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Love of Variety and Gains from Trade

Christophe Gouel & Sébastien Jean

Highlights

- In standard modeling practices, the love-of-variety elasticity is determined by the elasticity of substitution between varieties which prevents researchers from understanding its role independently from product substitutability.

- We develop a multi-country, multi-sector gravity trade model where these two elasticities are parameterized separately and show analytically how gains from trade depend upon love of variety.

- Counterfactual simulations show that the love-of-variety elasticity is a key determinant of the gains from trade, an aspect that has been so far overlooked in the literature.

Abstract

This paper shows how gains from trade are conditioned by love of variety, defined as the extent to which an additional product variety generates benefits in either final or intermediate consumption. We develop a multi-country, multi-sector gravity trade model where love of variety is parameterized separately from product substitutability using a generalized CES demand function, and show analytically how gains from trade depend on love of variety through different channels that we identify and interpret. In this context, except for very specific parameterizations, gains from trade differ between a heterogeneous- and a homogeneous-firm model. Counterfactual simulations based on a calibrated version of this model show that, all other things being equal, the assessed gains from trade commonly vary by a proportion of one to three depending on the value of the love-of-variety elasticity, in a way that differs significantly across countries. Trade war simulations also point to the strong sensitivity of the assessed impacts. We conclude that love of variety is a key determinant of the gains from trade, an aspect that has so far been overlooked for the sake of convenience in the modeling framework and due to lack of empirical estimates.

Keywords

International Trade, Firm Heterogeneity, Gains from Trade, Gravity, Love of Variety.

JEL

F11, F12, F13.

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RESEARCH AND EXPERTISE
ON THE WORLD ECONOMY

Love of variety and gains from trade[1]

Christophe Gouel* and Sébastien Jean†

1. Introduction

Since characterizing the gains from trade is a fundamental aspect of international trade theories, it is also crucial to our understanding of the differences across model generations. By proving the equivalence of gains from trade across a large class of standard, one-sector CES models including models à la Melitz (2003) and homogeneous-firm models à la Krugman (1980) as long as they have the same trade elasticity, Arkolakis et al.'s results (2012) raise deep questions about the comparison of "old" and "new" theories. While several subsequent papers analyze how this equivalence evolves under alternative assumptions, pointing out for instance sensitivity to the assumption about the distribution of firm-level productivity (Melitz and Redding, 2015; Head et al., 2014), this stream of literature takes for granted that ensuring that the models have the same trade elasticity is enough to allow meaningful comparison. However, this is not obvious because across different models the value of the trade elasticity is fixed by different behavioral parameters, namely the elasticity of substitution between varieties in the Armington and Krugman models, and the shape of the distribution of firm heterogeneity in the CES-Pareto Melitz model. One of the problems related to this strategy of model benchmarking is that if Krugman and Melitz models are calibrated on the same trade elasticity, their underlying assumptions about the way consumers value product variety differ. This is not trivial: in his Nobel-winning modeling article, Krugman (1980, p. 953) noted that in the context of his (highly stylized) model, "there is no effect of trade on the scale of production, and the gains from trade come solely through increased product diversity."

In practice, under Krugman's model structure, the intensity of the love of variety, what we define below as the love-of-variety elasticity, is fixed by the trade elasticity. However, this does not apply to heterogeneous-firm models à la Melitz (2003) where the love of variety is determined jointly by the heterogeneity of firm sales and the trade elasticity. As a result, the love of variety is stronger in a heterogeneous-firm model than in an otherwise comparable model with homogeneous firms calibrated on the same trade elasticity, with a possible strong impact upon assessed gains from trade. Costinot and Rodríguez-Clare (2014) note though that is no reason to believe that just because we have a new trade theory, the love of variety should be

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stronger. So, do the higher gains from trade usually found in Melitz models compared to previous generations of models stem from taking into account of firm selection, or do they merely reflect a confusing, different assumption about the love of variety? Without further investigation, based on consistent parameterizations of the love of variety, it is impossible to reply to this question: the assumptions inherent in the use of the Dixit-Stiglitz framework have led most of the gains from trade literature to overlook the influence of the love of variety.

This paper aims to address this gap by proposing an exploration of the theoretical role of the love of variety in various model classes, and its quantitative implications. Our goal is to enable love of variety to be disentangled from other dimensions such as product substitutability or the distribution of firms, and to provide reasonable hints about the corresponding orders of magnitude.

There is nothing new in the notion that the love of variety conditions the gains from trade. However, paradoxically, and despite the unpublished elaboration about "diversity as a public good" in Dixit and Stiglitz (1975, Section 4), most of the literature relies on the very special case of CES preferences where the love of variety is not parameterized separately but instead is directly—and arbitrarily—linked to monopoly power via the elasticity of substitution between varieties. The consequence of this modeling choice is that the love of variety has been de facto ignored in most of this literature in which the corresponding behavioral parameters are set based on the available evidence on substitutability across products. A seminal exception is Benassy (1996) which emphasizes the importance of disentangling the two dimensions, especially for welfare evaluations, and proposes a simple way to generalize the CES framework to make this possible. This generalized CES framework has proved instrumental for analyzing the effects of productivity gains (Corsetti et al., 2007), the welfare implications of mark-up dispersion across firms and sectors (Epifani and Gancia, 2011), and the endogenous fluctuations of a monopolistic model (Seegmuller, 2008) for instance, showing in each case the important role played by the love of variety.[2] In Bilbiie et al. (2019), the valuation of new varieties is central to the analysis of distortions related to endogenous product creation under monopolistic competition; this work points out that the benefit to the consumer of an additional variety does not necessarily match the producer's profit incentive, and shows the potentially large importance of the ensuing distortion which depends directly on the consumers' love of variety.

The size of the gains from increased variety does not just depend on the consumer; it is related also to how input diversity is valued in production, and since Ethier (1982), the importance of external economies linked to inputs availability has been widely recognized in trade theory. For modeling purposes, this raises for the production function questions similar to those just discussed in relation to the utility function. Again, this problem is largely overlooked in the literature, where CES aggregation of input varieties has been overwhelmingly used in production

[2]Other works assume away any love of variety (Blanchard and Giavazzi, 2003; Egger and Kreickemeier, 2009), thus acknowledging that the welfare effects linked to changes in the number of varieties available might be sufficiently large to interfere significantly with the question at stake if the standard CES modeling of preferences is maintained.

functions. This calls for similar remarks: such modeling directly and arbitrarily links love of variety—here reflecting the extent to which increased input variety brings productivity gains—to monopoly power via the elasticity of substitution between input varieties. The problem was emphasized by Benassy (1998) who concluded that the returns to specialization should be disentangled from the monopolistic markup. The relevance of this distinction is illustrated inter alia by Alessandria and Choi's analysis (2007) of how sunk costs influence export dynamics, and by Felbermayr and Jung (2011) who study the welfare impacts of technical barriers to trade. In a world where global value chains are ubiquitous, this question plays a central role by defining the way input trade is modeled and assessed. Numerous empirical studies including Amiti and Konings (2007), Goldberg et al. (2010), and Halpern et al. (2015) for instance show the importance of this channel of the gains from trade. In their analysis of trade models key mechanisms, Costinot and Rodríguez-Clare (2014, p. 219) find that the "predicted gains from trade are much higher than those predicted by the same models without intermediate goods," suggesting that the gains from input variety are key. Under monopolistic competition, these authors acknowledge that this aspect also conditions the existence of an equilibrium (ibid., p. 220). Hence we conclude that proper assessment of the gains from trade requires explicit modeling of the intermediate inputs in a multi-sector framework, and paying particular attention to the way the love of variety is modeled and parameterized in both final and intermediate consumption.

We start from a multi-country, multi-sector gravity model with intermediate inputs similar to that developed in Costinot and Rodríguez-Clare (2014), and following Benassy's approach (1996) we allow the love-of-variety elasticity to be parameterized separately from the elasticity of substitution. Accounting for multiple sectors and intermediate inputs is crucial because this is the minimal tractable setting to generate different gains from trade between heterogeneous- and homogeneous-firm models (Costinot and Rodríguez-Clare, 2014). As in Costinot and Rodríguez-Clare (2014), depending upon its parameterization, our model in a single framework encompasses several different settings including monopolistic competition and firm-level heterogeneity.[3] It enables formulation of analytical expressions of the gains from trade and to carry out counterfactual simulations of trade policy scenarios.

This paper makes two main contributions. The first is that it sheds light on the way the love of variety conditions gains from trade. We show that a parsimonious analytical formulation of the gains from trade à la Arkolakis et al. (2012) can be obtained in which the role of love of variety is identified explicitly. Based on a calibrated version of the model, we then show that love of variety is a crucial determinant of the counterfactual results in a heterogeneous-firm model. The love-of-variety elasticity can have as much influence on the size of the gains from trade as the model type (Armington, Krugman, or Melitz) or the trade elasticity. However, this

[3] We do not cover in this article the Eaton and Kortum (2002) setting because in our model it is equivalent for counterfactual purposes to the Armington setting. Although varieties selection is fundamental in Eaton and Kortum, the mass of varieties available to consumers is constant and so this setting is not affected by the generalized CES we used here.

finding does not come without challenges. In particular, to the best of our knowledge, so far there are no reliable estimates of the love-of-variety elasticity, which means that we must guess its magnitude. Also, as soon as the intensity of the love of variety differs from its value under a Dixit-Stiglitz framework, calibrating the model requires knowing the initial number of varieties by sector and origin, a variable which generally is not observed in a usable way. Therefore, the simulations rely on educated assumptions in this respect.

The second contribution is to extend our understanding of the differences across generations of international trade models. We demonstrate theoretically the conditions required for a model with homogeneous firms to deliver exactly the same gains from trade as a model with heterogeneous firms. One condition is that both models should have the same love-of-variety elasticity, which should be equal to its value under Dixit-Stiglitz for the homogeneous-firm model. The other condition is that on the domestic market, the share of domestic firms in the total number of varieties must be the same as the share of domestic firms in total sales. This latter condition is unlikely to hold. If the share of domestic firms on the domestic market is larger in terms of varieties than in terms of sales, a natural assumption given the large number of small firms selling only in their domestic market, and if the love-of-variety elasticity is common across models and equal to its Dixit-Stiglitz specification for the Krugman model, then gains from trade are higher in a model with firm heterogeneity than in a model with homogeneous firms.

Our results on the comparison across model generations complement other contributions on the same topic. Melitz and Redding (2015) show that if firm-level productivity is distributed following a truncated Pareto, and not an untruncated distribution as in the standard Melitz-Chaney model, the welfare gains from trade liberalization are higher with a heterogeneous-firm than with a homogeneous-firm model. Simonovska and Waugh (2014) show that despite sharing a common gravity structure when estimated on micro price data, these models lead to different trade elasticities, and so they should not be calibrated on the same trade elasticities as suggested in Arkolakis et al. (2012) and done in this paper. Simonovska and Waugh's approach leads to a 30 percent lower trade elasticity estimate for Melitz than for Krugman, resulting in 30 percent higher gains from trade for the Melitz model. However, while not based on any information allowing estimation of the love of variety, these different estimates imply a love of variety that would be 30 percent higher in a Melitz model calibrated with the lower trade elasticity than in a Melitz model calibrated on Krugman's trade elasticity, which could explain the bulk of the differences in the gains from trade. While both these issues are important, a better understanding of the differences across models requires obtaining tractable expressions and limiting the differences across models. Accordingly, we assume an untruncated Pareto distribution and calibrate the models on the same trade elasticities.

The rest of the paper is organized as follows. Section 2 develops our general equilibrium trade model. Section 3 derives some analytical results useful for the counterfactual simulations: the exact hat algebra formulation, the welfare formula, and a comparison of the gains from trade between a homogeneous- and a heterogeneous-firm model. The model is calibrated in section 4 and used to analyze quantitatively the effect of love of variety on the gains from trade and a trade war. Section 5 concludes.

2. Model

The model presented here includes one production factor, several sectors, input-output linkages, and trade in final and intermediate consumption. It builds on the gravity model with heterogeneous firms in Costinot and Rodríguez-Clare (2014) and adds a generalized CES, i.e., an assumption that the love-of-variety elasticity can be parameterized separately from the elasticity of substitution between varieties (Benassy, 1996).

