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Modelling heterogeneous firms and non-tariff measures in free trade agreements using Computable General Equilibrium

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ABSTRACT

A vast body of literature supports with empirical evidence the findings of Melitz (2003) which has led to various attempts to integrate it into Computable General Equilibrium (CGE) models to distinguish the intensive and extensive trade margin and to consider love of variety effects as well as variable and fixed costs of bilateral trade. These viewpoints are especially important for modern free trade agreements (FTAs) analysis where impacts depend largely upon changes in non-tariff measures (NTMs) affecting trade cost. However, existing Melitz extensions for CGEs seem to struggle with numerical stability problems limiting sectoral and regional detail. That greatly reduces their usefulness for policy relevant analysis. We, therefore, develop a Melitz extension for a modular CGE with a focus on a numerical stability. Using the Transatlantic Trade and Investment Partnership (TTIP) proposal as an illustrative example, we treat 22 manufacturing out of 57 sectors based on Melitz in an application with ten global regions and compare our findings to an Armington specification. Our results confirm the larger welfare and trade changes under the Melitz setting suggested both by theory and by empirical findings. We finally compare the sensitivity of trade and welfare impact when the same cost savings associated with reduced NTMs are differently allocated to variable and fixed cost of bilateral trade. We find in our application that the change in traded quantities is more sensitive to bilateral variable cost while welfare increases are more driven by reduced fixed cost, reflecting love of variety effects. Overall, the application underlines that our numerically robust implementation of the Melitz model in a CGE allows applications with high sectoral detail and thus opens the door to a more widespread application in impact assessments.

1. Introduction

The rapid expansion of bilateral and regional FTAs since the mid-1990s in both number and depth (Horn et al., 2010) has led to higher demands for their quantitative impact analysis. While early FTAs mainly targeted tariff elimination, modern FTAs take into focus NTMs which are quite diverse in nature and thus affect the economy through different mechanisms (Limao, 2016). Equally, FTA negotiations and agreements encompass often highly differentiated concessions by sector and partner country. Besides gravity based approaches, impact assessment of FTAs relies mainly on global CGE models (Hertel et al., 2007) which cover bi-lateral trade and further economic transactions across all sectors and consider the interactions of various policy instruments (Devarajan and Robinson, 2002).

Since Armington (1969) proposed to treat imported and domestic varieties of the same (aggregated) goods as imperfect substitutes that approach dominated applied CGE analysis. It provides a powerful, but relatively simple framework for studying international trade policy, not at least as it can accommodate any observed pattern of trade flows and pertinent prices (i.e., the intensive margin of trade). However, preferences for each origin in the Armington model are fixed, such that changes in trade cannot impact average imported qualities per firm on a trade link. It hence neglects potential variations at the extensive margin of trade such as trade flows in new products and with new partners which are found as important in empirical analysis (Hummels and Klenow, 2005; Chaney, 2008).

The pioneer paper by Melitz (2003) introduced firm productivity heterogeneity drawing from Hopenayn (1992) into the monopolistic competition framework by Krugman (1980). The Melitz model can be understood as an extension of the Armington approach as it combines changes at the intensive and extensive margins of trade by allowing firms to self-select new export markets based on their productivity level. Many papers applying the model (Bernard et al., 2003, 2006; 2007; Eaton et al., 2004) could reproduce salient trade patterns observed in recent

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micro-level studies. Consequently, there have been a number of efforts to introduce it into CGE models (Zhai, 2008; Balistreri et al., 2011; Oyamada, 2014; Akgul et al., 2016; and Dixon et al., 2016). The Melitz model adds to the explanatory power of Armington type models (Hosoe, 2017) by considering changes at the extensive margin of trade and in industry productivity level with implications on both trade and welfare (Melitz and Redding, 2014). However, assessment of FTAs based on Melitz-type CGE models is still scarce. For example, none of the impact assessment reports of FTAs by the EU Commission mentions an application of a Melitz-type CGE model.[1] A possible reason is the increased complexity of a Melitz compared to an Armington model, mirrored by a modest sectoral and regional resolution in published application. The paper on GTAP-HET by Akgul et al. (2016), to give an example, uses a stylized example with three regions and two sectors, only. Balistreri et al. (2011) proposes a decomposition algorithm, where partial equilibrium models for Melitz sectors interact with an Armington model for perfectly competitive one. In their example, the authors include firm heterogeneity in just one sector. Dixon et al. (2016) and Oyamada (2014) include firm heterogeneity in variants of the global trade analysis project (GTAP) model coded in General Equilibrium Modelling PACKage (GEMPACK), but seem to run into dimensionality problems. Indeed, all studies up to present offer analysis with a rather limited number of sectors treated a la Melitz. Bekkers and Francois (2016), to give an example, report a maximum of 4 countries and 3 Melitz sectors for these applications.

