation from t, but a convex curve when the underlying variation comes from τ. Over the considered range of λ, the difference between the two scenarios can be very sizeable.

Figure 4: Foreign autarkiness and welfare

(a) Multilateral liberalization, symmetric

(b) Unilateral liberalization, symmetric

(c) Multilateral liberalization, asymmetric



Notes: Variation driving changes in openness stems from tariffs (solid curve) or iceberg trade costs (dashed curve); Home (black), Foreign (red). Symmetric refers to a uniform distribution of the world labor endowment; asymmetric has Home hold 60% of the endowment.

4.3 Unilateral liberalization in a symmetric world

Diagram (b) of Figure 4 keeps the symmetric distribution of labor endowments across countries, but assumes that one country sets its tariff unilaterally, while the other country has the benchmark tariff of 1.06%. Because of symmetry in fundamentals, when the adjustment takes place in iceberg trade costs, curves for both countries coincide. The situation is different, when one country adjusts its tariff. This country's welfare function exhibits a hump at about $\lambda = 0.66$, implying the existence of an optimal tariff t^*. The welfare function for the other (the passive) country is as under the iceberg scenario; specifically, there is no hump. Note that we have shown this analytically for the case $t = 1$. The intuition is that, in the absence of tariffs, both definitions of λ coincide, and so the simple welfare equation (12) applies. This is true regardless of the fact that 'autarkiness' is shifted by a foreign shock. The message of the picture is again that looking at tariffs as compared to iceberg costs makes an important quantitative difference, that can rise to up to 4 percentage points. In all those scenarios, since we start from autarky as the reference point, focusing on iceberg costs underestimates the gains from trade.

4.4 Multilateral liberalization in an asymmetric world

Finally, diagram (c) in Figure 4 maintains the calibration for the symmetric two country world with the only difference that labor endowments are now distributed unequally. Home (graphed in black) commands 60% of the world labor supply while Foreign (in red) commands the remainder. The scenario here is that trade liberalization is multilateral, i.e., tariffs or iceberg costs are identical in both countries. We know from our theoretical analysis that country size does not matter for the welfare effects of lower iceberg trade costs conditional on openness. So, the loci for Home and Foreign coincide.[20]

Looking at tariffs, the picture is different. Here, market size (expressed by population shares) does matter. Again, both countries are assumed to set the same import tariffs. However, the small country (Foreign) now benefits more from an increase in openness than the large country (Home). The reason, already alluded to in our theory section, is that the large country would, if it could, set a higher tariff than the small one. This is quite visible in the diagram, where the welfare maximum for the large country is reached at a λ of about 0.66, while the welfare maximimum for the small country is not reached as we restrict ourselves to $t \geq 1$. For the same value of λ and a 3:2 distribution of endowments, the gains from trade in the small country are

[20] To be more precise, the perfect coincidence of the curves has been analytically shown in the absence of tariffs ($t = 1$); in diagram (b) we have $t = 1.016$.

up to 3 percentage points larger than in the large one.

5 Conclusion

We extend the analysis of Arkolakis et al. (ACR, 2012) to *ad valorem* tariffs and multilateral policies. We use this framework to readdress the link between welfare and openness. We show that the major claim made in ACR, namely that, in a broad class of models, the exact microfoundations are largely irrelevant for normative analysis once one conditions on openness, remains correct. However, the relevant elasticities are no longer constant. We also establish that the gains from trade are always larger when the same variation in openness is obtained from changes in tariffs than when it comes from iceberg trade costs. Using a simple calibration of the model, we show that the ACR formula for ex post welfare evaluation, which assumes that variation in openness comes from changes in iceberg costs only, underestimates the gains from trade in a quantitatively substantial way.

In this paper, we have studied the Melitz (2003) model, which is a generalization of Krugman (1980), and we have discussed the role of the Melitz selection channel in shaping welfare outcomes. In the next step we will extend the analysis to a third related model: the Armington trade model. This setup is much simpler since it assumes perfect competition and free entry. It does, however, also give rise to a gravity type representation of trade flows. The objective of this extension will be to inquire whether the isomorphisms in our welfare formulas extends to the Armington model as well.

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A Proofs of Propositions, Details to Derivations

A.1 Derivation of equilibrium conditions in the Melitz-Pareto model

Zero cutoff profit conditions. Demand for any variety ω is given by

$$q_{ij}\left[\omega\right] = Y_j P_j^{\sigma-1} p_{ij}\left[\omega\right]^{-\sigma},$$

where the price index to the CES utility function is given by $P_i^{1-\sigma} = \int_{\omega\in\Omega_i} p\left[\omega\right]^{1-\sigma} d\omega$ and Y_i denotes aggregate expenditure.[21] Given the demand function, the price charged at the factory gate is $w_i/\left(\rho\varphi\right)$. Then, revenues of a firm from region i earned on market j are

$$r_{ij}\left[\varphi\right] = Y_j P_j^{\sigma-1} t_{ji}^{-\sigma}\left(\frac{\rho}{\tau_{ij} w_i}\varphi\right)^{\sigma-1}.$$

The zero cutoff profit conditions follow from noting that operating profits $\pi_{ij}\left[\varphi\right]$ are variable profits $r_{ij}\left[\varphi\right]/\sigma$ minus fixed access costs f_{ij}, and that for the cutoff firm, $\pi_{ij}\left[\varphi_{ij}^*\right] = 0$.