2.1. Model setup

Consider a world economy composed of regions indexed $i, j = 1, \ldots, I$, each composed of industries indexed $r, s = 1, \ldots, S$, with only one production factor, labor, whose the endowment is exogenous. Following Costinot and Rodríguez-Clare (2014), different settings are encapsulated in a single framework: perfect competition, monopolistic competition with homogeneous firms, and monopolistic competition with heterogeneous firms. In what follows, a dummy variable δ_s^M is used to characterize the market structure and is equal to 1 in monopolistic competition and 0 in perfect competition. The dummy variable δ_s^H represents the assumption made about the distribution of firm-level productivity which if equal to 0 is assumed to be homogeneous and it equal to 1 to be heterogeneous. Therefore, we can describe in a unified framework an Armington model ($\delta_s^M = 0, \delta_s^H = 0$), a model à la Krugman ($\delta_s^M = 1, \delta_s^H = 0$), and a model à la Melitz ($\delta_s^M = 1, \delta_s^H = 1$).

Households In country i, the representative household supplies a fixed quantity of labor and has Cobb-Douglas preferences over composite final goods:

$$U_j = \prod_{s=1}^{S} \left(D_{j,s}^c\right)^{\theta_{j,s}^U}, \tag{1}$$

where $D_{j,s}^c$ is the final demand for the composite good of industry s in country j, and $\theta_{j,s}^U$ is the share of expenditure spent on industry s varieties.

Composite final goods are represented by a generalized CES, i.e. Dixit-Stiglitz bundles over a continuum of varieties, modified following Benassy (1996) to sever the link between the love-of-variety elasticity and the elasticity of substitution between varieties:

$$D_{j,s}^c = \left\{ N_{j,s}^{[\nu_s(\sigma_s-1)-1]/\sigma_s} \sum_{i=1}^{I} \int_0^{N_{ij,s}} \left[d_{ij,s}^c(n)\right]^{(\sigma_s-1)/\sigma_s} \mathrm{d}\, n \right\}^{\sigma_s/(\sigma_s-1)}, \tag{2}$$

where

$$N_{j,s} = \sum_{i=1}^{I} N_{ij,s} \tag{3}$$

is the total number of imported varieties, $\sigma_s > 1$ is the elasticity of substitution between varieties, $N_{ij,s}$ is the number of varieties exported from i to j, and $d^c_{ijs}(n)$ is the exported quantity of the variety n. The love of variety is parameterized here using $\nu_s \geq 0$, which denotes what Benassy (1996) calls the marginal taste for additional variety, and what Bilbiie et al. (2019) refer to as the benefit of variety in elasticity form. In what follows, we call it the love-of-variety elasticity, in line with Costinot and Rodríguez-Clare terminology (2014, p. 214). This sector-specific constant represents the marginal gain in proportional terms, from spreading a constant total amount of consumption across one additional variety (see Benassy, 1996, p. 42, for a formal definition). If $\nu_s = 1/(\sigma_s - 1)$, the composite good demand collapses to the standard Dixit-Stiglitz framework.

Focusing on equation (2) provides a first intuition on our contribution. In a one-sector model with no intermediate consumption, $D^c_{j,s}$ simply becomes the utility function and ν_s does not affect the equilibrium. However, it changes the consumer's valuation of the equilibrium which depends positively on ν_s for a given number of varieties. Notice also that if ν_s is lower (higher) than its Dixit-Stiglitz value, $1/(\sigma_s - 1)$, utility is negatively (positively) tied to the number of varieties. This is the first channel through which our general-CES function approach matters for welfare. Of course, in the complete model with intermediates, ν_s will play a role in the equilibrium outcome and will have more complex implications for welfare.

The demand for each composite good is given by

$$D^c_{j,s} = \frac{\theta^U_{j,s}\mu_j Y_j}{P_{j,s}}, \tag{4}$$

where μ_j is the region-j ratio of final expenditures to income, Y_j is the region income, and $P_{j,s}$ is the price of the composite good. From (2), the price of the composite good is

$$P_{j,s} = \left(\sum_{i=1}^{I} P_{ij,s}^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}}, \tag{5}$$

with $P_{ij,s}$ the sector s price index of country j imports from country i.

Trade policy and trade costs Two types of bilateral trade costs are considered: iceberg costs and ad valorem tariffs. $\tau_{ij,s} \geq 1$ units must be shipped from country i to country j in order to sell one unit of a variety of sector s, and it must pay an ad valorem tariff denoted by $T_{ij,s} = 1 + t_{ij,s}$, where $t_{ij,s}$ is the tariff rate. Tariffs are modeled as a demand shifter, applied to all import revenues—variable production costs, transport costs, and markup.[4] Tariff revenue is fully rebated to the consumer budget as a lump-sum.

[4] Felbermayr et al. (2015) spell out the differences between modeling tariffs as cost or demand shifter.

Production costs Production combines labor and a composite intermediate good according to a Cobb-Douglas technology. For the sake of parsimony, we obtain the composite intermediate good using the aggregator used for the composite final good which assumes that the love-of-variety elasticity is the same for intermediate and final consumption. The unit costs of production can be written as:

$$c_{i,s} = Y_i^{1-\alpha_{i,s}} \prod_{r=1}^{S} P_{i,r}^{\alpha_{i,rs}}, \tag{6}$$

where Y_i is total labor income, which is proportional to the wage in the present setting with just one production factor and a fixed endowment. $\alpha_{i,rs} \in [0,1]$ are the input-output coefficients, and $\alpha_{i,s} \in [0,1]$ is the budget share of all intermediate goods in unit costs defined by $\alpha_{i,s} = \sum_{r=1}^{S} \alpha_{i,rs}$.

Pricing and fixed costs The variable profit of a firm in country i selling to country j with productivity ϕ is

$$\pi_{ij,s}(\phi) = \left[\frac{p_{ij,s}(\phi)}{T_{ij,s}} - \frac{\tau_{ij,s} c_{i,s}}{\phi}\right] d_{ij,s}(\phi), \tag{7}$$

where $p_{ij,s}(\phi)$ is the consumer price, $c_{i,s}$ is the unit production cost, and $d_{ij,s}(\phi)$ is the demand for the firm's product.

Under monopolistic competition, firms must pay a fixed entry cost, $c_{i,s} f^e_{i,s}$, to be able to produce. Under perfect competition there is no such cost. In the case of heterogeneous firms, selling to a given market requires payment of $c_{i,s} f_{ij,s}$, which we generally refer to as a sunk export cost.

Since final and intermediate demands involve the same kind of composite good, the same structure applies to total demand. From equation (2), the total demand for a firm with productivity ϕ from region i in market j can be written

$$d_{ij,s}(\phi) = p_{ij,s}(\phi)^{-\sigma_s} P_{j,s}^{\sigma_s - 1} E_{j,s} N_{j,s}^{\nu_s(\sigma_s - 1) - 1}, \tag{8}$$

where $E_{j,s}$ is total expenditure on industry s products in region j. Based on equation (7), the pricing rule then follows the general expression

$$p_{ij,s}(\phi) = \frac{T_{ij,s} \tau_{ij,s} c_{i,s}}{\phi} \left(\frac{\sigma_s}{\sigma_s - 1}\right)^{\delta_s^M}, \tag{9}$$

where as already mentioned, δ_s^M is a dummy variable for the market structure and is equal to 1 under monopolistic competition.

If firms are assumed heterogeneous, a free-entry framework à la Melitz (2003) is considered and following Helpman et al. (2004) and Chaney (2008), we assume that firm-level productivity will follow a Pareto distribution with a probability density function $g_s(\phi) = k_s \underline{\phi}_s^{k_s} / \phi^{k_s + 1}$ and a cumulative distribution function $G_s(\phi) = 1 - (\phi / \underline{\phi}_s)^{-k_s}$, where $k_s > \sigma_s - 1$ is the shape parameter and $\underline{\phi}_s$ is the lower bound.

2.2. Equilibrium in levels

As usual in this type of framework, equilibrium can be characterized by three conditions: zero cutoff profit, free entry and market clearing.

Zero cutoff profit condition Under firm heterogeneity only firms with variable profits that exceed their sunk costs will export to a given market. The corresponding productivity cutoff, $\phi_{ij,s}$, is defined by $\pi_{ij,s}(\phi_{ij,s}) = c_{i,s} f_{ij,s}$, so that,

$$T_{ij,s}^{-\sigma_s} \left(\frac{\tau_{ij,s} c_{i,s}}{\phi_{ij,s}} \frac{\sigma_s}{\sigma_s - 1} \right)^{1-\sigma_s} D_{j,s} P_{j,s}^{\sigma_s} N_{ij,s}^{\nu_s(\sigma_s-1)-1} = \sigma_s c_{i,s} f_{ij,s}. \tag{10}$$

Noting that variable profits can be expressed from bilateral trade value, $x_{ij,s}$, as

$$\pi_{ij,s}(\phi) = x_{ij,s}(\phi)/\sigma_s, \tag{11}$$

and using a property of the CES-Pareto Melitz model that the ratio of sales of the firm with minimum productivity to those of the average firm is constant,

$$\frac{x_{ij,s}(\phi_{ij,s})}{X_{ij,s}/N_{ij,s}} = \frac{k_s + 1 - \sigma_s}{k_s}, \tag{12}$$

where $X_{ij,s}$ is the (CIF) value of trade, the zero cutoff profit condition can be expressed as

$$X_{ij,s} \frac{k_s + 1 - \sigma_s}{\sigma_s k_s} = c_{i,s} f_{ij,s} N_{ij,s}. \tag{13}$$

One implication of this is that the amount spent on bilateral sunk export costs is a constant share of the value of bilateral trade.

Free entry condition Since under monopolistic competition entry is assumed to be free, the expected profits must be zero in the equilibrium. For a firm contemplating entry, this implies that the sum of the expected profits over all markets, net of bilateral fixed costs, must be equal to the fixed cost of entry:

$$\sum_{j=1}^{I} \int_{\phi_{ij,s}}^{\infty} \left[\pi_{ij,s}(\phi) - c_{i,s} f_{ij,s}\right] g_s(\phi)\, \mathrm{d}\,\phi = c_{i,s} f_{i,s}^{e}. \tag{14}$$

Noting that the mass of entered firms, $M_{i,s}$, is related to the number of firms exporting to j by

$$N_{ij,s} = M_{i,s}\left[1 - G_s(\phi_{ij,s})\right] = M_{i,s} \phi_{ij,s}^{-k_s}, \tag{15}$$

and using the zero cutoff profit condition (13) and the fact that variable profits can be expressed as a share of bilateral trade value (11), the integral in (14) can be expressed as

$$\int_{\phi_{ij,s}}^{\infty} \left[\pi_{ij,s}(\phi) - c_{i,s} f_{ij,s}\right] g_s(\phi)\, \mathrm{d}\,\phi = \frac{X_{ij,s}}{\sigma_s M_{i,s}} \left(\frac{\sigma_s - 1}{k_s}\right)^{\delta_s^H}. \tag{16}$$

Summing over the integral leads to the following free entry condition

$$\frac{R_{i,s}}{\sigma_s} \left(\frac{\sigma_s - 1}{k_s}\right)^{\delta_s^H} = c_{i,s} f_{i,s}^e M_{i,s}, \tag{17}$$

where

$$R_{i,s} = \sum_{j=1}^{I} X_{ij,s} \tag{18}$$

is the total revenue from sector s. Thus, fixed entry costs represent a constant share of the revenue from each sector. With or without firm heterogeneity, the total share of revenue spent on fixed costs is $1/\sigma_s$, but under firm heterogeneity it is split between fixed entry costs and sunk export costs.

From the expression for the bilateral trade value of the cutoff firm, $x_{ij,s}(\phi_{ij,s})$, we obtain the cutoff productivity expression:

$$\phi_{ij,s} = \frac{T_{ij,s}\tau_{ij,s}c_{i,s}}{P_{j,s}} \left[\frac{E_{j,s} N_{j,s}^{\nu_s(\sigma_s-1)-1}}{T_{ij,s}c_{i,s}}\right]^{-1/(\sigma_s-1)} \lambda_{ij,s}, \tag{19}$$

where $\lambda_{ij,s} = [\sigma_s/(\sigma_s - 1)](\sigma_s f_{ij,s})^{1/(\sigma_s-1)}$.

