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# Icebergs versus Tariffs:

## A Quantitative Perspective on the Gains from Trade\*

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### Abstract

We derive a simple equation for the welfare gains from trade when tariffs are liberalized or iceberg trade costs fall. Covering various one-sector trade models that may or may not feature extensive margins and imperfect competition, we generalize the analysis of Arkolakis, Costinot and Rodriguez-Clare (2012) to encompass revenue-generating import tariffs. Our formula permits easy quantification based on countries' observed degrees of openness, their tariff revenues, and gravity elasticities. We show analytically that an analysis based on iceberg costs necessarily underestimates the welfare gains from trade relative to autarky. Our quantitative exercise for 41 countries suggests that the bias can be numerically significant. For countries with relatively high status quo tariffs, our formula predicts 30-60% larger gains from trade than the icebergs only approach.

*JEL-Classification:* F10, F11, F12.

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

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# 1 Introduction

Arkolakis, Costinot and Rodriguez-Clare (2012, henceforth ACR) provide a simple formula that allows computing the welfare gains relative to autarky based on a single statistic, the observed share of a country's trade with itself, and on a single parameter, the trade elasticity obtained from a gravity equation. That formula holds in a class of single-sector models that have become popular in the quantitative literature.<sup>1</sup> While the required trade elasticity may have a different structural interpretation in the different models, it is always the trade flow elasticity of iceberg trade costs.

Hence, imperfect competition and the presence of an extensive margin—the novel features stressed in the recent literature—have no extra role to play for the *ex-post* analysis of trade liberalization scenarios. 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 to 1.4% of GDP). Two conclusions emerge from ACR: (i) the richer micro-level detail contained in new trade models “has not added much” to the gains from trade, and (ii) gains from trade are small.

In ACR's framework, the allowed exogenous variation includes changes in iceberg trade costs, foreign labor endowments, or fixed market access costs. It does not include tariffs. In this paper, we relax this assumption and show that conclusion (i) in ACR is robust: conditional on a country's observed trade share, and under the restriction that the gravity elasticities of iceberg trade costs and of tariffs coincide, the welfare gains from trade liberalization do not depend on the different models' micro structure. The two elasticities are the same in the Armington (1969), Krugman (1980) and Eaton and Kortum (2002) models, but they generally differ in the Melitz (2003) model. So, it appears that the presence of a selection channel combined with monopolistic competition has a quantitative bearing on the gains from trade.

Conclusion (ii) requires qualification because the welfare formula with tariffs differs from that without. For the quantitative exercise, besides the iceberg elasticity, one also requires the trade flow elasticity of tariffs, and, besides the trade share, one also requires the share of tariff

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<sup>1</sup>The frameworks covered include the Armington (1969), Krugman (1980), Eaton and Kortum (2002) and Melitz (2003) models.

revenue in total GDP. In any case, it turns out that the ACR formula necessarily underestimates the gains from trade relative to autarky: in the presence of a non-zero tariffs, the gains from trade are always larger than in their absence.

The generalized welfare formula can as easily brought to the data than ACR's. Using the same calibration strategy as ACR, and concentrating on models in which tariffs and iceberg trade costs feature the same gravity elasticity, we find that tariffs can matter very significantly: for example, in the year 2000, the icebergs-only specification underpredicts the gains from trade for Australia by 34.5 to 51.2%, for Korea by 21.6 to 35.3% and for the U.S. by 8 to 14.8%, where the ranges result from different choice of trade elasticities.

ACR acknowledge that “... *our main welfare formula would need to be modified to cover the case of tariffs. In particular, the results derived ... ignore changes in tariff revenues, which may affect real income both directly and indirectly (through the entry and exit of firms).*”<sup>2</sup> In this paper we propose such a modified formula. The fact that iceberg trade costs and tariffs may have quite different effects on outcomes has been discussed in various papers but, to the best of our knowledge, not in the context of a quantitative trade model à la ACR. Cole (2012) uses the framework of Chaney (2008) to show that the trade flow elasticity of tariffs is larger than that of iceberg trade costs. He argues that estimates derived from variables such as distance may underestimate the trade enhancing effects of tariff reforms. We show that the different welfare effects derive more from the fact that tariffs generate revenue rather than from differences in elasticities.

Result (i) of ACR has prompted responses from the CGE literature. 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). In a related paper, Balistreri and Markusen (2009) claim that “[*removing rent-generating tariffs have different effects in monopolistic competition versus Armington models, because optimal tariffs are different*”. These findings are based on simulations. Our analytical results show that the first assertion is indeed correct; it entirely depends on the difference between the iceberg

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<sup>2</sup>See ACR (2012, footnote 33). Moreover, in their analysis of tariff reform in Costa Rica, Arkolakis, Costinot and Rodriguez-Clare (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*”.

and the tariff elasticities in the Melitz (2003) model. The second assertion, in contrast, is not generally true, since, for example, the Krugman (1980) and the Armington (1969) models do admit identical welfare expressions.

Also, result (ii) has triggered substantial further work. One debate relates to the role of *pro competitive gains* from trade. Arkolakis, Costinot, Donaldson, and Rodriguez-Clare (2012) show for a single-sector Melitz (2003) model with Pareto distributed productivities and variable markups that pro-competitive gains from trade are negative. Edmond, Midrigan and Xi (2012) use a multi-sector framework with oligopolistic competition and come to opposite conclusions. Another strand of research highlights the role of cross-industry differences in trade elasticities. Ossa (2012a) shows that a multi-sector Armington framework yields substantially larger aggregate welfare gains than a single-sector model. Moreover, ACR have already noticed the role of *multiple sectors* for their result (i). In such an environment, some sectors have higher gains under monopolistic competition than under perfect competition and other sectors have lower gains. The aggregate welfare effect depends on sectoral weights and is ambiguous. In the presence of *intermediate goods* the gains from trade are always larger under monopolistic competition than under perfect competition.<sup>3</sup>

Our work is related to two more areas of research. First, recent quantitative trade models have acknowledged the role of tariffs besides iceberg trade costs. For example, Alvarez and Lucas (2007) use the Eaton and Kortum (2002) model to study the effects of tariff reform. Ossa (2012b) studies optimal tariffs and tariff wars in an extension of the Krugman (1980) model. Caliendo and Parro (2012) provide a quantitative analysis of tariff liberalization in the context of NAFTA and stress the role of input-output linkages across sectors. While these models study tariffs, they do not make the role of tariffs for ACR's results (i) and (ii) explicit. This is the focus of the present study. Second, our analysis links to the structural econometric estimation of gravity models since these deliver the elasticities that turn out so crucial. The problem is that iceberg trade costs are not directly observed and that tariff levels are likely to be endogenous. Crozet and Koenig (2010) have developed a method to estimate the tariff and iceberg elasticities

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<sup>3</sup>ACR also show that the gravity elasticity of trade cost is not sufficient to compute welfare gains in the presence of multiple sectors or intermediate goods.

without knowledge of trade frictions.

We have structured the remainder of this paper as follows: Section 2 introduces the model setup and explains how the introduction of tariffs alters the ACR framework. Section 3 characterizes welfare in the presence of tariffs. Using observed openness and tariff revenue, Section 4 shows that the gains from trade can be severely underestimated when the variation in openness is assumed to be due only to changes in iceberg costs while the reality does feature tariffs. Finally, Section 5 concludes.

## 2 Import tariffs in quantitative trade models

### 2.1 Preferences, technology, trade costs, and market structure

We introduce import tariffs into quantitative trade models à la ACR. We focus on three particular models that satisfy the primitive assumptions and macro-level restrictions outlined in ACR: (i) a simple Armington model, (ii) Eaton and Kortum (2002) as an example of a Ricardian model, and (iii) Melitz (2003) with Pareto-distributed productivities and foreign market access cost in terms of foreign labor as a monopolistic competition model.<sup>4</sup> Note that the Melitz model nests the Krugman (1980) model in a limiting case.

**Preferences.** The representative household in country  $i$ ,  $i \in 1..n$ , has symmetric CES preferences (Dixit-Stiglitz)

$$U_i = \left( \int_{\omega \in \Omega_i} q_i[\omega] \right)^{1/\rho}, \quad (1)$$

where  $\Omega_i$  is the set of differentiated varieties available in country  $i$ ,  $q_i[\omega]$  is the quantity of variety  $\omega$  consumed in country  $i$  and  $\sigma = 1/(1 - \rho) > 1$  is the constant elasticity of substitution.<sup>5</sup> The price index dual to (1) is  $P_i^{1-\sigma} = \int_{\omega \in \Omega_i} p_i[\omega]^{1-\sigma} d\omega$ .

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<sup>4</sup>Working with particular examples prevents us from using “hat” algebra in expressing welfare as a function of openness and tariff revenue. Expressing foreign market access costs in terms of foreign labor provides a gravity equation that obeys a particularly tractable functional form.

<sup>5</sup>We use square brackets to denote functional relationships.

**Technology and trade costs.** Labor is the only factor of production and is supplied inelastically at quantity  $L_i$  and price  $w_i$ . Output is linear in labor, and productivity may or may not differ across firms, with  $b_i$  denoting the minimum productivity level. International trade is subject to frictions while intranational trade is frictionless. In all models considered, exporting from  $i$  to  $j$  involves iceberg trade costs  $\tau_{ij}$ , where  $\tau_{ii} = 1$ . Moreover, in Melitz (2003) there are fixed market access costs, assumed to be in units of the destination country's labor, that have to be paid to serve the home or the foreign market.

