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A Parsimonious Approach to Incorporate Firm Heterogeneity in CGE-Models

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This paper proposes a parsimonious and intuitive way to incorporate Melitz-type firm heterogeneity in a CGE-model based on the conventional Armington trade structure. The Armington trade structure is extended with demand, supply, and trade cost shifters. Each sector can be modelled as either Melitz, Ethier-Krugman, or Armington, depending on the specification chosen for the shifters. The trade structure of the model can be calibrated based on two estimable parameters: the trade or tariff elasticity and the shape parameter of the size distribution of firms. With this setup fixed and iceberg trade costs are calibrated jointly based on observed import shares. The structure is incorporated within the standard GTAP model and changes to the GEMPACK code are discussed in detail. Changes in both trade values and welfare are decomposed. Experiments with global reductions in iceberg and fixed trade costs are simulated in a medium-size model with 11 countries, 11 sectors, and 6 production factors. The experiments show that the welfare effects are largest under Melitz, followed by Ethier-Krugman and Armington, although differences are modest.

JEL codes: F12, F14

Keywords: Firm heterogeneity; CGE model; Demand; Supply and Trade cost shifters

1. Introduction

The standard approach to specifying the structure of import demand in CGE models has been with the Armington assumption, featuring constant elasticity of substitution (CES) preferences with love-of-variety for varieties originating from

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(indexed by) different source countries. Although intra-industry trade can be modelled with the Armington assumption, products from each country are homogeneous and usually are produced under perfect competition with this approach, which is unsatisfactory for several reasons. Krugman (1980) and Ethier (1982) explain intra-industry trade in respectively final and intermediate goods combining love-of-variety in preferences, increasing returns to scale in production, and monopolistic competition as market structure. Preferences are characterized by love-of-variety between varieties produced by different firms. Intra-industry trade emerges naturally from the desire of consumers to buy as many different varieties and the benefits of sharing the fixed costs to develop new varieties through international trade in this model. An increase in the amount of inputs leads to a more than proportional increase in utility, because of love-of-variety. The Ethier-Krugman approach itself has been criticized because of the assumption that all firms are identical. Melitz (2003) introduces firm heterogeneity based on the basic Ethier-Krugman approach, modelling productivity at firm level (the inverse of marginal costs) as heterogeneous. The inclusion of firm heterogeneity adds realistic features that map to evidence on links between firm size, firm performance, and productivity. It allows for changes in productivity (new in the Melitz framework) and the number of varieties (already part of the Ethier-Krugman framework). Firm heterogeneity also provides an additional mechanism for welfare effects (gains and losses) from trade, with the reallocation of within-sector market shares between less productive firms producing for domestic markets and more productive exporting firms, and by the reallocation of resources across sectors, which can also then lead to productivity effects linked not only to earlier mechanisms, but also to changes in the collective productivity characteristics of firms in a given sector as resources are shifted between sectors.

In this paper we map out a parsimonious representation of Melitz-type firm heterogeneity with a Pareto productivity distribution enabling incorporation in multi-sector CGE models. In contrast to recent literature, our approach takes advantage of reduced form representations of the basic Melitz model, making for easier numerical implementation and compact analytical representation of the core drivers linked to including Melitz-type model features in a multi-sector, multi-country numerical model. Working with the representations we develop here, we show that both the Ethier-Krugman and the Melitz model can be defined as an Armington model by generalizing the expressions for iceberg trade costs and by including supply and demand shifters (sector level, country indexed externalities in both production and consumption) in the Melitz model. The Ethier-Krugman model also features a supply shifter which is a function of the number of input bundles leading to so-called variety scaling (Francois, 1998; Francois et al., 2013). An increase in the number of input bundles in a sector reduces the average sectoral price and raises effective output. This is driven by the presence of love-of-variety in preferences combined with fixed costs in production.[1]

Like the Ethier-Krugman model, variety scaling also props up in the Melitz model. However, in addition the sector-level externality (the supply shifter), and thus the average sectoral price, is a function of the price of input bundles as well. The reason is that both the extensive and compositional margin are affected by the price of input bundles. With a lower price of input bundles more firms can sell profitably to the different destination markets generating a positive effect through the extensive margin (more varieties) and a negative effect through the compositional margin (lower average productivity because of the survival of the least productive firms as well).[2] For the same reason there is a demand shifter in the Melitz model: in a larger market with a higher price index more firms can survive, raising the beneficial extensive margin but also the harmful compositional margin. Generalized iceberg trade costs are a function of fixed and iceberg trade costs and of tariffs. We show theoretically that the Ethier-Krugman model is a special, limiting case of the Melitz model for the firm size distribution becoming granular. Granularity corresponds with a trade elasticity in Melitz equal to the substitution elasticity minus one. The reason for the nesting is that under granularity the destination-varying component of the extensive margin cancels out against the compositional margin leaving only the intensive margin and the number of entrants-component of the extensive margin, the two channels also operative in Ethier-Krugman.

The trade structure of the firm heterogeneity model is calibrated based on two estimable parameters, the tariff or trade elasticity and the shape parameter of the firm size distribution. These two empirically identifiable parameters determine the substitution elasticity and the shape parameter of the Pareto productivity distribution. Separate values for fixed and iceberg trade costs are not needed within our framework and the two types of trade costs are calibrated jointly based on observed import shares. In the GEMPACK implementation explicit values of trade costs are not needed. Their implicit values serve to set baseline import shares equal to actual shares.

In calibration we also have to deal with well-known problems in solving multisector models with scale effects, the possibility of corner solutions and effects becoming infinitely large because of feedback loops through intermediate linkages. Three approaches have been followed in the literature to address these problems.

[1] As a point of clarification for the reader, underpinning the discussion in this section, and in what follows as we develop our model(s), we keep the constant returns to scale features of GTAP in terms of bundles of inputs (intermediates and value added) used in production. Under constant returns these bundles map directly into output. With increasing returns, fixed costs are specified in terms of bundles at the firm level, as are marginal costs. As such, in both the Ethier-Krugman and Melitz specifications developed here, markups over marginal cost are necessary to cover fixed costs measured in input bundles.

[2] Head and Mayer (2014) introduced the distinction between the intensive, extensive, and compositional margin in the context of the gravity model under international trade.

First, imperfect mobility of production factors (Francois, 2001). Second, nested import demand with a smaller substitution elasticity between imports and domestic goods than between imports from different sources. Both options make the model more convex and thus reduce the probability of corner solutions. Third, adjustment of the data such that intermediate import shares are smoother. As discussed in Costinot and Rodriguez-Clare (2014) the latter option reduces the probability of infinitely large effects. We incorporate the first two options in the code. We prefer to stick to the original GTAP-data in calibrating the model and thus do not adjust intermediate input shares in the data. In the simulation results we stick to a calibration with only imperfect mobility of labor (besides land and natural resources being already imperfectly mobile), as we want to implement a structure with authentic monopolistic competition between firms from different countries. We thus want to work with the same substitution elasticity between varieties of firms produced in all countries, as further motivated in Section 4.

We conduct numerical counterfactual experiments with our model in a medium-sized model with 11 regions, 11 sectors, and 6 factors of production. We run three sets of experiments with reductions in iceberg and fixed trade costs comparing the three trade structures. First, a uniform identical reduction in iceberg trade costs in the different models, and second and third an identical change in a hypothetical dummy variable in the gravity equation implied by the three trade models for the model calibrated to respectively the tariff and trade elasticity. For all three experiments the reduction in iceberg trade costs generates the largest effects in the Melitz model, followed by the Ethier-Krugman and Armington model. However, the differences are relatively modest with the Melitz model displaying maximum 10% larger welfare effects (measured as the change in world equivalent variation) of a 2% reduction in iceberg trade costs than the Armington model. The difference in welfare effects is only about 2% between Melitz and Ethier-Krugman. The welfare decomposition shows that the net contribution of the new margins due to changes in average imported and domestic productivity and imported and domestic number of varieties is relatively modest.

We view our approach as complementary to earlier work in both the CGE- and NQT-literature. Essentially, what we offer here is a hybrid, building on both strands of the literature, In particular, our approach contributes to the existing literature in the following three ways. First, we present a parsimonious and intuitive way to include firm heterogeneity in a CGE-model going along with straightforward estimation of the model parameters. By adding demand, supply, and trade cost shifters to the existing trade structure used in most CGE-models (Armington) we propose an intuitive and flexible way to switch between the different trade structures.[3] Second, with our framework we are able to conduct experiments with

[3] Dixon et al. (2016) and Dixon et al. (2018) also introduce an encompassing model for the three structures, but do not write the Melitz model as an Armington structure with only

the Melitz and Ethier-Krugman structures in a CGE model with intermediate linkages and a large number of countries and sectors. In this paper we present simulations with 11 regions, 11 sectors, and 6 factor of production. Third, we introduce additional features in the model like a decomposition of changes in trade values into three margins, a generalization of the CES utility function to separate the substitution elasticity and the strength of love-of-variety, and a welfare decomposition.

Relative to our companion paper, Bekkers and Francois (2018), we concentrate in this paper on the technical details of the implementation within the GTAP framework, the trade margin decomposition, and the welfare decomposition. We also show how ad valorem equivalents can be calculated and incorporate simulations with changes in policy variables estimated in a gravity model. The other paper identifies the factors generating the largest differences between model outcomes across models. However, the simulation results in the current manuscript also provide many valuable insights. We show that the ranking of models in terms of welfare effects is the same as in previous literature, but the differences are much more modest. This can be explained from the fact that we have implemented literal versions of the different models without extensions such as endogenous factor supply as in Bekkers and Francois (2018) and different input bundles for fixed and variable costs as in Akgul et al. (2016). The trade margin decomposition shows that changes in the extensive and compositional margin are large relative to the total change in trade, whereas the intensive margin is less important than in the Armington and Ethier-Krugman models. The welfare decomposition shows that changes in average importer productivity and number of varieties and changes in domestic productivity and number of varieties are large relative to the total change in welfare. This illustrates numerically the size of the composition effect first identified in the theoretical literature by Melitz (2003).

The paper is organized as follows. Section 2 goes into related literature, comparing our work with other approaches in the literature to incorporate firm heterogeneity in quantitative trade models. Section 3 outlines the theoretical structure and points out how the three different trade structures can be modelled within the existing trade structure in the GTAP model. Section 4 discusses calibration of the model and Section 5 presents the results of counterfactual experiments. Section 6 concludes.

2. Related Literature

Both the new quantitative trade (NQT) literature and the CGE literature have proposed ways to introduce firm heterogeneity in multi-sector multi-country mod-

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demand and supply shifters. They include additional equations in the Melitz structure to solve for example for the number of varieties and the average productivity, following mostly the set of equilibrium equations in Balistreri et al. (2012). A more detailed discussion of the differences with their work is included in the next section.

els, mostly focusing on the question whether firm heterogeneity generates larger welfare effects of different types of trade liberalization. In the CGE-literature variations in method are based on one of four basic approaches to including firm heterogeneity, discussed here in chronological order. Zhai (2008) is the first CGE-implementation of firm heterogeneity. Zhai (2008) follows the Melitz-setup with a Pareto productivity distribution and calibrates the model to GTAP Version 6.2 data with 11 sectors and 12 regions and finds that the welfare effects of tariff liberalization under Melitz are twice as large as under Armington. Crucially, however, Zhai (2008) abstracts from endogenous entry and exit, imposing a fixed number of entrants in each sector. This switches off entry and exit effects.

Second, Balistreri et al. (2012) have included firm heterogeneity in one sector in a CGE model with other sectors characterized by an Armington trade structure working with GAMS. They follow exactly the Melitz-Pareto structure and allow for an endogenous number of entrants. Balistreri et al. (2012) iterate between solving the equilibrium equations of the Melitz-sector and the general equilibrium equations of the entire economy. Employing the same structure, Balistreri et al. (2010) argue that the welfare effects are an order of magnitude larger under firm heterogeneity than under Armington when factor supply is endogenous. Balistreri et al. (2012) structurally estimate the parameters of their model, in particular the fixed export costs. We discuss differences with Balistreri et al. (2012) in terms of calibration in Section 4 on calibration. Britz and Jafari (2017) have implemented the model structure in Balistreri et al. (2012) in the GAMS-version of the GTAP-model, CGEBox, allowing for the Akgul et al. (2016)-feature discussed below that fixed costs bundles use only value added. Britz and Jafari (2017) present an example application of a 50% tariff and export subsidy reduction with a 10x10 aggregation of the GTAP8 database. They find like Balistreri et al. (2012) that welfare effects under Melitz are much larger, a factor four, than under Armington. To prevent corner-solutions they propose a change in intermediate firm demand with firms not demanding domestic intermediate input bundles from their own sector. It is not exactly clear how this is implemented and/or whether this goes along with an adjustment of the baseline data.

Third, Akgul et al. (2016) include firm heterogeneity in the GTAP-model (using GEMPACK) extending the standard model first with variety effects and increasing returns to scale to obtain a model of monopolistic competition (Ethier-Krugman) and then with productivity effects to obtain a model of firm heterogeneity. As such Akgul et al. (2016) also nest Armington, Ethier-Krugman, and Melitz in the GTAP model, although in a different way than we do. Akgul et al. (2016) also include a welfare decomposition, extending the standard decomposition in Huff and Hertel (2000). Akgul et al. (2016) employ a structure where input bundles used in fixed and variable costs are different. In particular, following the approach in Swaminathan and Hertel (1996), they assume that fixed costs only use the factors labor and capital and no intermediates. Akgul et al. (2016) find that the global welfare effects of trade liberalization are a factor 10 larger in their firm heterogeneity model than in the Armington model. As pointed out in Akgul et al. (2016) the assumption of fixed cost bundles consisting only of labor and capital implies that strong scale effects from trade liberalization emerge. Reductions in the price of intermediate inputs as a result of trade liberalization drive down the price of variable costs relative to fixed costs, thus raising the average size of firms. The much larger effects in the Melitz model is, however, also partially the result of another feature of the model, which differs from the Melitz setup, as also observed in Dixon et al. (2018). Akgul et al. (2016) define an average productivity for each exporting country, which determines the average export price, whereas in the Melitz model the average productivity determining the bilateral export price is exporter-importer specific. Hence, in Akgul et al. (2016) the average exporter productivity is not destination specific. This setup in Akgul et al. (2016) reduces the negative compositional effect, as export prices are only indirectly affected by the reduction in average export productivity (through its impact on the average productivity to all destinations) when it becomes cheaper to export in response to for example tariff liberalization. To explore the impact of this feature in Akgul et al. (2016), Dixon et al. (2018) deviate in Appendix 7.3 of their book from their main implementation of the Melitz model. In particular, on the basis of Akgul et al. (2016), they incorporate an exporter-specific cutoff productivity which does not vary by destination country. Phrased differently, the cutoff productivity is only varying by exporter and identical for all destination countries. They find that the welfare effects of a tariff experiment roughly double as a result of this change. As such this feature seems to explain a part of the much larger welfare effects in Akgul et al. (2016). Although the evidence in Dixon et al. (2018) looks convincing on this point, we also observe that they seem to switch off the free entry condition when implementing the model in Akgul et al. (2016). This leads to an incorrect representation of this model, since Akgul et al. (2016) do include a (sector-level) free entry condition.[4] Hence, we conclude by observing that there are various potential explanations for the much larger welfare effects under firm heterogeneity in Akgul et al. (2016), but that it is difficult to identify the exact mechanism.

Fourth, Dixon et al. (2016) propose a way to model the Melitz, Ethier-Krugman, and Armington structure in one encompassing model using GEMPACK. They argue that welfare effects are similar in the three structures if trade elasticities are adjusted such that trade responses to tariff changes are similar. Simulations are presented in a 2 country 2 commodity setting with identical industries and without intermediate linkages in Dixon et al. (2016). Hence, they do not calibrate the model in a complete CGE-structure with intermediate linkages and multiple dif-

[4] Technically, Dixon et al. (2018) endogenize the variable $dcolrevx_{sd,c}$, thus switching off the free entry condition.

ferent sectors to real-world data.[5]

Dixon et al. (2018) extend the work of Dixon et al. (2016) significantly by incorporating the Melitz structure into the standard GTAP model. In their book Dixon et al. (2018) outline the general structure of the Melitz firm heterogeneity model as in Balistreri et al. (2012), address welfare distortions in the Melitz model, outline how the Armington model can be extended to a Melitz model, discuss calibration, and map out how their structure can be incorporated into the GTAP-model. As such Dixon et al. (2018) and our work are significantly related. Nevertheless, there are significant differences between the two approaches in terms of model setup, calibration, and implementation, such that both approaches provide significant and independent contributions to the literature on firm heterogeneity in CGE-models. There are at least three differences within each of these characteristics of the model.

First, our model differs substantially in terms of model setup with at least three differences. First and most important, we work with a demand shifter, supply shifter, and generalized iceberg trade costs to eliminate the bilateral cutoff productivity and numbers of firms from the model and the non-linear zero cutoff profit condition, free entry condition and factor (labor) market equilibrium. Dixon et al. (2018) instead keep all the equilibrium conditions of the Melitz model and by reformulating their model stay still close to the original implementation in Balistreri et al. (2012). By eliminating the non-linear equations from the model and most of the bilateral equations (except for generalized iceberg trade costs), our exposition is computationally more tractable which enables us to solve medium-sized models with Melitz in all sectors without problems.[6] The second model setup difference is in the scope of the model. We nest both Ethier-Krugman and Melitz within the Armington structure of the GTAP-model, whereas in the extension of the GTAP-model Dixon et al. (2018) only nest the Melitz model. As such we are able to pinpoint exactly how the Armington model extends step-by-step to first an Ethier-Krugman model featuring variety effects (destination-generic for each supplying country) and then to a Melitz model featuring also productivity effects and destination-specific variety effects. Furthermore, our model allows for nested Armington preferences with a different (lower) substitution elasticity between domestic and imported varieties than between imports from different exporters and also firms in the monopolistic competition versions of the model, as in Feenstra et al. (2018) and Caliendo et al. (2015). Finally, we allow for a generalized way to model the strength of love of variety as in Jung (2015) and Felbermayr and Jung (2015) determined by a separate parameter distinct from the substitution elasticity.

[5] Itakura and Oyamada (2013) and Oyamada (2015) implement the Dixon et al. (2016) code in a calibrated model, but do not seem to move beyond a small number of countries and sectors and assume like Balistreri et al. (2012) only firm heterogeneity in one of the sectors.

[6] In larger models with more sectors, corner solutions start to play a role with values in small sectors tending to zero or even negative. How we deal with these problems is discussed into detail in Section 4.

The third difference in model setup relates to the welfare decomposition. We extend the existing welfare decomposition of the GTAP model as presented in Huff and Hertel (2000), whereas Dixon et al. (2018) set up their own decomposition focusing on the role of inter-sectoral reallocation of resources. We add productivity and variety terms to the existing welfare decomposition, aligning with the intuition on which additional effects Melitz and Ethier-Krugman introduce.

A second set of differences lies in the calibration of baseline and parameters. Like Dixon et al. (2018) we eliminate the shares spent on fixed costs and entry costs in baseline calibration and hence don't need baseline values for these shares. How this approach compares with the earlier approach in Balistreri et al. (2012) is explained very clearly in Chapter 4 of Dixon et al. (2018). As a first difference in calibration, we go one step further as we calibrate the model without baseline values for domestic and exporting cutoff productivity[7] by eliminating the cutoff productivities writing them as functions of other endogenous variables and parameters as further explained into detail below. Second, we calibrate the structural parameters, the substitution elasticity and the shape parameters of the productivity distribution to empirically estimable parameters, the trade or tariff elasticity and the shape parameter of firm size distribution. whereas Dixon et al. (2018) take values from the literature for the substitution elasticity and the firm productivity shape parameter. Third, when comparing the different trade structures (Armington, Ethier-Krugman, and Melitz), we impose that the empirically estimable parameters of the model (based on a gravity equation structurally derived directly from the model) are identical in the two models, whereas Dixon et al. (2018) calibrate the model to the structural parameters and discuss the idea (in Chapter 6) that the substitution elasticity in the Armington and Melitz model should be such that the sensitivity of trade to tariffs is equivalent. This position is taken more explicitly in Dixon et al. (2016). We instead contend that the empirically estimable parameters in the different models, in particular the trade or tariff elasticity, should be identical, with implied differences in the structural elasticities of the model.

A third set of differences with Dixon et al. (2018) concerns the implementation of the Melitz firm heterogeneity model. A first difference in this regard is that we present simulations with a Melitz trade structure in all (eleven) sectors, whereas Dixon et al. (2018) present results with Melitz present in only one (of the 57) sectors. Although this generates interesting results on the importance for welfare of sectoral reallocation of resources towards sectors with variety and scale effects, these results have been discussed at length in the new economic geography literature and also in Arkolakis et al. (2012). Balistreri et al. (2010) make a similar point based on the same mechanism, i.e. that welfare effects in a monopolistic competition model with scale and variety effects are much larger than in a model with perfect competition if factor supply can be increased in sectors with a monopolistic competition struc-

[7] The cutoff productivity is called minimum productivity in Dixon et al. (2018).

ture. In Dixon et al. (2018) this is about intersectoral reallocation of factor supply, whereas in Balistreri et al. (2010) it is about total factor supply. Our work instead incorporates a Melitz structure in an arbitrary number of sectors in medium-sized models without computational problems as a result of our parsimonious structure. Second and related to the previous point, we propose different ways to address computational problems and avoid corner solutions by convexifying the model both with imperfect mobility of labor and nested trade preferences. We also discuss the merits of other options in the literature. Third, we present a decomposition of trade values into the intensive, extensive, and compositional margin in response to different types of trade cost shocks.

In the NQT literature, two papers are particularly related to our work. First, Costinot and Rodriguez-Clare (2014) also nest the Armington, Ethier-Krugman, and Melitz trade structures in one framework and examine the different welfare effects of trade and changes in tariffs. Their approach differs from ours in the way they create the nesting of the different models and in the distinction between the different margins. We work with an intensive, extensive, and compositional margin, whereas Costinot and Rodriguez-Clare (2014) introduce an intensive, selection, and entry extensive margin. Furthermore, we show that the Melitz model approaches the Ethier-Krugman model when the firm size distribution becomes granular. Second, Caliendo et al. (2015) explore the effects of tariff liberalization in the Melitz model in a setting with 189 countries and 15 sectors, focusing on the additional welfare effects of the entry of firms. Both quantitative trade models feature multiple sectors and intermediate linkages (and Costinot and Rodriguez-Clare (2014) also multiple production factors), but omit capital accumulation, different final users, and non-homothetic preferences as in CGE models.[8] Also, they do not consider changes in fixed or iceberg trade costs, focusing instead on the effects of tariffs and on comparing trade with autarky.

3. Model

We start with the standard static GTAP model. To model the Armington, Ethier-Krugman, and Melitz model in one structure we add three components to the equations for international trade in the GTAP model: a demand shifter, a supply shifter, and a trade cost shifter (also called generalized iceberg trade costs). Depending on the specification of these three components, we can nest the three models within a single structure. The first subsection discusses how the existing trade equations are modified by including the supply and demand shifters. Then we present the expressions for the demand, supply, and trade cost shifters in the three models. After that we discuss the parameters added to the parameter file to capture the

[8] Also, this literature typically abstracts from a transport sector and assumes that consumers and firms demand the same bundle of goods from each sector, thus imposing that import and domestic shares are identical for these different groups.

three models with one code. The parameters are used to calibrate the different models, but also to determine the shift between the different market structures per sector. We continue by outlining in detail the blocks added to the GEMPACK code to model the shifters, in turn the supply shifter, the demand shifter, and the trade cost shifter. We finish this section describing how two decompositions are modelled, first the decomposition of the value of trade into intensive, extensive, and compositional margin and second the extensions to the welfare decomposition in the GTAP model. Equivalence between our exposition of the Melitz model with demand, supply and trade cost shifters and the original Melitz model is outlined in Appendix C in a basic two-country model, both for expositional purposes and to show equivalence between the two approaches with numerical simulations.