Price index. Using the zero cutoff profit condition, we can write the price level P_i as

$$\begin{aligned} P_i^{1-\sigma} &= \sum_{j\in\{H,F\}} m_{ji} N_j \int_{\varphi_{ji}^*}^{\infty}\left(\frac{\tau_{ji} t_{ij} w_j}{\rho\varphi}\right)^{1-\sigma}\frac{dG\left[\varphi\right]}{1-G\left[\varphi_{ji}^*\right]} \\ &= \frac{\theta}{\theta-(\sigma-1)}\sum_{j\in\{H,F\}} m_{ji} N_j\left(\frac{\rho\varphi_{ji}^*}{\tau_{ji} t_{ij} w_j}\right)^{\sigma-1}, \end{aligned}$$

where the second line follows from using the Pareto distribution.

[21] Note that each variety z is produced by a single firm with productivity level φ. We henceforth index varieties by φ.

Free entry condition. Using optimal demand and the zero cutoff profit condition, we obtain the following expression for expected profits of a firm in region i from entering:

$$\begin{aligned}
\bar{\pi}_i &= \sum_{j\in\{H,F\}} \int_{\varphi^*_{ij}}^{\infty} \pi_{ij}[\varphi] \frac{dG[\varphi]}{1-G[\varphi^*_{ii}]} \\
&= \sum_{j\in\{H,F\}} m_{ij} \left(\frac{\theta}{\theta-(\sigma-1)} \frac{Y_j P_j^{\sigma-1}}{\sigma} \left(\frac{\tau_{ij} t_{ji} w_i}{\rho}\right)^{1-\sigma} \left(\varphi^*_{ij}\right)^{\sigma-1} - w_i f_{ij} \right) \\
&= \sum_{j\in\{H,F\}} m_{ij} \left(\frac{\theta}{\theta-(\sigma-1)} Y_j P_j^{\sigma-1} \left(\frac{\tau_{ij} t_{ji} w_i}{\rho}\right)^{1-\sigma} Y_j^{-1} P_j^{1-\sigma} \left(\frac{\tau_{ij} t_{ji} w_i}{\rho}\right)^{\sigma-1} w_i f_{ij} - w_i f_{ij} \right) \\
&= \frac{\sigma-1}{\theta-(\sigma-1)} w_i \sum_{j\in\{H,F\}} m_{ij} f_{ij}.
\end{aligned}$$

Free entry means that expected profits, $(1-G[\varphi^*_{ii}])\,\bar{\pi}_i$, equalize the costs of innovation, $w_i f^e$.

Labor market clearing condition. Labor market clearing is given by

$$L_i = N_i^e f^e + N_i \sum_j m_{ij} f_{ij} + N_i \sum_j \int_{\varphi^*_{ij}} \frac{\tau_{ij} q_{ij}[\varphi]}{\varphi} \frac{dG[\varphi]}{1-G\left[\varphi^*_{ij}\right]} = N_i \theta\sigma \sum_j m_{ij} f_{ij},$$

where the second equality follows from inserting $N_i^e = N_i/(1-G[\varphi^*_{ii}])$, using the free entry condition to substitute out f^e, and using the zero cutoff profit conditions to substitute out the cutoff productivity levels. The formula in the text follows from using the free entry condition to substitute out $\sum_j m_{ij} f_{ij}$.

A.2 Derivation of relative nominal import demand

Melitz-Pareto model. Aggregate country i's export sales from selling to country j are given by

$$X_{ij} = N_i \int_{\varphi^*_{ij}}^{\infty} r_{ij}[\varphi] \frac{dG[\varphi]}{1-G[\varphi^*_{ii}]} = \frac{\theta}{\theta-(\sigma-1)} \sigma N_i w_i m_{ij} f_{ij}. \tag{22}$$

Then, relative exports are given by

$$\frac{X_{ji}}{X_{jj}} = m_{ji} \frac{f^x}{f^d} \text{ with } m_{ji} = \left(\frac{\varphi^*_{jj}}{\varphi^*_{ji}}\right)^{\theta} = \left(\frac{w_i}{w_j}\right)^{-\frac{\theta-\rho}{\rho}} t_{ji}^{-\frac{\theta}{\rho}} \tau_{ij}^{-\theta} \left(\frac{f^x}{f^d}\right)^{-\frac{\theta}{\sigma-1}} \frac{L_i}{L_j},$$

where we have used $f_{ij} = f_{ji} = f^x$ and balanced trade, $N_i w_i m_{ij} = N_j w_j m_{ji} \Leftrightarrow \frac{w_i}{w_j} = \frac{L_j}{L_i}\left(\frac{\varphi^*_{ij}}{\varphi^*_{ji}}\right)^\theta$, to substitute out φ^*_{ji} from m_{ji} and j's relative import demand as given by equation (4).