**Structure of product markets.** There are two types of market structures: perfect competition and monopolistic competition with free entry. In both situations, firms take wages and aggregate variables as given. With perfect competition, fixed innovation and market access costs are zero. With monopolistic competition, in contrast, firms have to pay to obtain blueprints for production. The allocation of these potentially heterogeneous blueprints across firms is random.

**Tariffs.** The key 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 to consumers. As opposed to iceberg trade costs, a tariff distorts consumption decisions towards domestic goods but does not entail loss in transit.

## 2.2 Macro-level restrictions

In their analysis, ACR impose three restrictions whose key role is to ensure that the framework described above gives rise to a gravity equation, i.a., a representation of bilateral trade flows where elasticities are constant. The first restriction, R1, requires that trade is balanced on a multilateral level; the second, R2, mandates that aggregate gross profits are proportional to aggregate revenue, and the third, R3', puts a functional form on the gravity equation.

R2 needs no further qualification in the context of our exercise. R1, the balanced trade condition, warrants a comment. In the presence of tariffs, it does not imply that aggregate firm revenue and aggregate consumer spending are the same. To see this, let  $X_{ij}$  denote the value of country  $j$ 's total imports from country  $i$  in *domestic* prices (i.e., gross of tariff, gross of iceberg

trade costs), then balanced trade requires

$$\sum_{i=1}^n \frac{X_{ji}}{t_{ij}} = \sum_{i=1}^n \frac{X_{ij}}{t_{ji}}, \text{ for all } j. \quad (2)$$

Aggregate revenue *accruing to firms* is given by  $R_j \equiv \sum_{i=1}^n X_{ji}/t_{ij}$ , while, with tariff income, *consumer's* aggregate expenditure is  $X_j \equiv \sum_{i=1}^n X_{ij}$ . Hence, balanced trade does not imply  $X_j = R_j$ , a restriction heavily employed by ACR.

R3' makes a restriction on functional forms so that trade flow equations resulting from the model are similar to known gravity model forms. We employ a similar, albeit slightly more general restriction (R3') of the form

$$\frac{X_{ij}}{X_{jj}} = \frac{\chi_{ij}}{\chi_{jj}} \frac{N_i}{N_j} \left( \frac{w_i}{w_j} \tau_{ij} \right)^\varepsilon t_{ji}^\zeta, \quad (3)$$

which accommodates the presence of tariffs. Dividing by  $X_{jj}$  eliminates income  $Y_j$  and the multilateral resistance term à la Anderson and van Wincoop (2003).  $\chi_{ij}$  collects constants different from iceberg costs  $\tau_{ij}$  and tariffs  $t_{ji}$ .  $N_i$  is the mass of firms potentially active in country  $i$ . That mass is endogenously determined, but due to R1 and R2,  $N_i$  is proportional to exogenous labor endowment  $L_i$  so that  $N_i$  does not change in a comparative statics exercise on  $\tau$  or  $t$ . The elasticities  $\varepsilon$  and  $\zeta$  are constants with negative signs. In ACR, the term  $t_{ji}^\zeta$  is not present.

ACR show that the Armington model by Anderson and van Wincoop (2003) satisfy R1 to R3' without further restrictions. However, the Eaton-Kortum (2002) and Melitz (2003) models satisfy R2 and R3 only under strong functional form assumptions on the distribution governing within country heterogeneity that make sure that there is a unique trade elasticity despite the presence of two margins of adjustment (intensive/extensive). The same functional form restrictions are required in the presence of tariffs (i.e., the Fréchet distribution in the Eaton and Kortum (2002) framework and the Pareto distribution in the Melitz (2003) case).

Table 1 provides the details on the structural interpretation of the tariff and iceberg elasticities from equation (3) for the different models considered in our analysis.<sup>6</sup>  $\gamma > \sigma - 1$  is

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<sup>6</sup>See Appendix B for the detailed derivations.



the (unique, positive) parameter of the Fréchet distribution governing unit labor requirements in Eaton and Kortum (2002), and  $\theta > \sigma - 1$  is the (unique, positive) parameter of the Pareto distribution governing firm-level productivity draws in a parameterized version of Melitz (2003). In Armington (1969) and Eaton and Kortum (2002), we have  $\varepsilon = \zeta$  since we define export flows as inclusive of tariffs.<sup>7</sup> In Melitz, we have  $\varepsilon \geq \zeta$  where the inequality strictly holds for  $\theta > \sigma - 1$ . In the Krugman (1980) model, which emerges as the limiting case of the Melitz (2003) model if  $\theta \rightarrow \sigma - 1$ , we also have  $\varepsilon = \zeta$ .

**Table 1:** Iceberg and tariff elasticities in various trade models

	Armington, Krugman (1980)	Eaton&Kortum (2002)	Melitz (2003)
Iceberg elasticity $\varepsilon$	$1 - \sigma$	$-\gamma$	$-\theta$
Tariff elasticity $\zeta$	$1 - \sigma$	$-\gamma$	$1 - \theta/\rho$

## 2.3 Identities

**Expenditure and income.** The government's *tariff revenue* is given by

$$T_j \equiv \sum_{i \neq j} \frac{t_{ji} - 1}{t_{ji}} X_{ij}, \quad (4)$$

where  $X_{ij}/t_{ji}$  is the value of imports from  $i$  exclusive of tariffs.  $T_j$  is rebated lump-sum to the representative household. So, *aggregate expenditure*  $X_j$  (equal to aggregate income) is made up of labor income  $w_j L_j$  and tariff revenue  $T_j$

$$X_j = w_j L_j + T_j = \mu_j w_j L_j, \quad (5)$$

where  $\mu_j$  is a tariff multiplier defined as

$$\mu_j \equiv \left(1 - \frac{T_j}{X_j}\right)^{-1} \geq 1.$$

<sup>7</sup>This is just a convention that somewhat eases notation in our framework. Writing trade flows net of tariffs yields a gravity coefficient  $\eta$  on tariffs of  $\varepsilon - 1$ , and requires rewriting the balanced trade condition. None of our results would change.

The multiplier  $\mu_j$  arises because spending labor income on imports generates tariff income which is part of aggregate income.<sup>8</sup> Equation (5) greatly simplifies our analysis for two reasons. First, there is no need to keep track of bilateral trade flows and bilateral tariffs. All relevant information is represented by the share of aggregate tariff revenue in aggregate income, which is an easily observable magnitude. Second, it allows expressing aggregate labor income as a function of total income and the share of tariff revenue in aggregate income (GDP). Since labor is the only factor of production, and profits are fully competed away by free entry, all firm revenue needs to be paid out to workers as *labor income*  $w_j L_j$ . Hence,

$$w_j L_j = \sum_i \frac{X_{ji}}{t_{ij}}, \quad (6)$$

where dividing by  $t_{ij}$  takes care of  $X_{ji}$  being defined as inclusive of tariffs.

**Expenditure share.** ACR express country  $j$ 's welfare as a function of the share of *expenditure* that falls on its own (domestically produced) goods, i.e.,

$$\lambda_{jj} \equiv \frac{X_{jj}}{X_j} = \left( 1 + \sum_i X_{ij}/X_{jj} \right)^{-1}. \quad (7)$$

That share is an inverse measure of  $j$ 's openness also referred to as its degree of “autarkiness”;  $1 - \lambda_{jj}$  would then be its openness.<sup>9</sup> The simplicity of ACR's analysis very much hinges on the fact that  $\lambda_{jj}$  summarizes the country's stance relative to the rest of the world.

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<sup>8</sup>Although we limit our analysis to import tariffs  $t_{ji} > 1$ , our model can easily be extended to import subsidies  $t_{ji} < 1$ . A tariff multiplier  $\mu_j$  larger than unity obtains if *net* tariff revenue is positive.

<sup>9</sup>In the following, with some abuse of wording, we similarly refer to changes in autarkiness or openness when describing changes in  $\lambda_{ii}$ .

### 3 Welfare analysis

#### 3.1 A generalized formula for the gains from trade

We are interested in the effects of import tariffs on welfare. Welfare is given by the per capita value of real income accruing to consumers

$$W_j = \frac{X_j}{L_j P_j} = \mu_j \frac{w_j}{P_j}, \quad (8)$$

where the second equality makes use of (5). Importantly, welfare not only depends on real labor income, but also on redistributed real tariff revenue.

As outlined above, the tariff multiplier  $\mu_j$  is computed from aggregate tariff revenue as a share of aggregate income. Real labor income is essentially unobserved. In Appendix C, however, we show that the change in real labor income can be expressed in a multiplicative fashion as a function of the change in the tariff multiplier and the change in the share of domestic expenditure share as

$$\widehat{\left(\frac{w_j}{P_j}\right)} = \widehat{\mu}_j^{\zeta-1} \widehat{\lambda}_{jj}^{1/\varepsilon}, \quad (9)$$

where as in ACR  $\widehat{x} \equiv x'/x$  denotes the change in any variable  $x$  between the initial and the new equilibrium.<sup>10</sup> Three observations stand out. First, with  $\varepsilon = \zeta$  the change in real income can be computed from the change in the share of domestic expenditure as in ACR. Second, with  $\varepsilon \neq \zeta$  computation of the change in real labor income becomes more complex since, additionally, information on the change in the tariff multiplier is necessary. The reason is that tariff income affects the mass of foreign firms exporting to country  $j$ , a margin which has repercussions on the price index and which is not active in the other models.<sup>11</sup> Finally, the change in real labor income does not represent the change in utility of country  $j$ 's representative consumer as tariff income has to be taken into account. Combining equations (8) and (9) leads to the following

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<sup>10</sup>The intuition behind the result is the same as in ACR. Our proof, however, is simpler as we do not make use of “hat” algebra. The reason is that we focus on three particular examples of quantitative trade models and not on the whole class of models.