Some authors (Dixon et al., 2016, for example) claim that Melitz models are not necessary, as Armington models are able to replicate their trade impacts with higher than usual elasticities of substitution. Dixon et al. (2016) used a trial and error approach to find the value of substitution elasticities in Armington–type CGE models that generates almost equal overall trade impacts compared to a Melitz-type CGE model in their simple two-sector modelling exercise. Balistreri and Rutherford (2013) draw the conclusion from such exercises that Armington-type models might produce almost any desired pattern of trade if modelers consider substitution elasticities as parameters of choice. Furthermore, even an Armington model tuned to replicate simulated trade pattern of a Melitz model will still not reproduce the welfare implications of considering fix cost at industry and trade link level along with love of variety.

Additionally, the differentiation between fixed and variable costs in bi-lateral trade embodied in Melitz-type CGE models allows a more realistic quantitative assessment of NTMs (Fugazza and Maur, 2008). That seems important as ad valorem equivalent estimations of NTMs suggest that their (partly) elimination is often more important than tariff reductions in FTAs (Horn et al., 2010). The need for more advanced approaches beyond the relatively simple assumption underlying an Armington model seems also be seen by governments; the European Commission (2016), namely, asks to make full use of the available information and techniques in the impact assessment of FTAs.

Our paper aims to discuss and finally ease the use of the Melitz model in detailed CGE analysis such that both the extensive and intensive margin of trade and productivity effects can be considered. It contributes to literature as follows. We discuss the development of a Melitz model into the modular and flexible CGE modelling platform CGEBox (Britz, 2017), focusing on numerical stability when working with many sectors and regions, a point we consider salient for policy relevant applications. Further, we present a sensitivity analysis of different approaches to model NTMs in the Melitz framework and compare resulting trade and welfare impacts to a standard Armington implementation.

We take TTIP between the US and EU as an illustrative case. Both the EU and US apply a multitude of non-harmonized complex sanitary and phytosanitary (SPS) measures as well as technical barriers to trade (TBT) regulations (Arita et al., 2014) which together with other trade-related regulatory differences create obstacles to trade. Thus, TTIP aimed not only to eliminate or to reduce tariffs, but also to unify "behind the border barriers (i.e., differences in regulations)". It offers hence an interesting case where bilateral trade modelling, high NTMs and the complex nature of NTMs are the core. To illustrate the impact of NTMs in different model configurations, we consider NTM reductions in all sectors.

2. Modelling framework

Global CGE models are considered especially suited to provide an ex-ante appraisal of trade agreements as they consider bi-lateral trade and related barriers in a consistent behavioral framework while accounting for interlinkages between sectors. The most widely used database, GTAP, currently offers 57 sectors and 140 regions (Aguiar et al., 2016). Still, the sectoral breakdown of the GTAP database is often considered insufficient to assess detailed trade negotiations. Therefore, CGE applications are regularly complemented by analysis at the tariff line; either based on a separate partial equilibrium model or by using a pre-model aggregation from changes at the tariff line to the GTAP sector with software such as TASTE (Narayanan et al., 2010). As tariff line detail is not at the focus of our paper and the example of TTIP is only illustrative, we leave out tariff line complications in the remainder of our paper, but work with the full sectoral resolution of 57 sectors. We use here the flexible and modular CGE model CGEBox. A full documentation of all equations of that open-source platform for CGE modelling offers Britz (2017). The model, encoded in the General Algebraic Modelling Language (GAMS), can provide an exact replica of the standard GTAP model (Hertel, 1997), but also allows to mimic features of many other well-known CGEs. We extend that CGE model platform by incorporating a module based on Melitz (2003). It considers firm heterogeneity, firm entry and exit in the industry as a whole and on specific trade links, and love of variety by the different agents, resulting in monopolistic competition. Below we discuss briefly the general structure of the standard GTAP model that treats sectors as perfectly competitive and subsequently provide detail on the Melitz module.