Market clearing and budget constraint In equilibrium, total expenditure must equal total demand for intermediate and final consumption in each market:

$$E_{j,r} = \theta_{j,r}^U \mu_j Y_j + \sum_{s=1}^{S} \alpha_{j,rs} R_{j,s}. \tag{20}$$

Clearing in the labor market requires labor income to be equal to labor costs:

$$Y_j = \sum_{s=1}^{S} \left(1 - \alpha_{j,s}\right) R_{j,s}. \tag{21}$$

Also, the budget constraint implies that in each country, total final expenditure must equal the sum of labor income, tariff revenue, defined by $\Pi_j = \sum_{i=1}^{I} \sum_{s=1}^{S} t_{ij,s} X_{ij,s}$, and trade deficits denoted Δ_j:

$$\mu_j Y_j = Y_j + \Pi_j + \Delta_j. \tag{22}$$

Gravity equation The same kind of explicit summary equations as in Costinot and Rodríguez-Clare (2014, especially equations (14) and (26)) can be obtained in the present framework. Indeed, given that final and intermediate demands are based on the same generalized CES aggregator, tariff-inclusive trade values follow a simple gravity equation:

$$T_{ij,s}X_{ij,s} = (P_{ij,s}/P_{j,s})^{1-\sigma_s} E_{j,s}, \tag{23}$$

where the price index for each sector's bilateral imports can be expressed as

$$P_{ij,s} = \underbrace{T_{ij,s}\tau_{ij,s}c_{i,s}}_{\substack{\text{Intensive}\\ \text{margin}}} \underbrace{\left[\frac{R_{i,s}}{c_{i,s}} N_{j,s}^{\nu_s(\sigma_s-1)-1}\right]^{\frac{\delta_s^M}{1-\sigma_s}}}_{\text{Ext. margin: entry}} \underbrace{\left\{\left[\frac{E_{j,s}N_{j,s}^{\nu_s(\sigma_s-1)-1}}{T_{ij,s}c_{i,s}}\right]^{\frac{1}{1-\sigma_s}} \frac{T_{ij,s}\tau_{ij,s}c_{i,s}}{P_{j,s}}\right\}^{\frac{\delta_s^H(\sigma_s-1-k_s)}{1-\sigma_s}}}_{\text{Extensive margin: selection}} \xi_{ij,s}, \tag{24}$$

where $\xi_{ij,s} > 0$ is a function of the structural parameters distinct from the trade costs.[5] This equation extends Costinot and Rodríguez-Clare (2014) analysis to the present framework, encompasses various settings, and explicitly models the love of variety. It makes it possible to show how love of variety, parameterized here through ν_s, influences trade flows through bilateral price indices. While this influence is nil at the intensive margin, it shows up on both dimensions of the extensive margin.

Interestingly, a straightforward consequence of equation (5) is that the ratio $P_{ij,s}/P_{j,s}$ does not depend directly on the number of varieties, $N_{j,s}$. Accordingly, trade shares are not affected directly by the love of variety. However, through its effect on the price index $P_{j,s}$, love of variety will affect final and intermediate demand at the sector level.

Equilibrium definition Based on the above, the market equilibrium can be characterized as a vector of the number of imported varieties ($N_{j,s}$), the price of composite goods ($P_{j,s}$), the unit production costs ($c_{i,s}$), the varieties exported ($N_{ij,s}$), the mass of entered firms ($M_{i,s}$), total revenue ($R_{i,s}$), sectoral expenditure ($E_{j,s}$), labor income (Y_j), ratio of final expenditure to labor income (μ_j), trade flows ($X_{ij,s}$), and import prices ($P_{ij,s}$) such that equations (3), (5), (6), (13), (17), (18), and (20)–(24) hold.

3. Counterfactual analysis

In addition to characterizing specific equilibrium situations, the advantage of this modeling framework lies in its capacity to enable counterfactual analysis, i.e., comparison across equilibria. Following the recent literature, it is convenient to focus this analysis on the relative changes across equilibrium situations, and we denote the change in any variable x as $\hat{x} \equiv x'/x$, where x' and x respectively refer to its final and initial levels.

[5] See Appendix A for full details of the derivation.

3.1. Exact hat algebra reformulation

Manipulating the equilibrium equations presented above makes it possible to derive a set of equations that completely characterize the change between two equilibria as follows (using $\mathbf{1}_{(\cdot)}$ as the indicator function):

$$\hat{N}_{j,s} : \hat{N}_{j,s} = \begin{cases} \sum_{i=1}^{I} \left(N_{ij,s}/N_{j,s}\right) \left(\hat{X}_{ij,s}/\hat{c}_{i,s}\right) & \text{if } \delta_s^H = 1, \\ \sum_{i=1}^{I} \mathbf{1}_{X_{ij,s}>0} \left(M_{i,s}/N_{j,s}\right) \left(\hat{R}_{j,s}/\hat{c}_{i,s}\right) & \text{if } \delta_s^H = 0, \end{cases} \tag{25}$$

$$\hat{P}_{ij,s} : \hat{P}_{ij,s} = \hat{T}_{ij,s}\hat{\tau}_{ij,s}\hat{c}_{i,s} \left[\frac{\hat{R}_{i,s}}{\hat{c}_{i,s}} \hat{N}_{j,s}^{\nu_s(\sigma_s-1)-1}\right]^{\frac{\delta_s^M}{1-\sigma_s}} \left\{ \frac{\hat{T}_{ij,s}\hat{\tau}_{ij,s}\hat{c}_{i,s}}{\hat{P}_{j,s}} \left[\frac{\hat{E}_{j,s}\hat{N}_{j,s}^{\nu_s(\sigma_s-1)-1}}{\hat{T}_{ij,s}\hat{c}_{i,s}}\right]^{\frac{1}{1-\sigma_s}} \right\}^{\frac{\delta_s^H(\sigma_s-1-k_s)}{1-\sigma_s}}, \tag{26}$$

$$\hat{c}_{i,s} : \hat{c}_{i,s} = \hat{Y}_i^{1-\alpha_{i,s}} \prod_{r=1}^{S} \hat{P}_{i,r}^{\alpha_{i,rs}}, \tag{27}$$

$$\hat{R}_{i,s} : \hat{R}_{i,s} = \sum_{j=1}^{I} \theta_{ij,s}^R \hat{X}_{ij,s}, \tag{28}$$

$$\hat{X}_{ij,s} : \hat{T}_{ij,s}\hat{X}_{ij,s} = \hat{P}_{ij,s}^{1-\sigma_s}\hat{P}_{j,s}^{\sigma_s-1}\hat{E}_{j,s}, \tag{29}$$

$$\hat{P}_{j,s} : \hat{P}_{j,s} = \left(\sum_{i=1}^{I} \theta_{ij,s}^X \hat{P}_{ij,s}^{1-\sigma_s}\right)^{1/(1-\sigma_s)}, \tag{30}$$

$$\hat{E}_{j,r} : E_{j,r}\hat{E}_{j,r} = \theta_{j,r}^U \mu_j \hat{\mu}_j Y_j \hat{Y}_j + \sum_{s=1}^{S} \alpha_{j,rs} R_{j,s} \hat{R}_{j,s}, \tag{31}$$

$$\hat{Y}_j : Y_j\hat{Y}_j = \sum_{s=1}^{S} (1-\alpha_{j,s}) R_{j,s}\hat{R}_{j,s}, \tag{32}$$

$$\hat{\mu}_j : \mu_j\hat{\mu}_j Y_j\hat{Y}_j = Y_j\hat{Y}_j + \sum_{i=1}^{I}\sum_{s=1}^{S} t'_{ij,s} X_{ij,s}\hat{X}_{ij,s} + \Delta_j\hat{\Delta}_j, \tag{33}$$

where $\theta_{ij,s}^X = T_{ij,s}X_{ij,s}/E_{j,s}$ is the (tax inclusive) share of expenditure in sector s in country j devoted to imports from country i and $\theta_{ij,s}^R \equiv X_{ij,s}/R_{i,s}$ is the share of the bilateral export flow from j to i in sector revenue. Calibrating this model for counterfactual simulations requires inputting two sets of parameters: behavioral parameters (ν_s, σ_s and k_s) and initial values and distributive parameters ($X_{ij,s}$, $\alpha_{i,rs}$, $\theta_{i,s}^U$, $N_{ij,s}/N_{j,s}$, or $M_{i,s}/N_{j,s}$ in the case of a homogeneous-firm model, $t_{ij,s}$, μ_j). This allows all the other parameters or initial values to be derived: $R_{i,s}$, $\theta_{ij,s}^X$, $\theta_{ij,s}^R$, Y_j, Δ_j, $\alpha_{j,s}$, $E_{j,s}$.

A key difference with respect to other quantitative trade models based on a Melitz-Chaney framework is that the calibration here requires the initial share of imported varieties by origin country and sector, $\theta^N_{ij,s} = N_{ij,s}/N_{j,s}$. The value of this share conditions the magnitude of the variety gains to be expected from trade changes, since it determines how a given proportional change to imports modifies the total number of varieties available to the consumer. The CES-Pareto framework hugely simplifies the calibration of heterogeneous-firm models by not requiring some difficult-to-observe parameters such as the fixed costs or the lower bound of the Pareto distribution, and it is a standard result from the literature that deviating from this framework requires more observables for the calibration. For example, alternative firm productivity distributions such as in Helpman et al. (2008) and Head et al. (2014) require information on fixed entry costs for their calibration. Given the link in equation (13) between bilateral trade, fixed costs, and number of varieties, we could use fixed costs for the calibration instead of the number of varieties, but the number of varieties makes the calibration easier in our setting.

3.2. Welfare formula and gains from trade

Relying on the expression of utility as real expenditure, the equations above allow us to decompose welfare effects into their various components, thereby extending Costinot and Rodríguez-Clare's welfare formula (2014) to the present framework. To facilitate comparison across models, we substitute some of the structural parameters with two parameters that have clear empirical counterparts, i.e. the trade elasticity, ϵ_s, and the heterogeneity of sales across firms, η_s.

In practice, the trade elasticity can be written as $\epsilon_s \equiv k_s + (1 - \delta^H_s)(\sigma_s - 1 - k_s)$, meaning that $\epsilon_s = k_s$ if firms are assumed to be heterogeneous, and $\epsilon_s = \sigma_s - 1$ if firms are assumed to be homogeneous. In other words, as already emphasized, the same structural parameters do not lead to the same trade elasticity if firms are assumed to be heterogeneous compared to if they are not. Sales heterogeneity, $\eta_s \equiv k_s/(\sigma_s - 1) - 1$, is set by convention to $\eta_s = 0$ in a homogeneous-firm model. After some intermediate manipulations detailed in Appendix B, and assuming balanced trade (i.e., $R_i = E_i$), the welfare effects are given by the following proposition.

Proposition 1. *Following a foreign shock in trade costs, τ_{ij}, or trade policies, T_{ij}, for $i \neq j$, the change in welfare can be expressed as*

$$\hat{U}_j = \hat{\mu}_j \prod_{r,s=1}^{S} \left[\hat{\theta}^X_{jj,s} \left(\frac{\hat{R}_{j,s}}{\hat{Y}_j} \right)^{-\delta^M_s} \hat{N}_{j,s}^{\delta^M_s (\nu^{CES}_s - \nu_s)\epsilon_s} \left(\frac{\hat{E}_{j,s}}{\hat{Y}_j} \right)^{-\eta_s} \right]^{-\theta^U_{j,r} \tilde{a}_{j,rs}/\epsilon_s}, \tag{34}$$

where $\tilde{a}_{j,rs} \equiv ([I_S - \tilde{A}_j]^{-1})_{rs}$ are the elements of the Leontief inverse adjusted by the love of variety in the CES case: $(\tilde{A}_j)_{rs} = [1 + \delta^M_s/(\sigma_s - 1)]\alpha_{j,rs}$.

Proposition 1 extends equation (28) in Costinot and Rodríguez-Clare (2014) by accounting for the effects of varieties as long as the love-of-variety elasticity does not coincide with its level under the CES formulation. Equation (34) will be used to calculate welfare changes following trade policy shocks in section 4, but for now we use it here is as a first step to characterizing the gains from trade.

From the welfare formula, we can derive the gains from trade as the absolute value of the relative change in real income that would be associated with moving to autarky, as follows (see Appendix C for the proof)

$$G_j = 1 - \prod_{r,s=1}^{S} \left\{ \theta^X_{jj,s} \left(\frac{r_{j,s}}{b_{j,s}}\right)^{-\delta^M_s} \left[\left(\frac{r_{j,s}}{b_{j,s}}\right)^{-1} \frac{\theta^N_{jj,s}}{\left(\theta^R_{jj,s}\right)^{\delta^H_s}} \right]^{\delta^M_s(\nu_s - \nu^{\text{CES}}_s)\epsilon_s} \left(\frac{e_{j,s}}{b_{j,s}}\right)^{-\eta_s} \right\}^{\theta^U_{j,r}\tilde{a}^A_{j,rs}/\epsilon_s}, \quad (35)$$

where $e_{j,s} \equiv E_{j,s}/E_j$ is the share of total expenditure in sector s, $r_{j,s} \equiv R_{j,s}/R_j$ is the share of the revenue from sector s, $b_{j,s} \equiv (\sum_{r=1}^{S} a_{j,sr}\theta^U_{j,r})Y_j/R_j$, and the $\tilde{a}^A_{i,rs} \equiv ([I_S - \tilde{A}^A_i]^{-1})_{rs}$ are the elements of the adjusted Leontief inverse in the autarky case with $(\tilde{A}^A_i)_{rs} = (1 + \delta^M_s \nu_s)\alpha_{i,rs}$.