3.1 Modifying International Trade in the GTAP Model

In the standard GTAP there are four types of agents (or end users) in country s : private households with superscript pr, government with superscript go, investors with superscript in, and firms from sector j with superscript fi_j. We assume the reader is familiar with the structure of the GTAP model.[9] Each of the agents divide their demand in sector i, q_{is}^{ag}, into domestic demand, $q_{is}^{d,ag}$, and import demand, $q_{is}^{m,ag}$, according to a CES utility function with substitution elasticity ρ:

$$q_{is}^{ag} = \left(\left(q_{is}^{d,ag} \right)^{\frac{\rho_i - 1}{\rho_i}} + \left(q_{is}^{m,ag} \right)^{\frac{\rho_i - 1}{\rho_i}} \right)^{\frac{\rho_i}{\rho_i - 1}} \tag{1}$$

Total import demand, q_{is}^{m}, consists of the sum over the four groups of agents, $q_{is}^{m} = \sum_{ag} q_{is}^{m,ag}$, and is in turn allocated across demand from the different sourcing countries, q_{irs}, according to a CES utility function, featuring a demand-shifter, e_s^m:

$$q_{is}^{m} = e_{is}^{m} \left(\sum_{r=1}^{S} \left(q_{irs} \right)^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{\frac{\sigma_i}{\sigma_i - 1}} \tag{2}$$

The demand shifter e_{is}^{m} will differ from 1 in the Melitz model. Import demand can be written as follows:

$$q_{irs} = \left(e_{is}^{m} \right)^{\sigma_i - 1} \left(\frac{p_{irs}}{p_{is}^{m}} \right)^{-\sigma_i} q_{is}^{m} = \left(e_{is}^{m} \right)^{\sigma_i - 1} \left(\frac{\frac{t_{irs} ta_{irs} p_{irs}^{cif}}{c_{ir}^{m}}}{p_{is}^{m}} \right)^{-\sigma_i} q_{is}^{m} \tag{3}$$

[9] We refer to for example Hertel (1997), Corong et al. (2017), and Bekkers et al. (2018) for a description of the general structure of the GTAP-model. We describe here only the parts of the model that are changed by extending the model with monopolistic competition and firm heterogeneity.

t_{irs} are the (generalized) iceberg trade costs, c^m_{ir} is a supply shifter, p^{cif}_{irs} is the cif-price, exclusive of the iceberg trade costs, and ta_{irs} are the bilateral tariffs. p_{irs} is the price of q_{irs}, hence the cif-price inclusive of tariffs, iceberg trade costs and a supply shifter. p^m_{is} is the price index of total import demand, q^m_{is}, and defined as:

$$p^m_{is} = \left(\sum_{r=1}^{S} \left(\frac{t_{irs} ta_{irs} p^{cif}_{irs}}{c^m_{ir} e^m_{is}} \right)^{1-\sigma_i} \right)^{\frac{1}{1-\sigma_i}} \tag{4}$$

Hat differentiating equation (3) generates the corresponding expression in the GTAP code. As in the standard code we need the quantity in physical units (to be used in the calculation of tax revenues) and therefore multiply the quantity q_{irs} by iceberg trade costs, t_{irs}, and divide by the supply shifter, c^m_{ir}. In GEMPACK notation we get:

```
Equation IMPORTDEMAND
# regional demand for disaggregated imported commodities by source #
(all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
qxs(i,r,s) = - ams(i,r,s) - sshiftx(i,r) - dshiftm(i,s) + qim(i,s) - ESUBM(i)
          * [pms(i,r,s) - ams(i,r,s) - sshiftx(i,r) - dshiftm(i,s) - pim(i,s)];
```

ams(i,r,s) is formally the technology shifter in international trade, and defined as minus the relative change in iceberg trade costs. We will endogenize the expression for *ams(i,r,s)* in the Melitz version of the model. *sshiftx(i,r)* is the supply shifter, $\widehat{c^m_{ir}}$, and *dshiftm(i,s)* is the demand shifter, $\widehat{e^m_{is}}$. *pms(i,r,s)* is the landed price, i.e. the cif-price inclusive of tariffs, $\widehat{ta_{irs} p^{cif}_{irs}}$. Variables with a hat indicate relative or percentage changes. Hence, compared to the standard code, our equation for import demand is extended with both a demand- and supply-shifter.

Equation (4) corresponds with the expression for the price of imports in the code:

```
Equation DPRICEIMP
# price for aggregate imports #
(all,i,TRAD_COMM)(all,s,REG)
pim(i,s) = sum(k,REG, MSHRS(i,k,s) * [pms(i,k,s) - ams(i,k,s) -
             sshiftx(i,k) - dshiftm(i,s)]);
```

MSHRS(i,k,s) is the importer market share from exporter region k in importer region s. Hence this expression is also extended with a supply shifter c^m_{ir} and a demand shifter e^m_{is} compared to the standard code.

$q^{d,ag}_{is}$ also features a demand shifter and domestic demand, $q^{d,ag}_{iss}$, is given by $q^{d,ag}_{is} = e^d_{is} q^{d,ag}_{iss}$. We can thus express $q^{d,ag}_{iss}$ as follows:[10]

[10] $q^{d,ag}_{iss}$ is the domestic equivalent of q_{irs} and therefore we can write $q^{d,ag}_{is} = e^d_{is} q^{d,ag}_{iss}$. Utility maximization leads to $q^{d,ag}_{is} = \left(\frac{p^{d,ag}_{is}}{p^{ag}_{is}} \right) q^{ag}_{is}$, which implies in turn equation (5) by using

$$q_{iss}^{d,ag} = \left(e_{is}^{d}\right)^{\rho-1}\left(\frac{p_{iss}^{d,ag}}{p_{is}^{ag}}\right)^{-\rho_i} q_{is}^{ag} = \left(e_{s}^{d}\right)^{\rho_i-1}\left(\frac{\frac{ta_{is}^{d,ag}tp_{is}p_{is}^{ib}}{c_{is}^{d}}}{p_{is}^{ag}}\right)^{-\rho_i} q_{is}^{ag} \tag{5}$$

p_{is}^{ib} is the domestic production price or the price of input bundles, c_{is}^{d} is the domestic supply shifter, $ta_{is}^{d,ag}$ and tp_{is} are respectively the group specific import tariffs and the production taxes, and p_{is}^{ag} is the price index corresponding with aggregate sectoral demand of group ag, q_{is}^{ag}, and defined as:

$$p_{is}^{ag} = \left(\left(\frac{ta_{is}^{d,ag}tp_{is}p_{is}^{ib}}{e_{is}^{d}c_{is}^{d}}\right)^{1-\rho_i} + \left(ta_{is}^{m,ag}p_{is}^{m}\right)^{1-\rho_i}\right)^{\frac{1}{1-\rho_i}} \tag{6}$$

Since the demand and supply shifters are already part of p_{is}^{m} they only appear in the domestic price part.

Hat differentiating the expression for domestic demand in (5) leads to the following expression in GEMPACK notation:

```
Equation GHHLDDOM
# government consumption demand for domestic goods #
(all,i,TRAD_COMM)(all,s,REG)}
qgd(i,s) = - dshiftd(i,s) - sshiftd(i,s) + qg(i,s)
         - ESUBD(i) * [pgd(i,s) - dshiftd(i,s) - sshiftd(i,s) - pg(i,s)];
```

Equation (5) holds for all four groups of agents, $ag = go, pr, fi$ and here we have only displayed the expression for government demand, *qgd(i,s)*. The expressions for *qpd(i,s)* and *qfd(i,j,s)* are equivalent. As in the expression for import demand we have divided domestic government demand, $q_{is}^{d,go}$, by the supply shifter, c_{is}^{d}, to get the quantity in physical units. *pgd(i,s)* is the domestic price inclusive of the government-specific import tariff, corresponding with $\widehat{ta_{is}^{d,go}tp_{is}p_{is}^{ib}}$. *pg(i,s)* corresponds with $\widehat{pg_{is}^{go}}$. *dshiftd(i,s)* and *sshiftd(i,s)* are the domestic demand and supply shifters, respectively $\widehat{e_{is}^{d}}$ and $\widehat{c_{is}^{d}}$.

Hat differentiating the price index for group ag in equation (6) generates for $ag = go$ in GEMPACK-notation (with *GMSHR(i,s)* the share spent on imported goods):

```
Equation GCOMPRICE
# government consumption price for composite commodities #
(all,i,TRAD_COMM)(all,s,REG)
pg(i,s) = GMSHR(i,s) * (pgm(i,s)) + [1 - GMSHR(i,s)] * (pgd(i,s)
        - dshiftd(i,s) - sshiftd(i,s));
```

$q_{is}^{d,ag} = e_{is}^{d}q_{iss}^{d,ag}$ and $p_{is}^{d,ag} = \frac{p_{iss}^{d,ag}}{e_{is}^{d}}$.

3.2 Modelling Armington, Ethier-Krugman, and Melitz

This subsection presents the three trade structures and the theoretical expressions for the demand, supply, and trade cost shifters. The implementation in the code is presented in the next subsections. Formal derivations of expressions for the different shifters can be found in Appendix A.

3.2.1 Armington

The Armington model is the default trade structure in the standard GTAP model. Goods are differentiated by country of origin and all goods produced by the same country are homogeneous. This means that all goods from country r imported by country s have the same price as modelled in the previous subsection with the demand and supply shifters, e_{is} and c_{ir}, equal to one (and the corresponding variables in the code in relative changes equal to zero). The trade cost shifter, t_{irs}, is equal to plain iceberg trade costs, τ_{irs}. To model iceberg trade costs explicitly in the code, we include the variable *itc(i,r,s)* with *ams(i,r,s)=-itc(i,r,s)* in the Armington world.

3.3 Ethier-Krugman

The Ethier-Krugman model combines love-of-variety in consumption, increasing returns in production, and monopolistic competition as market structure. Utility of agent ag in country s is a CES aggregate over the different varieties $\omega \in \Omega_{irs}$ produced in r and consumed in s. The dual price index can be written as an aggregate over the price of the varieties, $p^o(\omega)$:

$$\left(p_{is}^{ag}\right)^{1-\rho_i} = \left(M_{is}^{\nu_i - 1} \sum_{r=1}^{S} \int_{\omega \in \Omega_{irs}} p^{ag,o}(\omega)^{1-\sigma_i} d\omega\right)^{\frac{1-\rho_i}{1-\sigma_i}} + \left(M_{is}^{\nu_i - 1} \int_{\omega \in \Omega_{is}^{d}} p^{ag,o}(\omega)^{1-\sigma_i} d\omega\right)^{\frac{1-\rho_i}{1-\sigma_i}} \tag{7}$$

p_{is}^{ag} could be price index of private household and government consumption or of intermediate input demand of one of the sectors, both featuring love-of-variety. Krugman (1980) focused on trade in final goods, whereas Ethier (1982) emphasized trade in intermediates. Since the GTAP model features both final goods and intermediates, we talk about the Ethier-Krugman model.

To separate the strength of love of variety from the substitution elasticity, we include the term M_{is} in the utility function as in Benassy (1996), Ardelean (2007), Jung (2015), and Felbermayr and Jung (2015). M_{is} is destination-specific and equal to the number consumed varieties in country s, equal to the sum of domestic and imported varieties. With $\nu_i = 1$ the utility function collapses to the standard CES and a smaller ν_i weakens the strength of love-of-variety.[11]

Firms produce under increasing returns to scale with identical fixed cost a_{ir} and marginal costs b_{ir}. Combining increasing returns to scale in production with love-of-variety preferences implies that an increase in the number of input bundles used in production leads to a more than proportional increase in utility, since more varieties can be produced. Phrased differently marginal costs at the aggregate level (for the entire sector) fall in the number of input bundles. This can be modelled by a supply shifter c_{ir}^{so} (with $so = d, m$) falling in the number of input bundles. Combining markup pricing, free entry, and factor market equilibrium generates the following expression for c_{ir} (with $\gamma_{ek,i}$ a function of σ_i):

$$c_{ir}^{so} = \gamma_{ek,i} \left(\frac{\widetilde{q_{ir}^{ib}}}{a_{ir}} \right)^{\frac{1}{\sigma_i - 1}} \tag{8}$$

$\widetilde{q_{ir}^{ib}}$ is nearly proportional to the number of input bundles, q_{ir}^{ib}.[12] So the supply shifter rises with the number of input bundles relative to fixed costs. More input bundles relative to fixed costs implies that more varieties can be produced and given the love of variety in both consumption and production (for intermediates) this leads to a more than proportional increase in variety-scaled output.[13]

Due to the presence of a transport sector we cannot write the number of varieties from country r, N_{ir}, exactly as a function of the number input bundles, q_{ir}^{ib}, and we have to subtract a term which is a function of the amount of transport services

---

[11] In particular, with $\nu_i = 0$ love of variety would disappear. The cited literature argues that the strength of love of variety should be separately determined from the ease with which varieties are substituted. Empirical work by Ardelean (2007) suggests that the strength of love of variety is smaller than what is implied by the standard CES utility function. We follow the specification in Felbermayr and Jung (2015) with the strength of the love of variety being destination specific.

[12] Equation (8) is derived in Appendix A.1.

[13] Marginal costs do not play a role in the supply shifter, since they affect the cost of production directly and in the same way as in the Armington model.

paid:[14]

$$\widetilde{q_{ir}^{ib}} = q_{ir}^{ib} - \frac{\sigma_i - 1}{\sigma_i} \left(\sum_{s=1}^{S} \frac{N_{ir}\overline{r}_{irs}}{tp_{ir}p_{ir}^{ib}ta_{irs}\left(te_{irs} + \frac{p_{irs}^{ts}}{tp_{ir}p_{ir}^{ib}a_{irs}^{ts}}\right)} - \frac{N_{ir}\overline{r}_{irs}}{tp_{ir}p_{ir}^{ib}ta_{irs}} \right) \tag{9}$$

$\overline{r}_{irs}$ are the per-firm revenues net of the group-specific import tariffs. As discussed below, inclusion of the additional term on the RHS of equation (9) has only a marginal effect on the simulation results.

To capture the additional love-of-variety term, M_{is}, the demand-shifter e_{is}^{so} is written as a function of the number of input bundles from all trading partners:

$$e_{is}^{so} = \left(\sum_{r=1}^{S} \frac{\widetilde{q_{ir}^{ib}}}{a_{ir}} \right)^{\frac{\nu_i - 1}{\sigma_i - 1}} \tag{10}$$

Since fixed costs are not destination-specific, varieties are shipped to all trading partners. Therefore, the number of varieties in the Ethier-Krugman model does not vary by destination country and the expression on the RHS in equation (10) does not vary by country. Therefore, this term could also have been included in the supply-shifter. Putting this term in the demand-shifter makes it easier to switch between the Ethier-Krugman and the Melitz model, as in the Melitz model the additional love-of-variety term varies by country as a result of destination-specific fixed trade costs. The absence of destination-specific fixed costs also implies that the trade cost shifter, t_{irs}, is equal to iceberg trade costs, τ_{irs}.

3.4 Melitz

Demand under Melitz is like under Ethier-Krugman described by equation (7) with love-of-variety between varieties produced by different firms. The cost function is also identical, except for the fact that marginal costs, or its inverse productivity, φ, is heterogeneous across firms. Firms get to know their productivity upon paying sunk entry costs, en_{ir}, by drawing from a known distribution $G_{ir}(\varphi)$. We work with a Pareto distribution with shape parameter θ_i and size parameter κ_{ir}:

$$G_{ir}(\varphi) = 1 - \frac{\kappa_{ir}^{\theta_i}}{\varphi^{\theta_i}} \tag{11}$$

[14] N_{ir} follows from the free entry condition together with factor market equilibrium. Because separate input bundles are used to produce transport services, employed in each sector, we have to subtract the demand for these bundles to calculate demand for input bundles from a specific sector in a specific country. The result is that for given zero-profit-revenues higher transport costs generate less labor demand. The implication is that a higher sharer of transport costs implies that an increase in the number of input bundles has a bigger impact on the number of varieties.

Firms are subject to a fixed death probability δ and there is a steady state of entry and exit with the mass of entering and exiting firms identical.[15] Firms producing in country r and selling in country s pay both iceberg trade costs τ_{irs} and fixed export costs f_{irs}. For technical reasons we assume that the productivity level φ applies both to production and transportation costs, implying that more productive firms also require less transport services. Without this assumption the model would become intractable. Fixed costs are paid in input bundles of the exporting country. In our setting with multiple end users, importing country specific input bundles for fixed costs would lead to ambiguity as to which input bundles should be used and therefore we stick to the assumption that fixed costs are paid in terms of exporting country bundles.

To determine the equilibrium price index we can impose an ex post zero cutoff profit condition (after firms know their productivity), an ex ante free entry condition (before drawing productivity), and factor market equilibrium. Like in the Ethier-Krugman model the combination of love-of-variety preferences with increasing returns to scale in production implies that marginal costs at the sectoral level fall with the number of input bundles, modelled by the supply shifter rising in the number of input bundles. However, sectoral marginal costs are now also affected by the price of input bundles. To make this clear we use the decomposition of changes in trade in Head and Mayer (2014) into an intensive margin, extensive margin, and compositional margin. An increase in the price of input bundles reduces trade along the intensive margin as in the Armington and Ethier-Krugman model, so is captured by the impact of p_{irs}^{cif} and p_{ir}^{ib} for respectively importer and domestic demand in equations (3) and (5). However, in the Melitz model there are two additional effects. Higher priced input bundles reduce the number of firms exporting, the extensive margin effect. As a result sectoral exports fall. This occurs because input bundles used in both marginal costs and fixed export costs are more expensive. But higher priced input bundles also imply that less productive firms cannot export anymore, the compositional margin effect. And as a result exports rise again. On net the extensive margin dominates the compositional margin. The extensive and compositional margin effects are captured by the impact of the price of input bundles on the supply shifter, as specified in the following equations (with $\gamma_{m,i}$ a function of σ_i and θ_i):

[15] The number of entrants is constant in the absence of shocks. In case of shocks to exogenous variables or parameters, such as to the number of workers or iceberg trade costs, the number of entrants will change.

$$c^{m}_{ir} = \gamma_{m,i} \left(\frac{\kappa^{\theta_i}_{ir} \widetilde{q^{ib}_{ir}}}{\delta en_{ir}} \right)^{\frac{1}{\sigma_i - 1}} \left(tp_{ir} p^{ib}_{ir} \right)^{-\frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}} \tag{12}$$

$$c^{d}_{ir} = \gamma_{m,i} \left(\frac{\kappa^{\theta_i}_{ir} \widetilde{q^{ib}_{ir}}}{\delta en_{ir}} \right)^{\frac{1}{\sigma_i - 1}} \left(tp_{ir} p^{ib}_{ir} \right)^{-\frac{\sigma_i (\theta_i - \sigma_i + 1)}{(\sigma_i - 1)^2}} \tag{13}$$

$\widetilde{q^{ib}_{ir}}$ is defined as in the Ethier-Krugman model in equation (9). The coefficient p^{ib}_{ir} differs for the domestic and import supply shifter. The reason is that the coefficient on p^{ib}_{ir} in the domestic supply shifter captures the impact on the extensive relative to the compositional margin through the price of bundles used in both marginal and fixed costs, whereas the coefficient on p^{ib}_{ir} in the import supply shifter only captures the impact through the price of bundles used in fixed costs. The impact through marginal costs of the extensive relative to the compositional margin adjustment will be captured in the trade cost shifter.

The trade cost shifter is also affected by the three margins of adjustment and is given by the following expression:

$$t_{irs} = \left(\left(p^{cif}_{irs} \right)^{\frac{\theta_i - \sigma_i + 1}{\sigma_i - 1}} \tau_{irs}^{\frac{\theta_i - \sigma_i + 1}{\sigma_i - 1}} ta_{irs}^{\frac{\theta_i - \sigma_i + 1}{\sigma_i - 1} + \frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}} f_{irs}^{\frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}} \right) \tau_{irs} \tag{14}$$

The last term outside of the brackets represents the impact of iceberg trade costs on the intensive margin, like in the other two models. In the Melitz model, iceberg trade costs also have an impact through the extensive and compositional margin, corresponding with the second term within brackets. For the same reason the cif-price, p^{cif}_{irs}, bilateral tariffs, ta_{is}, the fixed costs, f_{irs}, also appears between brackets. We see that larger iceberg and fixed trade costs raise generalized trade costs, t_{irs}, if $\theta_i > \sigma_i - 1$, corresponding with the extensive margin effect dominating the compositional margin effect, as will be discussed further in the subsection on trade margin decomposition.

The demand-side shifter in the Melitz model is also driven by the strength of the extensive margin relative to the compositional margin. In a market with a large effective market size (larger price indices p^{ag}_{is} and p^{so}_{is} and larger expenditures E^{ag}_{is}) more firms can profitably sell, so both the extensive margin and the compositional margin are larger. The demand shifter for source $so = d, m$ is thus defined as:

$$e^{so}_{is} = M_{is}^{\frac{\nu_i - 1}{\sigma_i - 1}} \left(\sum_{ag} M_{is}^{\nu_i - 1} \left(\frac{p^{ag}_{is}}{ta^{so,ag}_{is} p^{so}_{is}} \right)^{\rho_i - 1} \frac{\left(p^{so}_{is} \right)^{\sigma_i - 1} E^{ag}_{is}}{ta^{so,ag}_{is}} \right)^{\frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}} \tag{15}$$

M_{is} is equal to the sum of the number of varieties from all sourcing countries and

Table 1. Parameterization of the four models

Name		**Min**	**Max**	**Use**	**ARM**	**ETK**	**MEL**
$VARS$		0	1	Variety scaling	0	1	1
ETK		0	1	Ethier-Krugman	0	1	0
$GRAN$	ξ	0	1	Granularity	1	1	< 1
$ETIL$	$\varepsilon^{v,ta}$	$-$	$-$	Tariff elasticity			
$ETRA$	$\varepsilon^{v,\tau}$	$-$	$-$	Trade elasticity			
$CATA$		0	1	Dummy to switch between $\varepsilon^{v,ta}$ and $\varepsilon^{v,\tau}$			
$PRSD$	υ	1	$-$	Ratio σ and ρ			
NU	ν	0	1	Love-of-variety			

Notes: The parameter names ar further defined in the main text.

Source: Authors own elaboration of parsimonious firm heterogeneity model.

defined in Appendix B. There is only one demand-shifter for the different groups of agents ag. The reason is that exporter fixed costs are not agent specific. Upon paying the fixed costs to sell in destination market s, we assume that they are able to sell to all end users. So, the effective market size determining how many firms are able to sell in the market consists of the sum of demands by the different groups of agents.

3.5 New Parameters in the Model

We add the eight parameters in Table 1 to the parameter file, which are all sector-specific. These parameters are used to switch between the different models and parameterize the model, using empirically observable parameters. Some of the behavioral parameters employed in the code are functions of these parameters. We have decided to switch between models through changes in the parameter file instead of closure swaps in the command file. Although there are only a small number of additions to the core code, the trade and welfare decompositions imply quite a large number of equations that are model-dependent, thus implying quite a large number of swaps. Working with parameter values to switch between models is therefore easier. Since the same equations would apply for the three different models if we would switch between the models using closure swaps instead of changes in the parameter file, we would get the same results.