2.1. Perfectly competitive sectors as in the standard GTAP model

Sectors with perfect competition are depicted as in the standard GTAP model (Hertel, 1997), a comparative static, global CGE model based on the Walrasian general equilibrium structure. It assumes cost-minimizing behavior under constant returns to scale production technologies along with utility maximizing consumers in competitive markets. There is a single virtual representative household in each region that owns the production factors and receives factor returns net of taxes. That so-called regional household also collects income from taxation such as tariff revenues and rents accruing from export or import licenses, depicted as exogenous ad-valorem price wedges. The regional income is then allocated to different agents (private household, government, and saving) based on a modified Cobb-Douglas (CD) utility function. The private household's demands for Armington commodities are derived from a non-homothetic constant difference elasticity (CDE) implicit expenditure function,[2] while government and saving demands for Armington commodities are driven by constant elasticity of substitution (CES) functions. A CES composite of domestic and import demand for each and product agent defines their Armington demands. The import demand composition from bi-lateral trade flows is depicted by a second CES nest that is not agent specific. On the supply side, production is defined as the Leontief aggregate of value added and intermediate inputs bundles; the value added composition is based on a CES aggregate of primary factors while the composition of intermediate demand is based on fixed physical input coefficients. Each sector features its own Armington nest to determine the composition of intermediate input demand for each

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[1] See the documents archive of the European Commission on trade policy analysis, http://ec.europa.eu/trade/policy/policy-making/analysis/.

[2] The CDE can be classified as somewhat more flexible as the CES and linear expenditure system (LES) functional forms as it allows for marginal budget shares varying with expenditure levels (Hertel, 1997).

commodity from domestic product and imports. However, the import composition is identical across sectors and final demand, as mentioned above. The model assumes in the default layout fixed stocks for primary factors and full mobility for capital, skilled and unskilled labor, sluggish mobility for land and sector specific and thus immobile natural resources. Van der Mensbrugghe (2015) presents the implementation of the standard GTAP model in the GAMS language underlying CGEBox. Note that the standard GTAP model as detailed in Hertel (1997) is coded in GEMPACK and presents a mix of equations in levels and in linearized relative differences instead, whereas CGEBox is written in levels.

2.2. Implementation of the Melitz module

Our approach for imperfect competition sectors follows the average firm definition by Melitz (2003)[3] and builds on Balistreri et al. (2011, 2013) and Akgul et al. (2016); the technical Appendix 1 provides the details of the Melitz module. Each agent's demand is depicted as a Dixit-Stiglitz composite of average firm level varieties of each importer and domestic sales. Each productivity heterogeneous firm produces one single unique variety over a continuum of varieties under conditions of monopolistic competition arising from imperfect substitution in demand for these varieties. Accordingly, the number of varieties produced in a regional industry is equal to the number of firms operating. Production in the monopolistic sectors follows Akgul et al. (2016) by introducing fixed and variable cost components at industry and trade link level. The variable costs are proportional to the quantity of output produced and use the nesting of the production function in the standard GTAP model as described above. Fixed costs are associated with establishing the firm and with operating on each bilateral trade link; they typically only use primary factors.[4] Consistent with the large group monopolistic assumption, each small firm does not consider its impact on the aggregate price index. Therefore, the usual markup-pricing rule reflects the demand elasticity and marginal cost, in the Melitz model corrected for the average productivity effect of firms operating on each bilateral trade link.

The average productivity of firms on each trade link is determined from a Pareto distribution function as discussed in Balistreri et al. (2011) which encompasses a so-called cut-off productivity level. Only firms with productivity equal or higher than that specific threshold level for each bilateral trade link will operate on that link; the remaining entered firms are forced to exit. Hence, a zero marginal profit condition ensures that the revenue of the average firm equals its fixed and variable cost. However, ensuring zero profit for operating firms on each trade link does not ensure zero profits for the industry as a whole due to sunk costs associated with the entry of new firms in the industry. Therefore, zero profit at industry level is assured by a free entry condition in the industry, indicating that the expected profit for firms over their life time must be equal to the overall industry fixed set up costs.

2.3. Sectoral and regional aggregation

Table A2 in Appendix 2 provides details how we treat the 57 sectors in our application. We apply the Melitz module to all 22 manufacturing sectors, the remaining ones face perfect competition. That choice is motivated by literature showing the importance of considering firm heterogeneity in manufacturing sectors (Balistreri et al., 2011; and Akgul et al., 2016), including food processing sectors (Luckstead and Devadoss, 2016; Berden et al., 2009; and Olper et al., 2014). We keep the full sector detail of the GTAP database to prevent bias (Britz et al., 2016) and use post-model aggregation (Table A2) to summarize results for the Melitz and Armington commodities. Further, in order to capture the impact of TTIP on major world regions, we aggregate the GTAP data to ten regions (EU, US, Canada, MERCOSUR, China, ASEAN 10, Mediterranean countries, Other Northern Europe,[5] low-income countries,[6] Other OECD and Other Regions). Post model aggregation summarizes the information for the world as a total and for a rest of the world (ROW) aggregate which excludes the EU and US.