Armington model. Given optimal demand (9), relative nominal import demand is

$$\frac{X_{ji}}{X_{ii}} = t_{ij}^{-\sigma}\left(\frac{w_j \tau_{ji}}{w_i}\right)^{1-\sigma}.$$

A.3 Proof of Lemma 1 (ACR generalized)

Melitz-Pareto model. The change in autarkiness is given by

$$\hat{\lambda}_{ii} = -\left(1-\lambda_{ii}\right)\hat{m}_{ij} = -\theta\left(1-\lambda_{ii}\right)\left(\hat{\varphi}^*_{ii} - \hat{\varphi}^*_{ij}\right).$$

Free entry implies

$$\hat{\varphi}^*_{ii} = -\frac{1-\lambda_{ii}}{\lambda_{ii}}\hat{\varphi}^*_{ij}.$$

Hence,

$$\hat{\lambda}_{ii} = -\left(1-\lambda_{ii}\right)\hat{m}_{ij} = -\theta\hat{\varphi}^*_{ii}. \tag{23}$$

Armington model. The change in autarkiness is given by

$$\frac{\hat{\lambda}_{ii}}{\left(\sigma-1\right)\left(1-\lambda_{ii}\right)} = \hat{\tau}_{ji} + \hat{w}_j - \hat{w}_i = \hat{q}_{ij} - \hat{q}_{ji} + \hat{\tau}_{ij}, \tag{24}$$

where the second equality follows from balanced trade.

Labor market clearing implies

$$\hat{q}_{ji} = -\frac{\lambda_{ii}}{1-\lambda_{ii}}\hat{q}_{ii} - \hat{\tau}_{ij}.$$

Hence,

$$\frac{\hat{\lambda}_{ii}}{\left(\sigma-1\right)\left(1-\lambda_{ii}\right)} = -\frac{\lambda_{ii}}{1-\lambda_{ii}}\hat{q}_{ii} - \hat{q}_{ji}.$$

Totally differentiating relative import demand, we obtain

$$\hat{q}_{ij} = -\sigma\left(\hat{\tau}_{ji} + \hat{w}_j - \hat{w}_i\right) + \hat{q}_{ii} = -\frac{\sigma\hat{\lambda}_{ii}}{(\sigma-1)(1-\lambda_{ii})} + \hat{q}_{ii},$$

where the second equality follows from (24). Combining these observations, we obtain

$$\hat{\lambda}_{ii} = \hat{q}_{ii}.$$

A.4 Derivation of indirect utility in the Melitz-Pareto model

Using optimal demand and the zero cutoff profit conditions, indirect utility can be rewritten as

$$\begin{aligned}
W_i &= \left(N_j \int_{\varphi^*_{ji}} \left(q_{ij}[\varphi]\right)^\rho \frac{dG[\varphi]}{1-G\left[\varphi^*_{jj}\right]}\right)^{\frac{1}{\rho}} \\
&= \left(\sum_j m_{ji} N_j Y_i^\rho P_i^{(\sigma-1)\rho} \left(\frac{\tau_{ji} t_{ij} w_j}{\rho}\right)^{1-\sigma} \int_{\varphi^*_{ji}}^{\infty} \varphi^{\sigma-1} \frac{dG[\varphi]}{1-G\left[\varphi^*_{ji}\right]}\right)^{\frac{1}{\rho}} \\
&= \left(\frac{\theta}{\theta-(\sigma-1)} \sum_j m_{ji} N_j Y_i^\rho P_i^{(\sigma-1)\rho} \left(\frac{\tau_{ji} t_{ij} w_j}{\rho}\right)^{1-\sigma} \left(\varphi^*_{ji}\right)^{\sigma-1}\right)^{\frac{1}{\rho}} \\
&= \left(\frac{\theta}{\theta-(\sigma-1)} \sum_j m_{ji} N_j \left(\sigma w_j f_{ji}\right)^\rho t_{ij}^{\sigma-1} \left(\frac{\tau_{ji} w_j}{\rho}\right)^{(\sigma-1)\rho} \left(\varphi^*_{ji}\right)^{(1-\sigma)\rho} \left(\frac{\tau_{ji} t_{ij} w_j}{\rho}\right)^{1-\sigma} \left(\varphi^*_{ji}\right)^{\sigma-1}\right)^{\frac{1}{\rho}} \\
&= (\sigma-1)\left(\frac{\theta}{\theta-(\sigma-1)} \sum_j m_{ji} N_j \left(\frac{f_{ji}}{\tau_{ji}} \varphi^*_{ji}\right)^\rho\right)^{\frac{1}{\rho}}.
\end{aligned}$$

In percentage changes, we have

$$\begin{aligned}
\hat{W}_i &= \frac{1}{\rho}\left(\sum_j \frac{m_{ji} N_j \left(\frac{f_{ji}}{\tau_{ji}} \varphi^*_{ji}\right)^\rho}{\sum_k m_{ki} N_j \left(\frac{f_{ki}}{\tau_{ki}} \varphi^*_{ki}\right)^\rho} \left(\rho \varphi^*_{ji} + \hat{m}_{ji} + \hat{N}_j\right)\right) \\
&= -\frac{\theta-\rho}{\rho}\left(\sum_j \frac{m_{ji} N_j \left(\frac{f_{ji}}{\tau_{ji}} \varphi^*_{ji}\right)^\rho}{\sum_k m_{ki} N_k \left(\frac{f_{ki}}{\tau_{ki}} \varphi^*_{ki}\right)^\rho} \hat{\varphi}^*_{ji}\right),
\end{aligned}$$