Before introducing the parameters, we first observe that if the granularity parameter $\xi_i = \frac{\sigma_i - 1}{\theta_i}$ would go to 1 the model would approach so-called full granularity with $\theta_i = \sigma_i - 1$. Under full granularity the Melitz model collapses to the Ethier-Krugman model. However, full granularity is a limiting case of the Melitz model, since average firm sales and other aggregates would not be defined anymore. In turn switching off variety scaling the two monopolistic competition models fall back to Armington. The first three parameters in Table 1 enable us to switch between the different models, and the last six parameters (from $GRAN$ to NU) determine the parameterization of the model:

1) The parameter $VARS\,(i)$ determines whether there is variety-scaling with $VARS\,(i) = 1$ corresponding with variety scaling. Hence, in both the Ethier-Krugman and the Melitz model this parameter is equal to 1 and in the Armington model it is equal to 0.
2) $ETK\,(i)$ is a dummy variable indicating that the sector is Ethier-Krugman. We need this dummy variable for the model with the love-of-variety term, M_{is}, and for the trade decomposition. Equivalence between Melitz under granularity and Ethier-Krugman breaks down in this case. Moreover, the decomposition of the value of trade into intensive, extensive, and compositional margin is not identical under Melitz approaching granularity and under Ethier-Krugman.
3) $GRAN\,(i)$ is the degree of granularity introduced in equation (18). To model a sector as either Armington or Ethier-Krugman, $GRAN\,(i)$ should be set equal to 1.
4) $ETIL\,(i)$ is the estimated tariff elasticity, the elasticity of the value of trade with respect to the power of the tariff.
5) $ETRADE\,(i)$ is the estimated trade elasticity, the elasticity of the value of trade with respect to iceberg trade costs.
6) $CATA\,(i)$ is a dummy variable indicating whether the model is calibrated to the tariff elasticity ($CATA\,(i) = 1$) or to the trade elasticity ($CATA\,(i) = 0$).
7) $PRSD\,(i)$ is measure for the degree of nestedness of preferences equal to $ESUBM\,(i)\,/ESUBD\,(i)$. The lower-nest substitution elasticity between varieties from different sourcing countries, $ESUBM\,(i)$, is determined by the estimated tariff or trade elasticity and the degree of granularity. Hence, $PRSD\,(i)$ determines ρ_i ($ESUBD\,(i)$) and a larger $PRSD\,(i)$ corresponds with a smaller upper-nest elasticity ρ_i (between domestic and imported varieties).
8) $NU\,(i)$ determines the strength of love of variety. $\nu_i = 1$ corresponds with normal CES preferences and $\nu_i = 0$ completely switches off love of variety.

Four behavioral parameters in the code are affected by the parameters in 1. In the Armington and Ethier-Krugman model we need values for the substitution elasticities parameters, σ_i and ρ_i, and the love of variety parameter, ν_i. In the Melitz model we also need values for the shape parameter, θ_i. These parameters correspond in the code respectively with *ESUBM(i)*, *ESUBD(i)*, *NU(i)*, and *THETA(i).* From the empirics we have estimates for the tariff elasticity $\varepsilon_i^{v,ta}$ or the trade elasticity $\varepsilon_i^{v,\tau}$ and the degree of granularity ξ_i, defined in the Melitz model as:[16]

[16] The tariff elasticity is derived in Subsection 4.1.

$$\varepsilon_i^{v,ta} = \theta_i + 1 + \frac{\theta_i - \sigma_i + 1}{\sigma_i - 1} \quad (16)$$

$$\varepsilon_i^{v,\tau} = \theta_i \quad (17)$$

$$\xi_i = \frac{\sigma_i - 1}{\theta_i} \quad (18)$$

We can thus express θ_i and σ_i as a function of $\varepsilon_i^{v,ta}$ and ξ_i as follows if we calibrate to the tariff elasticity:

$$\sigma_i = \xi_i * \varepsilon_i^{v,ta} \quad (19)$$

$$\theta_i = \varepsilon_i^{v,ta} - \frac{1}{\xi_i} \quad (20)$$

In the Armington and Ethier-Krugman model the tariff elasticity $\varepsilon_i^{v,ta}$ is equal to the substitution elasticity σ_i with $\xi_i = 1$.

If we calibrate to the trade elasticity, we get:

$$\sigma_i = \xi \varepsilon_i^{v,\tau} + 1 \quad (21)$$

$$\theta_i = \varepsilon_i^{v,\tau} \quad (22)$$

In the Armington and Ethier-Krugman model the trade elasticity $\varepsilon_i^{v,\tau}$ is equal to $\sigma_i - 1$. We allow for calibration to both the trade and tariff elasticity, since some researchers have estimated tariff elasticities and others might have estimated trade elasticities.

In the non-nested version of the model $\rho_i = \sigma_i$ and in the nested version $\rho_i < \sigma_i$. As discussed below, we work with the non-nested version of the model, but allow also for the nested version in the code, which is implemented for example in Feenstra et al. (2018). Dixon et al. (2018) also incorporate the Melitz structure in the existing nested preference structure of the GTAP model, but strictly impose $\rho_i = \sigma_i$. In Akgul et al. (2016) imports are sourced directly to GTAP agents, which corresponds also with a non-nested structure. Note that Francois (1998) also employs $\rho_i = \sigma_i$ and $\rho_i < \sigma_i$ versions of Ethier-Krugman monopolistic competition, while Harrison et al. (1997) employ a nested version of Ethier-Krugman monopolistic competition.

The love of variety parameter ν_i governs the strength of love of variety. We summarize the relation between the parameters appearing in the code and the parameters of the parameter file for calibration to the tariff elasticity in Table 2. The table shows the values for *ESUBM(i)*, *ESUBD(i)*, *NU(i)*, and *THETA(i)* implied by the values set in the parameter file.

Table 2. Parameterization of the four models

Name		Meaning	ARM	ETK	MEL
$THETA$	θ	Shape parameter Pareto distribution	–	–	$\varepsilon_{v,ta} - \frac{1}{\zeta}$
$ESUBM$	σ	Substitution elasticity between imports	$\varepsilon^{v,ta}$	$\varepsilon^{v,ta}$	$\zeta * \varepsilon^{v,ta}$
$ESUBD$	ρ	Subst. elasticity imports/domestic	$\varepsilon^{v,ta}/v$	$\varepsilon^{v,ta}/v$	$\zeta * \varepsilon^{v,ta}/v$
NU	ν	Strength love-of-variety	ν	ν	ν

Source: Authors own elaboration of parsimonious firm heterogeneity model.

3.6 Supply Shifter

The supply-side shifter in the Ethier-Krugman and Melitz model can be gathered by log differentiating respectively equations (8) and (12)-(13):

$$\widehat{c_{ir}^{so}} = -\frac{1}{\sigma_i - 1}\widehat{q_{ir}^{ib}} \tag{23}$$

$$\widehat{c_{ir}^{m}} = -\frac{1}{\sigma_i - 1}\widehat{q_{ir}^{ib}} + \frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}\widehat{tp_{ir}p_{ir}^{ib}} \tag{24}$$

$$\widehat{c_{ir}^{d}} = -\frac{1}{\sigma_i - 1}\widehat{q_{ir}^{ib}} + \frac{\sigma_i(\theta_i - \sigma_i + 1)}{(\sigma_i - 1)^2}\widehat{tp_{ir}p_{ir}^{ib}} \tag{25}$$

As mentioned in Appendix 3.3, the love-of-variety term in the Ethier-Krugman model, M_{is}, can be modelled as part of the demand shifter and this is what we do. Equations (23)-(25) correspond with the following equations for the domestic and exporting marginal cost shifter, *sshiftx(i,r)* and *sshiftd(i,r)*:

```
EQUATION O_SCALEMD (all,i,TRAD_COMM)(all,r,REG)
sshiftd(i,r) = [VARS(i)/(esubm(i)-1)] * nne(i,r) - zeta(i) * esubm(i)
             * [pm(i,r) - num];

EQUATION O_SCALEMEX (all,i,TRAD_COMM)(all,r,REG)}
sshiftx(i,r) = [VARS(i)/(esubm(i)-1)] * nne(i,r) - zeta(i) * [pm(i,r) - num];
```

$nne\,(i,r)$ is the percentage change in the number of varieties produced (in Ethier-Krugman) or the number of potential entrants (in Melitz) and equal to the change in the number of input bundles (or nearly proportional with the number of input bundles), $\widehat{q_{ir}^{ib}}$. As pointed out in Appendix 3.4, the expressions for the number of varieties, N_{ir}, in the Ethier-Krugman model and for the number of potential entrants, NE_{ir}, in the Melitz model are identical.

Zeta(i) (or ζ_i) is a function of parameters and defined as $\zeta_i = \frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}$. So *zeta(i)* is equal to 0 when *GRAN* is equal to 1 and *GRAN* can thus be used to switch between Melitz and Ethier-Krugman in the expression for the supply shifters, $sshiftd$ and $sshiftx$. Moreover, the parameter *VARS(i)* is used as a coefficient on *nne(i)* enabling us to switch off variety scaling and thus reduce Ethier-Krugman/Melitz to Armington.

We deflate the price change term $pm\,(i,r)$ in the calculation of the Melitz-shifter in equation by the numeraire, such that a change in the numeraire does not change the size of the shifter and is thus neutral to a shock in the numeraire. This is also done at other places where price terms appear in the demand and marginal cost shifters. The variable *num* is defined at the introduction of the module and set equal to the default numeraire *pfactwld*. Hence, if a user changes the numeraire in the cmf, it should be changed as well in the code.[17]

Hat differentiating equation (9) gives the following expression in GEMPACK-code:

```
EQUATION O_SCALE (all,i,TRAD_COMM)(all,r,REG)}
nne(i,r) = (VOM(i,r)/(VOM(i,r) - [esubm(i)/(esubm(i)-1)]
         * SUM(t,reg, (VXMD(i,r,t)-VIWS(i,r,t))))) * qo(i,r)
         - [esubm(i)/(esubm(i)-1)]
         * SUM(s,reg, (VXMD(i,r,s)/(VOM(i,r)
         - SUM(t,reg,(VXMD(i,r,t)-VIWS(i,r,t)))))
         * (pcif(i,r,s)+qxs(i,r,s) - (VXWD(i,r,s)/VIWS(i,r,s))
         * (pm(i,r) - num -tx(i,r) - txs(i,r,s))}
         - ((VIWS(i,r,s)-VXWD(i,r,s))/VIWS(i,r,s))
        * ptrans(i,r,s))) + [esubm(i)/(esubm(i)-1)]}
        * SUM(s,reg, (VIWS(i,r,s)/(VOM(i,r)
        - SUM(t,reg,(VXMD(i,r,t)-VIWS(i,r,t))))) }
        * (pcif(i,r,s)+qxs(i,r,s)-(pm(i,r)- num)));
```

In the code we use an approximation of the above formula which generates almost identical results as discussed below that solves faster and in a more stable way:

```
EQUATION O_SCALE (all,i,TRAD_COMM)(all,r,REG)
nne(i,r) = qo(i,r);
```

The second formula does not deal exactly correct with the transport sector. The first expression contains additional terms, reflecting the impact of the size of transport services and export subsidies to all destination partners on the number of varietes. In Appendix D we show that the difference between using the two expressions for *nne* are very small. In this appendix we furthermore show that implementation of the Ethier-Krugman framework as in Francois (1998) also generates very similar results from counterfactual experiments. Francois (1998) also writes the variety-scaling term $nne\,(i,r)$ as a function of $qo\,(i,r)$ (or $qva\,(i,r)$ which is equivalent to using $qo\,(i,r)$ given the Leontief structure between intermediates and value added in gross output). However, he includes the variety-scaling term in the technology shifter, $ao\,(i,r)$, so before transport costs are paid. In Appendix D we conduct an experiment of variations in iceberg trade costs between all regions from -25% to 25% for the aggregation also used in the simulations presented below with three ways to model variety scaling: first, as in Francois (1998) including variety scaling before transport costs are paid; second, including variety scaling after transport costs are paid but with the variety scaling term $nne\,(i,r)$ proportional to $qo\,(i,r)$; and third, using the theoretically correct approach with variety scaling

[17] Alternatively, the variable numeraire could be set equal to zero (as exogenous variable), as long as no numeraire shock is implemented.

after transport costs are paid and $nne\,(i,r)$ a non-linear function of $qo\,(i,r)$. We find that changes in the world equivalent variation are virtually identical for the three approaches and especially the second and third approach generate very similar results. This indicates that, at least to us, it is reasonable to work with $nne\,(i,r)$ being proportional to $qo\,(i,r)$ instead of the non-linear specification.

3.7 Demand Shifter

To determine the demand shifters, we log differentiate the theoretical expression for the shifter in equation (15):

$$\widehat{e_{is}^{so}} = (\nu_i - 1)\left(\frac{1}{\sigma_i - 1} + \zeta_i\right)\widehat{M_{is}} + \zeta_i \sum_{ag} \frac{\left(\frac{P_{is}^{ag}}{ta_{is}^{so,ag}}\right)^{\rho_i - 1} \frac{E_{is}^{ag}}{ta_{is}^{so,ag}}}{\sum\limits_{ag'}\left(\frac{P_{is}^{ag'}}{ta_{is}^{so,ag'}}\right)^{\rho_i - 1} \frac{E_{is}^{ag'}}{ta_{is}^{so,ag'}}}$$
$$* \left((\rho_i - 1)\left(\widehat{P_{is}^{ag}} - \widehat{ta_{is}^{so,ag}}\right) + (\sigma_i - \rho_i)\,\widehat{p_{is}^{so}} + \left(\widehat{E_{is}^{ag}} - \widehat{ta_{is}^{so,ag}}\right)\right) \tag{26}$$

ζ_i is defined as before as $\zeta_i = \frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}$. Multiplying the numerator and denominator of the coefficient by $\left(\frac{p_j^d}{e_j^d}\right)^{1-\rho}$ and $\left(p_j^m\right)^{1-\sigma}$ for respectively domestic and imported values, we can rewrite equation (26) as follows:

$$\widehat{e_{is}^{so}} = (\nu_i - 1)\left(\frac{1}{\sigma_i - 1} + \frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}\right)\widehat{M_{is}} + \zeta_i \sum_{ag=} \frac{p_{is}^{so} q_{is}^{so,ag}}{\sum\limits_{ag'} p_{is}^{so} q_{is}^{so,ag'}}$$
$$* \left((\rho_i - 1)\left(\widehat{P_{is}^{ag}} - \widehat{ta_{is}^{so,ag}}\right) + (\sigma_i - \rho_i)\,\widehat{p_{is}^{so}} + \left(\widehat{E_{is}^{ag}} - \widehat{ta_{is}^{so,ag}}\right)\right) \tag{27}$$

To find the equivalent expression in GTAP notation, we observe that the coefficient in the summation term is equal to the share of expenditures of group ag in expenditures by all groups for source $so = d, m$. Equation (27) can thus be written in GEMPACK notation as follows for $so = d$:

```
EQUATION D_SCALED (all,i,TRAD_COMM)(all,r,REG)}
dshiftd(i,r) = (nu(i) - 1) * ((1/(esubm(i) - 1)) + zeta(i)) * mh(i,r)
              - zeta(i) * esubd(i) * tariffDd(i,r)
            + zeta(i) * (esubd(i) - 1) * [priceDd(i,r) - num]
            + zeta(i) * (valueDd(i,r) - num)
            + zeta(i) * (esubm(i) - esubd(i)) * (pm(i,r) - sshiftd(i,r)
            - dshiftd(i,r) - num);
```

For $so = m$ we get:

```
EQUATION D_SCALEM (all,i,TRAD_COMM)(all,r,REG)}
dshiftm(i,r) = (nu(i) - 1) * ((1/(esubm(i) - 1)) + zeta(i)) * mh(i,r)
             - zeta(i) * esubd(i) * tariffDm(i,r)
             + zeta(i) * (esubd(i) - 1) * [priceDm(i,r) - num]
             + zeta(i) * (valueDm(i,r)-num)}
             + zeta(i) * (esubm(i) - esubd(i)) * (pim(i,r) - num);
```

$priceDm\,(i,r)$ is the price index term of the shifter in sector i in country r, while $valueDm\,(i,r)$ is the value term, and $tariffDm\,(i,r)$ is the tariff term, defined respectively as:

```
EQUATION PREGDEMANDm
# change in value of regional price for commodity i #
(all,i,TRAD_COMM)(all,r,REG)
priceDm(i,r) = SHRIPM(i,r) * pp(i,r) + SHRIGM(i,r) * pg(i,r)
             + sum(j,PROD_COMM, (SHRIFM(i,j,r) * pf(i,j,r)));

EQUATION VREGDEMANDm
# change in value of regional expenditure for commodity i #
(all,i,TRAD_COMM)(all,r,REG)
valueDm(i,r) = SHRIPM(i,r)*[pp(i,r) + qp(i,r)]
              + SHRIGM(i,r) * [pg(i,r) + qg(i,r)]
              + sum(j,PROD_COMM, (SHRIFM(i,j,r) * [pf(i,j,r) + qf(i,j,r)]));

EQUATION TREGDEMANDm
# change in value of regional tariff for commodity i #
(all,i,TRAD_COMM)(all,r,REG)
tariffDm(i,r) = SHRIPM(i,r) * tpm(i,r) + SHRIGM(i,r) * tgm(i,r)
               + sum(j,PROD_COMM, (SHRIFM(i,j,r) * tfm(i,j,r)));
```

The supply-shifter $zeta\,(i)$ is equal to zero when $GRAN(i) = 1$, implying that only the term in $mh\,(i,r)$ remains as required in the Ethier-Krugman model. In the domestic demand shifter, we have to subtract $sshiftd\,(i,r)$ and $dshiftd\,(i,r)$ from the domestic price $pm\,(i,r)$. The reason is that $\widehat{p_{is}^{d}}$ in equation (27) is the price inclusive of the supply and demand shifter (the price corresponding with quantity $q_{is}^{d,ag}$), whereas $pm\,(i,r)$ is the price without shifter ($tp_{is}p_{is}^{ib}$ in our theoretical model-notation).

pp, pg, and pf are percentage price changes for respectively private households, government and firms and qp, qg, and qf the quantity equivalents. $SHRIPM\,(i,r)$ is the share of import value spent on private goods and the terms $SHRIGM\,(i,r)$ and $SHRIFM\,(i,j,r)$ are defined similarly for shares spent on government goods and intermediates respectively. As with the marginal cost shifter, we deflate the price and value changes (based on price changes) in the calculation of the shifter by the numeraire.

The expression for *mh(i,r)*, the percentage change in the total number of varieties consumed, is derived and presented in Appendix B.

3.8 Trade Cost Shifter

The generalized iceberg trade costs (or trade cost shifter) are equal to the normal iceberg trade costs in the Armington and Ethier-Krugman model. Only in the Melitz model the two are distinct and generalized iceberg trade costs are defined in equation (14). Hat differentiating this equation gives:

$$\begin{aligned}\widehat{t_{irs}} &= \frac{\theta_i - \sigma_i + 1}{\sigma_i - 1}\widehat{p_{irs}^{cif}} + \frac{\theta_i}{\sigma_i - 1}\widehat{\tau_{irs}} \\ &+ \frac{\sigma_i\left(\theta_i - \sigma_i + 1\right)}{\left(\sigma_i - 1\right)^2}\widehat{ta_{irs}} + \frac{\theta_i - \sigma_i + 1}{\left(\sigma_i - 1\right)^2}\widehat{f_{irs}}\end{aligned} \tag{28}$$

To convert equation (28) into the equivalent expression in the GTAP code, we introduce two new variables, $itc\,(i,r,s)$ and $fex\,(i,r,s)$, representing respectively iceberg and fixed trade costs. The corresponding expression for generalized iceberg trade costs, $genitc\,(i,r,s)$, in the code is given by:

```
EQUATION GENITCEQ (all,i,trad_COMM)(all,r,REG)(all,s,REG)
genitc(i,r,s) = zeta(i)*esubm(i)*(tm(i,s)+tms(i,r,s))
            + [theta(i)/(esubm(i)-1)] * itc(i,r,s) + zeta(i) * fex(i,r,s)
            + zeta(i) * (esubm(i) - 1) * (pcif(i,r,s) - num);
```

GRAN(i)=1 implies $zeta\,(i) = 0$ as argued above. The coefficient on *itc* will then be 1, whereas all other terms zero, as required in the Ethier-Krugman and Melitz model. We observe that the variable $ams\,(i,r,s)$ is a technology shifter for international trade in the standard code, equal to minus the percentage change in iceberg trade costs. We endogenize $ams\,(i,r,s)$ and express it as follows:

```
EQUATION AMSEQ (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
ams(i,r,s)= - genitc(i,r,s);
```

Fixed trade costs and iceberg trade costs determine together generalized iceberg trade costs in the Melitz version of the model. Since the computer code is written in percentage changes, we do not need explicit values for baseline shifter parameters or trade costs. This also holds for both iceberg and fixed trade costs. As is customary in CGE-models, baseline trade shares are equal to actual trade shares in the data. The calibration of fixed trade costs is further discussed in Section 4.

3.9 Margin Decomposition of Trade

As discussed, in the Melitz model there are three margins, the intensive margin, the extensive margin, and the compositional margin; in the Ethier-Krugman model only the first two margins are operative; and in the Armington mode only the intensive margin is operative. We first present the margin decomposition in the Melitz model and then go into the decomposition in the Ethier-Krugman model. Total trade flows as measured in cif-terms, inclusive of bilateral import tariffs, but exclusive of group-specific importer tariffs, v_{irs}, can be written as the number of varieties, N_{irs}, times the average revenues exclusive of group-specific tariffs, $\widetilde{\overline{r}}_{irs}$:

$$v_{irs} = N_{irs}\widetilde{\overline{r}}_{irs} = N_{irs}\frac{1}{1 - G\left(\varphi_{irs}^{*}\right)}\int_{\varphi_{irs}^{*}}^{\infty} \overline{r}_{irs}\left(\varphi\right) g\left(\varphi\right) d\varphi \tag{29}$$

Log differentiating equation (29) on the RHS and LHS wrt to the endogenous variables gives:

$$d\ln V_{irs} = d\ln N_{irs} + N_{irs}\frac{1}{1-G\left(\varphi^*_{irs}\right)}\int\limits_{\varphi^*_{irs}}^{\infty} d\ln \bar{r}_{irs}\left(\varphi\right)\frac{r_{irs}\left(\varphi\right)}{r_{irs}\left(\widetilde{\varphi}\right)}g\left(\varphi\right)d\varphi$$
$$+\frac{\partial\ln\left(1-G\left(\varphi^*_{irs}\right)\right)}{\partial\ln\varphi^*_{irs}}d\ln\varphi^*_{irs}\left(\frac{\bar{r}_{irs}\left(\varphi^*_{irs}\right)}{\bar{r}_{irs}\left(\widetilde{\varphi}_{irs}\right)}-1\right) \tag{30}$$

The first term represents the extensive margin, EM, i.e. the change in the mass of firms. The second term is the intensive margin, IM, so the change in sales of already exporting firms, not changing the cutoff productivity yet. The third term is the compositional margin, CM, expressing the change in export sales, because of a change in the cutoff productivity and thus in the composition of firms exporting.