<sup>11</sup>Although the Eaton and Kortum (2002) model features selection, the mass of firms active in international trade has no particular role due to perfect competition. In the special case in which Melitz (2003) replicates the Krugman (1980) model,  $\theta \rightarrow \sigma - 1$  also yields  $\zeta \rightarrow \varepsilon$ .

proposition.

**Proposition 1** *In the considered trade models (Armington (1969), Krugman (1980), Eaton and Kortum (2002), and Melitz (2003)), the change in real income associated with a change in tariffs and/or iceberg trade costs can be computed as*

$$\widehat{W}_j = \widehat{\mu}_j^{\frac{\zeta}{\varepsilon}} \widehat{\lambda}_{jj}^{\frac{1}{\varepsilon}}.$$

*Conditional on observed  $\widehat{\lambda}_{jj}$ ,  $\widehat{\mu}_j$  and given trade elasticities  $\varepsilon, \zeta$ ,  $\widehat{W}_j$  is larger in the Melitz (2003) model (where  $\zeta/\varepsilon > 1$ ) than in the other models (where  $\zeta/\varepsilon = 1$ ).*

**Proof.** *Immediately follows from combining equations (8) and (9). ■*

Proposition 1 states that for the set of quantitative trade models considered, the change in welfare can be computed from the change in the tariff multiplier and the change in the domestic expenditure share, given the elasticities  $\varepsilon$  and  $\zeta$ . The formula collapses to the one presented by ACR in the absence of tariffs, i.e.,  $\widehat{W}_j^{ACR} = \widehat{\lambda}_{jj}^{1/\varepsilon}$ . As in ARC, Proposition 1 can be used to infer welfare consequences of past episodes of trade liberalization. In particular, one can very easily compute the gains from trade relative to autarky, for which  $\lambda_{jj} = 1$  and  $\mu_j = 1$ .

As long as one imposes the restriction on gravity parameters  $\varepsilon = \zeta$ , the exact micro foundation of the models does not matter for the size of welfare gains, even in the presence of tariffs. However, this isomorphism breaks in the Melitz (2003) model where  $\varepsilon > \zeta$ . Hence, the combination of tariff revenue, firm selection and monopolistic competition matters for the gains from trade.<sup>12</sup>

### 3.2 Ignoring tariffs leads to underestimation of the true gains from trade

In general, the ACR welfare formula may over- or underestimate the true gains from trade. Conditional on the observed change in the domestic expenditure share, the ACR formula overestimates the welfare gains if  $\widehat{\mu}_j < 1$ . This overestimation occurs if the share of tariff income in aggregate income has fallen during liberalization. If, on the other hand, this share has risen,

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<sup>12</sup>With  $\varepsilon = \zeta$ , firm selection stops operating in the Melitz (2003) model.

the ARC formula underestimates the gains from trade reform. In particular, the ACR formula underestimates the gains from trade in the case of moving from autarky to the observed equilibrium. By definition, trade costs (either icebergs or tariffs) are prohibitive under autarky, such that the economy raises no tariff revenue in the initial equilibrium.

How sensitive is the underestimation of the the welfare gains from trade for a given domestic expenditure share and given tariff multiplier to the changes in the elasticities  $\varepsilon$  and  $\zeta$  and their determinants  $\sigma$ ,  $\gamma$ , and  $\theta$ ? We answer this question in the following proposition.

**Proposition 2** *Ignoring tariff revenue, the ACR formula underestimates the true gains from trade relative to autarky by*

$$\kappa_j \equiv 100 \left| \frac{\lambda_{jj}^{\frac{1}{\varepsilon}} - 1}{\mu_j^{\frac{\zeta}{\varepsilon}} \lambda_{jj}^{\frac{1}{\varepsilon}} - 1} - 1 \right| \%$$

- (a)  $\kappa$  is increasing in the share of domestic expenditure  $\lambda_{jj}$  and in the tariff multiplier  $\mu_j$ .
- (b) If iceberg and tariff elasticities coincide as in Armington (1969), Eaton and Kortum (2002), and Krugman (1980),  $\kappa$  is decreasing in the trade elasticity.
- (c) If iceberg and tariff elasticities are given by respectively  $\varepsilon = -\theta$  and  $\zeta = 1 - \theta/\rho$  as in Melitz (2003),  $\kappa$  is decreasing in the degree of productivity dispersion  $1/\theta$  and in the elasticity of substitution  $\sigma$ .

**Proof.** See Appendix D. ■

Proposition 2 implies that in the Armington case and in Krugman as a special case of the Melitz model, underestimation becomes more severe the larger the elasticity of substitution. In the Eaton-Kortum case, underestimation falls in the degree of heterogeneity across goods in countries' labor efficiency levels.<sup>13</sup> In the Melitz framework,  $\kappa_j$  falls in the elasticity of substitution, which contrasts the findings for the Armington and the Krugman model.<sup>14</sup> The effect of productivity dispersion is *a priori* unclear, as the domestic expenditure share is smaller than one, whereas the tariff multiplier is larger than one. We show in Appendix D that  $\kappa_j$

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<sup>13</sup>Recall that  $\gamma$  is inversely related to heterogeneity.

<sup>14</sup>Note that  $\sigma$  and  $\rho$  are positively correlated.

is unambiguously increasing in  $\theta$ . Hence, for given  $\lambda_{jj}$  and  $\mu_j$ , higher productivity dispersion (lower  $\theta$ ) leads to less severe underestimation.

### 3.3 Effects of symmetric liberalization

In order to build intuition for what happens if trade is liberalized along both margins, icebergs and tariffs, we characterize the tariff multiplier and analyze the gains from trade for two polar cases: We consider the welfare effects of reducing (i) icebergs for given tariffs, and (ii) tariffs for given icebergs. It turns out that allowing for variation in icebergs but fixing tariffs retains the convex relationship between welfare and the share of domestic expenditure known from ACR. Quite to the contrary, dismantling tariffs yields a concave relationship. In the data, of course, we see a combination of both.

To derive our theoretical argument, we employ a framework with two symmetric countries. In this setting, we can abstract from terms-of-trade considerations. Moreover, we can express the tariff and therefore the tariff multiplier as a function of the domestic expenditure share, which allows for a simple graphical representation of gains from trade in a two-dimensional diagram.

**The tariff multiplier.** With two symmetric countries, the tariff multiplier can be written as

$$\mu = \frac{t}{\lambda(t-1) + 1}, \quad (10)$$

which follows from the definition of tariff revenue  $T$  implicitly given by equation (5). Totally differentiating this expression, we obtain

$$d \ln \mu = \frac{1 - \lambda}{\lambda(t-1) + 1} d \ln t - \frac{\lambda(t-1)}{\lambda(t-1) + 1} d \ln \lambda, \quad (11)$$

where the first term on the right hand side of the equation represents a *tariff rate effect*. The second term is a *tax base effect*. Evaluated at the free trade equilibrium,  $t = 1$ , the tax base effect is inactive, but the tariff rate effect amounts to  $(1 - \lambda) d \ln t$ . Under autarky,  $\lambda = 1$ , the tariff rate effect is inactive, but the tax base effect is given by  $(1 - 1/t) d \ln \lambda$ .

Exploiting the functional form restriction on gravity (3), for fixed non-tariff barriers the

change in the domestic expenditure share and the change in the tariff are linked by

$$d \ln \lambda = -(1 - \lambda) \zeta d \ln t. \quad (12)$$

Substituting this expression back into equation (11), the tariff  $t^*$  that maximizes the tariff multiplier, i.e., tariff revenue relative to aggregate income, is implicitly given by

$$t^* = 1 - \frac{1}{\zeta \lambda} > 1,$$

where the inequality follows from recalling that  $\zeta$  is a negative elasticity.<sup>15</sup> The  $\mu$ -schedule follows the logic of a Laffer curve. Tariff revenue rises in the tariff for small tariffs up to its maximum and then falls to zero as the tariff grows larger and larger. The extent to which the ACR formula underestimates the welfare gains from trade relative to autarky is therefore larger for intermediate values of the domestic expenditure share.

Clearly, the tariff that maximizes the tariff multiplier is larger than the tariff that maximizes welfare. Given the absence of terms-of-trade considerations, the welfare-maximizing tariff is given by  $t^o = 1$ .

**Icebergs in the presence of tariffs.** Consider now a change in iceberg trade costs in the presence of a constant tariff. The change in welfare is

$$\left. \frac{d \ln W}{d \ln \lambda} \right|_{t=\bar{t}} = \frac{1}{\varepsilon} \left( 1 - \zeta \frac{\lambda(t-1)}{\lambda(t-1)+1} \right). \quad (13)$$

Recall that  $\varepsilon$  and  $\zeta$  are negative elasticities. Welfare is therefore strictly decreasing in  $\lambda$ . The first term in brackets on the right hand side represents an import price effect, and the second term is a tax base effect. Clearly there is no tax base effect in the absence of tariffs,  $t = 1$ . In this case, the formula collapses to the ACR result, and welfare is strictly convex in  $\lambda$ . Using equation (13), we show in Appendix E that welfare is still convex in  $\lambda$  in the presence of tariffs.