where the second line follows from the definition of the export participation rate, $\hat{m}_{ji} = \theta\left(\hat{\varphi}^*_{jj} - \hat{\varphi}^*_{ji}\right)$, and the labor market clearing condition, $\hat{N}_j = -\theta\hat{\varphi}^*_{jj}$. In order to see that

$$\frac{N_i\left(f_{ii}\varphi^*_{ii}\right)^\rho}{\sum_k m_{ki}N_k\left(\frac{f_{ki}}{\tau_{ki}}\varphi^*_{ki}\right)^\rho} = \frac{1}{1+m_{ki}\frac{N_k}{N_i}\left(\frac{f^x}{f^d}\frac{\varphi^*_{ki}/\tau_{ki}}{\varphi^*_{ii}}\right)^\rho} = \lambda_{ii},$$

note that balanced trade implies $\frac{N_k}{N_i} = \frac{w_i}{w_k}\frac{m_{ik}}{m_{ki}}$, and that the import cutoff condition in its relative form is given by

$$t_{ik}^{-\sigma}\left(\frac{\varphi^*_{ki}w_i}{\varphi^*_{ii}\tau_{ki}w_k}\right)^{\sigma-1} = \frac{w_k}{w_i}\frac{f^x}{f^d} \Leftrightarrow \frac{w_i}{w_k} = \left(\frac{f^x}{f^d}\right)^{\frac{1}{\sigma}} t_{ik}\left(\frac{\varphi^*_{ii}\tau_{ki}}{\varphi^*_{ki}}\right)^\rho. \tag{25}$$

A.5 Proof of Proposition 1 (Multilateral trade liberalization with symmetric countries)

We have to prove concavity of welfare in λ when variation in λ is induced by variation in the tariff. By definition, we have

$$\frac{\hat{W}}{\hat{\lambda}} = \frac{\partial W}{\partial\lambda}\frac{\lambda}{W} \Leftrightarrow \frac{\partial W}{\partial\lambda} = \frac{\hat{W}}{\hat{\lambda}}\frac{W}{\lambda}.$$

Then, the second derivative of welfare in λ is given by

$$\frac{\partial^2 W}{\partial\lambda^2} = \frac{W}{\lambda}\frac{\partial\left(\hat{W}/\hat{\lambda}\right)}{\partial\lambda} + \frac{\hat{W}}{\hat{\lambda}}\frac{\partial\left(W/\lambda\right)}{\partial\lambda},$$

where

$$\frac{\partial\left(W/\lambda\right)}{\partial\lambda} = \frac{\frac{\partial W}{\partial\lambda}\lambda - W}{\lambda^2} = \frac{W\left(\frac{\hat{W}}{\hat{\lambda}} - 1\right)}{\lambda^2} < 0. \tag{26}$$

Recall that the elasticity of welfare in λ can be written as (using equation (15) and $\hat{\lambda} = \frac{t\lambda}{\lambda(t-1)+1}$)

$$\frac{\hat{W}}{\hat{\lambda}} = -\frac{1}{\rho}\frac{\lambda\left(t-1\right)}{\lambda\left(t-1\right)+1}$$

Then,

$$\frac{\partial\left(\hat{W}/\hat{\lambda}\right)}{\partial\lambda} = -\frac{1}{\rho}\frac{\left[\lambda\left(t-1\right)+1\right]\left[t-1+\lambda\frac{\partial t}{\partial\lambda}\right]-\lambda\left(t-1\right)\left[t-1+\lambda\frac{\partial t}{\partial\lambda}\right]}{\left[\lambda\left(t-1\right)+1\right]^{2}} \tag{27}$$
$$= -\frac{1}{\rho}\frac{t-1+\lambda\frac{\partial t}{\partial\lambda}}{\left[\lambda\left(t-1\right)+1\right]^{2}}.$$

Using equations (26) and (27), we can rewrite the second derivative as

$$\frac{\partial^2 W}{\partial\lambda^2} = \frac{W}{\lambda}\left(-\frac{1}{\rho}\frac{t-1+\lambda\frac{\partial t}{\partial\lambda}}{\left[\lambda\left(t-1\right)+1\right]^{2}}\right) - \frac{1}{\rho}\frac{\lambda\left(t-1\right)}{\lambda\left(t-1\right)+1}\frac{W\left(\frac{\hat{W}}{\hat{\lambda}}-1\right)}{\lambda^2}.$$

Collecting terms and using $\frac{\hat{t}}{\hat{\lambda}} = \frac{\partial t}{\partial\lambda}\frac{\lambda}{t}$, we obtain

$$\frac{\partial^2 W}{\partial\lambda^2} = -\frac{1}{\rho}\frac{W}{\lambda}\frac{t}{\left[\lambda\left(t-1\right)+1\right]^{2}}\left[\frac{\hat{\lambda}}{\hat{t}} - \frac{\left(t-1\right)^2}{t}\frac{1+\rho}{\rho}\lambda\right],$$

where

$$\frac{\hat{t}}{\hat{\lambda}} = \left(1-\lambda\right)\frac{\theta-\rho}{\rho} > 0.$$