We can determine the extensive margin from the fact that in steady state the number of firms exiting (the number of varieties, N_{irs}, times the death probability) is equal to the number of potential entrants, NE_{ir}, times the probability of entry, $1-G_i\left(\varphi^*_{irs}\right)$. Reorganized this gives:

$$N_{irs} = \frac{\left(1-G_i\left(\varphi^*_{irs}\right)\right)NE_{ir}}{\delta} = \left(\frac{\kappa_{ir}}{\varphi^*_{irs}}\right)^{\theta_i}\frac{NE_{ir}}{\delta} \tag{31}$$

The second equality sign follows from imposing the Pareto distribution (equation (11)). Hat differentiating equation (31) we can write the extensive margin as follows:

$$EM_{irs} = d\ln N_{irs} = -\theta_i\widehat{\varphi^*_{irs}} + \widehat{NE_{ir}} \tag{32}$$

To express the compositional margin, CM, we recognize that the ratio of average revenues and cutoff revenues is proportional to the ratio of cutoff productivities, $\frac{\bar{r}_{irs}\left(\varphi^*_{irs}\right)}{\bar{r}_{irs}\left(\widetilde{\varphi}\right)} = \left(\frac{\varphi^*_{irs}}{\widetilde{\varphi}_{irs}}\right)^{\frac{1}{\sigma-1}}$. Under the Pareto distribution the average productivity is proportional to the cutoff productivity, $\widetilde{\varphi}_{irs} = \left(\frac{\theta_i}{\theta_i-\sigma_i+1}\right)^{\frac{1}{\sigma_i-1}}\varphi^*_{irs}$. Combining these two facts, the compositional margin can be written as:

$$CM_{irs} = -\theta_i\widehat{\varphi^*_{irs}}\left(\frac{\theta_i-\sigma_i+1}{\theta_i}-1\right) = \left(\sigma_i-1\right)\widehat{\varphi^*_{irs}} \tag{33}$$

Comparing the expressions for the extensive and compositional margin in equations (32) and (33), we see that the terms in φ^*_{irs} in both expressions cancel out if the firm size distribution moves to granularity ($\theta_i = \sigma_i - 1$). Hence, only the number of entrants part of the extensive margin would remain in place. This term is only non-zero in a setting with multiple sectors and/or endogenous factor supply, such that the number of input bundles per sector can change.

Finally, we can elaborate on the intensive margin, IM, using the expression for revenues in Appendix A (equation (A.12)):

$$IM_{irs} = \int_{\varphi^*_{irs}}^{\infty} [d \ln \left(\left(\frac{\frac{\sigma_i}{\sigma_i - 1} ta_{irs} \tau_{irs} p^{cif}_{irs}}{\varphi} \right)^{1-\sigma_i} \sum_{ag} \frac{M_{is}^{\nu_i - 1} \left(\frac{P^{ag}_{is}}{ta^{so,ag}_{is} p^{so}_{is}} \right)^{\rho_i - 1} \left(p^{so}_{is} \right)^{\sigma_i - 1} E^{ag}_{is}}{ta^{so,ag}_{is}} \right)$$

$$* \frac{g(\varphi)}{1 - G(\varphi^*_{irs})} d\varphi]$$

$$= (1 - \sigma_i) \left(\widehat{\tau_{irs}} + \widehat{ta_{irs}} + \widehat{p^{cif}_{irs}} \right) + \sum_{ag} \frac{p^{so}_{is} q^{so,ag}_{is}}{\sum_{ag'} p^{so}_{is} q^{so,ag'}_{is}}$$

$$* \left((\nu_i - 1) \widehat{M_{is}} + (\rho_i - 1) \widehat{P^{ag}_{is}} + (\rho_i - \sigma_i) \widehat{p^{so}_{is}} + \widehat{E^{ag}_{is}} - \rho_i \widehat{ta^{ag}_{is}} \right) \tag{34}$$

Under Armington only the intensive margin is operative. Under Ethier-Krugman both the extensive and the intensive margin are operative with the following straightforward decomposition:

$$d \ln V_{irs} = d \ln N_{ir} + d \ln \bar{r}_{irs} \tag{35}$$

To derive expressions for the three margins in the code, we need an expression for the cutoff productivity, which is given by (derivation in Appendix A):

$$\varphi^*_{irs} = \frac{\frac{\sigma_i}{\sigma_i - 1} ta_{irs} \tau_{irs} p^{cif}_{irs}}{\left(\sigma_i f_{irs} tp_{ir} p^{ib}_{ir} ta_{irs} \right)^{\frac{1}{1-\sigma}}} \left(\sum_{ag} \left(\frac{P^{ag}_{is}}{ta^{so,ag}_{is} p^{so}_{is}} \right)^{\rho_i - 1} \frac{M_{is}^{\nu_i - 1} \left(p^{so}_{is} \right)^{\sigma_i - 1} E^{ag}_{is}}{ta^{so,ag}_{is}} \right)^{\frac{1}{1-\sigma_i}} \tag{36}$$

Log differentiating equation (36) leads to:

$$\widehat{\varphi^*_{irs}} = \frac{1}{\sigma_i - 1} \widehat{p^{ib}_{ir}} + \left(1 + \frac{1}{\sigma_i - 1} \right) \widehat{ta_{irs}} + \widehat{\tau_{irs}} + \widehat{p^{cif}_{irs}} + \frac{1}{\sigma_i - 1} \widehat{f_{irs}} - \frac{1}{\sigma_i - 1} \sum_{ag} \frac{p^{so}_{is} q^{so,ag}_{is}}{\sum_{ag'} p^{so}_{is} q^{so,ag'}_{is}}$$

$$* \left((\nu_i - 1) \widehat{M_{is}} + (\rho_i - 1) \widehat{P^{ag}_{is}} + (\rho_i - \sigma_i) \widehat{p^{so}_{is}} + \widehat{E^{ag}_{is}} - \rho_i \widehat{ta^{ag}_{is}} \right) \tag{37}$$

In GEMPACK notation equation (37) corresponds with the following expression:

```
EQUATION PSISTAREQ (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
psistar(i,r,s) = VARS(i) * (1 - ETK(i)) * {(1/(esubm(i) - 1)) * [pm(i,r)]
              + (1 + (1/(esubm(i) - 1))) * (tm(i,s) + tms(i,r,s))
              + (itc(i,r,s) + pcif(i,r,s)) + (1/(esubm(i)-1)) * fex(i,r,s)
               - ((nu(i) - 1)/(esubm(i) - 1)) * mh(i,s)
               - ((esubd(i) - 1)/(esubm(i) - 1)) * priceDm(i,s)
               - (1/(esubm(i) - 1)) * valueDm(i,s)
              + (esubd(i)/(esubm(i) - 1)) * tariffDm(i,s)
              - ((esubm(i) - esubd(i))/(esubm(i) - 1)) * pim(i,s)};
```

The three margins are expressed in values as (linear,change)-variables. In this way the three margins add up to the total margin. The extensive margin can be expressed as a function of the cutoff productivity, *psistar*, and the number of entrants, *nne*, according to equation (32). We define the contribution of these two terms separately and also account for the fact that the extensive margin is equal to the change in the number of entrants only in the Ethier-Krugman model:

```
EQUATION EXTM1EQ (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
extmpsi(i,r,s) = 0.01 * VXMD(i,r,s) * VARS(i) * (1 - ETK(i))
               * { - theta(i) * psistar(i,r,s)};

EQUATION EXTM2EQ (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
extmn(i,r,s) = 0.01 * VXMD(i,r,s) * VARS(i) * nne(i,r);

EQUATION EXTMPSIEQ (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
extmparts(i,r,s) = extmpsi(i,r,s) + extmn(i,r,s);
```

Next, the compositional margin is a function of the change in cutoff productivity:

```
EQUATION COMPMPSIEQ (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
compmparts(i,r,s) = 0.01 * VXMD(i,r,s) * (esubm(i) - 1) * psistar(i,r,s);
```

Finally, the intensive margin is defined in equation (34) for the Melitz model. For the Ethier-Krugman model the intensive margin is equal to the total change in trade exclusive of the supply shifter. This corresponds with the following expression in the GEMPACK-code:

```
EQUATION INTMEQ (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
intm(i,r,s) = 0.01 * VXMD(i,r,s) * {VARS(i)*(1-ETK(i)) * { - (esubm(i) - 1)
           * (tm(i,s) + tms(i,r,s) + itc(i,r,s) + pcif(i,r,s))
          + (nu(i) - 1) * mh(i,s) + (esubd(i) - 1) * priceDm(i,s)
          + valueDm(i,s) - esubd(i)*tariffDm(i,s)
          + (esubm(i)-esubd(i)) * pim(i,s)} + ((1 - VARS(i)) + ETK(i))
          * {pms(i,r,s) - ams(i,r,s) + qim(i,s)
           - ESUBM(i) * [pms(i,r,s) - ams(i,r,s) - pim(i,s)]
          + (nu(i) - 1) * mh(i,s)}};
```

For domestic sales we get somewhat different expressions, since there are no export taxes, cif-fob margins, and import tariffs for domestic sales. We should keep in mind that the international margins are also defined for trade flows within the same region, representing international trade between countries within a region. Although these values are formally also defined for entire countries, like the USA, they do not have a meaning.

The change in the domestic cutoff productivity, $psistard\,(i,s)$, is defined as:

```
EQUATION PSISTARDEQ (all,i,TRAD_COMM)(all,s,REG)
psistard(i,s) = VARS(i) * (1 - ETK(i)) * {(esubm(i)/(esubm(i) - 1)) * [pm(i,s)]
             - ((nu(i)-1)/(esubm(i)-1)) * mh(i,s)
             - ((esubd(i) - 1)/(esubm(i) - 1)) * priceDd(i,s)
             - (1/(esubm(i) - 1)) * valueDd(i,s)
             + (esubd(i)/(esubm(i) - 1)) * tariffDd(i,s)
             - ((esubm(i) - esubd(i))/(esubm(i) - 1))
             * [pm(i,s) - sshiftd(i,s) - dshiftd(i,s)]};
```

The compositional and extensive margin are a function of *psistard* and *nne* as above for the international margins. Only the expression for the intensive margin changes:

```
EQUATION INTMDEQ (all,i,TRAD_COMM)(all,s,REG)
intmd(i,s) = 0.01 * VXMD(i,r,s) * {VARS(i) * (1 - ETK(i))
            * { - (esubd(i) - 1) * (pm(i,s))}
           + (nu(i)-1)*mh(i,s) + (esubd(i)-1) * priceDd(i,s)
           + valueDd(i,s) - esubd(i) * tariffDd(i,s)}
           - VARS(i) * {(esubm(i) - esubd(i)) * (sshiftd(i,s) + dshiftd(i,s))}
          {+ ((1 - VARS(i)) + ETK(i)) * {SHRDPM(i,s)
          * {pm(i,s) + qp(i,s) - ESUBD(i) * [ppd(i,s) - pp(i,s)]}
          + sum(j,PROD_COMM, SHRDFM(i,j,s)
          * {pm(i,s) + qf(i,j,s) - ESUBD(i) * [pfd(i,j,s) - pf(i,j,s)]})
          + SHRDGM(i,s) * {pm(i,s) + qg(i,s) - ESUBD(i)
          * [pgd(i,s) - pg(i,s)]} + (nu(i) - 1) * mh(i,s)}};
```

As a check on the correctness of our expressions we compare the sum of the three margins with the change in the value of trade, *qxs(i,r,s)* + *pms(i,r,s)* for international flows, and *pm(i,s)* + *qds(i,s)* for domestic flows. Finally, we decompose the change in the value of sectoral sales, *pm(i,r)* + *qo(i,r)*, into changes in domestic sales, exporting sales, and sales to the transport sector. Domestic and exporting sales can in turn be decomposed into the intensive, extensive, and compositional margins. For example the contribution of the domestic intensive margin to the total change in the value of sectoral sales is defined as follows with $SHRDM$ the share of domestic sales in total sectoral sales:

```
Equation decomp_intmd_eq
# Domestic intensive margin contribution to total sales #
(all,i,TRAD_COMM)(all,s,REG)
decomp_intmd(i,s) = SHRDM(i,s) * intmd(i,s);
```

3.10 Welfare Decomposition

We extend the welfare decomposition of the standard GTAP model as developed by Huff and Hertel (2000) to account for the additional effects in the Ethier-Krugman and Melitz model. We start by extending the decomposition mapped out in Huff and Hertel (2000) to account for the two additional terms in our analysis, the demand and supply shifters. Then we point out how these additional terms, together with the trade cost shifter, can be expressed as a function of changes in the mass of varieties, in the average productivity, and iceberg trade costs. This last step shows that in the firm heterogeneity model welfare is affected in two additional ways, by a change in the number of varieties and a change in the average productivity.

We start from the derivation of the EV decomposition in the multi-region model in Appendix B of Huff and Hertel (2000). The presence of the demand and supply shifters means that we have to make three changes in the steps taken to generate their welfare decomposition. First, the expression for zero profits has to be extended to take into account the presence of the demand and supply shifters. The new zero profit condition becomes:

$$\begin{aligned}
&VOA\,(j,r) * [ps\,(j,r) * ao\,(j,r)] \\
&= sum\,(i, ENDW_COMM, VFA\,(i,j,r) * [pfe\,(i,j,r) - afe\,(i,j,r) - ava\,(j,r)]) \\
&+ sum\,(i, TRAD_COMM, VIFA\,(i,j,r) * [pfm\,(i,j,r) - af\,(i,j,r)]) \\
&+ sum(i, TRAD_COMM, \\
&VDFA\,(i,j,r) * [pfd\,(i,j,r) - dshiftd\,(i,r) - sshiftd\,(i,r) - af\,(i,j,r)])
\end{aligned} \tag{38}$$

Second, in defining real income the impact of the demand and supply shifters on pp and pg should be taken into account. Real income is in the derivations defined as nominal income y minus weighted terms in $psave$, ppm, ppd, pgm, and pgd. However, pp for example is a function of ppm and ppd minus $dshiftd$ and $sshiftd$. The last two terms thus have to be added on the RHS of the expression of real welfare.

Third, we should take into account that pim is a function of pms and moreover of $dshiftm$, $sshiftx$ and ams, implying that we have the following:

$$\begin{aligned}
&sum\,\{i, sum\,(s, VIMS\,(i,s,r) * pms\,(i,s,r))\} - sum\,\{i, VIM\,(i,r) * pim\,(i,r)\} = \\
&sum\{i, sum\{s, VIMS\,(i,s,r)\,[ams\,(i,s,r) + sshiftx\,(i,s) + dshiftm\,(i,r)]\}\}
\end{aligned} \tag{39}$$

Hence, the terms on the second line of equation (39) become part of the welfare decomposition when the two terms on the first line are consolidated.

Taking into account the above three changes means that we have to add the contribution to EV of the demand shifter, $CNTdemr$, and of the supply (or variety scaling) shifter, $CNTvarr$:

```
Equation CONT_EV_demr (all,r,REG)
CNTdemr(r) = [0.01 * EVSCALFACT(r)]
             * {sum(i,TRAD_COMM,sum(s,REG,VIMS(i,s,r)) * dshiftm(i,r))
             + sum(i,TRAD_COMM,[{VDPA(i,r) + VDGA(i,r)
             + sum(j,PROD_COMM,VDFA(i,j,r))} * dshiftd(i,r)])};

Equation CONT_EV_varr (all,r,REG)
CNTvarr(r) = [0.01 * EVSCALFACT(r)]
             * {sum(i,TRAD_COMM, sum(s,REG, VIMS(i,s,r) * sshiftx(i,s)))
             + sum(i,TRAD_COMM,[{VDPA(i,r) + VDGA(i,r)
             + sum(j,PROD_COMM,VDFA(i,j,r))} * sshiftd(i,r)])};
```

Adding these additional terms to the expression for the alternative equivalent variation, *EVALT*, we find that *EVALT* is equal to *EV*.

As a next step we can rewrite the additional demand shifter and supply shifter terms together with generalized iceberg trade costs as a function of the number of varieties N_{irs}, average productivity $\widetilde{\varphi_{irs}}$ and the love of variety term M_{is}. We write the bilateral price inclusive of all shifters as follows:

$$\frac{ta_{irs} t_{irs} c^m_{ir} p^{cif}_{irs} ta^{s,ag}_{is}}{e^m_{is}} = \frac{\sigma_i}{\sigma_i - 1}\left(M^{\nu_i - 1}_{is} N_{irs}\left(ta_{irs} ta^{so,ag}_{is} \tau_{irs} p^{cif}_{irs}\right)^{1-\sigma_i} \widetilde{\varphi}^{\sigma_i - 1}_{irs}\right)^{\frac{1}{1-\sigma_i}} \tag{40}$$

Hence, we can write the additional terms in c_{ir}, e^m_{is}, and t_{irs} as follows:

$$\frac{t_{irs}c^m_{ir}}{e^m_{is}} = \frac{\sigma_i}{\sigma_i - 1} M_{is}^{\frac{\nu_i - 1}{1-\sigma_i}} \frac{N_{irs}^{\frac{1}{1-\sigma_i}}}{\widetilde{\varphi}_{irs}} \tau_{irs} \tag{41}$$

Hat differentiating equation (41) gives in GEMPACK notation the following:

$$\begin{aligned} &ams\,(i,r,s) - sshiftx\,(i,r) - dshiftm\,(i,s) \\ &= \frac{\nu - 1}{1-\sigma} mh\,(i,s) - \frac{1}{1-\sigma} nvi\,(i,r,s) - psistar\,(i,r,s) + itc\,(i,r,s) \end{aligned} \tag{42}$$

Therefore, we can replace the two terms introduced above, $CNTdemr$ and $CNTvarr$, by CNT_M, CNT_nvi, CNT_nvd, CNT_psii, CNT_psid, and CNT_tc, representing the contribution to the change in welfare of respectively changes in the love of variety term, changes in imported and domestic varieties, changes in importer and domestic average productivity, and changes in iceberg trade costs. These terms are defined as follows (CNT_nvd, and CNT_psid are omitted as they are similar):

```
Equation CONT_EV_M (all,r,REG)
CNT_M(r) = [0.01 * EVSCALFACT(r)]
           * {sum(i,TRAD_COMM,{[{VDPA(i,r)+VDGA(i,r)
           + sum(j,PROD_COMM,VDFA(i,j,r))}
           + sum(s,REG,VIMS(i,s,r))]
           * ((nu(i) - 1)/(ESUBM(i) - 1)) * mh(i,r)})};

Equation CONT_EV_nvi (all,r,REG)
CNT_nvi(r) = [0.01 * EVSCALFACT(r)]
            * sum(i,TRAD_COMM,sum(s,REG,VIMS(i,s,r)
            * (1/(ESUBM(i) - 1)) * NV(i,s,r)));

Equation CONT_EV_psii (all,r,REG)
CNT_psii(r) = [0.01 * EVSCALFACT(r)]
            * sum(i,TRAD_COMM,sum(s,REG,VIMS(i,s,r) * psistar(i,s,r)));

Equation CONT_EV_tc (all,r,REG)
CNT_tc(r) = - [0.01 * EVSCALFACT(r)]
           * sum(i,TRAD_COMM,sum(s,REG,VIMS(i,s,r) * itc(i,s,r)));
```

An alternative welfare decomposition can now be defined as

```
Equation EV_DECOMP_partsw}
# decomposition of Equivalent Variation from parts with N and psi #
(all,r,REG)
EV_ALT_partsw(r) = CNTdpar(r) + CNTalleffr(r) + CNTendwr(r) + CNTtotr(r)
                   + CNTtechr_pure(r) + CNTcgdsr(r) + CNT_tc(r)
                   + CNT_psii(r) + CNT_psid(r)
                   + CNT_nvi(r) + CNT_nvd(r) + CNT_M(r);
```

4. Calibration

Table 1 shows that we need values for four new parameters in the model, the tariff elasticity, $\varepsilon_i^{v,ta}$, the degree of granularity, ξ_i, the degree of nested preferences, υ, and the strength of love of variety, ν. The latter variable is set equal to 1, thus imposing standard CES preferences. The degree of granularity is taken from the literature. We work with a degree of granularity of 5/6 in all sectors, thus setting it in between the value of 2/3 employed by Caliendo et al. (2015) and full granularity.[18] Akgul et al. (2015), Akgul and Ahmad (2017) and di Giovanni et al. (2011) report substantial heterogeneity across sectors in the degree of firm size granularity. Following Caliendo et al. (2015), we have decided to stick to a uniform value for the degree of granularity. The estimates reported in di Giovanni et al. (2011) for a cross-section of sectors based on French firm level data suggest that in many sectors the degree of granularity ξ_i is larger than 1, which implies that the Melitz model cannot be solved since average firm level sales would tend to infinity. Equivalently, Akgul and Ahmad (2017) find that the degree of granularity in the motor vehicles sector with American data is larger than 1. Given this lack of conclusive evidence on the degree of granularity at the sector level in the Melitz-model with Pareto productivity distribution, we decided to work with a uniform value for the degree of granularity across sectors.

The degree of nested preferences, σ_i/ρ_i, is set equal to 1, as motivated below. We could also calibrate to the trade elasticity, $\varepsilon_i^{v,\tau}$, instead of the tariff elasticity. Since most estimates at the sectoral level on trade responsiveness to costs seems to focus on the tariff elasticity (Aichele et al. (2014), Egger et al. (2015), Caliendo and Parro (2015), and Spearot (2016) for example estimate tariff elasticities at the sectoral or product level), we concentrate here on calibration to the tariff elasticity, also discussing the possibility of calibration to the trade elasticity.

Before going into estimation of the tariff elasticity and calculation of the ad valorem equivalent of trade policy measures based on gravity estimation, we address two other points related to calibration. First, we observe that we do not need explicit values for the size of fixed costs. Iceberg trade costs together with fixed costs are assumed implicitly to be such that the baseline import shares are equal to actual import shares. So, the size of fixed trade costs does not matter in the model. Dixon et al. (2018) follow a similar approach without explicit calibration of fixed costs and discuss in their Chapter 4 how this approach compares with the approach in Balistreri et al. (2012) where fixed costs are explicitly estimated. In our model generalized iceberg trade costs are a multiplicative function of iceberg and fixed trade costs. Henceforth, the relative importance of the two types of trade costs does not matter for calibration of the baseline.[19] As discussed in the simulation results, in case of shocks to trade costs, it matters whether shocks are imposed on iceberg or on fixed trade costs, in particular in the decomposition of the effects on trade into the intensive, extensive, and compositional margin. We want to stress that it is of-

[18] Caliendo et al. (2015) cite Eaton et al. (2011) who find a value of $\theta_i/(\sigma_i - 1)$ of 1.5, which corresponds with a degree of granularity in our definition of 2/3.

[19] In other models the distinction between iceberg and fixed trade costs matters. In Akgul et al. (2016) for example input bundles employed in marginal and fixed costs are different and henceforth the size of fixed costs in the baseline matters.

tentimes difficult to identify whether trade policy measures, which will be of most interest in counterfactual experiments, affect iceberg trade costs, fixed trade costs, or both.