2.4. Model parameterization and calibration

In order to apply the above-described framework, the different parameters chosen must recover the observed benchmark consisting of the global social accounting matrix (SAM) provided by the GTAP database. That global SAM comprises many small entries both in relative and absolute terms, which can affect the numerical stability during solution of a CGE. We, therefore, filter out small transactions in relative terms in a systematic way after aggregation to our ten regions while maintaining a balanced global SAM (Britz et al., 2016).

Similar to the Armington approach, a major advantage of the Melitz model is that it requires relatively little information on the industry and its consumers, namely firstly parameters which describe the productivity based on a Pareto distribution and secondly the elasticity of substitution among varieties. We use the estimate of 3.8 from Bernard et al. (2003) for the elasticity of substitution, and an estimate of 4.6 for the Pareto shape parameter from Balistreri et al. (2011).

2.5. Computational issues

Memory needs and solution time of simulations with a CGE model depend on model detail and complexity. Detail reflects both detail in the database, notably the number of regions and sectors, and assumptions such as with regard to the number of different CES nest in production and constant elasticity of transformation (CET) nests in factor supply. In a key Equation (1)[7] of Melitz (2003) depicting the bi-lateral import demands, an increase in the number of sectors (which are a sub-set of the agents a and each produce a product i in case of a diagonal make matrix) rises by the square the number of left hand side (LHS) variables Q_{airs} and the related prices of the agents $\widetilde{PA}_{aisr}$:

$$Q_{aisr} = \tilde{Q}_{aisr} N_{isr} = \lambda_{aisr} N_{isr} Q_{air} \left(\frac{P_{air}}{\widetilde{PA}_{aisr}} \right)^{\sigma_{ir}} \tag{1}$$

That is different from the typical implementation of the Armington system in the standard GTAP model and many similar CGEs where bi-lateral import shares and related prices are not agent specific. That explains why Melitz models are more sensitive to increased sectoral details. Our implementation, therefore, substitutes out the Q_{aisr} and $\widetilde{PA}_{aisr}$, along with other variables and equations with a bi-lateral regional index such as free on board (FOB) and cost insurance and freight (CIF) prices and trade margins. The same holds for industry by industry transactions.[8] Consequently, in our implementation, model size increases only moderately in regional and sector detail. However, that does not decrease the number of Jacobian and Hessian elements and thus increases the density of the Jacobian and the Hessian. Furthermore, most equations allow for sparsity such that e.g. not all elements of Q_{airs} needs to be present such that we benefit from removing small transactions as discussed above (Britz, 2017, page 68ff). Furthermore, we scale the LHS and right hand side (RHS) in all equations relating to

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[3] The Melitz model defines the so-called "average firm" depicting the average productivity of all firms operating on a specific trade link.

[4] The model uses a threshold during calibration that ensures that variable costs always comprise some minimum share of primary factor cost. That implies that in some cases the fix cost nest might also comprise intermediates.

[5] Other Northern Europe include Switzerland, Norway and Rest of European Free trade Association (EFTA).

[6] Our mapping of regions to the low-income countries aggregate follows the current World Bank classification.

[7] For the description of variables see the technical Appendix 1.

[8] Note that a GEMPACK based model might automatically substitute such variables and therefore scales better when the number of sectors is increased (Horridge and Pearson, 2011).

quantities and values with factors derived from the LHS in the benchmark to support CONOPT's automatic scaling and improve numerical stability. Not at least, our implementation allows to pre-solve single country model under the shock before the full global model is solved which can speed up solution of larger model (Britz et al., 2016).

The reason why Melitz based CGEs can be hard to solve and may end up infeasible is partly based on convexity issues based on the following mechanism under a shock that reduces demand for a sector such as resulting from increased imports under an FTA. The resulting drop in output following less demand leads to two countervailing impacts in the Melitz model: firstly, average productivity increases as the least efficient firms leave the industry and trade links which decreases costs, and, secondly, fix costs are distributed over a smaller output quantity which increases per unit costs, the latter is typically the dominating effect. Consequently, also costs for using the domestic industry's own output in its production increase. That leads to reduced demand by the industry for its own output, substituted by imports, or by other inputs if the production function allows for it. The love of variety effect amplifies the impact as the shrinking output quantities go along with fewer firms operating on the domestic link.