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<sup>15</sup>The tariff-multiplier maximizing tariff  $t^*$  follows from setting  $d \ln \mu / d \ln \lambda$  to zero.

**Lowering tariffs.** Consider a change in tariffs for given iceberg costs. Using equation (12) to substitute out  $d \ln t$  from equation (11), we can write the change in welfare as

$$\left. \frac{d \ln W}{d \ln \lambda} \right|_{\tau=\bar{\tau}} = \frac{1}{\varepsilon} \left( 1 - \zeta \frac{\lambda(t-1)}{\lambda(t-1)+1} - \frac{1}{\lambda(t-1)+1} \right), \quad (14)$$

where as in equation (13) the first term is the import price effect, and the second term is a tax base effect. These terms are accompanied by the tariff rate effect. Evaluated at free trade equilibrium,  $t = 1$ , the second term in brackets disappears, and the third term simplifies to unity. Hence, the import price effect is exactly offset by the tax rate effect, and a small tariff therefore has no net welfare consequences. Evaluated at the autarky equilibrium,  $t \rightarrow \infty$ , the tariff rate effect is absent, and the tax base effect converges to  $-\zeta$ . Clearly, there would be no tax base effect if autarky was generated through prohibitive non-tariff barriers.

Using equation (14), we show in Appendix E that welfare is concave in domestic expenditure share when variation in the expenditure share is solely driven by changes in import tariffs.

**Proposition 3** *In a symmetric two-country world with tariffs  $t$  and icebergs  $\tau$*

- (a) *variation in  $\tau$  for given  $t$  yields a convex downward sloping relationship between welfare and autarkiness  $\lambda$  while*
- (b) *variation in  $t$  for given  $\tau$  generates a concave, downward sloping relationship.*

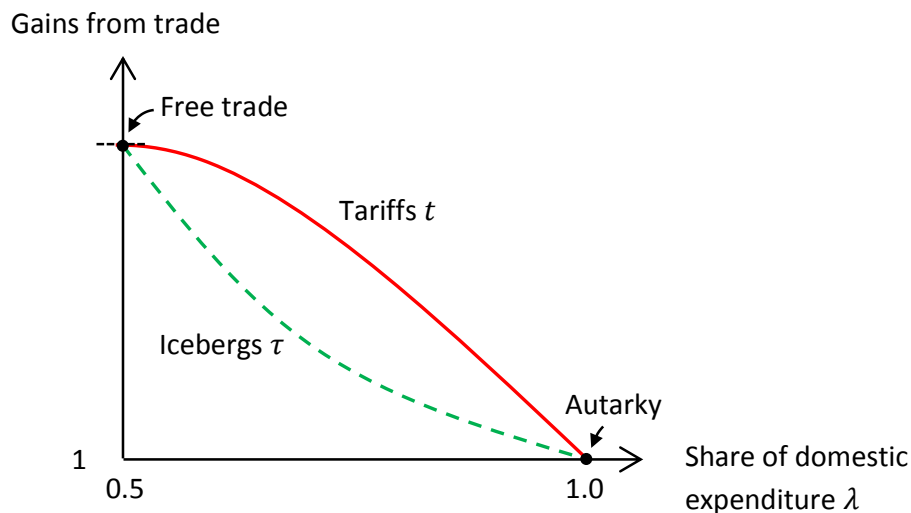
**Proof.** See Appendix E. ■

Figure 1 provides an illustration of the two polar cases, with autarky welfare normalized to unity. Clearly, since welfare is the same for the two cases in either autarky (when either  $\tau$  or  $t$  or both are prohibitively high) or free trade (when trade is entirely free), for values of  $\lambda \in [0.5, 1]$ , the concave curve has to lie above the convex one, so that a lens opens up. The height of the lens describes the potential maximum amount of underestimation that arises when all variation in  $\lambda$  is attributed to changes in  $\tau$ .

The existence of the lens is most easily rationalized by the fact that, at  $\lambda = 0.5$ , a small tariff has no welfare implications while a small iceberg yields a welfare loss. Starting at  $\lambda = 1 - \epsilon$ , where  $\epsilon$  is arbitrarily small, a further marginal increase in  $\tau$  brings the economy to autarky, but



**Figure 1:** Gains from trade and share of domestic expenditure: Icebergs vs. tariffs



also implies that no more resources are lost in transit. In contrast, a further increase in  $t$ , which results in the same autarky welfare, eliminates all tariff revenue. Hence, the absolute value of the slope of the welfare function is higher when  $t$  changes than when  $\tau$  changes.

Figure 1 generalizes easily to the case of asymmetric countries. In such a setup, in all the models considered a strictly positive optimal tariff exists.<sup>16</sup> This means that there is some  $\lambda^o \in [0, 1]$  that maximizes welfare when openness changes due to  $t$ . In other words, the welfare function under variation of  $t$  must be concave for a maximum at  $\lambda^o$  to exist. The welfare function under variation of  $\tau$  remains convex, as before. Hence, a lens opens up and our underestimation result appears.

## 4 Quantitative exercise

As a final step in this paper, we bring our Propositions 1 and 2 to the data with the aim to quantify the role of tariff income for the size of the gains from trade. We require data on domestic expenditure shares  $\lambda_{jj}$  and on tariff multipliers  $\mu_j$  for as many countries as possible. We also need to know the iceberg elasticity  $\varepsilon$  and the tariff elasticity  $\zeta$ . To enable comparison

<sup>16</sup>See Gros (1987) for the case of the Krugman (1980) model, Alvarez and Lucas (2007) for Eaton and Kortum (2002), and Felbermayr, Jung and Larch (2013) for the Melitz (2003) model.

with ACR, we stick as close as possible to their quantitative exercise.

ACR suggest to compute  $\lambda_{jj}$  based on import penetration ratios defined as imports over *gross* output rather than GDP. These two measures differ as the former includes imported intermediates while the second does not. Imported intermediates also appear in imports. So, either one computes  $\lambda_{jj}$  based on the value added content of imports and GDP, or on gross imports and gross output.<sup>17</sup> We follow ACR and use the latter approach. Note that dividing gross imports by GDP would result in lower values of  $\lambda_{jj}$ , leading to overestimation of welfare gains. For the year 2000, we have information on gross output from OECD input-output tables for 41 countries.

Tariff revenue as a share of gross output is computed from combining trade-weighted average tariffs from the World Development Indicators data base with information on imports and gross output from the input-output tables. For six countries, the year 2000 average tariff is missing. We use the averaged value from the years 1999 and 2001 instead.<sup>18</sup>

Finally, we need information on  $\varepsilon$  and  $\zeta$ . Ideally, to obtain estimates for these parameters, we would have data on iceberg trade costs and tariffs. In the cases of the Armington (1969), Krugman (1980) and Eaton and Kortum (2002) models, one would estimate a gravity equation under the assumption  $\varepsilon = \zeta$ . In the Melitz (2003) case, we have  $\varepsilon \neq \zeta$ , and so one would have to estimate a gravity model and allow parameters to differ. This paper is not about the consistent estimation of trade elasticities, which is a non-trivial task.<sup>19</sup> Rather, we demonstrate the quantitative importance of taking observed tariffs into account based on estimates taken from the literature and staying as close to ACR as possible. Hence, we set the elasticity to either  $-5$  or  $-10$  when the underlying model mandates  $\varepsilon = \zeta$ . For the Melitz (2003) model, we use recent estimates by Crozet and Koenig (2010) obtained from structural estimation based on firm-level data. They report an elasticity of substitution of  $\sigma = 2.25$  and a Pareto decay parameter of  $\theta = 3.09$ . These estimates imply  $\varepsilon = -3.09$  and  $\zeta = -4.562$ .

In our 41 country sample, in the year 2000, import penetration ratios vary between 5.2%

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<sup>17</sup>Imports are evaluated at c.i.f. prices (cost, insurance, freight); see OECD Input-Output Database edition 2006 - STI Working Paper 2006/8.

<sup>18</sup>The six countries are: India, Korea, Russian Federation, South Africa, Turkey, and Vietnam.

<sup>19</sup>E.g., one would have to deal with the possibility that tariffs are endogenous.

in Japan at the lower end to 53.9% in Luxembourg at the higher end. The average is 22.9% and the standard deviation across our country sample is 11.7%.<sup>20</sup> The trade-weighted average import tariff varies between 27.5% in India and 1.1% in Norway. The average tariff rate is 4.2%; the standard deviation is 5.3%. So, in 2000, tariffs are not negligible for a considerable number of countries. Similarly, in the data, there is substantial variation in the share of tariffs in gross output; it ranges between 0.1% (Japan, USA) and Vietnam (5.2%) with a mean of 0.8% and a standard deviation of 0.8%.

The tariff multiplier, computed according to equation (5), ranges from 1.0014 for less open and low-tariff countries like the US and Japan to 1.0548 for Vietnam, a country that, in the year 2000, imposes an import tariff of about 18% but is still relatively open. The mean multiplier is 1.0079 and the standard deviation is 1.0057. The tariff multipliers seem to be very small in size. However, since the gains from trade are rather small as well (as demonstrated by ACR), the amount of underestimation can still be sizeable.