Second, a general characteristic of models combining love of variety with increasing returns to scale is the emergence of corner solutions and infinitely large effects, which makes the solution of counterfactual experiments oftentimes a difficult exercise. Three approaches have been identified in the literature to confront this problem. First, scholars propose the use of nested preferences. As discussed in Caliendo et al. (2015) working with nested preferences helps to prevent corner solutions. Second, production factors can be assumed to be imperfectly mobile, an approach used in Francois (1998). Third, as discussed in Balistreri et al. (2012) and Costinot and Rodriguez-Clare (2014) the share of intermediate inputs in gross output sourced from a specific sector k in a using sector i can be smoothened by setting it equal to the country-average share of intermediates from sector k times the share of intermediate inputs in gross output in sector i. Hence, the share of intermediates sourced from different sectors in total intermediates demand of a using sector is not specific to the using sector, but is the same across all using sectors. For example, the intermediate share of metals in gross output of motor vehicles would be equal to the average share of metals in total intermediates demand (by all sectors) times the share of intermediates in gross output in motorvehicles. Britz and Jafari (2017) follow a similar approach to prevent infinitely large effects leading to corner solutions, focusing in particular on the share of intermediates sourced domestically.

We limit ourselves to the second approach. Adjusting the data to retain numerical tractability seems a bigger step than adopting nested preferences and imperfect factor mobility. We decided to abstract from nested preferences. Caliendo et al. (2015) set σ_i 1.25 times larger than ρ_i to avoid corner solutions. In the context of monopolistic competition nested preferences would imply that competition between varieties from different countries is indirect. Feenstra et al. (2018) show that there is no evidence for significant differences between σ_i and ρ_i in 3/4 of the manufacturing sectors. Our code is, however, general and allows for nesting of preferences, which enables researchers to avoid corner solutions with more detailed aggregations.

As discussed in for example Francois (2001) and Francois and Nelson (2002) models of monopolistic competition with perfect factor mobility are highly likely to run into corner solutions. Therefore, we impose imperfect labor mobility. Empirical literature finds strong support for the presence of labor adjustment costs. Cruz et al. (2017) estimate average labor adjustment costs equal to 1.4 times the annual wage in 235 country times year surveys. Other studies like Artuc et al. (2015) and Dix-Carneiro (2014) find even larger adjustment costs.

We set the elasticity of transformation of the three types of labor between sectors at 5. This level prevents corner solutions and at the same time guarantees that aggregate affects are not affected very much. Francois (2001) shows that the aggregate welfare effects (in Francois (2001) changes in real GDP) hardly vary with the degree of factor mobility, whereas sectoral variation, as expected, does. Since we are mainly interested in aggregate effects, our assumptions on imperfect labor mobility are harmless. Scholars interested in sectoral effects could reduce the degree of factor mobility, but should be careful in interpreting results with extreme effects where certain sectors expand a lot in a country and others almost disappear. Multi-sector increasing returns to scale models contain multiple equilibria, so one cannot be very confident that the sectoral output effects found are unique.

4.1 Tariff Elasticities, Trade Elasticities, and AVEs

We can write the value of trade (net of bilateral tariffs), $v_{irs} = \frac{1}{ta_{irs}} p_{irs} q_{irs}$, in the Armington and Ethier-Krugman model on the one hand and in the Melitz model on the other hand, focusing on the differences in the bilateral term. Substituting the expressions for t_{irs} in Armington/Ethier-Krugman, $t_{irs} = \tau_{irs}$, and in Melitz, t_{irs} as defined in equation (14), into the expression for demand in (3) gives:

$$v_{irs}^{arm,etk} = \left(\tau_{irs} te_{irs} \left(1 + itm_{irs}\right)\right)^{1-\sigma_i} ta_{irs}^{-\sigma_i} \left(\frac{e_{is}^m p_{is}^m}{tp_{ir} p_{ir}^{ib} c_{ir}^m}\right)^{\sigma_i - 1} E_{is}^m \tag{43}$$

$$v_{irs}^{mel} = \left(\tau_{irs} te_{irs} \left(1 + itm_{irs}\right)\right)^{-\theta_i} ta_{irs}^{-\left(\theta_i + 1 + \frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)}\right)} f_{irs}^{-\frac{\theta_i - \sigma_i + 1}{\sigma_i - 1}} * \left(\frac{e_{is}^m p_{is}^m}{tp_{ir} p_{ir}^{ib} c_{ir}^m}\right)^{\sigma_i - 1} E_{is}^m \tag{44}$$

The expression $p_{irs}^{cif} = te_{irs} tp_{ir} p_{ir}^{ib} \left(1 + itm_{irs}\right)$ defines the cif-price, with te_{irs} the export tax and itm_{irs} the international transport margin, $itm_{irs} = \frac{p_{ijr}^{ts}}{tp_{ir} p_{ir}^{ib} a_{ijr}^{ts}}$. The coefficient on tariffs features an additional term in the Melitz model. This follows from the assumption that tariffs are paid on the marked-up prices (called revenue-shifting tariffs in for example Costinot and Rodriguez-Clare (2014) and Caliendo et al. (2015)). Therefore, the zero cutoff profit condition is affected differently by tariffs than by the iceberg trade costs and the export taxes, implying a different coefficient on the gravity equation. Further discussion is in Bekkers and Francois (2018).

The empirical gravity equation can be written as follows:[20]

$$\begin{aligned} v_{irs}^{emp} \quad = \quad & \exp\{-\varepsilon_i^{v,ta} \ln ta_{irs} - \varepsilon_i^{v,te} \left(te_{irs} \left(1 + itm_{irs}\right)\right) + a_i^{tcc} \ln tcc_{irs} + a_i^{tcd} tcd_{irs} \\ & + \psi_{ir} + \eta_{is} + \varepsilon_{irs}\} \end{aligned} \tag{45}$$

[20] We include a minus sign before the tariff and trade elasticities, $\varepsilon_i^{v,ta}$ and $\varepsilon_i^{v,\tau}$ respectively, implying that these elasticities are positive.

Exporter and importer fixed effects, ψ_{ir} and η_{is}, capture the exporter and importer specific terms, respectively $\left(tp_{ir}p_{ir}^{ib}c_{ir}^{m}\right)^{1-\sigma_i}$ and $\left(e_{is}^{m}p_{is}^{m}\right)^{\sigma_i-1}E_{is}^{m}$. Comparing equations (43)-(45) shows that the tariff elasticity, $\varepsilon_i^{v,ta}$, (based on the value of trade net of import tariffs) is equal to σ_i in the Ethier-Krugman/Armington model and equal to $\left(\theta_i+1+\frac{\theta_i-\sigma_i+1}{\sigma_i-1}\right)$ in the Melitz model. Equations (43)-(45) show as well that the trade elasticity, the elasticity of v_{irs}^{emp} with respect to iceberg trade costs, τ_{irs}, is θ_i in the Melitz model and σ_i-1 in the Armington and Ethier-Krugman models. In principle the tariff elasticities could be estimated structurally, as for example in Egger et al. (2015) or Caliendo and Parro (2015). However, in this paper we use the estimates in the GTAP database, assuming that the substitution elasticities, $ESUBM\left(i\right)$, are based on estimated tariff elasticities. If the GTAP elasticities are used, the tariff elasticity, $\varepsilon_i^{v,ta}$, should be set equal to the substitution elasticities between varieties from different countries, $ESUBM\left(i\right)$.[21]

We include continuous measures of bilateral trade costs like distance and NTMs denoted by tcc_{irs} (trade costs continuous), and dummy measures of bilateral trade costs like contiguity, common language, common religion and membership of an FTA denoted by the vector tcd_{irs} (trade costs dummy) in the gravity equation. Turning to counterfactual experiments these measures can be mapped into their ad valorem equivalent (AVE) to determine the effects of a change in these measures. The AVE of a measure is defined as the equivalent ad valorem trade cost of a 1% change of the measure or in case of a dummy variable of a change of the measure from 0 to 1:

$$AVE^{tcc}=\frac{d\ln\tau_{irs}}{d\ln tcc_{irs}} \tag{46}$$

$$AVE^{tcd}=\frac{\tau_{irs}\left|tcd_{irs}=1-\tau_{irs}\right|tcd_{irs}=0}{\tau_{irs}\left|tcd_{irs}=0\right.} \tag{47}$$

The most common approach in the literature to determine the AVE is through the estimation of a gravity equation. We show now how equations (43)-(45) can be combined to express the AVE of a continuous variable as a function of the estimated

[21] Also other empirically estimable elasticities could be used. It is important, however, that the model is calibrated to the empirically estimated elasticities. So, if for example the estimated tariff elasticities from Spearot (2016) are used, which give the shape parameters θ_i in the Melitz-Ottaviano model, then these estimates should not be used as measures for the shape parameters θ_i in the Melitz model. They should be used to identify the tariff elasticities instead as well and from this the shape parameters in the Melitz model can be identified in turn.

gravity coefficients (using $\frac{d \ln v_{irs}}{d \ln tcc_{irs}} = \frac{d \ln v_{irs}}{d \ln \tau_{irs}} \frac{d \ln \tau_{irs}}{d \ln tcc_{irs}}$):[22]

$$AVE^{tcc}_{arm,etk} = \frac{a^{tcc}_i}{1-\sigma_i} = -\frac{a^{tcc}_i}{\varepsilon^{v,\tau}_i} = -\frac{a^{tcc}_i}{\varepsilon^{v,ta}_i - 1} \tag{48}$$

$$AVE^{tcc}_{mel} = \frac{a^{tcc}_i}{-\theta_i} = -\frac{a^{tcc}_i}{\varepsilon^{v,\tau}_i} = -\frac{a^{tcc}_i}{\varepsilon^{v,ta}_i - 1/\xi_i} \tag{49}$$

For a dummy variable we get (using for example for the Melitz model $\frac{v_{irs}|tcd_{irs}=1}{v_{irs}|tcd_{irs}=0} = \left(\frac{\tau_{irs}|tcd_{irs}=1}{\tau_{irs}|tcd_{irs}=0}\right)^{-\theta_i} = \exp\left(a_{tcd} tcd_{irs}\right)$):

$$AVE^{tcd}_{arm,etk} = \exp\left(\frac{a^{tcd}_i}{1-\sigma_i}\right) - 1 = \exp\left(-\frac{a^{tcd}_i}{\varepsilon^{v,\tau}_i}\right) = \exp\left(-\frac{a^{tcd}_i}{\varepsilon^{v,ta}_i - 1}\right) - 1 \tag{50}$$

$$AVE^{tcd}_{mel} = \exp\left(\frac{a^{tcd}_i}{-\theta_i}\right) - 1 = \exp\left(-\frac{a^{tcd}_i}{\varepsilon^{v,\tau}_i}\right) = \exp\left(-\frac{a^{tcd}_i}{\varepsilon^{v,ta}_i - 1/\xi_i}\right) - 1 \tag{51}$$

So to calculate the AVE in the Melitz model based on the tariff elasticity an estimate of the degree of granularity ξ_i is required. We have included the AVE based on both the estimated tariff and trade elasticities , respectively $\varepsilon^{v,ta}_i$ and $\varepsilon^{v,\tau}_i$. In the Armington and Ethier-Krugman models the tariff elasticity (based on cif prices net of tariffs) is equal to the trade elasticity plus one, but in the Melitz model the tariff elasticity features an additional term. Therefore, the AVE calculated from the same estimated coefficient on a trade measure, a^{tcd}_i, is identical in the Armington/Ethier-Krugman models and the Melitz model when the trade elasticity is used to convert the trade measure into the AVE. But the AVE is different when the tariff elasticity is used to convert the trade measure.

In the Melitz model we have to take into account that a trade cost measure can affect trade flows both through iceberg and through fixed trade costs. We can define the fixed cost equivalents (FCEs) of trade cost measures as follows:

$$FCE^{tcc}_{mel} = \frac{-a^{tcc}_i}{-\frac{\theta_i - \sigma_i + 1}{\sigma_i - 1}} = \frac{a^{tcc}_i}{\frac{1}{\xi_i} - 1} \tag{52}$$

$$FCE^{tcd}_{mel} = \exp\left(\frac{a^{tcd}_i}{\frac{1}{\xi_i} - 1}\right) - 1 \tag{53}$$

Equation (52) indicates that FCE^{tcc}_{mel} would go to infinity when the firm size distribution tends to granularity (with $\xi_i = 1$). The reason is that fixed exporting costs should not have any effect on trade flows under granularity (with the destination-specific extensive margin and the compositional margin cancelled out against each

[22] The alternative approach to determine AVEs is the price approach, attributing price differences to the presence of AVEs (see for example Cadot and Gourdon (2016))

other) thus implying that the effect of fixed trade costs should be zero.

The trade cost shifter, t_{irs} from equation (14) is proportional with $\left(\tau_{ij}^{\theta} f_{ij}^{\frac{\theta-\sigma+1}{\sigma-1}}\right)^{\frac{1}{\sigma-1}}$. Therefore, the elasticity of t_{irs} with respect to the trade cost measure tcc_{irs} is equal to $\frac{a_i^{tcc}}{\sigma_i-1}$ both when tcc_{irs} affects iceberg trade costs and when it affects fixed trade costs. So for the total effect of a change in the trade cost measure tcc_{irs} in a counterfactual experiment it does not matter whether it affects iceberg or fixed trade costs. Only for the margin decomposition it does matter how the change is operationalized. In general though it will be hard to determine conceptually whether observable trade cost measures affect trade flows through iceberg or through fixed trade costs. For example, it is likely that distance or the presence of a free trade agreement (FTA) affects trade flows through both. It is less costly to start exporting in a country at a shorter distance or in an FTA-partner. It is hard to find measures that only affect one of the two trade costs. Our framework shows, however, that only for the decomposition of the different trade margins it is necessary to identify the type of trade costs affected (fixed or iceberg) by a generic trade cost measure.

5. Counterfactual Experiments

We conduct experiments with reductions in iceberg and fixed trade costs to illustrate our model. We do this in a setting with 11 countries, 11 sectors, and 6 factors of production based on the GTAP10 data for 2014. An overview of the aggregation can be found in Table E2. The parameters are as discussed in the previous section. We set the values for the tariff elasticity, $\varepsilon_i^{v,ta}$, and trade elasticity, $\varepsilon_i^{v,\tau}$, equal to respectively *ESUBM(i)* and *ESUBM(i)-1*, thus using the parameter values implied by the standard GTAP model with Armington preferences. We do this for the three different models. We conduct three sets of trade cost experiments. First, we start with a plain identical percentage change in iceberg trade costs in all sectors equal to 2%, thus abstracting from possible reasons for different sizes of shocks in the different models. For comparison, we also implement a shock to fixed trade costs in the Melitz model. To get a seemingly comparable shock in size to the 2% shock to iceberg trade costs, we reduce fixed trade costs by 56.9%. This number is based on the fact that the elasticity of generalized trade costs with respect to iceberg trade costs and fixed trade costs are respectively $\frac{\theta_i}{\sigma_i-1}$ and $\frac{\theta_i-\sigma_i+1}{(\sigma_i-1)^2}$. Based on a trade weighted average tariff elasticity of 7 and a degree of granularity of 0.83, we get that a fixed trade cost reduction of 56.9% is expected to be roughly equivalent to an iceberg trade cost shock of 2%.[23]

Second, we implement a reduction in iceberg trade costs corresponding with a coefficient of -0.1 for a_i^{tcd} and the tariff elasticity, $\varepsilon_i^{v,ta}$, to transfer a_i^{tcd} into the corresponding AVE and iceberg trade costs shock based on equations (50)-(51). We

[23] $56.9\% = \widehat{f} = \frac{\theta(\sigma-1)}{\theta-\sigma+1}\widehat{\tau} = \frac{\xi\varepsilon^{v,ta}-1}{1-\xi}\widehat{\tau} = \frac{0.83*7.03-1}{1-0.83} * 2\%$

also implement this shock through a reduction in fixed trade costs in the Melitz model employing equations (53). $a_i^{tcd} = -0.1$ could be for example the coefficient on a dummy variable for the presence of an FTA between countries. Since the elasticities vary across sectors, shocks also vary across sectors. Furthermore, the size of the shock differs between the Melitz model on the one hand and the Armington/Ethier-Krugman models on the other hand. The reason is that the denominators in calculating the AVEs in equations (50)-(51) differ between the models. The denominator is smaller in the Melitz model for the same tariff elasticity, thus implying larger trade cost shocks. Given that the gravity equations are observationally equivalent for the different models, we should employ the same tariff elasticity. The tariff elasticity in the Melitz model contains an additional positive term relative to the trade elasticity, whereas this is not the case in the Armington/Ethier-Krugman models. Therefore, transforming a trade cost measure which is part of iceberg trade costs leads to a larger AVE in the Melitz model than in the other models.

Dixon et al. (2016) also implement different shocks in the Melitz and Armington model to make the models comparable (besides working with different substitution elasticities). Their reason is different, however. They argue that the tariff bases are different in the two models, with tariffs operating only on variable costs in the Melitz model and not on fixed costs, whereas they operate on all costs in the Armington model. Therefore, the tariff shock in the Armington model must be lower in their representation of the different models. In later work, Dixon et al. (2018), the tariff shock operates on cif prices in both models, so the adjustment in the tariff shock to make the two models comparable is not needed anymore.

We argue that the starting point should be the empirically estimated tariff elasticities and the estimated coefficients on trade policy measures, which are to be changed in a counterfactual exercise. The estimated tariff elasticities and policy measure coefficients should be identical across models. Subsequently the structure of the different models should be employed to calculate the shocks to trade costs and the behavioral parameters, the substitution elasticity, σ_i, and the shape parameter of the Pareto distribution, θ_i. Since the trade structure of the two models is different, trade volume responses can then also be different.

As a third set of experiments, we use the same coefficient $a_i^{tcd} = -0.1$, but employ the trade elasticity, $\varepsilon_i^{v,\tau}$, to calculate the corresponding AVE. In this case the size of the shocks is identical in the different models.

Table 3 displays the changes in the total equivalent variation in all countries (wev) for the three sets of experiments and the three models. Three conclusions can be drawn from the table. First, the different trade structures can be ranked in terms of the size of welfare effects as in previous work: the largest welfare gains occur in the Melitz model, followed by the Ethier-Krugman and Armington model. The differences are relatively modest. The welfare gains in the Melitz model are about 10% larger than in the Armington model, but the differences with the Ethier-Krugman

Table 3. Changes in world equivalent variation (WEV) in millions of dollars in different models and for different shocks

Experiment	Calibration parameter	Model	Shock variable	Size shock	Change WEV
1	Tariff elasticity $\varepsilon_i^{v,ta}$	Armington	τ_{irs}	-2%	550175
		Ethier-Krugman	τ_{irs}	-2%	581626
		Melitz	τ_{irs}	-2%	589167
		Melitz	f_{irs}	-56.9%	1007820
2	Tariff elasticity $\varepsilon_i^{v,ta}$	Armington	a_i^{tcd}	-0.1	524617
		Ethier-Krugman	a_i^{tcd}	-0.1	541857
		Melitz	a_i^{tcd} (through τ_{irs})	-0.1	571887
		Melitz	a_i^{tcd} (through f_{irs})	-0.1	571887
3	Trade elasticity $\varepsilon_i^{v,\tau}$	Armington	a_i^{tcd}	-0.1	524617
		Ethier-Krugman	a_i^{tcd}	-0.1	541857
		Melitz	a_i^{tcd} (through τ_{irs})	-0.1	545907
		Melitz	a_i^{tcd} (through f_{irs})	-0.1	545907

Notes: In experiments 1 and 2 the model is calibrated to the tariff elasticity and in experiment 3 to the trade elasticity. Experiment 1 contains uniform shocks to iceberg and fixed trade costs, whereas experiments 2 and 3 contain uniform shocks in the estimated trade cost dummy, tcd_i, from zero to one with different implied shocks to iceberg and fixed trade costs, depending on respectively tariff and trade elasticities in experiments 2 and 3. The implied changes in iceberg trade costs in different models are calculated as explained in the text, based on equations (50), (51), and (53).

Source: Authors calculations with parsimonious firm heterogeneity model.

model are more modest, in the range of 1%-2%. The differences are much smaller than in some of the previous literature. However, the experiments conducted do not include features which are likely to drive the large effects in the Melitz model, endogenous factor supply and different bundles in fixed and variable costs in respectively Balistreri et al. (2010) and Akgul et al. (2016).

Second, Table 3 shows that the way equality of shocks is operationalized has some impact on the welfare effects. In particular, the difference between the Melitz welfare effects and the Ethier-Krugman welfare effects are largest when identical shocks to trade cost measures are converted into ad valorem equivalents based on the model calibrated using tariff elasticities.

Third, as expected, the total effects are identical for shocks to fixed export costs and shocks to iceberg trade costs for the second and third experiment. But we see that the rough conversion of the iceberg trade cost reduction into the reduction in fixed export costs in the first experiment, based on the trade-weighted average tariff elasticity and degree of granularity was not very successful. A shock to fixed export costs of 56.9% has a much lager impact than the 2% shock to iceberg trade costs. The reason for the larger effect in case of the shock to fixed trade costs is that the conversion from iceberg to fixed trade cost shocks based on a single trade-weighted average tariff elasticity leads to different shocks to generalized iceberg trade costs, *genitc*. Shocks to sectors with a small trade elasticity become bigger and shocks to sectors with a large elasticity become smaller. It turns out that this leads to larger welfare effects.

Table 4. Decomposition of welfare effects in millions of dollars

Shock variable	Model	Regions	Welfare (EV)	Allocative efficiency	Investment -savings price	Terms of Trade	Pure iceberg trade costs	Importer productivity	Domestic productivity	Importer variety	Domestic variety
		Total	550175	105653	11	-200	444711	0	0	0	0
Iceberg trade costs	Armington	East Asia	139036	41567	-2332	14530	85271	0	0	0	0
		EU	176353	33059	-728	16494	127528	0	0	0	0
		Total	581626	111929	3	-187	446617	0	0	6485	16778
Iceberg trade costs	Ethier-Krugman	East Asia	140804	44676	-1152	12673	85565	0	0	144	-1101
		EU	185280	33212	-462	13251	127818	0	0	-1464	12924
		Total	589167	114158	0	-195	446235	-260395	272550	326242	-309429
Iceberg trade costs	Melitz	East Asia	141354	44670	-1005	12150	85453	-61391	57619	74261	-70403
		EU	190929	34562	-455	13021	127662	-73579	71813	86898	-68991
		Total	1007820	187556	-13	-387	0	-4442176	551853	5378431	-667510
Fixed trade costs	Melitz	East Asia	209481	68177	-77	9879	0	-786514	105592	948763	-136363
		EU	352469	62683	-577	18748	0	-1350459	158666	1625096	-161744

Notes: The total welfare effect, EV, is decomposed for experiment 1 with uniform reductions in iceberg and fixed trade costs

Source: Authors calculations with parsimonious firm heterogeneity model.

Next, we turn to the decomposition of the welfare effects for the first set of experiments with identical reductions in iceberg and fixed trade costs in the three models in Table 4.[24] We see that the direct impact of reductions in iceberg trade costs (the term ”pure iceberg trade costs”) is very similar across the three models. The additional welfare gains under Ethier-Krugman and Melitz are partially driven by larger allocative efficiency effects, but mostly by the additional terms importer and domestic productivity and importer and domestic variety. We see that in the Melitz model the increase in domestic productivity is somewhat larger than the fall in importer productivity. Domestic productivity rises, because the least-productive firms are squeezed out of the market, whereas the productivity of importers into the country evaluated falls, as it becomes less costly to import into foreign markets.[25] The same holds for changes in the number of varieties. The positive contribution to welfare of an increase in the number of imported varieties is somewhat larger than the negative contribution of the fall in the number of domestic varieties. In the Ethier-Krugman model we see that changes in both the number of domestic and imported varieties are positive. The reason for this difference with the Melitz model is that in the Melitz model the share of firms involved in international trade changes. In the Ethier-Krugman model instead the number of firms from a certain country is identical for all destination markets by the absence of destination-specific fixed costs.