In the CES case, $\nu_s = \nu^{\text{CES}}_s = 1/(\sigma_s - 1)$, and the equation collapses to equation (29) in Costinot and Rodríguez-Clare (2014). However, if this does not apply, the gains from trade depend on the love-of-variety elasticity in two ways. Firstly, it modifies the magnitude of the scale effects related to the input-output loop, reflected in the exponent $\theta^U_{j,r}\tilde{a}^A_{j,rs}/\epsilon_s$, which is different from its value in equation (34) because of the different adjustment to the Leontief inverse. Secondly, it introduces an additional determinant of gains from trade, which is the ratio of the number of varieties under autarky to the number of varieties under free trade: $N^A_{j,s}/N_{j,s} = (b_{j,s}/r_{j,s})[\theta^N_{jj,s}/(\theta^R_{jj,s})^{\delta^H_s}]$. This second channel, possibly associated with negative impacts of trade, emerges from the interaction between trade openness and what Bilbiie et al. (2019) describe as a "static" distortion, namely a "misalignment between the benefit of an extra variety to the consumer and the profit incentive for an entrant to produce that extra variety." Based on the second-best theorem, we know that the interaction between the obstacles to trade and this type of distortion may well be welfare-reducing or welfare-enhancing. Here, its sign depends on the comparison between the love-of-variety elasticity, ν_s, and its value under the Dixit-Stiglitz case, $\nu^{\text{CES}}_s = 1/(\sigma_s - 1)$.

3.3. Comparing the gains from trade in different models

Our setup allows analytical comparison of the gains from trade in the Krugman and Melitz models when calibrated on the same trade and love-of-variety elasticities, because the exponent in equation (35), $\theta^U_{j,r}\tilde{a}^A_{j,rs}/\epsilon_s$, is the same in both models, which is not the case in Costinot and Rodríguez-Clare (2014). To enable this comparison, we use the same calibration for both models, which allows us to derive the following proposition.

Proposition 2. *The ratio of welfare changes from free trade to autarky between a heterogeneous-firm model and a homogeneous-firm model can be expressed as*

$$\frac{\hat{U}^M_j}{\hat{U}^K_j} = \prod_{r,s=1}^{S} \left[\left(\theta^N_{jj,s}\right)^{-\eta_s} \left(\theta^R_{jj,s}\right)^{1+\eta_s - \nu_s\epsilon_s} \left(\frac{e_{j,s}}{r_{j,s}}\right)^{-\eta_s} \right]^{\theta^U_{j,r}\tilde{a}^A_{j,rs}/\epsilon_s}. \quad (36)$$

Proof. See Appendix D. □

Note that we expect $\hat{U} < 1$ since for most countries welfare should decrease with the change to autarky, so that $\hat{U}_j^M/\hat{U}_j^K > 1$ will imply higher gains from trade in the Krugman model, and lower if the ratio is <1.

This expression has two components: a variety effect, $(\theta^N_{jj,s})^{-\eta_s}(\theta^R_{jj,s})^{1+\eta_s-\nu_s\epsilon_s}$ and a selection effect, $(e_{j,s}/r_{j,s})^{-\eta_s}$, because thanks to the common exponent the intensive margin and the entry effects cancel one another. Interpretation of the selection effect is fairly straightforward since it is present only in the heterogeneous-firm model. Interpreting the variety effect is more complex since the two models are calibrated on the same love-of-variety elasticity. Two mechanisms are at play here. First, the variety effect in equation (35) depends on the difference between the love-of-variety elasticity and its value in a Dixit-Stiglitz specification, $\nu_s - \nu_s^{\text{CES}}$, which varies across models. Second, although both models are calibrated on the same initial number of varieties in free trade, their counterfactual number of varieties in autarky will differ by a factor $\theta^R_{jj,s}$, because the number of varieties evolves differently in the two models (see equation (25)).

Notably, although equation (35) can be simplified without intermediate consumption or with only one sector, as long as the love-of-variety elasticity is different from its CES value the equation never collapses to Arkolakis et al.'s formula (2012), and the gains from trade remain different between the homogeneous- and heterogeneous-firm models for a one-sector model without intermediate consumption. Put differently, Arkolakis et al.'s results about the equivalence of the gains from trade between old and new trade models no longer holds when the particular relationship linking love of variety to product substitutability under the Dixit-Stiglitz framework is dropped.

To provide more insights into the welfare ranking among the models, we can express the ratio in equation (36) differently. Given that

$$\frac{e_{j,s}}{r_{j,s}} = \frac{E_{j,s}}{R_{j,s}} = \frac{X_{jj,s}}{R_{j,s}}\frac{E_{j,s}}{X_{jj,s}} = \frac{\theta^R_{jj,s}}{\theta^X_{jj,s}}, \tag{37}$$

the ratio can be simplified in two terms

$$\frac{\hat{U}_j^M}{\hat{U}_j^K} = \prod_{r,s=1}^{S}\left[\left(\theta^R_{jj,s}\right)^{1-\nu_s\epsilon_s}\left(\frac{\theta^N_{jj,s}}{\theta^X_{jj,s}}\right)^{-\eta_s}\right]^{\theta^U_{j,r}\tilde{a}^A_{j,rs}/\epsilon_s}. \tag{38}$$

The first term appears because changes in the traded varieties differ between Krugman and Melitz. It collapses to 1 if $\nu_s = 1/\epsilon_s$, i.e. if love of variety corresponds to its Dixit-Stiglitz value in the Krugman model. This term depends on the love of variety but not on the degree of firm heterogeneity. The second term depends not on the love-of-variety elasticity but on firm heterogeneity, and combines a variety and a selection effect. These two effects are canceled out if the domestic producers' share is the same in terms of both varieties and sales, $\theta^N_{jj,s} = \theta^X_{jj,s}$.

To analyze the welfare difference between the two models, let us consider each term separately. If $\theta^N_{jj,s} = \theta^X_{jj,s}$, then

$$\frac{\hat{U}^M_j}{\hat{U}^K_j} = \prod_{r,s=1}^{S} \left(\theta^R_{jj,s}\right)^{(1/\epsilon_s-\nu_s)\theta^U_{j,r}\tilde{a}^A_{j,rs}}. \tag{39}$$

This is a situation where the selection effect is fully offset by the variety effect. In this case, the gains from trade under Krugman are smaller (larger) than under Melitz if $\nu_s\epsilon_s < (>)1$, i.e. if the love of variety is smaller (larger) than under the Krugman-CES case.

We can now neutralize this effect by assuming that $\nu_s\epsilon_s = 1$ and $\theta^N_{jj,s} \neq \theta^X_{jj,s}$, we then have

$$\frac{\hat{U}^M_j}{\hat{U}^K_j} = \prod_{r,s=1}^{S} \left(\frac{\theta^N_{jj,s}}{\theta^X_{jj,s}}\right)^{-\eta_s\theta^U_{j,r}\tilde{a}^A_{j,rs}/\epsilon_s}. \tag{40}$$

If we assume that the share of domestic firms in the domestic market is larger in terms of varieties than in terms of sales (i.e., $\theta^N_{jj,s} > \theta^X_{jj,s}$), as could be expected given the widespread evidence of the huge number of small firms selling only in their domestic market (see, e.g., Bernard et al., 2007), then this implies larger gains from trade in the Melitz case.

The corollary to this decomposition is that models with heterogeneous and homogeneous firms obtain exactly the same gains from trade if $\nu_s\epsilon_s = 1$ and $\theta^N_{jj,s} = \theta^X_{jj,s}$. However, if these conditions do not hold, there is no definite welfare ranking across models, because the two above-mentioned effects can go in opposite directions if $\nu_s\epsilon_s > 1$. In the absence of reliable empirical estimate of the love-of-variety elasticity, we can claim no certainty in this respect. We therefore must rely on counterfactual simulations over a wide range of parameter values to shed light on how the gains from trade vary across models.

4. Quantitative analysis

This modeling framework makes it relatively simple to carry out counterfactual analyses. We first discuss the model calibration, and the questions raised by some of its original features. We then show the quantitative implications under different theoretical frameworks of the model for the gains from trade, comparing the initial situation to both autarky, and a tariff war scenario, represented as a uniform increase in tariff duties.

4.1. Calibration

The model's exact hat algebra formulation lends itself to relatively straightforward counterfactual simulations, which are parsimonious in terms of data and parameters. Therefore, the calibration is quite standard (see Costinot and Rodríguez-Clare, 2014, for a discussion of the issues at stake). However, there are two exceptions: compared to the standard framework, our setup requires calibration of the value of the parameter representing the love-of-variety elasticity as well as the initial distribution of varieties. As equation (38) makes clear, these two values play a central role in determining how the assessed gains from trade compare across models. Unfortunately, none of them is easily evaluated.

Love-of-variety elasticity Emphasizing proper modeling of the gains from variety highlights the central importance of the parameter used to reflect the magnitude of the corresponding effects, whether in terms of consumer welfare or of producer productivity. In the present framework, both are represented through ν_s, the love-of-variety elasticity.

The ideal approach would be to use our model to carry out a structural estimate of the love-of-variety elasticity, but this proved impossible. This estimation would require analyzing the cross-sectional relationship between sectoral expenditures and the total number of available varieties. However, data on available varieties is not commonly available in usable format. Note also that the gravity equation is uninformative about this parameter even were information about the number of varieties to be available. ν_s matters for the (unobservable) dual price indices $P_{ij,s}$ and $P_{j,s}$ (see equations (26) and (30)) but it does not influence the value of or variation in their ratio, which are the only elements relevant when setting import shares (equation (29)). The absence of information about varieties at the trade level leaves us with no usable empirical counterpart on which to rely to estimate this elasticity.

An alternative would be to take estimates from the literature. To our knowledge, the only estimates of this parameter in the trade literature[6] appear in an unpublished working paper (Ardelean, 2006) are based on the strong assumption that classification subheadings represent varieties irrespective of the number of producing firms, and are contingent on a modeling framework which in our view is inconsistent with our framework.[7] Thus, they are not fit for the calibration of our model. Analyses of the link between imported inputs and productivity (e.g., Goldberg et al., 2010) are also not helpful for evaluating the magnitude of this parameter since the data used in these studies do not make it possible to identify the number of imported varieties. A nascent literature estimates the role of varieties in consumption using consumer-level data (households survey in Li, 2021, and scanner data in Neiman and Vavra, 2020, and Kroft et al., 2021). Only Kroft et al. (2021) provide an estimate compatible with our framework. Carrying the estimation on data about grocery stores in the United States, they find a love-of-variety elasticity 6 times lower than what would be predicted by a CES framework.

Given our inability to estimate this parameter and the limited empirical evidence to date, the numerical simulations below use a range of values, between 0, its lower bound if we consider that consumers have a preference for varieties, and 0.4, a value larger that implied by the

[6] If one excludes indirect estimates based on Dixit-Stiglitz such as Broda and Weinstein (2006).

[7] In particular, the utility function used in this model accounts for the love of variety by individual country of origin (see Ardelean, 2006, equation 2.1) instead of summing all varieties as is done here. See also Oyamada (2020) for an application of this approach.

CES functional form in the heterogeneous-firm model below, and which corresponds to a trade elasticity of 2.5 in a homogeneous-firm model in the lower part of the distribution of typical structural estimates (Head and Mayer, 2014).

Initial distribution of varieties Carrying out counterfactual simulations based on the exact hat algebra form of the model requires information on the distribution across origin countries of the varieties sold in a given market, measured here by share parameters $\theta^N_{ij,s}$. We are not aware of readily available information on this distribution which would require knowing the identity of all the producers selling in a market as well as the number of different product varieties they are selling; in contrast, firm-level data are compiled based on production place.

However, although we do not have this precise empirical evidence, our theoretical framework offers some useful inferences. For example, the zero cutoff profit condition, equation (13), implies that

$$N_{j,s} = \frac{k_s + 1 - \sigma_s}{\sigma_s k_s} E_{j,s} \sum_{i=1}^{I} \frac{\theta^X_{ij,s}}{c_{i,s} f_{ij,s}}, \tag{41}$$

and

$$\theta^N_{ij,s} = \frac{\theta^X_{ij,s}/c_{i,s} f_{ij,s}}{\sum_{i'=1}^{I} \theta^X_{i'j,s}/c_{i',s} f_{i'j,s}}. \tag{42}$$

This equation shows that a producing country's share of varieties is proportional to the ratio between the trade share and the bilateral fixed cost it incurs to serve this market. Thus, a country with bilateral fixed costs lower than the weighted harmonic average across all selling countries ($c_{i,s} f_{ij,s} < [\sum_{i'=1}^{I} \theta^X_{i'j,s}(c_{i',s} f_{i'j,s})^{-1}]^{-1}$) will exhibit a higher share of varieties than its share of sales ($\theta^N_{ij,s} > \theta^X_{ij,s}$), a statement that is unrelated to our generalized CES modeling.