Table 2 reports welfare gains from trade relative to autarky for the models in which iceberg and tariff elasticities  $\varepsilon = \zeta$  coincide. As ACR, we set  $\varepsilon \in \{-5, -10\}$ . The columns entitled “ACR” assume, counterfactually, that tariff revenue in all countries is zero. This case yields gains from trade that replicate the findings of ACR for the US and also turn out very small for many other countries. For the conservative case of  $\varepsilon = \zeta = -5$ , the mean value for the gains from trade is 5.6% with a standard deviation of 3.6%. The columns entitled “Data” refer to the situation where tariff revenue, as observed, is taken into account and the iceberg trade costs are implicitly set such that the observed levels of  $\lambda$  are reproduced as equilibrium outcomes. As predicted by theory, in this case, the gains from trade are substantially larger: the mean is 6.4% and the standard deviation is 3.9%. The third column reports the degree by which the ACR formula underestimates the true gains from trade. Our exercise suggests that the amount of underestimation can be very substantial: for the case  $\varepsilon = \zeta = -5$  it can range as high as 57.7% in India, 45.7% in Vietnam or 41.7% in China. All these countries still have substantial tariffs in place as of year 2000. The average amount of underestimation is 13.0%; the median is 10.3%.

When ignoring tariffs, the gains from trade fall by about 50% on average relative to the

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<sup>20</sup>Table 4 in the Appendix reports the full data.

**Table 2:** Gains from trade when iceberg and tariff elasticities coincide (year 2000)

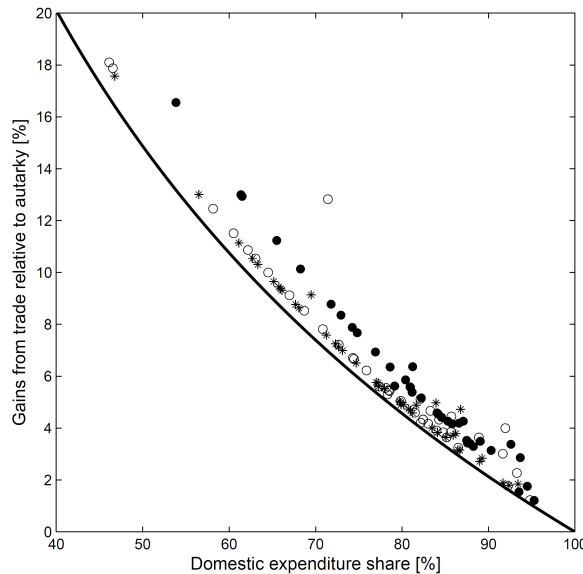
	<i>Trade elasticities: -5</i>			<i>Trade elasticities: -10</i>		
	<b>ACR</b>	<b>Data</b>	<b>Underest.</b>	<b>ACR</b>	<b>Data</b>	<b>Underest.</b>
Australia	2.4%	3.6%	34.5%	1.2%	2.4%	51.2%
Austria	6.1%	6.7%	8.8%	3.0%	3.6%	15.9%
Belgium	10.0%	10.9%	8.3%	4.9%	5.7%	15.0%
Brazil	1.4%	2.3%	38.3%	0.7%	1.6%	55.3%
Bulgaria	5.1%	5.6%	8.9%	2.5%	3.0%	16.2%
Canada	5.0%	5.3%	5.6%	2.5%	2.8%	10.5%
China	1.8%	3.0%	41.7%	0.9%	2.1%	58.7%
Cyprus	9.7%	10.5%	8.3%	4.7%	5.6%	15.0%
Czech Republic	6.6%	7.2%	8.7%	3.2%	3.8%	15.8%
Denmark	6.1%	6.7%	8.7%	3.0%	3.6%	15.9%
Estonia	10.6%	11.5%	8.2%	5.2%	6.0%	14.8%
Finland	3.9%	4.3%	9.1%	2.0%	2.3%	16.5%
France	3.4%	3.8%	12.3%	1.7%	2.1%	21.7%
Germany	4.2%	4.6%	9.0%	2.1%	2.5%	16.4%
Greece	5.7%	6.2%	8.8%	2.8%	3.3%	16.0%
Hungary	9.2%	10.0%	8.4%	4.5%	5.3%	15.1%
India	1.7%	4.0%	57.7%	0.8%	3.1%	73.1%
Indonesia	3.5%	4.3%	19.6%	1.7%	2.6%	32.5%
Ireland	11.5%	12.5%	8.1%	5.6%	6.5%	14.6%
Italy	2.9%	3.2%	9.2%	1.5%	1.8%	16.8%
Japan	1.1%	1.2%	12.1%	0.5%	0.7%	21.6%
Korea	4.0%	5.1%	21.6%	2.0%	3.1%	35.3%
Luxembourg	16.7%	18.1%	7.5%	8.0%	9.3%	13.5%
Malta	16.5%	17.9%	7.5%	7.9%	9.2%	13.6%
Netherlands	8.3%	9.1%	8.5%	4.1%	4.8%	15.3%
New Zealand	3.3%	3.6%	10.4%	1.6%	2.0%	18.7%
Norway	4.0%	4.2%	4.7%	2.0%	2.2%	8.9%
Poland	3.9%	4.3%	9.1%	2.0%	2.3%	16.5%
Portugal	5.0%	5.5%	8.9%	2.5%	2.9%	16.2%
Romania	4.6%	5.0%	9.0%	2.3%	2.7%	16.3%
Russian Fed.	3.1%	4.4%	29.6%	1.6%	2.8%	45.5%
Slovak Republic	7.8%	8.5%	8.5%	3.8%	4.5%	15.5%
Slovenia	7.1%	7.8%	8.6%	3.5%	4.2%	15.6%
South Africa	3.1%	3.9%	18.4%	1.6%	2.3%	30.9%
Spain	3.8%	4.2%	9.1%	1.9%	2.2%	16.5%
Sweden	4.9%	5.4%	8.9%	2.4%	2.9%	16.2%
Switzerland	5.3%	5.6%	5.9%	2.6%	2.9%	11.0%
Turkey	3.7%	4.7%	20.1%	1.8%	2.8%	33.2%
United Kingdom	3.5%	3.9%	9.1%	1.8%	2.1%	16.6%
United States	1.6%	1.8%	8.0%	0.8%	0.9%	14.8%
Vietnam	7.0%	12.8%	45.7%	3.4%	9.1%	62.3%
<i>Mean</i>	5.6%	6.4%	13.0%	2.7%	3.6%	22.9%
<i>Median</i>	4.6%	5.1%	10.3%	2.3%	2.9%	22.0%
<i>Std. Dev.</i>	3.6%	3.9%	7.0%	1.7%	2.1%	16.2%

**ACR:** Gains from trade stem from a pure reduction of icebergs. **Data:** Gains from trade stem from a joint reduction of icebergs and tariffs that is consistent with observed tariff revenue shares. **Underest.:** Percentage amount of underestimation of ACR relative to Data. In the conservative specification (Trade elasticities:  $-5$ ), the ACR formula underestimates gains from trade by 4.7% for Norway to 57.7% for India.

conservative parametrization when a higher trade elasticity of  $\varepsilon = \zeta = -10$  is assumed. When taking tariffs into account, the gains are also lower than under the baseline, but by less than 50%. The degree of underestimation goes up substantially in most countries: on average it is now 22.9% instead of 13.0%. The largest bias now appears in Australia (almost 105%); it is also very large in the high-tariff countries discussed above. However, underestimation appears important in some rich countries such as France, too.

Figure 2 reproduces the ACR welfare formula for  $\varepsilon = \zeta = -5$  as a function of  $\lambda$ . It also plots the gains from trade in the presence of tariff revenue for the years of 1995 (filled circles), 2000 (empty circles), and 2005 (asterisks). As tariffs have come down over time, the underestimation implied by the ACR formula has become smaller. The figure also shows that the difference between the iceberg-only situation and the case with icebergs and tariffs increases when the domestic expenditure share falls.

**Figure 2:** Gains from trade: ACR versus data



**ACR:** Gains from trade stem from a pure reduction of icebergs. **Data:** Gains from trade stem from a joint reduction of icebergs and tariffs that is consistent with observed shares of tariff revenue in GDP. Data are given for the years 1995 (filled circles), 2000 (empty circles), and 2005 (asterisks).