This decomposition provides important insights into the workings of the different models. In the Armington model only the conventional welfare effects are present. In the Ethier-Krugman model also changes in the number of varieties start to play a role. In particular, reductions in iceberg trade costs lead to an increase in welfare for the world as a whole (”Total”), because of an increase in the number of both domestic and imported varieties. However, the contribution of changes in the number of varieties to welfare is not positive for all regions. Table 4 shows for example that the contribution to welfare of changes in the number of domestic varieties is negative, whereas changes in the number of imported varieties is positive. The reason for these opposite signs is that resources are reallocated across sectors. A net reallocation of resources to sectors with weak love-of-variety effects (high substitution elasticities) will reduce welfare, whereas a reallocation towards sectors with strong love-of-variety will raise welfare. Dixon et al. (2018) and Francois et al. (2005) also stress the impact of intersectoral reallocation towards sectors with scale and love-of-variety effects, although Dixon et al. do so in simulations in which only one sector features monopolistic competition and the other sectors remaining Armington.

[24] To save space we only present the global results (”Total ”) and for two regions, East Asia and the European Union. Results for the other regions are in the appendix.

[25] We use the term importer productivity, because this term measures the impact of changes in productivity of all countries importing into the country for which the welfare change is measured.

In the Melitz model both changes in productivity and in the number of varieties play a role. With a fall in iceberg trade costs it becomes easier to export and therefore more firms will export. In terms of the impact on welfare this will on the one hand raise welfare through an increase in the number of varieties imported, the term ”importer variety.” On the other hand this will imply that also less productive firms can start to export and therefore we see a negative contribution to welfare of the term ”importer productivity.” The average productivity level of firms exporting to a given importer will fall with trade liberalization. However, also in the domestic market we will see changes. As first shown theoretically by Melitz (2003) a so-called composition effect will occur. As a result of intensified competition the real wage will rise (or in the present context real bundle prices rise) and some of the least productive firms will be squeezed out of the market. This affects welfare in two ways. On the one hand welfare is increasing through a rise in domestic productivity. On the other hand, the number of domestic varieties supplied will also fall.

Comparing the four additional terms in Table 4 shows that for the world as a whole (”Total”) the positive domestic productivity effects tend to dominate the negative domestic variety effect and the positive importer variety effect tends to dominate the negative importer productivity effect. As a result, the additional mechanisms in the Melitz model raise the total welfare effects of global reductions in trade costs in comparison with the Ethier-Krugman and Armington models. Akgul et al. (2016) find similar results, although the differences in welfare effects in their model are much bigger. This is due to the fact that their model features an important additional mechanism in the firm heterogeneity model. In their model fixed costs employ only value added input bundles, whereas marginal costs employ a combination of value added and intermediate input bundles. Trade liberalization will reduce the costs of intermediate input bundles and thus of marginal costs relative to fixed costs. As a result average firm size can increase, generating a positive scale effect.

The decomposition for the shock to fixed costs deserves additional explanation. The pure iceberg trade costs term is zero, as obviously there is no shock to iceberg trade costs. However, we also did not include a separate term for the change in fixed trade costs. The reason is that the effects of changes in fixed trade costs all run through changes in the number of varieties and productivity. We observe that the negative contribution of the change in importer productivity is an order of magnitude larger than the positive contribution of the change in domestic productivity. At the same time the positive contribution of the change in imported varieties is an order of magnitude larger than the negative contribution of the change in the number of domestic varieties. A reduction in fixed trade costs provokes a huge increase in the number of imported varieties in the model, which harms welfare through the reduction in average productivity of exporting firms (a compositional margin effect) and raises welfare through the increase in the number of imported varieties available. Reductions in fixed costs mainly lead to an increase in the number of small firms able to export. On net the contribution of the increase in the number of firms exporting is positive.

Table 5. Changes in the value of trade in millions of dollars along the different trade margins

Shock variable	Model	Regions	Margins			
			Intensive	Extensive	Compositional	Total
		Total	34058	0	0	34058
Iceberg trade costs	Armington	East Asia	15165	0	0	15165
		EU	9684	0	0	9684
		Total	42080	5589	0	47668
Iceberg trade costs	Ethier-Krugman	East Asia	16320	-29	0	16291
		EU	11492	-1302	0	10190
		Total	31742	59277	-41542	49477
Iceberg trade costs	Melitz	East Asia	12764	17408	-14395	15777
		EU	8637	11376	-10489	9523
		Total	-86636	898728	-724526	87568
Fixed trade costs	Melitz	East Asia	-13596	197346	-162817	20934
		EU	-22090	241575	-202180	17306

Notes: Changes in the value of trade are decomposed for experiment 1 with uniform reductions in iceberg and fixed trade costs

Source: Authors calculations with parsimonious firm heterogeneity model.

Table 5 decomposes the change in the value of trade into the three margins introduced before, the intensive, extensive, and compositional margin. Three things stand out from the table. First, the total change in the world value of trade for an identical shock to iceberg trade costs of 2% is largest in the Melitz model, followed by the Ethier-Krugman model, and then the Armington model.[26] We do not take into account the changes in the Melitz model provoked by shocks to fixed costs, since the total welfare effects are also much larger for this shock due to the size of the shock. Second, the intensive margin is smallest in the Melitz model, which is compensated for by a large value of the extensive margin relative to the compositional margin. Third, we see that the contribution of the extensive margin in the Ethier-Krugman model is an order of magnitude smaller than in the Melitz model. In the Ethier-Krugman model the extensive margin is exclusively driven by changes in the number of entering firms to the market, whereas in the Melitz model also changes in the number of firms exporting to specific destinations play

[26] Dixon et al. (2016) have argued that a fair comparison between the three models would require an identical change in the volume of trade. As pointed out before, we argue that empirical observable elasticities should be identical. The two do not correspond, because in the Melitz model there are additional changes in the model leading to changes absorbed by the fixed effects in a gravity estimation. Imposing equal changes in trade volumes would likely imply in our model that the welfare effects under Melitz would become (much) smaller than under Armington, since changes in the value of trade in the Melitz model are almost 50% larger.

a role.

The trade margin decomposition is another way to examine the different mechanisms operative in the three models. Whereas in the welfare decomposition we focused on variety and productivity effects, here we decompose trade into three margins. In the Armington model only the intensive margin is operative, since productivity of all firms from a certain country is identical and the number of firms is not explicitly identified in this model. In the Ethier-Krugman model both the intensive and extensive margins are operative. However, by absence of destination-specific fixed costs the contribution of the number of firms to changes in the value of trade is limited in this model. The extensive margin only consists of changes in the number of producing firms. In the Melitz model all three margins are operative. A reduction in iceberg trade costs raises trade along the intensive margin: firms already exporting will export more when trade costs are falling. Trade rises, however, also along the extensive margin. Lower trade costs enable more firms to export. Finally, the value of trade falls with a reduction in trade costs along the compositional margin: lower trade costs enables also the less-productive firms to export and this will exert a negative influence on the value of exports. The compositional margin reflects that lower trade costs make it easier for firms to export and therefore also the less productive firms can export. The reduction in average exporter productivity leads to lower exporter sales. Other CGE-models with firm heterogeneity do not focus on this decomposition of trade flows.

In the analysis we have worked with the assumption that labor is imperfectly mobile between sectors. The question is what the influence is of this assumption on the welfare ranking of the different models. To explore this question we have replicated the simulations presented in this section varying the elasticity of transformation of labor between sectors from 1 to 7. The results reported above are based on an elasticity of transformation for the three types of labor of 5. Table 6 shows the change in world equivalent variation (WEV) for the experiments also presented in Table 3 and Figure 1 displays the change in WEV for the Armington, Ethier-Krugman, and Melitz model for an identical change of 2% in global iceberg trade costs. We get three main insights from the table and figure. First, the relative welfare ranking in terms of models is robust to variation in the degree of sluggishness of labor. We find that the welfare effect is largest for the Melitz model, followed by the Ethier-Krugman model, and finally the Armington model. Second, for lower values of the elasticity of transformation shocks to a_i^{tcd}, a variable appearing in the gravity equation, generate the same effect in different implementations of the Melitz models, regardless of whether the shocks are implemented through a change in iceberg or in fixed trade costs. For larger values small differences in the change in world equivalent variation start to emerge.[27] Third, Figure 1 shows that

[27] This equivalence also holds for shocks to a_i^{tcd} and calibration to either the tariff or trade elasticity in the Ethier-Krugman model and the Armington model. However, for larger

Table 6. Changes in world equivalent variation (WEV) in millions of dollars for different degrees of labor mobility

Exp.	Model	Shock variable	Size shock	Elasticity of transformation labor						
				1	2	3	4	5	6	7
1	Armington	τ_{irs}	-2%	523752	524214	524422	524540	524617	524663	524714
	Ethier-Krugman	τ_{irs}	-2%	536157	538511	539985	541054	541857	542435	542811
	Melitz	τ_{irs}	-2%	565309	568130	569915	571146	571887	572108	571943
	Melitz	f_{irs}	-56.9%	565308	568130	569915	571145	571887	572102	571869
2	Armington	a_i^{tcd}	-0.1	523752	524214	524422	524539	524617	524670	524706
	Ethier-Krugman	a_i^{tcd}	-0.1	536156	538510	539986	541054	541857	542435	542800
	Melitz	a_i^{tcd} (τ_{irs})	-0.1	539343	542086	543840	545085	545907	546280	546263
	Melitz	a_i^{tcd} (f_{irs})	-0.1	539343	542086	543840	545086	545907	546278	546277
3	Armington	a_i^{tcd}	-0.1	548928	549593	549891	550063	550175	550251	550311
	Ethier-Krugman	a_i^{tcd}	-0.1	574141	577106	579004	580448	581626	582598	583371
	Melitz	a_i^{tcd} (τ_{irs})	-0.1	580488	583897	586138	587853	589167	590001	590163
	Melitz	a_i^{tcd} (f_{irs})	-0.1	994459	1000135	1003606	1006100	1007866	1009121	1010492

Notes: See Table 3 for description of different experiments.

Source: Authors calculations with parsimonious firm heterogeneity model.

the difference in welfare effects rises somewhat with the degree of labor mobility. As the elasticity of transformation rises, the WEV stays fairly constant for the Armington model, whereas it rises slowly though steady for the Ethier-Krugman and Melitz model. This result can be explained from the fact that labor mobility has stronger beneficial effects for the models featuring scale effects and love-of variety.

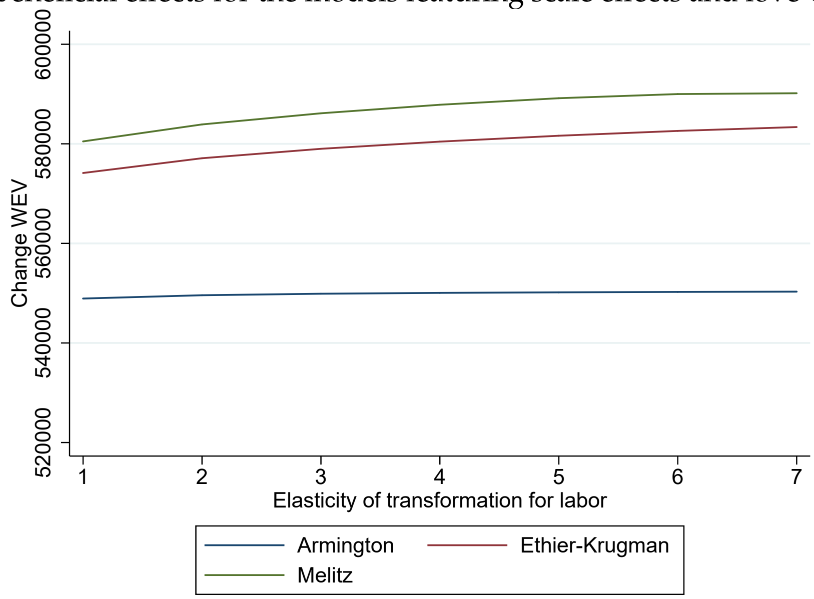

Figure 1. Change in world equivalent variation (WEV) for different degrees of labour mobility

Notes: The table displays the change in WEV for values of the elasticity of transformation of labor across sectors varying between 1 and 7 of a 2% reduction in iceberg trade costs.

Source: Authors calculations with parsimonious firm heterogeneity model.

6. Concluding Remarks

In this paper we have proposed a setup to capture three trade models (Armington, Ethier-Krugman, and Melitz) in the standard trade framework of the GTAP model by including demand, supply, and trade cost shifters. We have shown how the expressions in the standard trade framework are adapted, outlined their implementation in the GTAP framework, provided intuition for the expressions, and included a detailed derivation (in the appendix). Our framework does not require solving for additional pairwise variables like the cutoff productivity and the mass of firms, keeping the dimensionality of the model limited. We have also extended the standard welfare decomposition in the GTAP framework adding terms for changes in domestic and imported average productivity and numbers of vari-

degrees of labor mobility small differences appear between the welfare effects.

eties.

We have presented the gravity equations in the different trade structures and discussed ad valorem equivalents based on gravity estimates of trade policy measures. We have used these estimates to conduct experiments of reductions in iceberg and fixed trade cost reductions with a medium-sized model with 11 countries, 11 sectors, and 6 factors of production. The simulations show that the welfare effects are largest in the Melitz model, followed by the Ethier-Krugman, and Armington model, although the differences are modest. In our companion paper, Bekkers and Francois (2018), we focus on the factors determining differences in outcomes of counterfactual experiments in the different models. In that paper we show first that the comparison of welfare effects across the models is sensitive to the calibration of parameters in a simple single-sector two-country model without intermediate linkages.In particular, calibration can be such that the structural parameters are identical (the substitution elasticity and the shape parameter of the productivity distribution) or such that the empirically observed parameters are identical (the trade or tariff elasticity and the level of granularity of the firm size distribution). Second, we show which modelling features matter most for the differences between models in the impact of multilateral trade liberalization on welfare in a medium-sized model like in the current paper. As also shown in Bekkers and Romagosa (2018) for the case of trade cost reductions in the framework of TTIP, welfare effects tend to be magnified with stronger intermediate linkages and endogenous labor supply and capital accumulation. In comparison to the work in the CGE-literature on firm heterogeneity, such as Akgul et al. (2016) and Dixon et al. (2018) these conditional results are new. Akgul et al. (2016) show that welfare effects in their model with firm heterogeneity are much larger than in the model with Armington preferences without an impact of other modelling features on this result. Dixon et al. (2018) conduct experiments with firm heterogeneity in one of the 57 sectors, showing that this generates larger welfare effects because of reallocation of resources towards the firm heterogeneity sector which features scale effects.

Most CGE-models handle international trade with Armington preferences. Our parsimonious and straightforward implementation of the three trade models in the widely used Armington framework makes it relatively easy to incorporate the three trade models into other CGE-models. In our approach the expressions for domestic and importer demand and the price index only have to be extended using demand, supply, and trade cost shifters. Our framework comes along with a relatively easy calibration of parameters and baseline, requiring only tariff elasticities, shape parameters of the firm size distribution, and import shares without needing specific information about the size of fixed trade costs or markups.

Our current work could be extended into at least three directions. First, we could impose country-specific values for the substitution elasticities and the trade parameters, although this obviously would also require the estimation of country-specific tariff/trade elasticities and firm size shape parameters. Second, we could extend our parsimonious setup with features addressed in the literature on firm heterogeneity like endogenous unemployment, endogenous innovation, and multinational activity. Third, we could estimate the CET-parameters governing the degree of labor immobility based on labor market data and or changes in the GTAP data over time.

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References

Aichele, R., G. Felbermayr, and I. Heiland. 2014. "Going Deep: The Trade and Welfare Effects of TTIP." Center for Economic Studies and Ifo Institute, CESifo Working Paper No. 5150. https://www.cesifo-group.de/DocDL/wp-2016-219-aichele-felbemayr-heiland-welfare-ttip.pdf.

Akgul, Z., and S. Ahmad. 2017. "Using Power Laws to Identify the Structural Parameters of Trade Models with Firm Heterogeneity." USITC Working Paper, Report No. 2017-5-B. https://www.gtap.agecon.purdue.edu/resources/download/8990.pdf.

Akgul, Z., N. Villoria, and T. Hertel. 2016. "GTAP-HET: Introducing firm heterogeneity into the GTAP model." *Journal of Global Economic Analysis*, 1(1): 111–180.

Akgul, Z., N. Villoria, and T. Hertel. 2015. "Theoretically-Consistent Parameterization of a Multi-Sector Global Model with Heterogeneous Firms." Organized Session Presentation at the 18th Annual Conference on Global Economic Analysis, Melbourne, Australia, Report. https://www.gtap.agecon.purdue.edu/resources/download/7455.pdf.

Ardelean, A. 2007. "How strong is love of variety?" Purdue University, Report. https://www.gtap.agecon.purdue.edu/resources/download/3323.pdf.

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

Artuc, E., D. Lederman, and G. Porto. 2015. "A Mapping of Labor Mobility Costs in the Developing World." *Journal of International Economics*, 95(1): 28–41.

Balistreri, E.J., R.H. Hillberry, and T.F. Rutherford. 2012. "Structural Estimation and Solution of International Trade Model with Heterogeneous Firms." *Economic Letters*, 83(1): 95–108.

Balistreri, E.J., R.H. Hillberry, and T.F. Rutherford. 2010. "Trade and Welfare: Does Industrial Organization Matter?" *Economic Letters*, 109(2): 85–87.

Bekkers, E., and J. Francois. 2018. "The Effects of Trade Liberalization on Welfare in Quantitative Trade Models." Unpublished, working paper, University of Bern.

Bekkers, E., J. Francois, and H. Rojas-Romagosa. 2018. "Melting Ice Caps and the Economic Impact of Opening the Northern Sea Route." *Economic Journal*, 128(610): 1095–1127.

Bekkers, E., and H.R. Romagosa. 2018. "The welfare effects of free trade agreements in quantitative trade models. A comparison of studies about Transatlantic Trade and Investment Partnership." *World Economy*, Forthcoming.

Benassy, J.P. 1996. "Taste for variety and optimum production patterns in monopolistic competition." *Economics Letters*, 52: 41–47.

Britz, W., and Y. Jafari. 2017. "Introducing Firm Heterogeneity Theory into CGE-Box." University of Bonn, Report. http://www.ilr.uni-bonn.de/em/rsrch/cgebox/GTAP_Melitz.pdf.

Cadot, O., and J. Gourdon. 2016. "Non-tariff measures, preferential trade agreements, and prices: new evidence." *Review of World Economics*, 152(2): 227–249.

Caliendo, L., R.C. Feenstra, J. Romalis, and A.M. Taylor. 2015. "Tariff Reductions, Entry, and Welfare: Theory and Evidence for the Last Two Decades." NBER Working Paper, Report No. 21768. https://ideas.repec.org/p/nbr/nberwo/21768.html.

Caliendo, L., and F. Parro. 2015. "Estimates of the Trade and Welfare Effects of NAFTA." *Review of Economic Studies*, 82(1): 1–44.

Corong, E.L., T.W. Hertel, R.A. McDougall, M. Tsigas, and D. van der Mensbrugghe. 2017. "The Standard GTAP Model, Version 7." *Journal of Global Economic Analysis*, 2(1): 1–119.

Costinot, A., and A. Rodriguez-Clare. 2014. "Trade Theory with Numbers: Quantifying the Consequences of Globalization." In *Handbook of International Economics*, edited by G. Gopinath, E. Helpman, and K. Rogoff. Elsevier, vol. 4, pp. 197–261.

Cruz, M., E. Milet, and M. Olarreaga. 2017. "Labor Adjustment Costs across Sectors and Regions." World Bank Policy Research Working Paper, Report No. 8233. http://documents.worldbank.org/curated/en/181111509642976782/Labor-adjustment-costs-across-sectors-and-regions.

di Giovanni, J., A. Levchenko, and R. Ranciere. 2011. "Power laws in firm size and openness to trade: Measurement and implications." *Journal of International Economics*, 85: 42–52.

Dix-Carneiro, R. 2014. "Trade Liberalization and Labor Market Dynamics." *Econometrica*, 82(3): 825–885.

Dixon, P.B., M. Jerie, and M.T. Rimmer. 2016. "Modern trade theory for CGE modelling: the Armington, Krugman and Melitz models." *Journal of Global Economic Analysis*, 1(1): 111–180.

Dixon, P.B., M. Jerie, and M.T. Rimmer. 2018. *Trade theory in computable general equilibrium models: Armington, Krugman and Melitz, Advances in Applied General Equilibrium Modelling*. Springer Nature.

Eaton, J., S. Kortum, and F. Kramarz. 2011. "An Anatomy of International Trade: Evidence from French Firms." *Econometrica*, 79(5): 1453–98.

Egger, P., J. Francois, M. Manchin, and D. Nelson. 2015. "Non-tariff Barriers, Integration, and the Transatlantic Economy." *Economic Policy*, 30(1): 539–584.

Ethier, W. 1982. "National and International Returns to Scale in the Modern Theory of International Trade." *American Economic Review*, 72(3): 389–405.

Feenstra, R.C., P. Luck, M. Obstfeld, and K.N. Russ. 2018. "In Search of the Armington Elasticity." *Review of Economics and Statistics*, 100(1): 135–150.

Felbermayr, G., and B. Jung. 2015. "Market Size and TFP in New New Trade Theory." Cesifo Working Paper, Report No. 5583. http://www.cesifo-group.de/de/ifoHome/publications/docbase/DocBase_Content/WP/WP-CESifo_Working_Papers/wp-cesifo-2015/wp-cesifo-2015-10/12012015005583.html.

Francois, J. 2001. "Factor Mobility, Economic Integration, and the Location of Industry." In *Economic Impact of EU Membership on Entrants*, edited by R. Baldwin and A. Brunetti. Springer Science+Business Media: New York, pp. 73–91.

Francois, J. 1998. "Scale Economies and Imperfect Competition in the GTAP Model." GTAP, Report No. Technical Paper 14. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=317.

Francois, J., M. Manchin, and W. Martin. 2013. "Market Structure in CGE Models of Open Economies." In *Handbook of computable general equilibrium modeling*, edited by P. Dixon and D. Jorgenson. Elsevier, pp. 1571–1600.

Francois, J., and D. Nelson. 2002. "A Geometry of Specilization." *Economic Journal*, 112(481): 649–678.

Francois, J., H. Van Meijl, and F. Van Tongeren. 2005. "The Doha Round and Developing Countries." *Economic Policy*, 20(42): 349–391.

Harrison, G.W., T.F. Rutherford, and D.G. Tarr. 1997. "Quantifying the Uruguay round." *The Economic Journal*, 107(444): 1405–1430.

Head, K., and T. Mayer. 2014. "Gravity Equations: Workhorse, Toolkit, and Cookbook." In *Handbook of International Economics*, edited by G. Gopinath, E. Helpman, and K. Rogoff. Elsevier, vol. 4, pp. 131–195.

Hertel, T. 1997. *Global Trade Analysis: Modeling and Applications*. Cambridge University Press.

Huff, K.M., and T.W. Hertel. 2000. "Decomposing Welfare Changes in the GTAP Model." GTAP, Report No. Technical Paper 5. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=308.

Itakura, K., and K. Oyamada. 2013. "Incorporating Firm Heterogeneity into the GTAP Model." Paper presented at the 16th Annual conference on Global Economic Analysis, Shanghai, China, Report. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4190.