One solution to the calibration would be to recover the bilateral fixed production costs $c_{i,s} f_{ij,s}$. Balistreri et al. (2011) is an interesting attempt to estimate the $f_{ij,s}$, based on an additivity assumption related to two components: one specific to the region of origin, and the other specific to the destination (assumed to be nil if origin and destination are the same). Balistreri et al. found that this second component was much larger than the first, and took values that varied widely from region to region. While these results are interesting by and of themselves, and even if Balistreri et al.'s method was applicable in a large-scale setting (their model includes only one sector in monopolistic competition), we would still require the marginal production cost, $c_{i,s}$, which depends on the unobservable dual price indices $P_{i,r}$.

Instead, we exploit the fact that we do not need to identify the value of these bilateral fixed costs but only their value relative to one another (among producers selling in the same markets), and we simply assume that bilateral fixed costs for foreign producers are a multiple ($\beta \geq 1$, assumed constant across countries of origin) of those faced by domestic producers: $c_{i,s} f_{ij,s} = \beta c_{j,s} f_{jj,s}$, for all $i \neq j$.[8] Using equation (42), the share parameters $\theta^N_{ij,s}$ are then easily obtained from the trade shares $\theta^X_{ij,s}$, which are observable in the initial equilibrium:

$$\theta^N_{ij,s} = \frac{1 + (\beta - 1)\,\mathbf{1}_{i=j}}{1 + (\beta - 1)\,\theta^X_{jj,s}} \theta^X_{ij,s}. \tag{43}$$

A straightforward consequence of this assumption is that $\theta^N_{jj,s} = \theta^X_{jj,s}$ if $\beta = 1$, while $\theta^N_{jj,s} > \theta^X_{jj,s}$ if $\beta > 1$. As already noted, the latter case is a more natural assumption. For the sake of convenience, in what follows β is referred to as the relative fixed cost of exporting (understood as relative to the fixed costs of selling in the domestic market).

Other parameters The remaining calibration generally follows Costinot and Rodríguez-Clare (2014). All the statistics required for the benchmark equilibrium are based on World Input-Output Database (WIOD) for year 2008 (Timmer et al., 2015). The details of the treatment to map WIOD to the model are described in Appendix E. Only calculation of the input-output coefficients, $\alpha_{i,rs}$, deserves explanation here. As noted by Costinot and Rodríguez-Clare (2014), the combination of increasing return to scale and intermediate inputs can lead to undefined gains from trade because any change in the number of varieties triggers an infinite loop where more varieties lower the input costs which stimulates additional entry and more varieties. To avoid this situation, we follow Balistreri et al. (2011) and Costinot and Rodríguez-Clare (2014) and adjust the input-output shares so that every sector uses the same input shares in a country. This reduces consumption by individual sectors of inputs from itself (i.e., the diagonal elements of the input-output matrix) such that the gains from trade are well-defined.

The trade elasticity is assumed to be the same for all sectors with $\epsilon_s = 5$, a value corresponding to the typical elasticity estimated in the literature surveyed in Head et al. (2014). While sector-specific trade elasticity estimates are available (e.g., Caliendo and Parro, 2015), to ease interpretation we use a common value (specifically, a unique trade elasticity implies a unique love-of-variety elasticity in the CES case). For the distribution of firm heterogeneity, we use Balistreri et al.'s (2011) estimate of $\eta_s = 0.65$ (adopted also by Costinot and Rodríguez-Clare, 2014). Note that this value implies a love of variety that is 65% higher in a heterogeneous-firm model with CES compared to a homogeneous-firm model with CES.

The simulations presented below rely on two different aggregations of WIOD countries and sectors. A detailed aggregation encompassing 34 countries and 31 sectors is used to assess the gains from trade whose calculation relies on equation (35) without any model resolution. In contrast, simulating a trade war requires solving new model equilibria, hence the more aggregated approach encompassing 10 regions and 15 sectors, adopted to limit numerical problems. The correspondence between WIOD countries and sectors and those used here is provided in Appendix tables A1 and A2.

[8] Faced with the same problem of information on fixed costs, Cavallo et al. (2021) assume also a constant ratio of fixed costs.

4.2. Gains from trade

This calibration allows us to put numbers on the comparison of gains from trade across modeling setups, using the formula provided in equation (35). The calculations based on a homogeneous-firm model à la Krugman assume only a love of variety which coincides with the level implied by the CES function (0.2 in our case). As soon as this level does not apply, the assessed gains from trade in a Krugman model depend on the initial distribution of varieties, as shown for instance in equation (35). This is a problem because it would be impossible to credibly calibrate such a model to be consistent with evidence on the distribution of firms which is far from uniform. In this sense, a Krugman model with a generalized CES function cannot be considered to have any empirical relevance even for the stylized counterfactual simulations carried out here. For consistency, we refrain from simulating such cases although from a numerical point of view it would be possible in exact hat algebra.

Based on the calibration just described, figure 1 compares the average gains from trade across countries for different model types with the love-of-variety elasticity on the x-axis varying between 0 and 0.4 which includes the Dixit-Stiglitz values for the homogeneous-firm model at 0.2 and for the heterogeneous-firm at 0.33. In addition, we consider alternative calibrations of heterogeneous-firm models, depending on the value of the relative fixed costs of exporting (1, 1.5 or 2). Table 1 presents the results also by individual country for $\beta = 1.5$, and for selected levels of the love-of-variety elasticity.

It should be noted that the gains from trade in a Krugman model correspond exactly to those obtained using a Melitz model where $\beta = 1$ and $\nu_s = 0.2$. This is consistent with the already mentioned corollary of equation (38) according to which as soon as the love-of-variety elasticity is equal to its CES value in a homogeneous-firm setting ($\nu_s \epsilon_s = 1$ for any s) and the share of domestic producers is the same in terms of varieties as in terms of sales ($\beta = 1$) the gains from trade in a homogeneous-firm setting are equal to those obtained under a heterogeneous-firm setting.

Beyond this singular point, figure 1 shows that the gains from trade under a heterogeneous-firm model à la Melitz depend heavily upon the love-of-variety elasticity. As already emphasized, in the absence of reliable empirical estimates of this elasticity, the range of values considered here covered a range of positive love-of-variety elasticities that could be implied from trade models calibrated under typical estimates of trade elasticities. The results show that within the range of values assessed gains from trade using an otherwise identical heterogeneous-firm model can vary by a factor of up to three if the calibration assumes the relative fixed cost of exporting to be equal to one ($\beta = 1$), and up to almost two otherwise. This is a very pronounced dependence, as illustrated by the comparison with other benchmarks: for instance, assuming $\beta = 1$ a low love-of-variety elasticity implies that the gains from trade under a Melitz model are lower than under either a Krugman model or an Armington model. However, they are much larger for a relatively high level of this elasticity. In other words, comparison of the assessed gains from trade across model generations can be turned upside-down by a different assumption about the

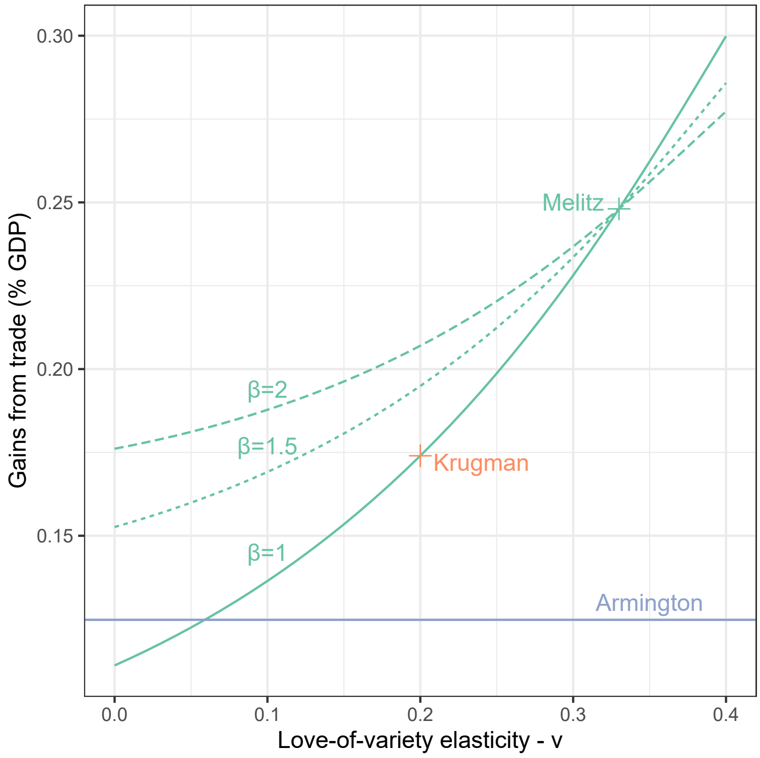

Figure 1 – Average gains from trade and love of variety.

love-of-variety elasticity.

The gains from trade are less sensitive to the love-of-variety elasticity if the relative fixed costs of exporting are larger than one ($\beta > 1$). Indeed, a higher β implies that domestic firms account for a larger share of varieties in the domestic market. In this case, since the availability of varieties is less affected for domestic than foreign ones, this means that the welfare impact of trade openness is less dependent on the love-of-variety elasticity. Figure 1 shows the ambiguous effect of the share of domestic varieties on gains from trade. According to equation (35), the gains from trade increase with the share of domestic firms if the benefits of varieties are lower than under the CES case, and decrease with the share of domestic varieties if $\nu_s > \nu_s^{\mathrm{CES}}$. So, below $\nu = 0.33$, the average gains from trade increase with β, while above this value the opposite is true. The intuition for this result is as follows. For $\nu_s < \nu_s^{\mathrm{CES}}$, the benefits of additional varieties are lower than their social costs (Bilbiie et al., 2019), so consumers and producers would benefit from a smaller number of varieties and trade is associated with less varieties for increasing values of β, which concentrate varieties in domestic firms. The opposite applies for For $\nu_s > \nu_s^{\mathrm{CES}}$.

For lower values of love-of-variety elasticity or for a lower relative fixed cost of exporting than represented in figure 1 ($\beta < 1$), the gains from trade can turn negative for many countries. These are situations where the social benefits of additional varieties are lower than their social costs or where the number of varieties coming from abroad is disproportionate to the number of

Table 1 – Gains from trade expressed in percentages of free-trade GDP ($\beta = 1.5$)

		Krugman	Melitz			
	Armington	$\nu = 0.2$	$\nu = 0.1$	$\nu = 0.2$	$\nu = 0.33$	$\nu = 0.4$
Country	(1)	(2)	(3)	(4)	(5)	(6)
AUS	6.4	2.0	5.7	3.5	−0.2	−2.7
AUT	17.0	20.3	22.1	22.9	24.8	26.3
BEL	28.1	35.6	35.0	38.8	46.8	53.4
BRA	3.1	4.6	4.8	5.4	6.8	8.0
CAN	9.9	9.0	11.8	10.8	9.3	8.4
CHN	6.2	37.8	20.6	39.3	77.4	97.2
CZE	19.9	33.5	30.4	37.1	52.3	66.0
DNK	17.5	20.1	20.9	22.7	26.1	28.8
FIN	11.1	15.9	15.8	18.2	23.2	27.2
FRA	7.5	7.3	9.2	8.9	8.8	9.1
DEU	11.8	14.9	15.8	17.0	19.5	21.6
GRC	8.0	6.4	7.6	8.0	9.2	10.2
HUN	25.5	37.2	35.4	40.6	50.9	58.9
IND	6.0	8.5	8.5	9.7	12.6	15.0
IDN	7.1	12.7	11.5	14.2	19.2	22.9
IRL	21.1	33.0	30.3	36.4	48.0	56.5
ITA	7.4	10.6	10.4	12.2	16.2	19.7
JPN	5.0	5.8	5.9	6.9	9.4	11.8
KOR	15.4	39.9	26.2	42.2	71.7	89.2
MEX	7.8	12.4	11.8	13.9	17.9	20.8
NLD	17.9	20.9	23.0	23.6	24.9	26.1
POL	12.1	13.7	16.2	16.1	16.1	16.2
PRT	11.4	13.9	15.0	16.0	18.3	20.3
ROU	11.2	13.2	14.9	15.4	16.8	18.2
RUS	6.9	6.9	7.4	8.2	10.6	12.7
SVK	24.8	32.0	32.5	35.6	42.2	48.0
SVN	26.7	29.7	30.5	32.8	37.5	41.3
ESP	7.6	1.5	7.1	3.3	−4.7	−12.0
SWE	13.3	16.9	18.2	19.3	21.7	23.7
TWN	20.1	35.4	28.4	38.1	55.7	67.7
TUR	6.7	6.3	8.5	7.7	6.6	6.1
GBR	8.6	11.4	12.0	12.9	15.1	16.9
USA	3.3	3.3	4.3	4.1	4.4	5.0
RoW	11.8	18.9	17.5	21.1	28.0	33.2
Average	12.5	17.4	16.9	19.5	24.8	28.6

domestic varieties, with the result that more varieties reduces welfare under free trade compared to autarky.