Table 3 turns to the case where  $\varepsilon \geq \zeta$  such as in the Melitz (2003) model. We employ the parameter estimates provided by Crozet and Koenig (2010) which imply  $\varepsilon = -3.09$  and  $\zeta = -4.562$ . To facilitate comparison, we report welfare gains under the assumption that both

**Table 3:** Gains from trade when iceberg and tariff elasticities differ (year 2000).

	<i>Iceberg elasticity: -3.09</i>				
	<b>ACR</b>	<i>Tariff el.: -3.09</i>		<i>Tariff el.: -4.562</i>	
		<b>Data</b>	<b>Underest.</b>	<b>Data</b>	<b>Underest.</b>
Australia	3.9%	5.2%	24.7%	5.8%	32.7%
Austria	10.0%	10.6%	5.7%	10.9%	8.2%
Belgium	16.6%	17.6%	5.4%	18.0%	7.8%
Brazil	2.3%	3.2%	27.8%	3.6%	36.3%
Bulgaria	8.3%	8.8%	5.8%	9.1%	8.3%
Canada	8.2%	8.5%	3.6%	8.7%	5.2%
China	2.9%	4.1%	30.8%	4.7%	39.7%
Cyprus	16.1%	17.0%	5.4%	17.5%	7.8%
Czech Republic	10.9%	11.5%	5.7%	11.8%	8.1%
Denmark	10.1%	10.7%	5.7%	11.0%	8.2%
Estonia	17.7%	18.7%	5.4%	19.1%	7.8%
Finland	6.4%	6.9%	5.9%	7.0%	8.4%
France	5.5%	6.0%	8.0%	6.2%	11.4%
Germany	6.8%	7.3%	5.8%	7.5%	8.4%
Greece	9.3%	9.9%	5.7%	10.2%	8.2%
Hungary	15.2%	16.1%	5.5%	16.5%	7.9%
India	2.8%	5.1%	45.8%	6.2%	55.7%
Indonesia	5.7%	6.6%	13.2%	7.0%	18.3%
Ireland	19.2%	20.3%	5.3%	20.8%	7.7%
Italy	4.8%	5.1%	5.9%	5.3%	8.5%
Japan	1.7%	1.9%	7.9%	2.0%	11.2%
Korea	6.6%	7.7%	14.7%	8.3%	20.3%
Luxembourg	28.5%	30.0%	5.0%	30.7%	7.2%
Malta	28.1%	29.6%	5.0%	30.3%	7.2%
Netherlands	13.8%	14.7%	5.5%	15.0%	8.0%
New Zealand	5.3%	5.7%	6.7%	5.9%	9.7%
Norway	6.6%	6.8%	3.0%	6.9%	4.4%
Poland	6.5%	6.9%	5.9%	7.0%	8.4%
Portugal	8.2%	8.7%	5.8%	8.9%	8.3%
Romania	7.5%	8.0%	5.8%	8.2%	8.4%
Russian Fed.	5.1%	6.5%	20.8%	7.1%	28.0%
Slovak Republic	12.9%	13.7%	5.6%	14.0%	8.0%
Slovenia	11.8%	12.5%	5.6%	12.8%	8.1%
South Africa	5.1%	5.9%	12.3%	6.2%	17.2%
Spain	6.2%	6.6%	5.9%	6.8%	8.4%
Sweden	8.1%	8.6%	5.8%	8.9%	8.3%
Switzerland	8.7%	9.0%	3.8%	9.2%	5.5%
Turkey	6.1%	7.1%	13.6%	7.5%	18.8%
United Kingdom	5.8%	6.2%	5.9%	6.3%	8.5%
United States	2.6%	2.8%	5.1%	2.9%	7.4%
Vietnam	11.5%	17.6%	34.7%	20.6%	44.3%
<i>Mean</i>	9.3%	10.1%	10.0%	10.5%	13.7%
<i>Median</i>	7.5%	8.0%	5.8%	8.3%	8.3%
<i>Std. Dev.</i>	6.1%	6.4%	9.6%	6.6%	11.8%

**ACR:** Gains from trade stem from a pure reduction of icebergs. **Data:** Gains from trade stem from a joint reduction of icebergs and tariffs that is consistent with observed tariff revenue shares. **Underest.:** Percentage amount of underestimation of ACR relative to Data. We set  $\theta = 3.09$  and – in the last two columns –  $\sigma = 2.25$ ; see Crozet and Koenig (2010). In this specification, the ACR formula underestimates gains from trade by 4.4% for Norway to 55.7% for India.

elasticities were equal to  $\varepsilon$ . This special situation reproduces the Krugman (1980) situation as a special case of the Melitz (2003) model. The column entitled “ACR” shows the associated gains when tariff revenue is ignored; the column entitled “Data” reports the gains when the observed tariff revenue is taken into account, and the column entitled “underest.” provides the degree of underestimation incurred. Gains from trade appear generally higher than in Table 2, where a higher trade elasticity ( $\varepsilon = -5$ ) was used. The average amount of underestimation goes down.

The final two columns of Table 3 impose  $\varepsilon = -3.09$  and  $\zeta = -4.562$ . Under this situation, trade responds more strongly to tariffs than to iceberg trade costs. Given observed tariffs, lower levels of iceberg trade costs are required to reproduce observed openness levels. This increases the difference between our calibration and the icebergs-only ACR case. Hence, in the Melitz (2003) model, the approximation achieved from focusing on icebergs alone is more inaccurate than in the other models considered. The average degree of underestimation is about still 13%, with peaks in countries such as India of more than 55%.

## 5 Conclusion

In this paper, we have revisited the welfare gains from trade for new trade models in the presence of revenue generating ad valorem tariffs. Thereby, we extend the analysis of Arkolakis et al. (ACR, 2012). We show analytically that the ex post gains from trade can be easily calculated from data on the domestic expenditure and the share of tariff revenue in total income of a country. Also, one needs estimates of the elasticities of trade flows with respect to iceberg trade costs and tariffs. When these two elasticities coincide, the gains from trade do not depend on micro structure. However, in our leading model, the Melitz (2003) framework, the elasticities differ. Given trade and tariff data, it follows that the welfare gains are larger under that framework than in other models (e.g., the Armington (1969), Krugman (1980) and Eaton and Kortum (2002) models).

For all the considered new trade models, we find that neglecting tariff revenue necessarily leads to an underestimation of the welfare gains from trade relative to autarky. The bias is largest in economies characterized by high tariff revenue and high domestic expenditure shares. For a sample of 41 countries observed at the year of 2000, we find that ignoring tariffs leads to an

underestimation of the true gains by 13-23% on average. This hides substantial cross-sectional variance. The underestimation can be higher than 30% for Australia, but can be below 5% for a country such as Norway.

Our results highlight the need for further research on at least two fronts. First, the structural estimation of welfare gains in new trade models requires unbiased and consistent estimates of both the iceberg and the tariff elasticities. Theory-consistent econometric exercises are still rare and plagued by problems such as the lack of observability of iceberg trade costs and possible endogeneity of average tariff rates. Second, the important differences between iceberg and tariff frictions suggest that other alternative trade policy instruments such as export subsidies may have important welfare consequences, too.



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## A Country summary statistics

**Table 4:** Country characteristics for the year 2000.

	Openness	Tariff rate	Tariff rev.	Multiplier
Australia	11.1%	10.9%	1.2%	1.012
Austria	25.6%	2.1%	0.5%	1.005
Belgium	37.8%	2.1%	0.8%	1.008
Brazil	6.7%	12.7%	0.8%	1.009
Bulgaria	21.9%	2.1%	0.5%	1.005
Canada	21.7%	1.3%	0.3%	1.003
China	8.3%	14.6%	1.2%	1.012
Cyprus	36.9%	2.1%	0.8%	1.008
Czech Republic	27.3%	2.1%	0.6%	1.006
Denmark	25.7%	2.1%	0.5%	1.006
Estonia	39.5%	2.1%	0.8%	1.009
Finland	17.6%	2.1%	0.4%	1.004
France	15.2%	3.0%	0.5%	1.005
Germany	18.5%	2.1%	0.4%	1.004
Greece	24.1%	2.1%	0.5%	1.005
Hungary	35.5%	2.1%	0.8%	1.008
India	8.0%	27.5%	2.2%	1.023
Indonesia	15.7%	5.2%	0.8%	1.008
Ireland	41.9%	2.1%	0.9%	1.009
Italy	13.5%	2.1%	0.3%	1.003
Japan	5.2%	2.8%	0.1%	1.001
Korea	17.9%	5.9%	1.1%	1.011
Luxembourg	53.9%	2.1%	1.2%	1.012
Malta	53.5%	2.1%	1.1%	1.012
Netherlands	33.0%	2.1%	0.7%	1.007
New Zealand	14.8%	2.5%	0.4%	1.004
Norway	17.8%	1.1%	0.2%	1.002
Poland	17.6%	2.1%	0.4%	1.004
Portugal	21.5%	2.1%	0.5%	1.005
Romania	20.1%	2.1%	0.4%	1.004
Russian Fed.	14.3%	8.8%	1.3%	1.013
Slovak Republic	31.3%	2.1%	0.7%	1.007
Slovenia	29.2%	2.1%	0.6%	1.006
South Africa	14.3%	4.8%	0.7%	1.007
Spain	17.0%	2.1%	0.4%	1.004
Sweden	21.4%	2.1%	0.5%	1.005
Switzerland	22.7%	1.4%	0.3%	1.003
Turkey	16.7%	5.4%	0.9%	1.009
United Kingdom	16.0%	2.1%	0.3%	1.003
United States	7.7%	1.8%	0.1%	1.001
Vietnam	28.6%	18.2%	5.2%	1.055
<i>Mean</i>	22.9%	4.2%	0.8%	1.008
<i>Median</i>	20.8%	2.1%	0.6%	1.006
<i>Std. Dev.</i>	11.7%	5.3%	0.8%	0.009

*Notes:* Openness is constructed from the OECD Input-Output Database as imports over gross output; see ACR. Trade-weighted average tariff rates come from World Development Indicators. For India, Korea, Russian Federation, South Africa, Turkey, and Vietnam, tariff rates are missing for the year 2000 and are replaced by average tariff rate for the years 1999 and 2001. Tariff revenue share is tariff revenue as a percentage of gross output. The tariff multiplier is calculated from the tariff revenue share; see equation (5).

## B Gravity

Preferences given by symmetric CES aggregator function, with elasticity of substitution  $\sigma > 1$ , expenditure for a given variety  $\omega$  from country  $i$  in country  $j$

$$x_{ij}(\omega) = \left[ \frac{p_{ij}(\omega)}{P_j} \right]^{1-\sigma} X_j$$

where  $p_{ij}(\omega)$  is the c.i.f. price such that  $p_{ij}(\omega) = p_i \tau_{ij} t_{ji}$ . We assume linear technologies such that variable production cost per unit of output in country  $i$  is given by  $w_i/\varphi(\omega)$ .