Hence, we can rewrite the second derivative as

$$\frac{\partial^2 W}{\partial\lambda^2} = -\frac{1}{\rho}\frac{W}{\lambda\left(1-\lambda\right)}\frac{t}{\left[\lambda\left(t-1\right)+1\right]^{2}}\left[\frac{\rho}{\theta-\rho} - \frac{\left(t-1\right)^2}{t}\lambda\left(1-\lambda\right)\frac{1+\rho}{\rho}\right].$$

Concavity of welfare in λ requires the term in squared brackets to bear a positive sign. In order to prove this, we rewrite the remaining λ as a function of the tariff t and the freeness of trade, $\eta \equiv \tau^{-\theta}\left(\frac{f^x}{f^d}\right)^{1-\frac{\theta}{\sigma-1}}$:

$$\lambda = \frac{1}{1+t^{-\frac{\theta-\rho}{\rho}}\eta}.$$

Concavity requires

$$\frac{\rho^2}{\left(\theta-\rho\right)\left(1+\rho\right)} > \frac{\left(t-1\right)^2}{1+t^{-\frac{\theta-\rho}{\rho}}\eta}\frac{t^{-\frac{\theta-\rho}{\rho}-1}\eta}{1+t^{-\frac{\theta-\rho}{\rho}}\eta}.$$

Collecting terms, we obtain

$$\frac{\rho^2}{\left(\theta-\rho\right)\left(1+\rho\right)} > \frac{t^2-2t+1}{\eta t^{-\frac{\left(\theta-2\rho\right)}{\rho}}+\eta^{-1}t^{\frac{\theta}{\rho}}+2t}. \tag{28}$$

Note that an upper bound for the expression on the right hand side is

$$f\left[t\right]\equiv\eta\left(t^{-\frac{\theta-2\rho}{\rho}}-2t^{-\frac{\theta-\rho}{\rho}}+t^{-\frac{\theta}{\rho}}\right)=\eta t^{-\frac{\theta}{\rho}}\left(t-1\right)^{2}=\frac{t^{2}-2t+1}{\eta^{-1}t^{\frac{\theta}{\rho}}}>\frac{t^{2}-2t+1}{\eta^{-1}t^{\frac{\theta}{\rho}}+\eta t^{-\frac{(\theta-2\rho)}{\rho}}+2t},$$

where we require $\theta>2\rho$. $f\left[t\right]$ has the following characteristics: $f\left[1\right]=0$ and $\lim_{t\to\infty}f\left[t\right]=0$. Moreover

$$\frac{\partial f\left[t\right]}{\partial t}=\eta\left[-\frac{\theta}{\rho}t^{-\frac{\theta}{\rho}-1}\left(t-1\right)^{2}+t^{-\frac{\theta}{\rho}}2\left(t-1\right)\right]=\eta\left(t-1\right)t^{-\frac{\theta}{\rho}}\left(-\frac{\theta}{\rho}+\frac{\theta}{\rho}t^{-1}+2\right).$$

$f\left[t\right]$ reaches its maximum at $t=1$ and

$$-\frac{\theta}{\rho}+\frac{\theta}{\rho}t^{-1}+2=0\Leftrightarrow t=\frac{\theta}{\theta-2\rho},$$

Evaluated at $t=\frac{\theta}{\theta/\rho-2}$, we have

$$\begin{aligned}f\left[\frac{\theta}{\theta-2\rho}\right]&=\eta\left(\frac{\theta}{\theta-2\rho}\right)^{-\frac{\theta}{\rho}}\left(\frac{2\rho}{\theta/\rho-2}\right)^{2}\\&<\left(\frac{\theta}{\theta/\rho-2}\right)^{-\frac{\theta}{\rho}}\left(\frac{2\rho}{\theta/\rho-2}\right)^{2},\end{aligned}$$

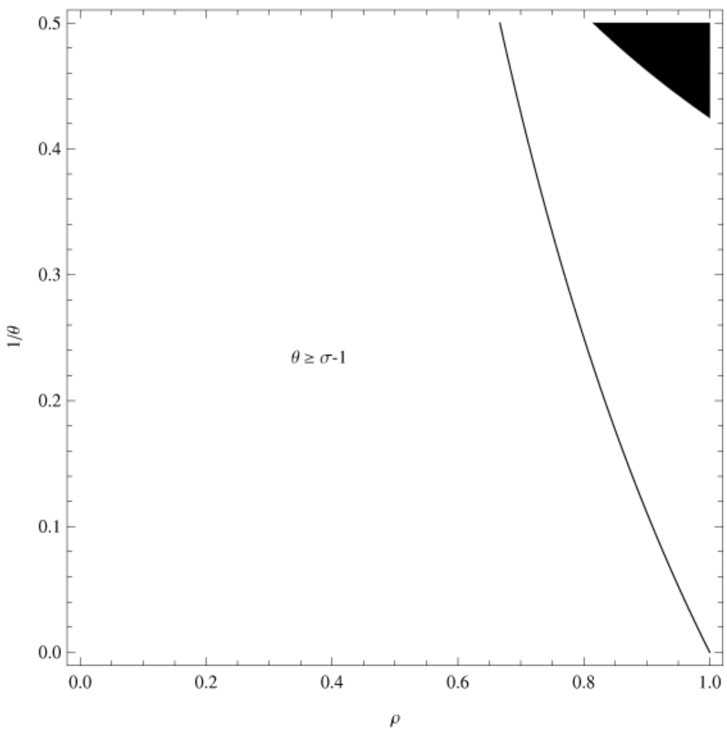
where the inequality follows from $\eta<1$. Replacing the left hand side of equation (28) by this expression, and rearranging terms, we obtain