These simulations can be used also to compare the models in the way they are usually compared, i.e. using a standard CES framework (as in Costinot and Rodríguez-Clare, 2014). This is akin to comparing columns 2 and 5 in table 1. For most countries, the gains from trade are approximately 50% larger assuming firm heterogeneity. However, in our case and similar to Costinot and Rodríguez-Clare (2014), using the CES framework implies that the heterogeneous-firm model assumes the love-of-variety elasticity to be 65% larger (value of η_s) compared to the homogeneous-firm setting. Given the impact of this parameter depicted in figure 1, this difference is likely to explain by itself a large part of the different gains from trade between these two models. We can confirm this if we compare a CES model with homogeneous firms to a model with heterogeneous firms using the same love-of-variety elasticity, as in column 4. We can see that for most countries the difference between the two models is quite small, generally in the order of 20%.

Column 5 in table 1 shows that in the standard Melitz-Chaney model two countries are found to have negative gains from trade which is in line with Costinot and Rodríguez-Clare (2014, Table 4.1). This occurs when for countries gains from the intensive margin are small and are lower than the losses derived from the entry and selection margins. Note also that although we highlighted that in the heterogeneous-firm models a higher love-of-variety elasticity implies higher gains from trade at the global level, this does not apply to all countries. For a few (Australia, Canada, Spain, Turkey), the relationship is downward-sloping and for a few others (France, Poland, USA) it is non-monotonic. This occurs if the number of varieties tends to increase in autarky because the entry of less productive domestic firms dominates the loss of foreign varieties; the corresponding positive variety effect in autarky is larger if love of variety is higher. The probability of these patterns depends on the initial varieties distribution, and we lack comprehensive information in this regard.

4.3. Trade war

We next analyze the part played by the taste for variety in the welfare effects of a trade war where all countries raise their tariffs by 25%. Computing this outcome requires solving for a counterfactual equilibrium using the system of equations (25)–(33). To minimize numerical problems, the solutions are obtained by solving a more concentrated system where the variables $P_{ij,s}$ and $X_{ij,s}$ are substituted away using equations (26) and (29).

Figure 2 reports how the worldwide equivalent variation of a trade war varies with the love-of-variety elasticity and the calibration of the initial number of firms. Adjusting for the sign, the broad pattern is close to that depicted in figure 1, and includes the same main mechanisms. However, there are several aspects which are worth commenting on. First, even in the case of very low love of variety, there are always less welfare losses in a model using perfect-competition (à la Armington). This is explained by stronger reductions in trade flows in the heterogeneous-firm model despite the models being calibrated on the same trade elasticity.

Second, comparing across heterogeneous-firm models, a higher love-of-variety elasticity implies larger welfare losses which is consistent with the results for the gains from trade. However, the sensitivity of this parameter differs significantly depending on the value of the relative fixed cost of exporting: if this parameter is equal to one (which means also that the share of domestic firms in the domestic market is the same measured in terms of varieties or sales), the estimated global welfare losses increase fourfold between estimates based on a low and a high love of variety, reflecting a very strong sensitivity. If this parameter is equal to 2, this sensitivity is much weaker.

Third, the exact equality of the welfare impact between a homogeneous- and a heterogeneous-firm model found in the case of autarky is no longer valid anymore in this case. This result is established only for autarky and it is remarkable that the difference remains small. The welfare difference is explained by the fact that for the same tariff increase trade flows are reduced more (by 88%) in the heterogeneous-firm model compared to the homogeneous-firm model (78%). This is despite a calibration using the same trade elasticity. In the limit case of tariffs increasing to infinity, international trade flows and the difference between the welfare effects in the two models (if $\nu_s = 0.2$) converge to zero.

Therefore, comparing welfare losses under homogeneous- and heterogeneous-firm models requires information on both the love-of-variety elasticity and the initial distribution of varieties (captured here in the value of β). This is logical since assessing effects linked to varieties requires information on their distribution, and how any changes are valued by final and intermediate consumers.

At the country (or region) level, welfare losses are always lowest under an Armington model (table A3). However, in the case of heterogeneous-firm models, sensitivity to the love-of-variety elasticity differs significantly. As already observed for the gains from trade, the relationship between love of variety and welfare effects, while upward-sloping on average (with a very large slope for China, in particular) becomes downward-sloping for several regions (Easter Europe, Latin America, North America), and non-monotonic for the Indian Ocean region. Again, this finding reflects changes in the number of varieties associated with the trade policy shock. For countries where a tariff war results in higher (less efficient) domestic firms entries than foreign firms exits, variety will increase, so that a greater love of variety reduces the welfare cost of the shock. Importantly, these cross-country differences mean also that love of variety not only significantly influences the models' average results, it also conditions how countries differ.

5. Concluding remarks

While love of variety has for long been acknowledged to be a potentially important determinant of the welfare consequences of international trade, it has been largely overlooked in the literature. This is in part for reasons of convenience. We adopted a model which allows consideration of this specific dimension separately from other behavioral parameters, and have shown that love

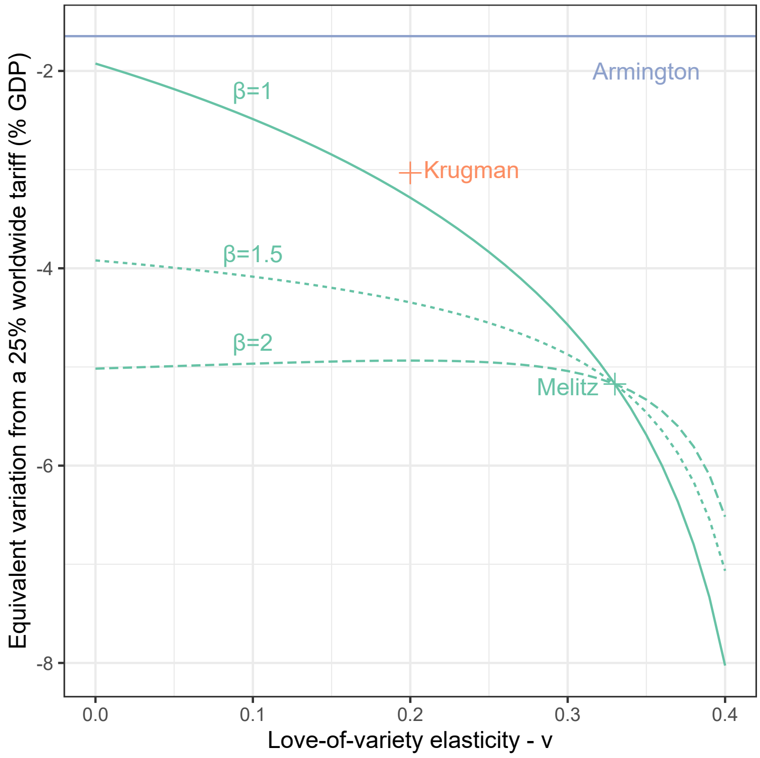

Figure 2 – Global welfare effect from trade war and love of variety

of variety matters. We analyzed the corresponding influence in detail, distinguishing among different effects and clarifying their interpretation.

What is the practical importance of our finding? It is true that it is impossible to properly model many different aspects of reality and to the extent that simplification is a defining feature of modeling, not a bug, this is not necessary a problem. However, a few important papers have argued that love of variety is central for understanding the gains from trade, and this was the motivation for our work. To substantiate this intuition, we used the modeling framework developed to carry out counterfactual simulations. Our findings for the assessment of the welfare gains from trade with respect to autarky and to a situation of trade war vindicate our approach: different assumptions about the magnitude of the love of variety can change the results by a factor of two to four, and can overturn comparisons across model generations. Moreover, cross-country differences in the sensitivity to this parameter mean that not only average impacts but also their distribution depend heavily on the love of variety. The influence of the love of variety on the model results is quantitatively large, and in some cases, is qualitatively decisive.

These findings show that in trade models love of variety is worthy of more attention than paid to it so far. However, we have shown also the difficulty involved especially from an empirical point of view. How love of variety affects trade assessments depends on two main parameters: love-of-variety elasticity which reflects the intensity of the benefits ensuing from access to a greater number of varieties; and the initial distribution of varieties (from all origins). Unfortunately, the available statistics do not provide comprehensive information on traded varieties. In the case of the love-of-variety elasticity, our modeling framework does not provide a satisfactory estimation strategy given the lack of data on traded varieties, but the recent research on the role of varieties at the consumer level (Neiman and Vavra, 2020; Kroft et al., 2021; Li, 2021) could contribute to reliable estimates. Further research on these issues would help to identify more clearly what is at stake.

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Appendix

A. Derivation of the gravity equation and aggregate price index

Trade in terms of CIF value, $X_{ij,s}$, is given by the integral over productivity of all firm-level trade multiplied by the mass of firms that have entered the market:

$$X_{ij,s} = M_{i,s} \int_{\phi_{ij,s}}^{\infty} \frac{p_{ij,s}(\phi)\, d_{ij,s}(\phi)}{T_{ij,s}} g_s(\phi)\, \mathrm{d}\,\phi. \tag{A1}$$

Using equations (8) and (9), the density of the Pareto distribution, and integrating over the productivity, we obtain

$$X_{ij,s} = M_{i,s} \left[\tau_{ij,s} c_{i,s} \left(\frac{\sigma_s}{\sigma_s - 1}\right)^{\delta_s^M}\right]^{1-\sigma_s} T_{ij,s}^{-\sigma_s} E_{j,s} N_{j,s}^{\nu_s(\sigma_s-1)-1} P_{j,s}^{\sigma_s-1} \left(\frac{k_s \underline{\phi}_s^{k_s}}{k_s + 1 - \sigma_s}\right)^{\delta_s^H} \phi_{ij,s}^{\sigma_s-1-k_s}. \tag{A2}$$

We substitute out the terms in $M_{i,s}$ and $\phi_{ij,s}$ using equation (15) and the definition of cutoff productivity (19) which leads to

$$\begin{aligned}\frac{T_{ij,s}X_{ij,s}}{E_{j,s}P_{j,s}^{\sigma_s-1}} = \left(T_{ij,s}\tau_{ij,s}c_{i,s}\right)^{1-\sigma_s} \left[\frac{R_{i,s}}{c_{i,s}} N_{j,s}^{\nu_s(\sigma_s-1)-1}\right]^{\delta_s^M} \cdot \\ \left\{\left[\frac{E_{j,s}N_{j,s}^{\nu_s(\sigma_s-1)-1}}{T_{ij,s}c_{i,s}}\right]^{\frac{1}{1-\sigma_s}} \frac{T_{ij,s}\tau_{ij,s}c_{i,s}}{P_{j,s}}\right\}^{\delta_s^H(\sigma_s-1-k_s)} \xi_{ij,s}^{1-\sigma_s},\end{aligned} \tag{A3}$$

which allows us to identify the gravity equation and the aggregate price index where

$$\xi_{ij,s}^{1-\sigma_s} = \left[\frac{1}{\sigma_s f_{i,s}^e}\left(\frac{\sigma_s}{\sigma_s-1}\right)^{(1-\sigma_s)}\right]^{\delta_s^M} \left\{\frac{\underline{\phi}_s^{k_s}(\sigma_s-1)}{k_s+1-\sigma_s}\left[\frac{\sigma_s}{\sigma_s-1}\left(\sigma_s f_{ij,s}\right)^{1/(\sigma_s-1)}\right]^{(\sigma_s-1-k_s)}\right\}^{\delta_s^H}. \tag{A4}$$

B. Derivation of the welfare formula (Proposition 1)

Utility is given by real expenditure: $U_i = \mu_i Y_i / P_i$, where P_i is the aggregate consumption price index corresponding to the Cobb-Douglas preferences over final goods in equation (1). In deviation from benchmark equilibrium, we have

$$\hat{U}_i = \frac{\hat{\mu}_i \hat{Y}_i}{\hat{P}_i} = \hat{\mu}_i \hat{Y}_i \prod_{s=1}^{S} \hat{P}_{i,s}^{-\theta_{i,s}^U}. \tag{A5}$$