### B.1 Armington

Perfect competition and identical linear technology  $\varphi(\omega) = 1$  across varieties such that  $p_i(\omega) = w_i$ . If country  $i$  produces  $N_i$  varieties, then

$$\frac{X_{ij}}{X_{jj}} = \frac{N_i}{N_j} \left( \frac{w_i}{w_j} \right)^{1-\sigma} (\tau_{ij} t_{ji})^{1-\sigma}. \quad (15)$$

Note that, different to the standard treatment,  $\tau_{ij}$  and  $t_{ji}$  have the same elasticities  $\varepsilon = \zeta = 1 - \sigma$  because trade flows are defined inclusive of tariff payments.

### B.2 Eaton-Kortum

In a perfect competition Ricardian trade model with a continuum of varieties a la Eaton-Kortum (2002), each countries productivity  $\varphi$  in producing a variety  $\omega$  is Fréchet distributed with  $F(\varphi) = \exp(-T_i \varphi^{-\gamma})$ , where  $T_i \geq 1$  measures the location (country  $i$ 's lowest possibly productivity draw) the location and  $\gamma$  the shape of the distribution. That model admits a gravity equation of the form

$$\frac{X_{ij}}{X_{jj}} = \frac{T_i}{T_j} \left( \frac{w_i}{w_j} \right)^{-\gamma} (\tau_{ij} t_{ji})^{-\gamma}. \quad (16)$$

Again,  $\tau_{ij}$  and  $t_{ji}$  have the same elasticities  $\varepsilon = \zeta = -\gamma$ .

### B.3 Melitz

Firms differ with respect to productivity  $\varphi$  which, in line with the literature, is assumed to follow a Pareto distribution with c.d.f.  $G_i(\varphi) = b_i - \varphi^{-\theta}$ , where again  $T_i$  governs location and  $\theta$  is the shape of the distribution. Presence of a firm from  $i$  on a market  $j$  requires payment of fixed costs  $w_j f_{ij}$  in terms of labor from the destination country  $j$ . Only firms with  $\varphi \geq \varphi_{ij}^*$  will be earning sufficiently much revenue on market  $j$  to support market presence in the presence of fixed access costs. Under these conditions the

gravity equation is given by

$$\frac{X_{ij}}{X_{jj}} = \frac{N_i}{N_j} \left(\frac{b}{b_j}\right)^\theta \left(\frac{f_{ij}}{f_{jj}}\right)^{1-\frac{\theta}{\sigma-1}} \left(\frac{w_i}{w_j}\right)^{-\theta} \tau_{ij}^{-\theta} t_{ji}^{1-\theta/\rho}, \quad (17)$$

The mass of potential entrants  $N_i$  and  $N_j$  are solved via a free-entry condition and turn out independent from trade costs  $(t_{ji}, \tau_{ji})$  and wages. Hence, in the Melitz case with Pareto-distributed productivity,  $\varepsilon = -\theta$  and  $\zeta = 1 - \theta/\rho$ . Letting  $\theta \rightarrow \sigma - 1$  to close down the selection effect, the Melitz gravity equation (17) collapses to the Krugman form with  $\varepsilon = \zeta = 1 - \sigma$ .

## C Derivation of equation (9)

**Armington.** The domestic expenditure share is given by

$$\lambda_{jj} = \frac{1}{1 + \sum_{i \neq j} \frac{X_{ij}}{X_{jj}}} = \frac{1}{1 + \sum_{j \neq i} \frac{N_i}{N_j} \left(\frac{w_i}{w_j} \tau_{ij} t_{ji}\right)^{1-\sigma}},$$

which follows from gravity (15). The price index reads

$$P_j^{1-\sigma} = N_j w_j^{1-\sigma} \left\{ 1 + \sum_{i \neq j} \frac{N_i}{N_j} \left(\frac{w_i}{w_j} \tau_{ij} t_{ji}\right)^{1-\sigma} \right\}.$$

Using the expression for the domestic expenditure share to substitute out the term in curly brackets and rearranging terms, we obtain

$$\frac{w_j}{P_j} = N_j \lambda_{jj}^{-\frac{1}{\sigma-1}}.$$

Equation (9) follows from noting that  $\varepsilon = \zeta = 1 - \sigma$  and noting that  $N_j$  is independent of trade costs.

**Eaton-Kortum.** Using equation (16), we can write the domestic expenditure share as

$$\lambda_{jj} = \frac{1}{1 + \sum_{i \neq j} \frac{T_i}{T_j} \left(\frac{w_i}{w_j}\right)^{-\theta} (\tau_{ij} t_{ji})^{-\theta}}.$$

The price index reads

$$\left(\frac{w_j}{P_j}\right)^\theta = \kappa^{-\theta} T_j \left\{ 1 + \sum_{i \neq j} \frac{T_i}{T_j} \left(\frac{w_i}{w_j}\right)^{-\theta} (\tau_{ij} t_{ji})^{-\theta} \right\},$$

where  $\kappa \equiv \left(\Gamma \left[\frac{\gamma-(\sigma-1)}{\gamma}\right]\right)^{-1/(\sigma-1)}$  with  $\Gamma[\cdot]$  denoting the Gamma function. Again, equation (9) follows from using the expression for the domestic expenditure share to substitute out the terms in curly brackets

and rearranging terms.

**Melitz.** Using equation (17), we can write the domestic expenditure share as

$$\lambda_{jj} = \frac{1}{1 + \sum_{i \neq j} \frac{N_i}{N_j} \left(\frac{b_i}{b_j}\right)^\theta \left(\frac{f_{ij}}{f_{jj}}\right)^{1-\frac{\theta}{\sigma-1}} \left(\frac{w_i}{w_j}\right)^{-\theta} \tau_{ij}^{-\theta} t_{ji}^{1-\theta/\rho}}.$$

The price index is given as

$$P_j^{1-\sigma} = \frac{\theta}{\theta - (\sigma - 1)} \sum_i \varphi_{ij}^{-\theta} N_i b_i^\theta \left(\frac{\rho \varphi_{ij}^*}{\tau_{ij} t_{ji} w_i}\right)^{\sigma-1},$$

where the zero profit cutoff productivities are given by

$$X_j P_j^{\sigma-1} t_{ji}^{-1} \left(\frac{\rho \varphi_{ij}^*}{\tau_{ij} t_{ji} w_i}\right)^{\sigma-1} = \sigma w_j f_{ij}.$$

Using this expression, we can rewrite the price index as

$$1 = \frac{\theta \sigma}{\theta - (\sigma - 1)} \frac{w_j}{X_j} \sum_i \varphi_{ij}^{-\theta} N_i b_i^\theta f_{ij} t_{ji}.$$

Making again use of the zero cutoff profit condition, we obtain

$$\left(\frac{w_j}{P_j}\right)^\theta = \frac{\theta \sigma^{1-\frac{\theta}{\sigma-1}} \rho^\theta}{\theta - (\sigma - 1)} N_j b_j^\theta f_{jj}^{1-\frac{\theta}{\sigma-1}} \left(\frac{w_j}{X_j}\right)^{1-\frac{\theta}{\sigma-1}} \left(1 + \sum_{i \neq j} \frac{N_i}{N_j} \left(\frac{b_i}{b_j}\right)^\theta \left(\frac{f_{ij}}{f_{jj}}\right)^{1-\frac{\theta}{\sigma-1}} \left(\frac{w_i}{w_j}\right)^{-\theta} \tau_{ij}^{-\theta} t_{ji}^{1-\frac{\theta}{\rho}}\right).$$

Recalling that  $w_j L_j / X_j = \mu_j^{-1}$  and using the expression of the domestic expenditure share, we obtain

$$\frac{w_j}{P_j} = \left(\frac{\theta \sigma^{1-\frac{\theta}{\sigma-1}} \rho^\theta}{\theta - (\sigma - 1)} N_j b_j^\theta f_{jj}^{1-\frac{\theta}{\sigma-1}} L_j^{\frac{\theta}{\sigma-1}-1}\right)^{\frac{1}{\theta}} \mu_j^{\frac{\theta-(\sigma-1)}{\theta(\sigma-1)}} \lambda_{jj}^{-\frac{1}{\theta}}.$$

Equation (9) follows from noting that  $\varepsilon = -\theta$  and  $\zeta = 1 - \theta/\rho$ .

## D Proof of proposition 2

For simplicity we suppress country indices in this Appendix. We can do so without causing confusion because we refer only to domestic variables.

**Part (a).** Taking the first derivative of  $\kappa$  with respect to  $\lambda$  for  $\mu$  and with respect to  $\mu$  for given  $\lambda$ , we obtain

$$\begin{aligned}\frac{\partial \kappa}{\partial \lambda} &= -\frac{\lambda^{\frac{1}{\varepsilon}-1} \left( \mu^{\frac{\zeta}{\varepsilon}} - 1 \right)}{\varepsilon \left( \mu^{\frac{\zeta}{\varepsilon}} \lambda^{\frac{1}{\varepsilon}} - 1 \right)^2} > 0, \\ \frac{\partial \kappa}{\partial \mu} &= \frac{\zeta \lambda^{\frac{1}{\varepsilon}} \left( \lambda^{\frac{1}{\varepsilon}} - 1 \right) \mu^{\frac{\zeta}{\varepsilon}-1}}{\varepsilon \left( \mu^{\frac{\zeta}{\varepsilon}} \lambda^{\frac{1}{\varepsilon}} - 1 \right)^2} > 0,\end{aligned}$$

which proves part (a) of the proposition.