The reduced demand by the industry for its own outputs implies that unchanged fix costs for selling to the domestic market need to be distributed over an even smaller quantity. That further decreases the competitiveness of the domestic origin and thus provokes additional demand reductions which let shrink industry output even more. If price feedback from factor and other intermediate markets does not offset these impacts, the model can end up in a vicious circle where a sector completely vanishes. That might drive the model into corner solutions where the solver ends up in infeasibilities as non-negativity bounds become binding in addition to the normal model equations such that the system of equations is no longer square. Tests have shown that PATH as an MCP solver might correctly identify the corner solution, but more often fails even under shocks where no corner solutions occur and CONOPT solves the problem. But more often both solvers declare the model as infeasible; we assume in cases where they find locally no search direction where the sum of infeasibilities decreases. In order to avoid that vicious circle of ever increasing costs, three different approaches have been successfully applied by us in test shocks with differently detailed data bases. The first one pushes up price feedback from factor markets by making the non-depreciated part of the capital sector specific. That requires additionally an assumption over the simulation horizon to determine the number of years to which the depreciation rate used in the standard GTAP model is applied. Other modifications such as using rather small elasticities of transformations for factor supply to sectors might work as well. Secondly, bi-lateral and domestic intermediate input demand by the different sector can be aggregated, such that in Equation (1) only four agents are left (final private demand, government, investment and an aggregate over all sectors). That implies not only identical shares for the bi-lateral composition of imports, but also for domestic sales and imports as a total across sectors. The latter is not assumed in the standard GTAP model. However, these two approaches sometimes fail to overcome the problem, even combined. We therefore present in here results based on the third approach which seems to work best by modifying the underlying mechanism directly. Specifically, we allow to define a maximal cost share of intermediate domestic demand for an industries own output.[9] If that threshold is exceeded in the benchmark, Equation (1) is replaced by a standard Armington formulation where s is equal r and commodity i is produced by agent a, while variable per unit costs are used as the price.

The decision about the threshold is defined based on the benchmark data. As such, the code will not decide on its own during the solution process to switch between price markups or not. Rather, it is up to analyst to define the threshold. He might be lucky and able to run the model without that modification. If that does not work, he can stepwise decrease the threshold to introduce only the minimal modification to solve the model. The use of this threshold can be justified as part of the intermediate domestic demand of an industry for its own output is indeed intra-firm demand which should also in reality not subject to price markups. Note that with increasing number of sectors, the share of the intermediate domestic demand of a sector for its own output will systematically become smaller in average, reducing the impact of that correction on the overall results. At the same time, unfortunately, the chance increases to find a sector/region combination where the share is quite high and price feedback from inputs markets is low. Given the manifold data corrections necessary to yield a globally balanced SAM with high sectoral and regional detail, it is not unlikely that some of these entries are artefacts from balancing. Note also that it is likely that part of what is shown as demand of an industry for its own domestic origin might be indeed intra-firm demand.

The combination of manual scaling factors, substitution out high-dimensional variables, allowing for sparsity as well as the use of a pre-solve algorithm along either with aggregation of intermediate demand across sectors or with the conceptual change might explain why we are able to solve larger shocks also with many sectors treated a la Melitz and a larger number of regions. Possibly, non-constant returns to scale might also render the interplay of solving the log-linearized equations and their updates to levels in the specialized solver inbuilt in GEMPACK less efficient, compared to using the more general nonlinear programming (NLP) solvers such as CONOPT in our GAMS application.

3. Quantifying the policy experiment

3.1. Quantification of NTMs

When simulating impacts of a potential TTIP agreement, most literature relies on the −25% reduction in the trade restrictiveness of NTMs from Berden et al. (2009) which reflects expectations of European and American entrepreneurs and regulators about the potential outcome of an agreement.

Egger and Larch (2011) show that the impact of an FTA can be assessed as a reduction in ad-valorem equivalents (AVE) of both changes in tariffs and NTMs. Accordingly, changing NTMs in an FTA can be seen and estimated as 'beyond tariff reductions'. Egger et al. (2015) present an approach to estimate cost saving impacts of a deep TTIP agreement based on a three step approach. First, they estimate a gravity model with country-specific fixed effects, bilateral control variables, a measure of political distance, and tariff margins by country-pair (within or outside FTAs). In order to assess cost saving effects, they add two explanatory variables: an integer value ranging from 0 (shallow) to 7 (deep) that measures the depth of existing FTAs based on Dür et al. (2014) and a dummy intra-EU relationship to distinguish EU membership and access to the EU common market from an FTA. Second, they simulate with that gravity model trade volume changes when introducing a deep FTA between the EU and US. Finally, they solve for the changes in the tariff rates that would yield the simulated bi-lateral trade volumes under a deep agreement without changing the "depth of FTA" variable. These changes in the AVE tariff rates provide an estimate for the cost saved related to the NTMs under a deep trade agreement. Egger et al. (2015) calls this the "ad valorem cost saving effects which are removable upon a deep TTIP trade agreement", reported in Table A3 in Appendix 2 [10]. Costs savings related

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[9] In this study, we used 20% as a maximal share in all industries and regions.