Let us now decompose the expression of $\hat{P}_{i,s}$. Using the gravity equation (23) for domestic trade, for which $T_{ii,s} = \tau_{ii,s} = 1$, gives

$$P_{i,s} = \left(\theta^X_{ii,s}\right)^{\frac{1}{\sigma_s-1}} P_{ii,s} \tag{A6}$$

$$= \left(\theta^X_{ii,s}\right)^{\frac{1}{(\sigma_s-1)}} c_{i,s} \left[\frac{R_{i,s}}{c_{i,s}} N_{i,s}^{\nu_s(\sigma_s-1)-1}\right]^{\frac{\delta^M_s}{(1-\sigma_s)}} \left\{\frac{c_{i,s}}{P_{i,s}} \left[\frac{E_{i,s} N_{i,s}^{\nu_s(\sigma_s-1)-1}}{c_{i,s}}\right]^{\frac{1}{1-\sigma_s}}\right\}^{\frac{\delta^H_s(\sigma_s-1-k_s)}{1-\sigma_s}} \xi_{ii,s}, \tag{A7}$$

which leads to

$$P_{i,s}^{1+\frac{\delta^H_s(\sigma_s-1-k_s)}{1-\sigma_s}} = \left(\theta^X_{ii,s}\right)^{\frac{1}{\sigma_s-1}} c_{i,s} \left[\frac{R_{i,s}}{c_{i,s}} N_{i,s}^{\nu_s(\sigma_s-1)-1}\right]^{\frac{\delta^M_s}{1-\sigma_s}} \left\{c_{i,s} \left[\frac{E_{i,s} N_{i,s}^{\nu_s(\sigma_s-1)-1}}{c_{i,s}}\right]^{\frac{1}{1-\sigma_s}}\right\}^{\frac{\delta^H_s(\sigma_s-1-k_s)}{1-\sigma_s}} \xi_{ii,s}. \tag{A8}$$

Replacing the unit costs by their expression in equation (6) and rearranging gives,

$$P_{i,s} = B_{i,s} \left(\prod_{r=1}^{S} P_{i,r}^{\alpha_{i,rs}}\right)^{1+\delta^M_s/(\sigma_s-1)}, \tag{A9}$$

where

$$B_{i,s} = \left(\theta^X_{ii,s}\right)^{\frac{1}{\epsilon_s}} Y_i^{1-\alpha_{i,s}\left(1+\frac{\delta^M_s}{\sigma_s-1}\right)} \left[\frac{R_{i,s}}{Y_i} N_{i,s}^{\nu_s(\sigma_s-1)-1}\right]^{-\frac{\delta^M_s}{\epsilon_s}} \left[\frac{E_{i,s}}{Y_i} N_{i,s}^{\nu_s(\sigma_s-1)-1}\right]^{\frac{\delta^H_s}{\epsilon_s}\left(1-\frac{k_s}{\sigma_s-1}\right)} \xi_{ii,s}^{\frac{\sigma_s-1}{\epsilon_s}}. \tag{A10}$$

Taking equation (A9) in logs, we then have

$$\sum_{r=1}^{S} \left[\mathbf{1}_{r=s} - \left(1 + \frac{\delta^M_s}{\sigma_s - 1}\right)\alpha_{i,rs}\right] \ln P_{i,r} = \ln B_{i,s}. \tag{A11}$$

This defines a linear problem between the vector of log prices, $\ln \mathbf{P}_i$, the vector of variables $\mathbf{B}_i$ in log:

$$\left[I_S - \tilde{A}_i\right] \ln \mathbf{P}_i = \ln \mathbf{B}_i, \tag{A12}$$

where $(\tilde{A}_i)_{rs} = [1 + \delta^M_s/(\sigma_s - 1)]\alpha_{i,rs}$. So, if the matrix $[I_S - \tilde{A}_i]$ is invertible, the $P_{i,s}$ are given by

$$P_{i,s} = \prod_{r=1}^{S} B_{i,r}^{\tilde{a}_{i,sr}}, \tag{A13}$$

where $\tilde{a}_{i,rs} \equiv ([I_S - \tilde{A}_i]^{-1})_{rs}$ are the elements of the adjusted Leontief inverse.

In relative deviations this gives:

$$\hat{P}_{i,s} = \prod_{r=1}^{S} \left\{\hat{\theta}^X_{ii,r} \hat{Y}_i^{\epsilon_r\left[1-\alpha_{i,r}\left(1+\frac{\delta^M_r}{\sigma_r-1}\right)\right]} \left[\frac{\hat{R}_{i,r}}{\hat{Y}_i} \hat{N}_{i,r}^{\nu_r(\sigma_r-1)-1}\right]^{-\delta^M_r} \left[\frac{\hat{E}_{i,r}}{\hat{Y}_i} \hat{N}_{i,r}^{\nu_r(\sigma_r-1)-1}\right]^{\delta^H_r\left(1-\frac{k_r}{\sigma_r-1}\right)}\right\}^{\frac{\tilde{a}_{i,sr}}{\epsilon_r}}. \tag{A14}$$

We note that the exponent on $\hat{Y}_i$ is $\sum_{r=1}^{S} \tilde{a}_{i,sr}\{1 - \alpha_{i,r}[1 + \delta_r^M/(\sigma_r - 1)]\}$, which in matrix notation and based on $\alpha_{i,r} = \sum_{s=1}^{S} \alpha_{i,sr}$ can be expressed as

$$J_{1,S}\left[I_S - \tilde{A}_i\right]\left[I_S - \tilde{A}_i\right]^{-1}, \tag{A15}$$

where $J_{1,S}$ is a $1 \times S$ vector of ones. Then $\sum_{r=1}^{S} \tilde{a}_{i,sr}\left\{1 - \alpha_{i,r}\left[1 + \delta_r^M/(\sigma_r - 1)\right]\right\} = 1$ and equation (34) follows from equations (A5) and (A14).

C. Derivation of the gains from trade

To derive an expression of the gains from trade, we follow the same steps as in Appendix B for the welfare formula, although now we can substitute the number of varieties by a simpler expression. From equations (25) and (28), the changes in the number of varieties between free trade and autarky can be expressed as

$$\hat{N}_{i,s}^A = \theta_{ii,s}^N \begin{cases} \hat{X}_{ii,s}^A/\hat{c}_{i,s}^A = (R_{i,s}/X_{ii,s})\left(\hat{R}_{i,s}^A/\hat{c}_{i,s}^A\right) & \text{if } \delta_s^H = 1, \\ \hat{R}_{i,s}^A/\hat{c}_{i,s}^A & \text{if } \delta_s^H = 0. \end{cases} \tag{A16}$$

Since assessing the gains from trade requires comparing the current equilibrium to autarky, it is worth noting that the autarkic equilibrium is characterized by $\mu_i^A = 1$, $\theta_{ii,s}^{X,A} = 1$ and

$$\frac{R_{i,r}^A}{Y_i^A} = \frac{E_{i,r}^A}{Y_i^A} = \sum_{s=1}^{S} a_{i,rs}\theta_{i,s}^U, \tag{A17}$$

where $a_{i,rs}$ are elements of the Leontief inverse (for the proof see the appendix in Costinot and Rodríguez-Clare, 2014).

Equation (A16) allows us to simplify the expression of the domestic prices. We start from equation (A8) in relative changes:

$$\hat{P}_{i,s}^{\frac{\epsilon_s}{\sigma_s-1}} = \left(\hat{\theta}_{ii,s}^X\right)^{\frac{1}{\sigma_s-1}} \hat{c}_{i,s}\left(\frac{\hat{R}_{i,s}}{\hat{c}_{i,s}}\hat{N}_{i,s}^{\nu_s(\sigma_s-1)-1}\right)^{\frac{\delta_s^M}{1-\sigma_s}}\left[\hat{c}_{i,s}\left(\frac{\hat{E}_{i,s}}{\hat{c}_{i,s}}\hat{N}_{i,s}^{\nu_s(\sigma_s-1)-1}\right)^{\frac{1}{1-\sigma_s}}\right]^{\frac{\delta_s^H(\sigma_s-1-k_s)}{1-\sigma_s}}, \tag{A18}$$

and substitute the number of varieties:

$$\hat{P}_{i,s}^{\frac{\epsilon_s}{\sigma_s-1}} = \left(\hat{\theta}_{ii,s}^X\right)^{\frac{1}{\sigma_s-1}} \hat{c}_{i,s}\left\{\frac{\hat{R}_{i,s}}{\hat{c}_{i,s}}\left[\theta_{ii,s}^N\left(\frac{R_{i,s}}{X_{ii,s}}\right)^{\delta_s^H}\frac{\hat{R}_{i,s}}{\hat{c}_{i,s}}\right]^{\nu_s(\sigma_s-1)-1}\right\}^{\frac{\delta_s^M}{1-\sigma_s}}$$
$$\left(\hat{c}_{i,s}\left\{\frac{\hat{E}_{i,s}}{\hat{c}_{i,s}}\left[\theta_{ii,s}^N\left(\frac{R_{i,s}}{X_{ii,s}}\right)^{\delta_s^H}\frac{\hat{R}_{i,s}}{\hat{c}_{i,s}}\right]^{\nu_s(\sigma_s-1)-1}\right\}^{\frac{1}{1-\sigma_s}}\right)^{\frac{\delta_s^H(\sigma_s-1-k_s)}{1-\sigma_s}}, \tag{A19}$$

Replacing the unit costs by their expression in equation (6) and rearranging gives,

$$\hat{P}_{i,s} = \hat{B}^{A}_{i,s} \left(\prod_{r=1}^{S} \hat{P}_{i,r}^{\alpha_{i,rs}} \right)^{1+\delta^M_s \nu_s}, \tag{A20}$$

where

$$\hat{B}^{A}_{i,s} = \left(\hat{\theta}^{X}_{ii,s}\right)^{\frac{1}{\epsilon_s}} \hat{Y}_i^{(1-\alpha_{i,s})\frac{\sigma_s-1}{\epsilon_s}} \left\{ \frac{\hat{R}_{i,s}}{\hat{Y}_i^{1-\alpha_{i,s}}} \left[\theta^{N}_{ii,s} \left(\frac{R_{i,s}}{X_{ii,s}} \right)^{\delta^H_s} \right]^{1-1/[\nu_s(\sigma_s-1)]} \right\}^{-\frac{\delta^M_s \nu_s(\sigma_s-1)}{\epsilon_s}}$$
$$\left(\hat{Y}_i^{1-\alpha_{i,s}} \left\{ \frac{\hat{E}_{i,s}}{\hat{Y}_i^{1-\alpha_{i,s}}} \left[\theta^{N}_{ii,s} \left(\frac{R_{i,s}}{X_{ii,s}} \right)^{\delta^H_s} \frac{\hat{R}_{i,s}}{\hat{Y}_i^{1-\alpha_{i,s}}} \right]^{\nu_s(\sigma_s-1)-1} \right\}^{\frac{1}{1-\sigma_s}} \right)^{\frac{\delta^H_s(k_s-\sigma_s+1)}{\epsilon_s}}. \tag{A21}$$

We can gather together the terms in $\hat{Y}_i$:

$$\hat{B}^{A}_{i,s} = \left(\hat{\theta}^{X}_{ii,s}\right)^{\frac{1}{\epsilon_s}} \hat{Y}_i^{1-\alpha_{i,s}\left(1+\delta^M_s \nu_s\right)} \left\{ \frac{\hat{R}_{i,s}}{\hat{Y}_i} \left[\theta^{N}_{ii,s} \left(\frac{R_{i,s}}{X_{ii,s}} \right)^{\delta^H_s} \right]^{1-1/[\nu_s(\sigma_s-1)]} \right\}^{-\frac{\delta^M_s \nu_s(\sigma_s-1)}{\epsilon_s}}$$
$$\left\{ \frac{\hat{E}_{i,s}}{\hat{Y}_i} \left[\theta^{N}_{ii,s} \left(\frac{R_{i,s}}{X_{ii,s}} \right)^{\delta^H_s} \frac{\hat{R}_{i,s}}{\hat{Y}_i} \right]^{\nu_s(\sigma_s-1)-1} \right\}^{\frac{\delta^H_s}{\epsilon_s}\left(1-\frac{k_s}{\sigma_s-1}\right)}. \tag{A22}$$

As in Appendix B, equation (A20) can be solved as a linear problem:

$$\hat{P}_{i,s} = \prod_{r=1}^{S} \left(\hat{B}^{A}_{i,r}\right)^{\tilde{a}^A_{i,sr}}, \tag{A23}$$

where $\tilde{a}^A_{i,rs} \equiv ([I_S - \tilde{A}^A_i]^{-1})_{rs}$ with $(\tilde{A}^A_i)_{rs} = (1+\delta^M_s \nu_s)\alpha_{i,rs}$.