Jung, B. 2015. "Allocational efficiency with heterogeneous firms: Disentangling love of variety and market power." *Economics Letters*, 134: 141–143.

Krugman, P. 1980. "Scale Economies, Product Differentiation, and the Pattern of Trade." *American Economic Review*, 70: 950–959.

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

Melitz, M.J., and S.J. Redding. 2013. "Firm Heterogeneity and Aggregate Welfare." CEPR, Report No. DP 9405. https://econpapers.repec.org/paper/cprceprdp/9405.htm.

Oyamada, K. 2015. "Behavioral characteristics of applied general equilibrium models with an Armington-Krugman-Melitz encompassing module." IDE Discussion Paper, Report No. 525. https://ideas.repec.org/p/jet/dpaper/dpaper525.html.

Spearot, A. 2016. "Unpacking the long run effects of tariff shocks: New structural implications from Firm Heterogeneity Models." *AEJMicroeconomics*, 8(2): 128–67.

Swaminathan, P., and T. Hertel. 1996. "Introducing monopolistic competition into the GTAP model." GTAP, Report No. Technical Paper 6. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=309.

Zhai, F. 2008. "Armington meets Melitz: introducing firm heterogeneity in a global CGE model of trade." *Journal of Economic Integration*, 23(3): 575–604.

Appendix A. Derivation Demand, Supply, and Trade Cost Shifter

In this section we derive the expressions for the demand, supply, and trade cost shifter in the Ethier-Krugman and Melitz models. To do so we write the price index in these two models, p_{is}^{ag}, as defined in equation (7) as in the standard GTAP model as in (4) and (6). The price index in the standard model is equal to the price index in the Ethier-Krugman/Melitz model if we have the following expressions:

$$\frac{p_{irs}}{e_{is}^{m}} = \frac{t_{irs} ta_{irs} p_{irs}^{cif}}{c_{ir}^{m} e_{is}^{m}} = \left(M_{is}^{\nu_i - 1} \int_{\omega \in \Omega_{irs}} p^{ag,o} \left(\omega \right)^{1-\sigma_i} d\omega \right)^{\frac{1}{1-\sigma_i}} \tag{A.1}$$

$$\frac{p_{iss}^{d,ag}}{e_{is}^{d}} = \frac{tp_{is} p_{is}^{ib}}{e_{is}^{d} c_{is}^{d}} = \left(M_{is}^{\nu_i - 1} \int_{\omega \in \Omega_{iss}^{d}} p^{ag,o} \left(\omega \right)^{1-\sigma_i} d\omega \right)^{\frac{1}{1-\sigma_i}} \tag{A.2}$$

We will now elaborate on the RHS of (A.1)-(A.2) for the two models. This will then give the expressions for t_{irs}, e_{is}^{so}, and c_{is}^{so}.

A.1 Ethier-Krugman Economy

To determine t_{irs}, e_{is}^{so}, and c_{ir}^{so} in the Ethier-Krugman model we rewrite the RHS of equation (A.1), recognizing that all firms (and thus all prices) are identical in this model:

$$\frac{t_{irs} ta_{irs} p_{irs}^{cif}}{c_{ir}^{m} e_{is}^{m}} = M_{is}^{\frac{\nu_i - 1}{1-\sigma_i}} N_{ir}^{\frac{1}{1-\sigma_i}} p_{irs}^{o} \tag{A.3}$$

Hence, we need to determine N_{ir} and p_{irs}^{o} in the model. To do so we combine the markup equation, the free entry condition, and factor market equilibrium, starting with the expression for firm demand.

Preferences as defined in equation (7) imply that a firm producing in country r faces the following demand in country s (since firms are identical we omit a variety or firm identifier):

$$o_{irs} = \left(M_{is} \right)^{\nu_i - 1} \left(\frac{p_{irs}^{o}}{p_{is}^{so}} \right)^{-\sigma_i} \sum_{ag} \left(\frac{ta_{is}^{so,ag} p_{is}^{so}}{p_{is}^{ag}} \right)^{-\rho_i} \frac{E_{is}^{ag}}{p_{is}^{ag}} \tag{A.4}$$

p_{irs}^{o} is the firm's price corresponding with quantity o_{irs} (exclusive of group-specific taxes $ta_{is}^{so,ag}$), p_{is}^{so} the price index of goods from source so (domestic or foreign), p_{is}^{ag} the aggregate price index for end user ag and E_{is}^{ag} its expenditures. Profits can be written as revenues minus costs:

$$\pi_{irs} = \frac{p_{irs}^{o} o_{irs}}{ta_{irs}} - \tau_{irs} \left(te_{irs} tp_{ir} b_{ir} p_{ir}^{ib} + \frac{p_{irs}^{ts}}{a_{irs}^{ts}} \right) o_{irs} - a_{ir} tp_{ir} p_{ir}^{ib} \tag{A.5}$$

This expression for profit in (A.5) implies the following standard markup pricing rule:

$$p^{o}_{irs} = \frac{\sigma_i}{\sigma_i - 1} ta_{irs} \tau_{irs} \left(te_{irs} tp_{ir} b_{ir} p^{ib}_{ir} + \frac{p^{ts}_{irs}}{a^{ts}_{irs}} \right) \tag{A.6}$$

Profits of a firm from country r can now be written as revenues divided by σ_i times ta_{irs} minus fixed costs and equalized to zero by free entry:

$$\pi_{ir} = \sum_{s=1}^{S} \frac{p^{o}_{irs} o_{irs}}{\sigma_i ta_{irs}} - a_{ir} tp_{ir} p^{ib}_{ir} = 0 \tag{A.7}$$

We can now determine the number of varieties produced in country r, N_{ir}, based on factor market equilibrium with q^{ib}_{ir} the quantity of input bundles from country r:

$$\left(\sum_{s=1}^{S} \tau_{irs} o_{irs} + a_{ir} \right) N_{ir} = q^{ib}_{ir} \tag{A.8}$$

We have to take into account the presence of transport costs, by rewriting physical output inclusive of iceberg trade costs as follows based on the markup equation in (A.6):

$$\tau_{irs} o_{irs} = \frac{\sigma_i - 1}{\sigma_i} \frac{p^{o}_{irs} o_{irs}}{tp_{ir} p^{ib}_{i} ta_{irs}} + \frac{\sigma_i - 1}{\sigma_i} \frac{p^{o}_{irs} o_{irs}}{tp_{ir} p^{ib}_{ir} ta_{irs}} \left(\frac{1}{te_{irs} tp_{ir} b_{ir} + \frac{p^{ts}_{irs}}{p^{ib}_{ir} a^{ts}_{irs}}} - 1 \right) \tag{A.9}$$

We can now combine equations (A.7)-(A.9) to solve for N_{ir}:

$$N_{ir} = \frac{\widetilde{q^{ib}_{ir}}}{\sigma_i a_{ir}} \tag{A.10}$$

We can now rewrite equation (A.3) as follows, using the expressions for p^{o}_{irs} and N_{ir} in (A.6) and (A.10):

$$\frac{t_{irs} ta_{irs} p^{cif}_{irs}}{c^{m}_{ir} e^{m}_{is}} = M_{is}^{\frac{\nu_i - 1}{1-\sigma_i}} \left(\frac{\widetilde{q^{ib}_{ir}}}{\sigma_i a_{ir}} \right)^{\frac{1}{1-\sigma_i}} \frac{\sigma_i}{\sigma_i - 1} ta_{irs} \tau_{irs} p^{cif}_{irs} \tag{A.11}$$

Equation (A.11) implies the expressions for t_{irs}, c^{m}_{ir}, and e^{m}_{is} in the main text.

A.2 Melitz Economy

The preferences defined in (7) imply the following expression for revenues of a firm with productivity φ:

$$r_{irs}(\varphi) = (M_{is})^{\nu_i - 1} \left(\frac{p^{o}_{irs}(\varphi)}{p^{so}_{is}} \right)^{1-\sigma_i} \sum_{ag} \left(\frac{ta^{so,ag}_{is} p^{so}_{is}}{p^{ag}_{is}} \right)^{1-\rho_i} E^{ag}_{is} \tag{A.12}$$

A standard markup pricing rule follows from profit maximization:

$$p^{o}_{irs}\left(\varphi\right)=\frac{\sigma_i}{\sigma_i-1}\frac{ta_{irs}\tau_{irs}p^{cif}_{irs}}{\varphi} \tag{A.13}$$

Profits for sales from country r to s can be written as:

$$\pi_{irs}\left(\varphi\right)=M_{is}^{\nu_i-1}\left(\frac{p^{o}_{irs}\left(\varphi\right)}{p^{so}_{is}}\right)^{1-\sigma_i}\sum_{ag}\left(\frac{ta^{so,ag}_{is}p^{so}_{is}}{p^{ag}_{is}}\right)^{1-\rho_i}\frac{E^{ag}_{is}}{ta^{so,ag}_{is}ta_{irs}\sigma} - f_{irs}tp_{ir}p^{ib}_{ir} \tag{A.14}$$

We can now define a zero cutoff profit (ZCP) and free entry (FE) condition. The ZCP dictates that a firm with a cutoff productivity level, φ^{*}_{irs}, makes zero profit ex post (so knowing its productivity and having already paid sunk entry costs). Substituting the pricing equation (A.13) into the expression for profit in (A.14) and solving for φ^{*}_{irs} leads to:

$$\varphi^{*}_{irs}=\frac{\frac{\sigma_i}{\sigma_i-1}ta_{irs}\tau_{irs}p^{cif}_{irs}}{\left(\sigma_i f_{irs}p^{ib}_{ir}ta_{irs}\right)^{\frac{1}{1-\sigma_i}}} * \left(\sum_{ag}M_{is}^{\nu_i-1}\left(\frac{ta^{so,ag}_{is}p^{so}_{is}}{P^{ag}_{is}}\right)^{1-\rho_i}\frac{M_{is}^{\nu_i-1}\left(p^{so}_{is}\right)^{\sigma_i-1}E^{ag}_{is}}{ta^{so,ag}_{is}}\right)^{\frac{1}{1-\sigma_i}} \tag{A.15}$$

According to the free entry condition, expected profit before entry (ex ante) is equal to the sunk entry costs:

$$\sum_{s=1}^{S}\left(1-G_{ir}\left(\varphi^{*}_{irs}\right)\right)\pi_{irs}\left(\widetilde{\varphi}_{irs}\right)=\delta en_{ir}tp_{ir}p^{ib}_{ir} \tag{A.16}$$

$\widetilde{\varphi}_{irs}$ is average productivity defined as:

$$\widetilde{\varphi}_{irs}=\left(\int_{\varphi^{*}_{irs}}^{\infty}\varphi^{\sigma-1}\frac{g_{ir}\left(\varphi\right)}{1-G_{ir}\left(\varphi^{*}_{irs}\right)}d\varphi\right)^{\frac{1}{\sigma_i-1}}=\left(\frac{\theta_i}{\theta_i-\sigma_i+1}\right)^{\frac{1}{\sigma_i-1}}\varphi^{*}_{irs} \tag{A.17}$$

The second equality follows from imposing a Pareto distribution for productivity φ, as in equation (11).

Imposing the ZCP and $\frac{r_{irs}(\varphi_1)}{r_{irs}(\varphi_2)}=\left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma_i-1}$, the FE can be expressed as:

$$\sum_{s=1}^{S}\left(1-G_{ir}\left(\varphi^{*}_{irs}\right)\right)tp_{ir}p^{ib}_{ir}f_{irs}\left(\left(\frac{\widetilde{\varphi}_{irs}}{\varphi^{*}_{irs}}\right)^{\sigma_i-1}-1\right)=\delta en_{ir}tp_{ir}p^{ib}_{ir} \tag{A.18}$$

Finally, we can rewrite the FE imposing the Pareto distribution and employing equation (A.17):

$$\sum_{s=1}^{S} \left(\frac{\kappa_{ir}}{\varphi^*_{irs}}\right)^{\theta} f_{irs} \frac{\sigma_i - 1}{\theta_i - \sigma_i + 1} = \delta en_{ir} \tag{A.19}$$

Before defining the bilateral price in the Melitz model, we still need to derive an expression for the number of varieties, N_{irs}. With a steady state of entry and exit, the number of entrants, NE_{ir}, times the probability of successful entry, $1 - G_{ir}\left(\varphi^*_{irs}\right)$, is equal to the number of exiting firms, δN_{irs}:

$$N_{irs} = \frac{\left(1 - G_{ir}\left(\varphi^*_{irs}\right)\right) NE_{ir}}{\delta} = \left(\frac{\kappa_{ir}}{\varphi^*_{irs}}\right)^{\theta_i} \frac{NE_{ir}}{\delta} \tag{A.20}$$

Combining the free entry condition with factor market equilibrium, enables us to write the number entrants, NE_{ir}, as a function of the number of factor input bundles, q^{ib}_{ir}:

$$NE_{ir} = \frac{\sigma_i - 1}{\theta_i \sigma_i} \frac{\widetilde{q^{ib}_{ir}}}{en_{ir}} \tag{A.21}$$

We have now expressions for all the components featuring in the bilateral price, defined in equation (A.1) and rewritten as follows:

$$\frac{p_{irs}}{e^m_{is}} = \frac{t_{irs} ta_{irs} p^{cif}_{irs}}{c^m_{ir} e^m_{is}} = M_{is}^{\frac{\nu_i - 1}{1-\sigma_i}} N_{irs}^{\frac{1}{1-\sigma_i}} p_{irs}\left(\widetilde{\varphi}_{irs}\right)$$

So, using the expression for N_{irs} in (A.20), for NE_{ir} in (A.21), for $p_{irs}\left(\varphi\right)$ in (A.13), and for $\widetilde{\varphi}_{irs}$ in (A.17), we can write:

$$\begin{aligned}\frac{p_{irs}}{e^m_{is}} &= \frac{t_{irs} ta_{irs} p^{cif}_{irs}}{c^m_{ir} e^m_{is}} \\ &= M_{is}^{\frac{\nu_i - 1}{1-\sigma_i}} \left(\frac{\kappa_{ir}}{\varphi^*_{irs}}\right)^{\frac{\theta_i}{1-\sigma_i}} \left(\frac{\sigma_i - 1}{\theta_i \sigma_i} \frac{\widetilde{q^{ib}_{ir}}}{\delta en_{ir}}\right)^{\frac{1}{1-\sigma_i}} \frac{\sigma_i}{\sigma_i - 1} \frac{ta_{irs} \tau_{irs} p^{cif}_{irs}}{\left(\frac{\theta_i}{\theta_i - \sigma_i + 1}\right)^{\frac{1}{\sigma_i - 1}} \varphi^*_{irs}}\end{aligned} \tag{A.22}$$

Rearranging and substituting for φ^*_{irs} from (A.15) gives after straightforward reorganizing the following final expression for international flows:

$$\begin{aligned}\frac{p_{irs}}{e^{so}_{is}} = \gamma_{m,i} &\left(\frac{\kappa^{\theta_i}_{ir} \widetilde{q^{ib}_{ir}}}{\delta en_{ir}}\right)^{\frac{1}{1-\sigma_i}} \left(p^{cif}_{irs}\right)^{\frac{\theta_i}{\sigma_i - 1}} \left(f_{ir} tp_{ir} p^{ib}_{ir}\right)^{\frac{\theta + \sigma - 1}{(\sigma-1)^2}} ta_{irs}^{\frac{\theta_i}{\sigma_i - 1} + \frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}} \left(\tau_{irs}\right)^{\frac{\theta_i}{\sigma_i - 1}} \\ * M_{is}^{\frac{\nu_i - 1}{1-\sigma_i}} &\left(\sum_{ag} M_{is}^{\nu_i - 1} \left(\frac{p^{ag}_{is}}{ta^{m,ag}_{is} p^m_{is}}\right)^{\rho - 1} \frac{\left(p^m_{is}\right)^{\sigma - 1} E^{ag}_{is}}{ta^{m,ag}_{is}}\right)^{-\frac{\theta_i - \sigma_i + 1}{(\sigma_i - 1)^2}}\end{aligned} \tag{A.23}$$

And for domestic flows we get:

$$\frac{p_{iss}^{d,ag}}{e_{is}^{d}} = \frac{tp_{is}p_{is}^{ib}}{e_{is}^{d}c_{is}^{d}} = \gamma_{m,i}\left(\frac{\kappa_{is}^{\theta_i}\widetilde{q_{is}^{ib}}}{\delta en_{is}}\right)^{\frac{1}{1-\sigma_i}} \left(tp_{is}p_{is}^{ib}\right)^{\frac{\theta_i}{\sigma_i-1}+\frac{\theta_i+\sigma_i-1}{(\sigma_i-1)^2}}$$
$$* M_{is}^{\frac{\nu_i-1}{1-\sigma_i}}\left(\sum_{ag} M_{is}^{\nu_i-1}\left(\frac{p_{is}^{ag}}{ta_{is}^{m,ag}p_{is}^{m}}\right)^{\rho-1}\frac{\left(p_{is}^{m}\right)^{\sigma-1}E_{is}^{ag}}{ta_{is}^{m,ag}}\right)^{-\frac{\theta_i-\sigma_i+1}{(\sigma_i-1)^2}} \quad \text{(A.24)}$$

The expressions for e_{is}^{so}, t_{irs}, and c_{ir}^{so} in the main text follow from equations (A.23)-(A.24). Comparing these two equations shows why the coefficients on $tp_{ir}p_{ir}^{ib}$ are different for imported and domestic flows: the impact through marginal costs in production runs through p_{irs}^{cif} for international flows.

Appendix B. Number of Consumed Varieties

We start with the expression for the number of consumed varieties in the Melitz model, M_{is}. Defining N_{iss}^{d} as the number of domestic varieties in country s and N_{irs} the number of varieties sold from r to s (also applying to intra-regional trade for $r = s$), we can employ $M_{is} = N_{iss}^{d} + \sum_{r=1}^{S} N_{irs}$ and the expression for N_{irs} in equation (A.20) and for φ_{irs}^{*} in (A.15) gives the following expression:

$$
\begin{aligned}
M_{is}^{\frac{\sigma_i - 1 - \theta_i(\nu_i - 1)}{\sigma_i - 1}} = \gamma_{M,i} * \Bigg\{ & \frac{\kappa_{is}^{\theta_i} \widetilde{q_{is}^{ib}}}{\delta en_{is}} \left(f_{iss}^{d} p_{is}^{ib}\right)^{\frac{\theta_i}{1-\sigma_i}} \left(p_{is}^{ib}\right)^{-\theta_i} * \\
& \left(\sum_{ag} \left(\frac{p_{is}^{ag}}{ta_{is}^{d,ag} p_{is}^{d}} \right)^{\rho_i - 1} \frac{\left(p_{is}^{d}\right)^{\sigma_i - 1} E_{is}^{ag}}{ta_{is}^{d,ag}} \right)^{\frac{\theta_i}{\sigma_i - 1}} \\
& + \sum_{s=1}^{S} \frac{\kappa_{ir}^{\theta_i} \widetilde{q_{ir}^{ib}}}{\delta en_{ir}} \left(f_{irs} p_{ir}^{ib} ta_{irs}\right)^{\frac{\theta_i}{1-\sigma_i}} \left(ta_{irs} \tau_{irs} p_{irs}^{cif}\right)^{-\theta_i} \\
& * \left(\sum_{ag} \left(\frac{P_{is}^{ag}}{ta_{is}^{m,ag} p_{is}^{m}} \right)^{\rho_i - 1} \frac{\left(p_{is}^{m}\right)^{\sigma_i - 1} E_{is}^{ag}}{ta_{is}^{m,ag}} \right)^{\frac{\theta_i}{\sigma_i - 1}} \Bigg\}
\end{aligned} \tag{B.1}
$$

We first derive the percentage change of M_{is} for the Melitz model and then for the Ethier-Krugman model. Hat differentiating the expression for M_{is}^{mel} in equation (B.1) gives:

$$
\begin{aligned}
\varpi \widehat{M_{is}^{mel}} = & \sum_{r=1}^{S} share_{irs}^{M} \left(\widehat{NE_{ir}} - \frac{\theta_i}{\sigma_i - 1} \left(\widehat{f_{irs}} + \widehat{tp_{ir} p_{ir}^{ib}} + \widehat{ta_{irs}} \right) - \theta_i \left(\widehat{ta_{irs}} + \widehat{\tau_{irs}} + \widehat{p_{irs}^{cif}} \right) \right) \\
& + \frac{\theta_i}{\sigma_i - 1} \sum_{r=1}^{S} share_{irs}^{M} \sum_{ag} \frac{p_{is}^{m} q_{is}^{m,ag}}{\sum_{ag'} p_{is}^{m} q_{is}^{m,ag'}} \{ (\rho_i - 1) \left(\widehat{P_{is}^{ag}} - \widehat{ta_{is}^{m,ag}} \right) \\
& + (\sigma_i - \rho_i) \widehat{p_{is}^{m}} + \left(\widehat{E_{is}^{ag}} - \widehat{ta_{is}^{m,ag}} \right) \} \\
& + share_{iss}^{dM} \left(\widehat{NE_{is}} - \frac{\theta_i}{\sigma_i - 1} \left(\widehat{f_{iss}^{d}} + \widehat{tp_{is} p_{is}^{ib}} \right) - \theta_i \widehat{tp_{is} p_{is}^{ib}} \right) \\
& + \frac{\theta_i}{\sigma_i - 1} share_{iss}^{dM} \sum_{ag=} \frac{p_{is}^{d} q_{is}^{d,ag}}{\sum_{ag'=\{s,p,f\}} p_{is}^{d} q_{is}^{d,ag'}} \{ (\rho_i - 1) \left(\widehat{P_{is}^{ag}} - \widehat{ta_{is}^{d,ag}} \right) \\
& + (\sigma_i - \rho_i) \widehat{p_{is}^{d}} + \left(\widehat{E_{is}^{ag}} - \widehat{ta_{is}^{d,ag}} \right) \}
\end{aligned} \tag{B.2}
$$

With $\varpi_i = \frac{\sigma_i - 1 - \theta_i(\nu_i - 1)}{\sigma_i - 1}$.