[10] It should be noted that one would expect the NTMs measures of trade in commodities between the US and EU to be region specific (asymmetrical), rather than the symmetric NTM estimates. However, Egger et al. (2015) were not interested to measure the current level of NTMs between the two regions – they are indeed higher and asymmetric - but rather to see how a deep trade agreement between the US and EU could save a trade cost between two regions. Therefore, these estimates indicate the amount of NTMs that these two regions could reduce under a deep FTA.

Table 1
Scenario layout.

	Melitz Sectors included	AVEs of NTMS			
		Rent generating AVES (40%)		Cost generating AVEs (60%)	
		Import tax (2/3)	*Export tax(1/3)*	*Production cost equivalent*	*Demand shift equivalent*
MLZ_base	✓	✓	✓	Relative reduction in bilateral fixed and variable cost	✓ Only in Armington sectors
ARM	×	✓	✓	×	✓
MLZ_VC	✓	✓	✓	Equivalent reduction in variable trade cost	✓ Only in Armington sectors
MLZ_FC	✓	✓	✓	Equivalent reduction in bilateral fixed cost **	✓ Only in Armington sectors
Modeled as		Reduction in import tariffs representing rents in importer country	Reduction in export taxes representing rents in exporter country	Converted to an equivalent reduction in bilateral fixed and variable trade cost	Converted to an equivalent reduction in demand

*If the bilateral fixed cost equivalent value of the cost generating NTMs exceeds 50% of the value of fixed cost, the remaining is allocated to variable cost.

to non-tariff barriers (NTBs) in service sectors shown in Table A3 stem from gravity estimates by Egger et al. (2015) who draw themselves on various sources, such as trade restrictions in services from the World Bank (Borchert et al., 2014), AVEs for trade barriers in services based on World Bank data (Jafari and Tarr, 2015), assessments of the General Agreement on Trade in Services (GATS) bindings and how these compare to Preferential Trade Agreement (PTA) services commitments from the WTO (Roy, 2014), and, finally, from available information on removability of the NTBs between the EU and US. We use that overall cost saving effect of moving to a deeper level of agreement in TTIP, beyond removing import duties and export subsidies. Note, as shown in Table A3, the removable NTMs are available for some aggregated sectors, only, which we apply consecutively for individual sectors within those categories. While this approach is hardly suitable for detailed empirical work, it fits our objective of pursuing an illustrative application of a CGE model with many different Melitz sectors under realistic shocks.

3.2. Modelling of NTMs

Several authors (Andriamananjara et al., 2003; Walkenhorst and Yasui, 2005; Fugazza and Maur, 2008) point out three general trade effects associated with NTMs and thus ways to allocate their cost: trade cost effects (or protectionism effects), supply shifting and demand shifting effects. The trade cost effect refers to an increase in bi-lateral export cost, for instance, costs for obtaining certification, while production costs for the exported and domestically produced quantities stay identical. Supply shifting effects result from additional cost in production for the export market, such as TBT regulations provoking compliance cost. The demand-shifting effect occurs when regulations affect consumer behavior, such as product labeling requirements. While trade cost and supply-shifting effects are always trade impeding, the impact of demand shifting effects is ambiguous. Furthermore, Fugazza and Maur (2008) underline that empirical quantification of demand shifting effects is both challenging and scarce. They acknowledge that changing the Armington elasticities might technically capture demand-shifting effects, but existing examples of that approach seem somewhat ad-hoc. Beckman et al. (2015), for instance, assume that a TTIP agreement will reduce the Armington demand elasticity by half. Furthermore, allowing for changes in the Armington elasticity on a specific trade link requires structural changes by introducing new CES nests. Although demand side shifting effects might be important for TTIP, we leave them out due to missing empirical evidence. The reader should note that the love of variety effect can be understood as demand shifting in the original Armington specification.