$$\rho^{2}>\left(\frac{\theta}{\theta-2\rho}\right)^{-\frac{\theta}{\rho}}\left(\frac{2\rho}{\theta-2\rho}\right)^{2}\left(1+\rho\right)\left(\theta-\rho\right),\tag{29}$$

which is a sufficient condition for concavity.

Figure 5 depicts this inequality (29) with $\rho\in(0,1)$ on the x-axis and $1/\theta\in(0,1/2)$ on the y-axis. The upper bound of the y-axis follows from $\theta>2$, which is a regularity condition to guarantee finite variance of the sales distribution. The black region indicates combinations of ρ and θ where the inequality fails to hold. Another regularity condition postulates $\theta>\sigma-1\Leftrightarrow 1/\theta<\frac{1-\rho}{\rho}$. Only combinations of ρ and θ to the left of the downward-sloping solid line fulfill this restriction. Hence, for all feasible combinations of ρ and θ, the inequality as given in equation (29) holds, which proves that welfare is concave in λ if variation in λ comes from changes in tariffs.

Figure 5: Sufficient condition for concavity



Notes: Feasible combinations of θ and ρ lie to the left of the downward-sloping curve. The black area indicates combinations for which inequality (29) does not hold. So, welfare is concave in λ for all feasible combinations of θ and ρ.

A.6 Proof of Lemma 3 (Welfare with unilateral tariff reforms)

A.6.1 Trading partner

Melitz-Pareto model. For the trading partner, the change in autarkiness is given by equation (23). Relative nominal import demand, $\hat{w}_i - \hat{w}_j = \rho\left(\hat{\varphi}^*_{ii} - \hat{\varphi}^*_{ji}\right)$ and balanced trade together with free entry, $\hat{w}_i - \hat{w}_j = -\theta\left(\frac{\lambda_{ii}}{1-\lambda_{ii}}\hat{\varphi}^*_{ii} + \hat{\varphi}^*_{ji}\right)$, allow to write $\hat{\varphi}^*_{ji}$ as a function of $\hat{\varphi}^*_{ii}$

$$\hat{\varphi}^*_{ji} = -\frac{\frac{\theta}{\rho}\frac{\lambda_{ii}}{1-\lambda_{ii}} + 1}{\frac{\theta}{\rho} - 1}\hat{\varphi}^*_{ii}.$$

Hence, the change in trading partner's welfare is given by

$$\hat{W}_i = -\frac{\theta-\rho}{\rho}\left(1 + \frac{1-\lambda_{ii}}{\lambda_{ii}}\frac{\hat{\varphi}^*_{ji}}{\hat{\varphi}^*_{ii}}\right)\lambda_{ii}\hat{\varphi}^*_{ii} = \hat{\varphi}^*_{ii} = -\frac{1}{\theta}\hat{\lambda}_{ii}.$$

Armington model. In analogy to the proof of Lemma 1, we have $\hat{\lambda}_{ii} = \hat{q}_{ii}$. Relative import demand, $\hat{w}_i - \hat{w}_j = \frac{1}{\sigma}(\hat{q}_{ij} - \hat{q}_{ii})$, and balanced trade together with labor market clearing, $\hat{w}_i - \hat{w}_j = \hat{q}_{ij} + \frac{\lambda_{ii}}{1-\lambda_{ii}}\hat{q}_{ii}$, allow to write $\hat{q}_{ij}$ as a function of $\hat{q}_{ii}$

$$\hat{q}_{ij} = -\frac{1+\sigma\frac{\lambda_{ii}}{1-\lambda_{ii}}}{\sigma-1}\hat{q}_{ii}.$$

Hence, the change in trading partner's welfare is given by

$$\hat{W}_i = \left(1 + \frac{1-\lambda_{ii}}{\lambda_{ii}}\frac{\hat{q}_{ij}}{\hat{q}_{ii}}\right)\lambda_{ii}\hat{q}_{ii} = -\frac{1}{\sigma-1}\hat{q}_{ii} = -\frac{1}{\sigma-1}\hat{\lambda}_{ii}.$$

A.6.2 Liberalizing country

Preliminaries. In the Melitz-Pareto model, the change in autarkiness is given by

$$\hat{\lambda}_{ii}^M = (1-\lambda_{ii})\frac{\theta-\rho}{\rho}\left(1+\frac{\hat{w}_j-\hat{w}_i}{\hat{t}_{ij}}\right)\hat{t}_{ij} = -(1-\lambda_{ii})\frac{\theta-\rho}{\rho}\rho\left(\hat{\varphi}_{ii}^* - \hat{\varphi}_{ji}^*\right),$$

where the second equality follows from relative import demand, $\hat{w}_i - \hat{w}_j = \hat{t}_{ij} + \rho\left(\hat{\varphi}_{ii}^* - \hat{\varphi}_{ji}^*\right)$. By analogy, the expression prevailing in the Armington model is

$$\hat{\lambda}_{ii}^A = (1-\lambda_{ii})(\sigma-1)\left(1+\frac{\hat{w}_j-\hat{w}_i}{\hat{t}_{ij}}\right)\hat{t}_{ij} = (1-\lambda_{ii})\rho(\hat{q}_{ii}-\hat{q}_{ij}),$$

where the second equality follows from relative import demand, $\hat{w}_i - \hat{w}_j = \hat{t}_{ij} - \frac{1}{\sigma}(\hat{q}_{ii} - \hat{q}_{ij})$.