This gives for $\hat{P}_{i,s}$:

$$\hat{P}_{i,s} = \prod_{r=1}^{S} \left(\hat{\theta}^{X}_{ii,r} \hat{Y}_i^{\epsilon_r\left(1-\alpha_{i,r}\left(1+\delta^M_r \nu_r\right)\right)} \left\{ \frac{\hat{R}_{i,r}}{\hat{Y}_i} \left[\theta^{N}_{ii,r} \left(\frac{R_{i,r}}{X_{ii,r}} \right)^{\delta^H_r} \right]^{1-1/[\nu_r(\sigma_r-1)]} \right\}^{-\delta^M_r \nu_r(\sigma_r-1)} \right.$$
$$\left. \left\{ \frac{\hat{E}_{i,r}}{\hat{Y}_i} \left[\theta^{N}_{ii,r} \left(\frac{R_{i,r}}{X_{ii,r}} \right)^{\delta^H_r} \frac{\hat{R}_{i,r}}{\hat{Y}_i} \right]^{\nu_r(\sigma_r-1)-1} \right\}^{\delta^H_r\left(1-\frac{k_r}{\sigma_r-1}\right)} \right)^{\frac{\tilde{a}^A_{i,sr}}{\epsilon_r}}. \tag{A24}$$

As before, we note that the exponent on Y_i is equal to 1, so we can rearrange equation (A24) into

$$\hat{P}_{i,s} = \hat{Y}_i \prod_{r=1}^{S} \left\{ \hat{\theta}^X_{ii,r} \left[\theta^N_{ii,r} \left(\frac{R_{i,r}}{X_{ii,r}} \right)^{\delta^H_r} \right]^{\frac{\epsilon_r}{\sigma_r - 1}\delta^M_r [1-\nu_r(\sigma_r-1)]} \left(\frac{\hat{R}_{i,r}}{\hat{Y}_i} \right)^{-\delta^M_r \left\{1 + \frac{\epsilon_r}{\sigma_r-1}[\nu_r(\sigma_r-1)-1]\right\}} \left(\frac{\hat{E}_{i,r}}{\hat{Y}_i} \right)^{\delta^H_r \left(1 - \frac{k_r}{\sigma_r - 1}\right)} \right\}^{\frac{\tilde{a}^A_{i,sr}}{\epsilon_r}} . \tag{A25}$$

This leads to the following expression of the welfare changes when going from free trade to autarky and assuming no trade deficit in free trade:

$$\hat{U}_i = \prod_{r,s=1}^{S} \left\{ \hat{\theta}^X_{ii,s} \left[\theta^N_{ii,s} \left(\frac{R_{i,s}}{X_{ii,s}} \right)^{\delta^H_s} \right]^{\frac{\epsilon_s}{\sigma_s - 1}\delta^M_s [1-\nu_s(\sigma_s-1)]} \left(\frac{\hat{R}_{i,s}}{\hat{Y}_i} \right)^{-\delta^M_s \left\{1 + \frac{\epsilon_s}{\sigma_s-1}[\nu_s(\sigma_s-1)-1]\right\}} \left(\frac{\hat{E}_{i,s}}{\hat{Y}_i} \right)^{\delta^H_s \left(1 - \frac{k_s}{\sigma_s - 1}\right)} \right\}^{-\theta^U_{i,r}\tilde{a}^A_{i,rs}/\epsilon_s} . \tag{A26}$$

When moving from free trade to autarky, we have

$$\hat{\theta}^X_{ii,s} = \frac{1}{\theta^X_{ii,s}}, \tag{A27}$$

$$\frac{\hat{R}_{i,s}}{\hat{Y}_i} = \frac{R^A_{i,s}}{Y^A_i}\frac{Y_i}{R_{i,s}} = \left(\sum_{r=1}^{S} a_{i,sr}\theta^U_{i,r} \right) \frac{R_i}{R_{i,s}}\frac{Y_i}{R_i} = \left(\sum_{r=1}^{S} a_{i,sr}\theta^U_{i,r} \right) \frac{Y_i/R_i}{r_{i,s}}, \tag{A28}$$

and similarly

$$\frac{\hat{E}_{i,s}}{\hat{Y}_i} = \frac{E^A_{i,s}}{Y^A_i}\frac{Y_i}{E_{i,s}} = \left(\sum_{r=1}^{S} a_{i,sr}\theta^U_{i,r} \right) \frac{E_i}{E_{i,s}}\frac{Y_i}{E_i} = \left(\sum_{r=1}^{S} a_{i,sr}\theta^U_{i,r} \right) \frac{Y_i/R_i}{e_{i,s}}, \tag{A29}$$

using the fact that in the absence of trade deficits $R_i = E_i$.

Equation (35) follows from equations (A26)–(A29).

D. Proof of Proposition 2

Let us start with the expression of welfare changes when going from free trade to autarky in the Krugman model, then from equation (35) and using the fact that $(\nu_s - \nu^{\text{CES}}_s)\epsilon_s = \nu_s\epsilon_s - 1$ we have:

$$\hat{U}^K_j = \prod_{r,s=1}^{S} \left[\theta^X_{jj,s} \left(\frac{r_{j,s}}{b_{j,s}} \right)^{-\nu_s\epsilon_s} \left(\theta^N_{jj,s} \right)^{\nu_s\epsilon_s - 1} \right]^{\frac{\theta^U_{j,r}\tilde{a}^A_{j,rs}}{\epsilon_s}} . \tag{A30}$$

In the Melitz case, $(\nu_s - \nu_s^{\text{CES}})\epsilon_s = \nu_s\epsilon_s - (1+\eta_s)$ and the expression of welfare change is

$$\hat{U}_j^M = \prod_{r,s=1}^{S} \left[\theta_{jj,s}^X \left(\frac{r_{j,s}}{b_{j,s}} \right)^{-\nu_s\epsilon_s} \left(\frac{\theta_{jj,s}^N}{\theta_{jj,s}^R} \right)^{\nu_s\epsilon_s-(1+\eta_s)} \left(\frac{e_{j,s}}{r_{j,s}} \right)^{-\eta_s} \right]^{\frac{\theta_{j,r}^U \tilde{a}_{j,rs}^A}{\epsilon_s}} . \qquad \text{(A31)}$$

Equation (36) follows from taking the ratio of equation (A31) to equation (A30).

E. Data

The first data step is removing the negative values from WIOD for year 2008. In this dataset, final demand includes negative values mostly in inventory changes but also in gross fixed capital formation (for four data points). Our theoretical model cannot accommodate negative final demands so we need to remove them. To do this and to maintain data consistency, we use a simple input-output model. WIOD allows us to calculate the technical coefficients matrix (the input-output coefficients). Then using standard matrix operations we can calculate the new production corresponding to total final demand excluding negative final demand. Using the new production, the technical coefficients, and the corrected final demand, we can to build a new world input-output table.

We then aggregate this table then to the desired region and sector levels using the mappings defined in tables A1 and A2. From this aggregate world input-output table, the calibration follows from the definition of all the share parameters in section 3. Here, we comment on the points that require further clarification. In the model, final demand is demand from households. So all final demand from WIOD (inventory changes, gross fixed capital formation, expenditures by non-profit, public expenditures, and households expenditures) is summed. We ignore much of the trade information included in the world input-output table since in our model final and intermediate demands aggregate varieties in the same way (based on equation (2)). Therefore, the only trade information of interest in the model is the aggregate trade flows by sector between two countries. Once the model is calibrated and, before employing it for the simulations in section 4, we ran a first simulation to remove the trade deficits. The $\hat{\Delta}_j$ are set to zero, and a new equilibrium is solved for, which serves as a basis to calibrate the model for the counterfactual simulations.

Table A1 – Mapping between countries in the model and countries in WIOD

	Model country (GFT)		
Model country (trade war)	Acronym	Name	Country in WIOD
China	CHN	China	China
Indian Ocean	IND	India	India
"	IDN	Indonesia	Indonesia
Latin America	BRA	Brazil	Brazil
"	MEX	Mexico	Mexico
Northern Europe	DNK	Denmark	Denmark
"	FIN	Finland	Finland
"	IRL	Ireland	Ireland
"	SWE	Sweden	Sweden
"	GBR	United Kingdom	United Kingdom
North America	CAN	Canada	Canada
"	USA	United States	United States
Pacific Ocean	AUS	Australia	Australia
"	JPN	Japan	Japan
"	KOR	Korea, Republic of	Korea, Republic of
"	TWN	Taiwan	Taiwan
Eastern Europe	CZE	Czech Republic	Czech Republic
"	HUN	Hungary	Hungary
"	POL	Poland	Poland
"	ROU	Romania	Romania
"	RUS	Russia	Russia
"	SVK	Slovak Republic	Slovak Republic
"	SVN	Slovenia	Slovenia
"	RoW	Rest of the World	Bulgaria
"	"	"	Estonia
"	"	"	Latvia
"	"	"	Lithuania
Southern Europe	GRC	Greece	Greece
"	ITA	Italy	Italy
"	PRT	Portugal	Portugal
"	ESP	Spain	Spain
"	TUR	Turkey	Turkey
"	RoW	Rest of the World	Cyprus
"	"	"	Malta
Western Europe	AUT	Austria	Austria
"	BEL	Belgium	Belgium
"	FRA	France	France
"	DEU	Germany	Germany
"	NLD	Netherlands	Netherlands
"	RoW	Rest of the World	Luxembourg
Rest of the World	"	"	Rest of the World

Table A2 – Mapping between sectors in the model and sectors in WIOD

Model sector (GFT)	Model sector (trade war)	Sector in WIOD	
1	1	1	Agriculture, Hunting, Forestry and Fishing
2	2	2	Mining and Quarrying
3	"	3	Coke, Refined Petroleum and Nuclear Fuel
4	3	4	Food, Beverages and Tobacco
5	4	5	Textiles and Textile Products
"	"	6	Leather, Leather and Footwear
6	5	7	Wood and Products of Wood and Cork
7	6	8	Pulp, Paper, Paper , Printing and Publishing
8	7	9	Chemicals and Chemical Products
9	8	10	Rubber and Plastics
10	9	11	Other Non-Metallic Mineral
11	10	12	Basic Metals and Fabricated Metal
12	11	13	Machinery, Nec
13	12	14	Electrical and Optical Equipment
14	13	15	Transport Equipment
15	14	16	Manufacturing, Nec; Recycling
16	15	17	Electricity, Gas and Water Supply
17	"	18	Construction
18	"	19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
"	"	20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
19	"	21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
20	"	22	Hotels and Restaurants
21	"	23	Inland Transport
22	"	24	Water Transport
23	"	25	Air Transport
24	"	26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
25	"	27	Post and Telecommunications
26	"	28	Financial Intermediation
27	"	29	Real Estate Activities
28	"	30	Renting of M&Eq and Other Business Activities
29	"	31	Public Admin and Defence; Compulsory Social Security
"	"	32	Other Community, Social and Personal Services
"	"	33	Private Households with Employed Persons
30	"	34	Education
31	"	35	Health and Social Work

F. Supplementary table

Table A3 – Welfare changes from trade war expressed in percentages of free-trade GDP, by region ($\beta = 1.5$)

		Krugman	Melitz			
Country	Armington (1)	$\nu = 0.2$ (2)	$\nu = 0.1$ (3)	$\nu = 0.2$ (4)	$\nu = 0.33$ (5)	$\nu = 0.4$ (6)
China	−1.49	−5.70	−5.32	−7.63	−16.23	−38.71
Eastern Europe	−2.42	−3.61	−5.32	−5.25	−5.11	−5.01
Indian Ocean	−1.56	−2.71	−3.86	−3.88	−3.88	−3.83
Latin America	−1.30	−1.95	−3.00	−2.91	−2.73	−2.60
Norhern Europe	−2.32	−3.96	−5.35	−5.51	−5.77	−5.94
North America	−0.84	−1.23	−2.00	−1.88	−1.66	−1.51
Pacific Ocean	−1.28	−2.95	−3.65	−4.14	−5.11	−5.91
Southern Europe	−1.52	−2.78	−3.94	−4.04	−4.22	−4.33
Western Europe	−1.87	−3.30	−4.62	−4.76	−4.99	−5.14
Rest of the World	−2.98	−4.58	−6.40	−6.59	−6.97	−7.24
World	−1.65	−3.03	−4.06	−4.33	−5.16	−7.06