To write this in GEMPACK-notation we elaborate on the share, $share^{M}_{irs}$, as follows:

$$share^{M}_{irs} = \frac{NE_{ir}\left(f_{irs}tp_{ir}p^{ib}_{ir}ta_{irs}\right)^{\frac{\theta_i}{1-\sigma_i}}\left(ta_{irs}\tau_{irs}p^{cif}_{irs}\right)^{-\theta_i}\left(p^{m}_{is}\right)^{\theta_i}\left(E^{m}_{is}\right)^{\frac{\theta_i}{\sigma_i-1}}}{sum^{M}_{is}+NE_{is}\left(f_{iss}p^{ib}_{is}\right)^{\frac{\theta_i}{1-\sigma_i}}\left(tp_{is}p^{ib}_{is}\right)^{-\theta}\left(p^{d}_{is}\right)^{\theta}\left(E^{d}_{is}\right)^{\frac{\theta}{\sigma-1}}} \tag{B.3}$$

With:

$$sum^{M}_{is} = \sum_{u=1}^{S} NE_{iu}\left(f_{ius}tp_{iu}p^{ib}_{iu}ta_{ius}\right)^{\frac{\theta_i}{1-\sigma_i}}\left(ta_{ius}\tau_{ius}p^{cif}_{ius}\right)^{-\theta_i}\left(p^{m}_{is}\right)^{\theta_i}\left(E^{m}_{is}\right)^{\frac{\theta_i}{\sigma_i-1}} \tag{B.4}$$

Comparing equation (B.3) with the Melitz gravity equation in (44) shows that our share term is equal to:

$$share^{M}_{irs} = \frac{\frac{v_{irs}}{f_{irs}tp_{ir}p^{ib}_{ir}}}{\sum\limits_{u=1}^{S}\frac{v_{ius}}{f_{ius}tp_{iu}p^{ib}_{iu}}+\frac{v^{d}_{iss}}{f_{iss}tp_{is}p^{ib}_{is}}} \tag{B.5}$$

By lack of information on the size of fixed costs, f_{irs}, we proxy $share^{M}_{irs}$ by the share spent on imports from country r, thus implicitly assuming that the value of fixed costs is equal in the different sourcing countries r. In GEMPACK-notation $share^{M}_{irs}$ and $share^{dM}_{iss}$ are given by:

```
FORMULA (all,i,trad_COMM)(all,r,REG)(all,s,REG)
SHRM(i,r,s) = VIMS(i,r,s)/(SUM(t,REG,VIMS(i,t,s))+VDM(i,s));

FORMULA (all,i,trad_COMM)(all,s,REG)
SHRD(i,s) = VDM(i,s)/(SUM(t,REG,VIMS(i,t,s))+VDM(i,s));
```

We can now write equation (B.2) in GEMPACK notation as follows, observing that $pm\left(i,s\right)$ is the producer price, inclusive of production taxes, corresponding with $\widehat{tp_{is}p^{ib}_{is}}$:[28]

```
EQUATION MMEL_EQ (all,i,trad_COMM)(all,s,REG)
varpi(i) * mmel(i,s) = SUM(r,REG,SHRM(i,r,s)
                       * (nne(i,r) - (theta(i)/(ESUBM(i) - 1)) * (fex(i,r,s)
                       + [pm(i,r) - num] + tm(i,s) + tms(i,r,s)) - theta(i)
                       * (tm(i,s) + tms(i,r,s) + itc(i,r,s) + pcif(i,r,s) - num)))
                       + (theta(i)/(ESUBM(i) - 1)) * (1 - SHRD(i,s))
                       * ((ESUBD(i)-1)*(priceDm(i,s)-num)
                       + (ESUBM(i)-ESUBD(i))*(pim(i,s)-num) + (valueDm(i,s)-num)
                       - ESUBD(i)*tariffDm(i,s))
                       + SHRD(i,s) * (nne(i,s) - (theta(i)/(ESUBM(i) - 1))
                       * [pm(i,s) - num] - theta(i) * (pm(i,s) - num))
                       + (theta(i)/(ESUBM(i) - 1)) * SHRD(i,s)
                       * ((ESUBD(i) - 1) * (priceDd(i,s) - num)
                       + (ESUBM(i) - ESUBD(i)) * (pm(i,s) - sshiftd(i,s)
                        - dshiftd(i,s) - num) + (valueDd(i,s) - num)
```

[28] Domestic fixed trade costs, represented by the term $\widehat{f^{d}_{iss}}$ in equation (B.2), are omitted from the code, because we do not include the possibility to change domestic fixed costs.

```
- ESUBD(i) * tariffDd(i,s));
```

Hat differentiating the expression for e_{is}^{so} in the Ethier-Krugman model in equation (10) and recognizing that $e_{is}^{so} = -\frac{\nu_i - 1}{\sigma_i - 1} M_{is}^{etk}$, generates:

$$\widehat{e_{is}^{so}} = \widehat{M_{is}^{etk}} = \frac{\nu_i - 1}{\sigma_i - 1} \widehat{M_{is}^{etk}} = \frac{\nu_i - 1}{\sigma_i - 1} \sum_{s=1}^{S} \frac{\frac{\widetilde{q_{is}}}{\sigma_i a_{is}}}{\sum_{u=1}^{S} \frac{\widetilde{q_{iu}}}{\sigma_i a_{iu}}} \widehat{\widetilde{q_{is}}} \tag{B.6}$$

Assuming like in the Melitz model that fixed costs are identical across countries, we can proxy the share terms in equation (B.6) by gross output shares, *SHGO(i,r)*, defined as:

```
FORMULA (all,i,TRAD_COMM)(all,r,REG)
SHGO(i,r) = VOM(i,r)/SUM(s,REG,VOM(i,s));
```

So the expression for $\widehat{M_{is}^{etk}}$ in the Ethier-Krugman model in the code becomes:

```
EQUATION METK_EQ (all,i,trad_COMM)
metk(i) = SUM(s,REG,(SHGO(i,s) * nne(i,s)));
```

We switch between the Ethier-Krugman and Melitz expression for M_{is} with the following equation.

```
EQUATION MH_EQ (all,i,trad_COMM)(all,s,REG)}
mh(i,s) = VARS(i) * {(1 - ETK(i)) * mmel(i,s) + ETK(i) * metk(i)};
```

Appendix C. Equivalence Code

We check the equivalence of the Melitz model formulated with demand and supply shifters with the Melitz model formulated with a larger set of equations following from Melitz (2003). We do this in a model with a single sector and two identical countries and with and without intermediate linkages.

To keep things simple we eliminate several institutional details from GTAP in our two-country model with intermediate linkages. So we examine a model without a transport sector, without import tariffs and export subsidies, without a separate nest between domestic and imported goods and with only one group of agents, private households. Imposing the general equilibrium condition that gross output $p_r^{ib} q_r^{ib}$ is equal to the value of exports to all destination countries s and using the fact that the absence of tariffs and trade imbalances implies that expenditures E_r are equal to the value of gross output $p_r^{ib} q_r^{ib}$, gives the following general equilibrium condition:

$$p_r^{ib} q_r^{ib} = \sum_{s=1}^{S} \left(\frac{p_{rs}}{p_s} \right)^{1-\sigma} p_r^{ib} q_r^{ib} \tag{C.1}$$

In a setting without intermediate linkages, the price and quantity of input bundles are respectively equal to wages w_r and quantity of labor L_r. The expressions for the price index and the bilateral price are:

$$p_s = \left(\sum_{i=1}^{J} p_{rs}^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \tag{C.2}$$

$$p_{rs} = \frac{ta_{rs} t_{rs} c_r p_r^{ib}}{e_s} \tag{C.3}$$

Following the setup in the main text for the large multi-sector model gives the following expressions for c_r, t_{rs} and e_s.

$$c_r = \gamma_m \left(\frac{\kappa_r^{\theta} q_r^{ib}}{\delta e n_r} \right)^{\frac{1}{1-\sigma}} \left(p_r^{ib} \right)^{\frac{\theta-\sigma+1}{\sigma-1} + \frac{\theta-\sigma+1}{(\sigma-1)^2}} \tag{C.4}$$

$$t_{rs} = \tau_{rs}^{\frac{\theta}{\sigma-1}} f_{rs}^{\frac{\theta-\sigma+1}{(\sigma-1)^2}} \tag{C.5}$$

$$e_s = \left(p_s^{\sigma-1} p_s^{ib} q_s^{ib} \right)^{\frac{\theta-\sigma+1}{(\sigma-1)^2}} \tag{C.6}$$

Because of the absence of per unit transport services, we have included the marginal cost term in p_r^{ib} in c_r instead of t_{rs} as in the main text.

Without intermediate linkages we solve equations (C.1)-(C.6) for p_r^{ib}, p_s, p_{rs}, c_r and e_s. With intermediate linkages we add the following two additional equilibrium equations implying that p_s has to be solved simultaneously with the other variables:

$$p_r^{ib} = w_r^{\beta_r} P_r^{1-\beta_r} \tag{C.7}$$

$$p_s^{ib} q_s^{ib} = \frac{w_s L_s}{\beta_s} \tag{C.8}$$

We assume that input bundles are a Cobb-Douglas aggregate over labor and intermediates with intermediates identical to final goods.[29] So with intermediates we solve equations (C.1)-(C.8) for p_r^{ib}, q_r^{ib}, w_r, p_r, p_{rs}, c_r and e_s.

We compare the Melitz model as formulated above with demand and supply shifters in a symmetric two-country setting with the Melitz model formulated with a full set of equilibrium equations. More specifically, we compare the Melitz general setup model with the following set of equilibrium equations: an expression for the price index; an expression for the number of varieties; a demand equation; an expression for cutoff revenues; a markup pricing expression; and a zero cutoff profit condition. The free entry condition is substituted in both the expression for the number of varieties and the demand equation. This corresponds with the following set of equations:

$$p_s^{1-\sigma} = \sum_{r=1}^{S} N_{rs} \frac{\theta}{\theta - \sigma + 1} p_{rs} \left(\varphi_{rs}^*\right)^{1-\sigma} \tag{C.9}$$

$$N_{rs} = \left(\frac{\kappa_r}{\varphi_{rs}^*}\right)^{\theta_r} \frac{\sigma - 1}{\sigma \theta_i} \frac{q_r^{ib}}{\delta e n_r} \tag{C.10}$$

$$p_r^{ib} q_r^{ib} = \sum_{r=1}^{S} N_{rs} \frac{\theta}{\theta - \sigma + 1} r_{rs} \left(\varphi_{rs}^*\right) \tag{C.11}$$

$$r_{ij}\left(\varphi_{ij}^*\right) = p_{rs} \left(\varphi_{rs}^*\right)^{1-\sigma} p_s^{\sigma-1} E_s \tag{C.12}$$

$$p_{rs}\left(\varphi_{rs}^*\right) = \frac{\sigma}{\sigma - 1} \frac{\tau_{rs} p_r^{ib}}{\varphi_{rs}^*} \tag{C.13}$$

$$r_{rs}\left(\varphi_{rs}^*\right) = \sigma f_{rs} p_r^{ib} \tag{C.14}$$

We solve equations (C.9)-(C.14) for p_s, p_{rs}, N_{rs}, φ_{rs}^*, p_r^{ib} and $r_{rs}\left(\varphi_{rs}^*\right)$. In the model with intermediate linkages we add equations (C.7)-(C.8) and solve as well for the q_r^{ib} and w_r.

We show that relative welfare changes as a function of relative changes in iceberg trade costs are identical employing the set of equations with demand and

[29] With a Leontief specification, we would have the following expressions:

$$p_{Z_i} = w_i \beta + (1 - \beta) P_i$$
$$Z_i = \frac{L_i}{\beta}$$

supply shifters and the fuller set of equations. We do this for different parameter values, finding that the results are identical.

Calibration of the parameters is fairly arbitrary for this exercise showing equivalence. Without loss of generality we set the parameters as described in the simulations with the two-country model in Bekkers and Francois (2018), which is based on the simulations presented Melitz and Redding (2013). In particular $\varepsilon^{v,ta} = 4$, $\xi = 3/4.25$, $f_{ss} = \tau_{ss} = en_r = \kappa_r = 1$, $\beta = 0.9$, and τ_{rs} and f_{rs} such that the domestic spending share is 0.89 and the share of exporting firms equal to 0.18 (as in the simulations presented in Melitz and Redding (2013)).

Appendix D. Alternative Modelling of Ethier-Krugman

In this appendix we compare the way variety scaling is modelled in the Ethier-Krugman model with the approach in Francois (1998). There are two differences. First, Francois (1998) models variety scaling on the production side before transportation costs are paid, whereas in our approach it is included after transport costs are paid. Technically, Francois (1998) includes the variety scaling term in *ao*, whereas we include it separately in import demand and domestic demand of the four groups of agents. Second, the calculation of the variety scaling term has changed a bit in the new approach. The reason is that the extent of variety scaling is affected by transportation costs.

In Figure D1 we compare the effects of changes in iceberg trade costs in the Ethier-Krugman model, using three approaches. First, the Francois (1998)-approach; second, the approximate approach with the number of intermediates proportional with the number of input bundles and the supply shifter in import and domestic demand; and third, the theoretically correct approach with the number of intermediates nearly proportional with the number of input bundles (correcting for the presence of transport costs). The figure shows that especially for trade cost reductions, the welfare effects are larger with the approximate and theoretically correct code than with the old code, though all three are virtually identical. So the largest change is provoked by including the variety scaling term in a different place and not by including additional transportation-cost related terms in calculating the variety-scaling term. These findings provide support for using the approach with the number of input bundles, $nne\,(i, r)$ being a function only of $qo\,(i, r)$, instead of the more complicated expression also discussed in the main text.

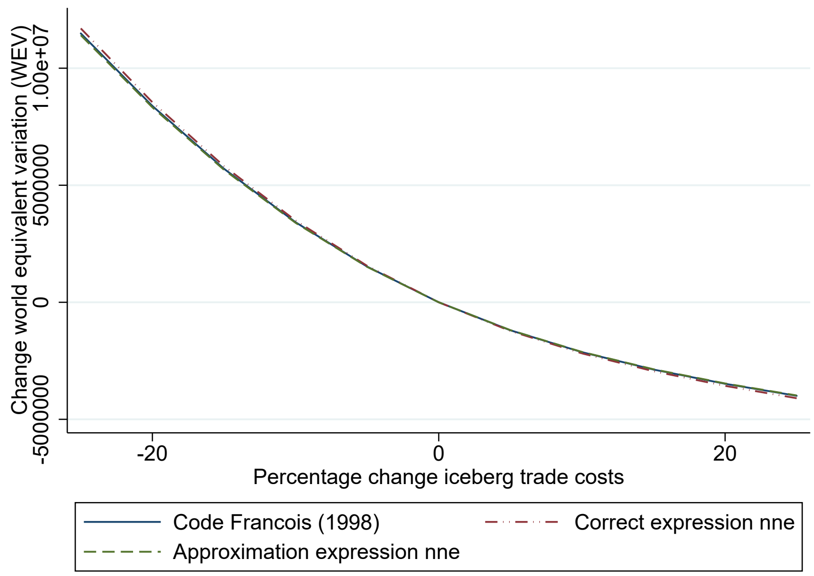

Figure D1. Comparison of simulation results with different treatment of variety scaling.

Notes: The figure displays world equivalent variation as a function of percentage change in iceberg trade costs with trade liberalization in all sectors Ethier-Krugman structures in all sectors, employing three approaches to model variety scaling, Francois (1998) with variety scaling before transportation costs are paid, and variety scaling after transportation costs are paid based on an approximation for nne and the exact expression for nne.

Source: Authors calculations with parsimonious firm heterogeneity model and with monopolistic competition model of Francois (1998).

Appendix E. Additional Tables

Table E1. Changes in the value of trade in millions of dollars along the different trade margins (all regions)

Shock variable	Model	Regions	Margins			
			Intensive	Extensive	Compositional	Total
Iceberg trade costs	Armington	Total	34058	0	0	34058
		EAA	15165	0	0	15165
		EU	9684	0	0	9684
		LatinAmer	863	0	0	863
		MENA	-2047	0	0	-2047
		NAmerica	2973	0	0	2973
		REE	-627	0	0	-627
		SEA	1542	0	0	1542
		SOA	1653	0	0	1653
		SSAROW	-490	0	0	-490
		USA	3431	0	0	3431
		efta	1911	0	0	1911
Iceberg trade costs	Ethier-Krugman	Total	42080	5589	0	47668
		EAA	16320	-29	0	16291
		EU	11492	-1302	0	10190
		LatinAmer	1201	-73	0	1128
		MENA	-983	-338	0	-1321
		NAmerica	2804	7690	0	10494
		REE	32	-126	0	-94
		SEA	2165	345	0	2510
		SOA	1868	-107	0	1761
		SSAROW	-153	201	0	48
		USA	4993	-309	0	4684
		efta	2340	-361	0	1979
Iceberg trade costs	Melitz	Total	31742	59277	-41542	49477
		EAA	12764	17408	-14395	15777
		EU	8637	11376	-10489	9523
		LatinAmer	903	1431	-1244	1090
		MENA	-1070	716	-878	-1232
		NAmerica	1829	14324	-2660	13493
		REE	-70	755	-744	-58
		SEA	1604	3068	-2182	2490
		SOA	1439	1856	-1647	1648
		SSAROW	-192	458	-213	54
		USA	4148	5677	-4963	4862
		efta	1751	2207	-2127	1831
Fixed trade costs	Melitz	Total	-86636	898728	-724526	87568
		EAA	-13596	197346	-162817	20934
		EU	-22090	241575	-202180	17306
		LatinAmer	-1634	20218	-16839	1745
		MENA	-17918	98638	-82082	-1359
		NAmerica	-11368	106612	-65953	29292
		REE	-6775	43742	-36385	581
		SEA	-4257	42399	-34834	3307
		SOA	-1171	22449	-18627	2651
		SSAROW	-3725	23253	-18884	643
		USA	-927	57008	-47751	8328
		efta	-3175	45488	-38173	4140

Notes: Changes in the value of trade are decomposed for experiment 1 with uniform reductions in iceberg and fixed trade costs

Source: Authors calculations with parsimonious firm heterogeneity model.

Table E2. Overview of regions, sectors, and production factors

Regions	Description	Sectors	Description	Production factors	
EAA	East Asia	Agriculture	Primary Agriculture	Land	Land
SEA	Southeast Asia	Extraction	Mining and Extraction	lowskill	Low-skilled
SOA	South Asia	ProcFood	Processed Food	medskill	Medium-skilled
USA	USA	OtherGoods	Other Goods	highskill	High-skilled
NAmerica	Canada and Mexico	Chemicals	Chemicals; Petrochemicals	capital	Capital
LatinAmer	Latin America	Machinery	Light Manufacturing	natres	Natural resources
efta	EFTA	Metals	Heavy Manufacturing		
EU	European Union 27	Motorvehicle	Motorvehicles		
MENA	Middle East and North Africa	PubServices	Public Services		
SSAROW	Sub-Saharan Africa and ROW	TransComm	Transport and Communication		
REE	Russia and Eastern Europe	OthServices	Other Services		

Table E3. Decomposition of welfare effects in millions of dollars (all regions)

Shock variable	Model	Regions	Welfare (EV)	Allocative efficiency	Investment -savings price	Terms of Trade	Pure iceberg trade costs	Importer productivity	Domestic productivity	Importer variety	Domestic variety
		Total	550175.2	105652.8	11.24173	-199.981	444710.5	0	0	0	0
		EAA	139036.4	41567.31	-2332.31	14529.79	85271.38	0	0	0	0
		EU	176353.1	33058.9	-728.369	16494.05	127528.3	0	0	0	0
		LatinAmer	18206.68	2119.246	-144.543	-3120.35	19352.34	0	0	0	0
		MENA	20122.28	3137.093	1498.777	-15256.8	30743.18	0	0	0	0
		NAmerica	25117.85	2577.65	479.9036	913.5087	21146.78	0	0	0	0
Iceberg trade costs	Armington	REE	13825.38	4604.421	840.9998	-7099.92	15479.89	0	0	0	0
		SEA	34860.49	5357.637	163.7785	653.5477	28685.48	0	0	0	0
		SOA	28500.98	2812.542	654.9606	2681.15	22352.33	0	0	0	0
		SSAROW	8463.369	1529.882	57.10655	-3934.08	10810.43	0	0	0	0
		USA	54637.23	4654.836	-688.213	-5836.72	56507.29	0	0	0	0
		efta	31051.46	4233.32	209.1559	-224.156	26833.14	0	0	0	0
		Total	581626.3	111929.5	3.472145	-186.759	446617.2	0	0	6484.507	16778.33
		EAA	140804.4	44676.42	-1152.28	12672.57	85565.01	0	0	143.7792	-1101.08
		EU	185279.8	33212.47	-461.731	13250.76	127817.5	0	0	-1463.8	12924.48
		LatinAmer	17494.4	1805.771	-189.248	-3243.98	19425.13	0	0	90.54828	-393.832
		MENA	29060.36	3336.246	1664.672	-11832.3	30832.12	0	0	237.4035	4822.333
		NAmerica	24350.75	3306.276	658.3024	4231.79	21487.38	0	0	-899.868	-4433.08
Iceberg trade costs	Ethier-Krugman	REE	17484.83	5543.658	804.8657	-5441.22	15533.09	0	0	-185.598	1230.053
		SEA	37412.75	6145.227	198.6793	2599.521	28814.82	0	0	-530.084	184.5529
		SOA	28111.75	2675.329	332.5346	793.1906	22430.8	0	0	483.7816	1396.105
		SSAROW	7786.685	2217.376	60.04337	-2522.38	10907.15	0	0	-346.774	-2528.77
		USA	61527.21	4787.698	-2087.75	-10846.3	56837.96	0	0	8160.242	4675.406
		efta	32313.42	4223.065	175.3867	151.6678	26966.23	0	0	794.8744	2.166121
		Total	589167	114158.5	0.351631	-195.147	446235.3	-260395	272549.4	326242.1	-309429
		EAA	141354.3	44670.2	-1004.83	12149.96	85453.25	-61390.6	57618.8	74261.02	-70403.5
		EU	190928.9	34561.75	-455.249	13020.95	127661.7	-73579	71812.52	86897.58	-68991.4
		LatinAmer	16450.72	1822.024	-185.415	-3173	19398.42	-9822.15	15578.58	12163.24	-19331
		MENA	29014.05	3251.107	1636.617	-11510.4	30796.36	-10405.2	18454.58	12899.08	-16108.2
		NAmerica	28411.94	4042.645	779.8876	4994.51	21574.72	-23556.3	4358.741	26924.52	-10706.8
Iceberg trade costs	Melitz	REE	17209.55	5509.61	797.2452	-5311.15	15511.67	-7478.6	9934.279	8778.188	-10531.7
		SEA	38539.86	6271.673	196.2914	2906.853	28787.63	-20135.8	13482.4	23576.26	-16545.4
		SOA	28595.97	2656.544	318.1564	683.6473	22402.05	-11903.5	13211.31	15029.17	-13801.4
		SSAROW	7269.27	2170.543	59.18806	-2441.48	10892.99	-5864.93	4883.726	6609.186	-9039.96
		USA	58919.91	4661.992	-2307.01	-11828.7	56814.46	-19052.4	47035.75	37373.38	-53777.6
		efta	32472.52	4540.41	165.4697	313.6773	26942.06	-17206	16178.73	21730.45	-20192.2
		Total	1007820	187555.9	-13.3138	-386.97	0	-4442176	551853.1	5378431	-667510
		EAA	209481.4	68176.77	-76.61	9878.944	0	-786514	105591.6	948762.7	-136363
		EU	352469.4	62682.86	-576.801	18747.79	0	-1350459	158666.3	1625096	-161744
		LatinAmer	31378.41	3251.481	-253.625	-3731.71	0	-198587	29733.8	239722	-38751.5
		MENA	57993.48	6603.472	2440.176	-12959.8	0	-300158	35190.96	362246.1	-35376.1
		NAmerica	49971.08	7438.935	1452.575	8168.444	0	-231482	9099.46	275291.4	-19998.3
Fixed trade costs	Melitz	REE	29239.98	6854.751	1406.152	-6087.85	0	-157445	19030.33	189343.3	-23857.9
		SEA	65972.52	10012.15	252.1478	4162.792	0	-285652	30549.16	343107.1	-36453.7
		SOA	42490.06	3916.61	179.5388	665.3707	0	-205653	26157.84	248892.9	-31667.8
		SSAROW	14650.23	4115.004	86.24783	-2869.24	0	-115036	9509.781	137701.8	-18857.2
		USA	91064.38	6062.863	-5137.64	-17693.7	0	-518866	91442.21	654202.1	-118938
		efta	63108.81	8441.057	214.5207	1331.978	0	-292325	36881.64	354065.4	-45503.6

Notes: The total welfare effect, EV, is decomposed for experiment 1 with uniform reductions in iceberg and fixed trade costs

Source: Authors calculations with parsimonious firm heterogeneity model.