Then, changes in welfare are given by, respectively

$$\begin{aligned}
\hat{W}_i^M &= \frac{1+t_{ij}\frac{1-\tilde{\lambda}_{ii}^M}{\tilde{\lambda}_{ii}^M}\frac{\hat{\varphi}_{ji}^*}{\hat{\varphi}_{ii}^*}}{1-\tilde{\lambda}_{ii}^M-\left(1-\tilde{\lambda}_{ii}^M\right)\frac{\hat{\varphi}_{ji}^*}{\hat{\varphi}_{ii}^*}}\frac{1}{\rho}\frac{1}{t_{ij}}\tilde{\lambda}_{ii}^M\hat{\lambda}_{ii}^M, \\
\hat{W}_i^A &= \frac{1+t_{ij}\frac{1-\tilde{\lambda}_{ii}^A}{\tilde{\lambda}_{ii}^A}\frac{\hat{q}_{ij}}{\hat{q}_{ii}}}{1-\tilde{\lambda}_{ii}^A-\left(1-\tilde{\lambda}_{ii}^A\right)\frac{\hat{q}_{ij}}{\hat{q}_{ii}}}\frac{1}{\rho}\frac{1}{t_{ij}}\tilde{\lambda}_{ii}^A\hat{\lambda}_{HH}^A.
\end{aligned}$$

General equilibrium effects on respectively $\left(\varphi_{ii}^*, \varphi_{ji}^*\right)$ and (q_{ii}, q_{ij}). The system of equilibrium conditions can be reduced to a system of two equations in two variables. For sake of exposition, we suppress variable trade costs. In the Melitz model, we have

$$
\begin{aligned}
\left(\varphi_{FH}^*\right)^{\rho-\theta}\left(\varphi_{HH}^*\right)^{-\rho} - t_{HF}\frac{L_H}{L_F}\left(\frac{\theta-(\sigma-1)}{\sigma-1}\frac{f^e}{f^x} - \left(\varphi_{HH}^*\right)^{-\theta}\frac{f^d}{f^x}\right)\left(\frac{f^x}{f^d}\right)^{\frac{1}{\sigma}} &= 0,\\
t_{FH}\left(\varphi_{FH}^*\right)^{-\theta}\frac{\left(\frac{\theta-(\sigma-1)}{\sigma-1}\frac{f^e}{f^x} - \left(\varphi_{HH}^*\right)^{-\theta}\frac{f^d}{f^x}\right)^{-\frac{\theta-\rho}{\theta}}}{\left(\frac{\theta-(\sigma-1)}{\sigma-1}\frac{f^e}{f^d} - \left(\varphi_{FH}^*\right)^{-\theta}\frac{f^x}{f^d}\right)^{\frac{\rho}{\theta}}}\left(\frac{f^x}{f^d}\right)^{\frac{1}{\sigma}} - \frac{L_H}{L_F} &= 0.
\end{aligned}
$$

In the Armington model, we have

$$
\begin{aligned}
\left(\frac{q_{HH}}{q_{HF}}\right)^{\frac{1}{\sigma}} - t_{HF}\frac{L_H-q_{HH}}{q_{HF}} &= 0,\\
\left(\frac{L_F-q_{HF}}{L_H-q_{HH}}\right)^{-\frac{1}{\sigma}} - \frac{1}{t_{FH}}\frac{L_H-q_{HH}}{q_{HF}} &= 0.
\end{aligned}
$$

In the Melitz model, the total differential of system can be written as

$$
\begin{vmatrix}
\rho\left(\frac{\varphi_{FH}^*}{\varphi_{HH}^*}\right)^{\rho} + \theta t_{HF}\frac{L_H}{L_F}\left(\frac{f^x}{f^d}\right)^{\frac{1}{\sigma}}\frac{f^d}{f^x}\left(\frac{\varphi_{FH}^*}{\varphi_{HH}^*}\right)^{\theta} & (\theta-\rho)\left(\frac{\varphi_{FH}^*}{\varphi_{HH}^*}\right)^{\rho-1}\\
(\theta-\rho)\left(\frac{\varphi_{FH}^*}{\varphi_{HH}^*}\right)^{\theta+1}\frac{L_H}{L_F}\frac{f^d}{f^x} & \left(1+\frac{\rho}{\theta}\left(\frac{\varphi_{FF}^*}{\varphi_{FH}^*}\right)^{\theta}\frac{f^x}{f^d}\right)\frac{\theta}{w_H}
\end{vmatrix}
\begin{vmatrix}
\mathrm{d}\varphi_{HH}^*\\
\mathrm{d}\varphi_{FH}^*
\end{vmatrix}
=
\begin{vmatrix}
-\frac{\varphi_{HH}^*}{w_H}\left(\frac{f^x}{f^d}\right)^{\frac{1}{\sigma}}\mathrm{d}t_{HF}\\
\frac{\varphi_{FH}^*}{t_{FH}w_H}\mathrm{d}t_{FH}
\end{vmatrix}.
\tag{30}
$$