**Part (b).** Let  $\varepsilon = \zeta$ . Taking the first derivative of  $\kappa$  with respect to  $\varepsilon$  for given  $\lambda$  and  $\mu$ , we obtain

$$\left. \frac{\partial \kappa}{\partial \varepsilon} \right|_{\varepsilon=\zeta} = \frac{(\mu - 1) \lambda^{\frac{1}{\varepsilon}} \ln \lambda}{\varepsilon^2 \left( \mu \lambda^{\frac{1}{\varepsilon}} - 1 \right)^2} \leq 0,$$

where the inequality strictly holds if  $\mu > 1$ . This proves part (b) of our proposition.

**Part (c).** Let  $\varepsilon = -\theta$  and  $\zeta = 1 - \theta/\rho$ . Taking the first derivative of  $\kappa$  with respect to  $\theta$  and  $\rho$  for given  $\lambda$  and  $\mu$ , we obtain

$$\begin{aligned}\frac{\partial \kappa}{\partial \theta} &= \mu^{\frac{1}{\theta}} \frac{\lambda^{\frac{1}{\theta}} \left( \mu^{\frac{1}{\theta}} - \mu^{\frac{1}{\rho}} \right) \ln \lambda + \mu^{\frac{1}{\rho}} \left( 1 - \lambda^{\frac{1}{\theta}} \right) \ln \mu}{\theta^2 \left( \mu^{\frac{1}{\rho}} - \lambda^{\frac{1}{\theta}} \mu^{\frac{1}{\theta}} \right)} > 0, \\ \frac{\partial \kappa}{\partial \rho} &= -\frac{\left( 1 - \lambda^{\frac{1}{\theta}} \right) \mu^{\frac{1}{\theta} + \frac{1}{\rho}} \ln \mu}{\rho^2 \left( \mu^{\frac{1}{\rho}} - \lambda^{\frac{1}{\theta}} \mu^{\frac{1}{\theta}} \right)^2} < 0,\end{aligned}$$

where the claim in part (c) of the proposition follow from noting that  $\rho$  and  $\sigma$  are positively correlated.

## E Proof of proposition 3

### E.1 Part (a): Lowering icebergs in the presence of tariffs

Rearranging equation (14), we obtain

$$\frac{\partial W}{\partial \lambda} = \frac{1}{\varepsilon} \frac{W}{\lambda} \left( 1 - \zeta \frac{\lambda(t-1)}{\lambda(t-1)+1} \right) < 0. \quad (18)$$

$$\begin{aligned}
\frac{\partial^2 W}{\partial \lambda^2} &= \frac{1}{\varepsilon} \frac{\frac{\partial W}{\partial \lambda} \lambda - W}{\lambda^2} \left( 1 - \zeta \frac{\lambda(t-1)}{\lambda(t-1)+1} \right) - \frac{\zeta(t-1)W}{\varepsilon \lambda} \frac{\lambda(t-1)+1-\lambda(t-1)}{[\lambda(t-1)+1]^2} \\
&= \frac{W}{\varepsilon \lambda^2} \left( \frac{1}{\varepsilon} \left( 1 - \frac{\zeta \lambda(t-1)}{\lambda(t-1)+1} \right)^2 - 1 + \frac{\zeta \lambda(t-1)}{\lambda(t-1)+1} - \frac{\zeta}{\varepsilon} \frac{\lambda(t-1)}{[\lambda(t-1)+1]^2} \right) > 0,
\end{aligned}$$

where the inequality follows from  $\varepsilon, \zeta > 0$ .

Differentiating this expression with respect to  $\lambda$ , we obtain

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

Substituting out  $\frac{\partial W}{\partial \lambda} \frac{\lambda}{W} = \frac{\lambda(t-1)(1-\zeta)+1}{\varepsilon(\lambda(t-1)+1)} < 0$ , the sign of  $\partial^2 W / \partial \lambda^2$  is given by

$$\begin{aligned}
&[\lambda(t-1)(1-\zeta)+1]^2 - \varepsilon[\lambda(t-1)(1-\zeta)+1](1+\lambda(t-1)) - \varepsilon\zeta\lambda(t-1) \\
&= [\lambda(t-1)(1-\zeta)+1]^2 - \varepsilon[\lambda(t-1)+1](1+\lambda_i(t_{ij}-1)) + \varepsilon\zeta\lambda^2(t-1)^2 > 0,
\end{aligned}$$

where the inequality follows from  $\varepsilon, \zeta < 0$ . Hence, welfare is convex in the domestic expenditure share when lowering iceberg trade costs in the presence of tariffs.

## E.2 Part (b). Lowering tariffs

Collecting terms in equation (14), we obtain

$$d \ln W = \frac{1-\zeta}{\varepsilon} \frac{\lambda(t-1)}{\lambda(t-1)+1} d \ln \lambda,$$

which implies

$$\frac{\partial W}{\partial \lambda} = \frac{1-\zeta}{\varepsilon} \frac{W(t-1)}{\lambda(t-1)+1}.$$

Then,

$$\begin{aligned}
\frac{\partial^2 W}{\partial \lambda^2} &= \frac{1-\zeta}{\varepsilon} \frac{[\frac{\partial W}{\partial \lambda}(t-1) + W \frac{\partial t}{\partial \lambda}][\lambda(t-1)+1] - W(t-1)[t-1 + \lambda \frac{\partial t}{\partial \lambda}]}{[\lambda(t-1)+1]^2} \\
&= \frac{1-\zeta}{\varepsilon} W \frac{\frac{1-\zeta-\varepsilon}{\varepsilon}(t-1)^2 + \frac{\partial t}{\partial \lambda}}{[\lambda(t-1)+1]^2}.
\end{aligned}$$

Concavity requires

$$\frac{1-\zeta-\varepsilon}{\varepsilon}(t-1)^2 + \frac{\partial t}{\partial \lambda} > 0 \Leftrightarrow \frac{\varepsilon}{\zeta(1-\zeta-\varepsilon)} - \frac{(t-1)^2}{t} \lambda(1-\lambda) > 0,$$

where the second line follows from  $d \ln \lambda = -(1-\lambda)\zeta d \ln t$ .

Recall that gravity implies that  $\lambda = (1 + \eta t^\zeta)^{-1}$ , where  $\eta < 1$  is a constant term that collects



non-tariff trade barriers. Then, the inequality can be rewritten as

$$\frac{\varepsilon}{\zeta(1-\zeta-\varepsilon)} > \frac{(t-1)^2}{\eta^{-1}t^{1-\zeta}(1+\eta t\zeta)^2} = \frac{(t-1)^2}{\eta t^{\zeta+1} + \eta^{-1}t^{1-\zeta} + 2t}.$$

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

$$f[t] \equiv \frac{(t-1)^2}{\eta^{-1}t^{1-\zeta}},$$

with  $f[1] = 0$ ,  $\lim_{t \rightarrow \infty} f[t] = 0$ , and

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

The function  $f[t]$  reaches its maxima at  $t = 1$  and

$$\zeta - 1 + (1 - \zeta)t^{-1} + 2 = 0 \Leftrightarrow t = \frac{1 - \zeta}{-\zeta - 1}$$

with

$$f\left[\frac{1-\zeta}{-\zeta-1}\right] = \eta\left(\frac{2}{\zeta-3}\right)^2\left(\frac{1-\zeta}{-\zeta-1}\right)^{\zeta-1} < \left(\frac{2}{-\zeta-1}\right)^2\left(\frac{1-\zeta}{-\zeta-1}\right)^{\zeta-1},$$

where the inequality follows from  $\eta < 1$ . Then, a sufficient condition for concavity is

$$\frac{\varepsilon}{\zeta(1-\zeta-\varepsilon)} > \left(\frac{2}{-\zeta-1}\right)^2\left(\frac{1-\zeta}{-\zeta-1}\right)^{\zeta-1}.$$

**Iceberg and tariff elasticities coincide.** If  $\varepsilon = \zeta$ , a sufficient condition for concavity is

$$\frac{1}{1-2\varepsilon} > \left(\frac{2}{-\varepsilon-1}\right)^2\left(\frac{1-\varepsilon}{-\varepsilon-1}\right)^{\varepsilon-1},$$

which holds for  $-\varepsilon > 1.63$ . Hence,  $\gamma > 1.63$  is a sufficient condition for concavity in Eaton-Kortum. This restriction is not binding as a finite variance of the Fréchet distribution requires  $\gamma > 2$ . In Amington and Krugman, the sufficient condition requires  $\sigma > 2.63$ .

**Iceberg and tariff elasticities differ.** If  $\varepsilon = -\theta$  and  $\zeta = 1 - \theta/\rho$  as in Melitz, a sufficient condition for concavity is

$$\left(\frac{\theta}{\theta-2\rho}\right)^{-\frac{\theta}{\rho}}\left(\frac{2}{\theta-2\rho}\right)^2(1+\rho)(\theta-\rho) > 1. \quad (19)$$

The regularity condition that guarantees finite variance of the sales distribution is  $\theta > 2$ . Another regularity condition postulates  $\theta > \sigma - 1 = \rho/(1-\rho)$ . A plot in the  $(\theta, \rho)$ -space shows that the inequality (19) holds for all feasible combinations of  $\theta$  and  $\rho$ .