We, however, address in detail the supply side, i.e., cost effects, drawing on the discussed studies estimating the AVEs of NTMs. CGEs model trade cost effects of non-tariff barriers in three different ways: as a pure efficiency loss also called “sand-in-the-wheels” or “productivity shock”, as an export tax equivalent and as tariff equivalent approach. Which approach or mix of approaches is appropriate depends on the nature of the NTMs, especially whether they are rent generating, i.e., allow market access only for certain agents, cost raising or both (Berden et al., 2009; Francois et al., 2013).

The tariff equivalent approach is appropriate when agents in the importing economy capture economic rents from NTMs. Symmetrically, rents accruing in the exporter country are modeled as an export tax equivalent. Here, Disdier et al. (2015, 2016) point out that in the presence of licensing measures, monopolistic rents can benefit the government of exporting countries if licenses are allocated via auctions or alternatively generate rents for foreign or local firms depending on the license allocation method (Junker and Heckelei, 2012). In our modelling framework, the rents are collected via ad-valorem taxes by the government in the importer and/or exporter country where they thus generate tax income and increase at the same time demand prices in the importing country. Note that due to the regional household approach in our CGE, an allocation of the rents to private households would not change results.

The efficiency loss approach is appropriate when NTMs and other regulatory measures increase costs while no rents accrue, for instance in case of customs and administrative procedures, TBT and SPS regulations. The SAM should already capture cost increasing effects of NTMs. In its simplest form, the efficiency loss approach, however, increases the offer price of the exporter based on a wedge, i.e., not considering related cost, which hence focuses on import demand effects (Hertel et al., 2001). Owing to the Melitz structure incorporated in our CGE model, we explicitly increase production cost on the specific bi-lateral trade link instead, based on the ad valorem estimates of these costs. Without further information, we allocated them first proportionally to the fixed and variable cost of trade, subsequently, we perform a sensitivity analysis on the distribution (see section 4.3). The iceberg cost approach to model NTMs often used in Armington models has to allocate the changes fully to variable costs as fixed costs are not present. Note that both approaches assume that domestic production cost drop. Reducing bi-lateral trade margins is another possibility to capture cost savings. However, the AVE of NTMs might often far exceed these margins.

3.3. Scenario specification

We analyze in the following the impact of dismantling any import tariffs, export subsidies, and removable non-tariff barriers for all commodities between the EU and US such that a deep agreement is reached. Using that same shock, we perform sensitivity analysis, first based on the structure of the model (Melitz vs. Armington) and, second, on how cost generating impact of NTMs are captured in the Melitz framework. While removal of tariff measures is straightforward given observed tariffs, the modeler needs to decide how to allocate estimated costs of NTMs.

In case of AVE estimates of NTMs in a TTIP assessment, the literature relies for the cost allocation on the split-up of NTMs effects for the EU-US relation proposed by Berden et al. (2009). They report cost increases in

60% of the cases and rents in the remaining 40%. Both Francois et al. (2013) and Egger et al. (2015) model the 60% cost-increasing effect as a pure efficiency loss following Hertel et al. (2001), while the remaining 40% rent generating cases where distributed to import and export taxes on a 2/3:1/3 basis. In here, the rent generating cases are distributed the same way for all sectors, but the cost generating cases are modeled differently for Melitz sectors in three variants. For Armington sectors, we apply the usual iceberg cost of trade shocks.

Table 1 presents the resulting four scenarios. The first scenario (hereafter, *MLZ_base*) considers 22 Melitz sectors (as shown in Table A2) and 35 Armington sectors. For the Melitz sectors, 60% of AVEs of NTBs for each sector and trade link are mapped into an identical relative reduction in bilateral fixed and variable cost. For the Armington sectors, the demand-shifting equivalent (DSE %) of trade cost is calculated and increases the bilateral preference shift parameter, the usual iceberg cost of trade approach. In the second scenario (*ARM*), all the sectors are considered perfectly competitive and thus use the iceberg cost of trade approach. Comparing *ARM* against *MLZ_base* thus shows the impact of considering many Melitz sectors under an identical shock. The third scenario *MLZ_VC* builds on *MLZ_base,* but allocates the trade cost shock to the trade link specific variable cost only.

The last scenario *MLZ_FC* allocates the trade cost shock on the fixed bi-lateral cost of trade. However, as fixed bi-lateral costs comprise more than just cost to comply with NTMs, we keep at least 50% of the fixed bi-lateral costs of the benchmark. If the shock exceeds that limit, the remaining shock is allocated to variable cost of trade. Comparing *MLZ_base*, *MLZ_VC* and *MLZ_FC* thus allows assessing how sensitive results are in a Melitz framework with regard to allocating cost generating impacts of NTMs.