In the Armington model, the corresponding system is

$$
\begin{vmatrix}
\frac{1}{\sigma}\left(\frac{w_H}{t_{HF}}\right)^{\sigma-1} + t_{HF} & t_{HF}\frac{1}{w_H}\rho\\
\frac{1}{\tau_{HF}}\rho & \frac{1}{w_H}\left(\frac{1}{\sigma}\frac{q_{HF}}{q_{FF}}+1\right)
\end{vmatrix}
\begin{vmatrix}
\mathrm{d}q_{HH}\\
\mathrm{d}q_{HF}
\end{vmatrix}
=
\begin{vmatrix}
\frac{1}{w_H}q_{HF}\mathrm{d}t_{HF}\\
-\frac{q_{HF}}{t_{FH}w_H}\mathrm{d}t_{FH}
\end{vmatrix}.
\tag{31}
$$

Unilateral liberalization. We now consider unilateral liberalization with $\mathrm{d}t_{FH} = 0$. The changes $\mathrm{d}\varphi_{HH}^*/\mathrm{d}t_{HF}$ and $\mathrm{d}\varphi_{FH}^*/\mathrm{d}t_{HF}$ for Melitz and $\mathrm{d}q_{HH}/\mathrm{d}t_{HF}$ and $\mathrm{d}q_{HF}/\mathrm{d}t_{HF}$ can be computed from (30) and (31), respectively. One obtains

$$
\begin{aligned}
\frac{\hat{\varphi}_{FH}^*}{\hat{\varphi}_{HH}^*} &= -\left(1-\frac{\rho}{\theta}\right)\frac{1}{1+\frac{\rho}{\theta}\frac{1-\tilde{\lambda}_{FF}}{\tilde{\lambda}_{FF}}}\frac{\tilde{\lambda}_{HH}}{1-\tilde{\lambda}_{HH}},\\
\frac{\hat{q}_{HF}}{\hat{q}_{HH}} &= -\left(1-\frac{1}{\sigma}\right)\frac{1}{\left(\frac{1}{\sigma}\frac{1-\tilde{\lambda}_{FF}}{\tilde{\lambda}_{FF}}+1\right)}\frac{\tilde{\lambda}_{HH}}{1-\tilde{\lambda}_{HH}}.
\end{aligned}
$$

Using these observations in the expressions for welfare changes, we obtain

$$\begin{aligned}
\hat{W}_H^M &= \frac{1-\left(\frac{\theta}{\rho}-1\right)\tilde{\lambda}_{FF}\left(t_{HF}-1\right)}{1-\tilde{\lambda}_{HH}+\left(\frac{\theta}{\rho}-1\right)\tilde{\lambda}_{FF}}\frac{1}{\rho}\frac{1}{t_{HF}}\tilde{\lambda}_{HH}\hat{\lambda}_{HH}, \\
\hat{W}_H^A &= \frac{1-\left(\sigma-1\right)\tilde{\lambda}_{FF}\left(t_{HF}-1\right)}{1-\tilde{\lambda}_{HH}+\left(\sigma-1\right)\tilde{\lambda}_{FF}}\frac{1}{\rho}\frac{1}{t_{HF}}\tilde{\lambda}_{HH}\hat{\lambda}_{HH}.
\end{aligned}$$

The expressions in the text follow from rearranging terms.

A.7 Proof of Lemma 5 (Welfare with multilateral tariff reforms, asymmetric countries)

The changes $\mathrm{d}\varphi_{HH}^*/\mathrm{d}t$ and $\mathrm{d}\varphi_{FH}^*/\mathrm{d}t$ for Melitz and $\mathrm{d}q_{HH}/\mathrm{d}t$ and $\mathrm{d}q_{HF}/\mathrm{d}t$ can be computed from (30) and (31) with $\mathrm{d}t = \mathrm{d}t_{HF} = \mathrm{d}t_{FH}$. One obtains

$$\begin{aligned}
\frac{\hat{\varphi}_{FH}^*}{\hat{\varphi}_{HH}^*} &= -\frac{1+2\left(\frac{\theta}{\rho}-1\right)\tilde{\lambda}_{HH}}{1+2\left(\frac{\theta}{\rho}-1\right)\tilde{\lambda}_{FF}}\frac{\tilde{\lambda}_{FF}}{1-\tilde{\lambda}_{HH}}, \\
\frac{\hat{q}_{HF}}{\hat{q}_{HH}} &= \frac{2\left(\sigma-1\right)\tilde{\lambda}_{HH}+1}{2\left(\sigma-1\right)\tilde{\lambda}_{FF}+1}\frac{\tilde{\lambda}_{FF}}{1-\tilde{\lambda}_{HH}}.
\end{aligned}$$