4. Scenario analysis

While we presume that costs related to NTMs are observed in the global SAM, rents related to NTMs probably hide in capital income flows and are clearly so far not allocated bi-laterally. We therefore first run a simulation to include the rent generating effects associated with NTMs currently in place between the US and EU by introducing respectively increasing bi-lateral import and/or export taxes. That augmented database serves as the benchmark.[11] In the following, we first discuss the simulated impacts of removal of tariffs and trade subsidies as well as NTMs based on the first scenario (*MLZ_base*), presenting the specific outcomes for the motor vehicle sector as an illustrative case with a focus on the variables simulated in the Melitz module. The motor vehicles and parts industry (MVH) of GTAP, according to Spearot (2016), has one of the highest productivity dispersions across firms. Our sensitivity analysis (not shown here) also reveals that this sector has one of the highest percentage changes in response to the shocks. Subsequently, we compare the results with and without Melitz sectors focusing on changes in trade, GDP, and welfare. Finally, we analyze the sensitivity of results in the configuration with Melitz sectors where cost-generating impacts of NTMs are modeled differently.

4.1. Illustrative firm-level impact of policy shocks in a Melitz framework

Table 2 shows in the rows the changes for the variables related to the average firm in the Melitz model associated with the production and sale of the “motor vehicle” sector in the EU on different bilateral trade markets. The first column refers to the domestic market, the second column denotes intra-EU trade, and the other columns show the EU trade with the US, other regions, and the total EU sale.

Table 2
Average firm results for EU domestic sales and exports of “motor vehicle” [% change].

	Domestic sales	EU[a]	US	ROW	World
Firm price	−3.5	−2.8	14.7	−1.7	−0.5
Number of operating firms	−3.7	−0.4	322.2	5.9	30.9
Average output per firm	4.0	3.3	−24.6	2.1	2.5
Average productivity per firm	2.4	1.6	−25.8	0.4	−1.4
Industry fix costs	0.4	0.4	−13.5	0.4	−0.1
Fix costs per unit	0.2	−2.4	−72.8	−7.1	−12.8
Industry variable costs	−1.7	0.0	265.1	5.5	6.4
Variable costs per unit	−1.8	−2.8	14.7	−1.4	−0.3
Total output sold	0.2	2.8	218.4	7.3	9.2

[a] The reader should note that the numbers presented in the column “EU” showing EU to EU exports are due to an aggregation effect. Sales to the domestic market of a nation are not reported as exports in the SAM. However, if we aggregate individual EU countries with GTAPAGG, the former bi-lateral trade links between two EU nations occur now inside one aggregate and become the diagonal trade flow in this column. The domestic sales of the EU aggregate are defined from adding up the domestic sales of individual EU countries.

The results on the EU-US trade link show one typical reaction of a Melitz model: the tariff removal reduces the average CIF price for EU imports into the US at unchanged per unit cost, and thus allows also new, however less productive, firms to operate on that trade link. That increases the number of varieties available in the US market by 322% and thus benefits the consumer. However, in average lower productivity lets variable per unit costs increase by about 14.7%, which is by definition equal to the change in the average FOB price before export taxation. The average firm after these changes is not only less productive, but also trades less: average output quantity per firm drops by about −24.6%. Considering both the increase in operating firms and falling average trade per firm, the traded quantity raises by about 218%. In other words, a larger part of the increase in the extensive margin (i.e., the number of operating firms) is offset by a reduction in the intensive margin of trade (i.e., the average output per firm). The large increase in the number of operating firms allows reducing per unit fix costs by about −72.8%, a change which already reflects that the average firm operating on that trade link is now less productive. Increasing the number of operating firms decreases the average productivity of the firms operating on that trade link (−25.8%), which implies that the average per unit variable costs (14.7%) and thus FOB prices increase. At the same, the average size of these firms also drops, as average output per firms decreases by about the same percentage. Together, these changes constitute a new equilibrium with zero profits for the firms operating on that trade link while monopolistic prices charged are equal to the willingness to pay for the specific quality delivered on that trade link given the number of varieties available. The finding is in line with the literature emphasizing the importance of the extensive margin of trade (Hummels and Klenow, 2005; Chaney, 2008). Moreover, only small changes of the variables on the link between EU and other regions link are observed, such that overall changes in trade mainly reflect the discussed changes on the EU-US link.

Table 3
Average firm results for US domestic sales and exports of “motor vehicle” [% change].

	Domestic sales	EU	ROW	World
Firm price	−2.3	23.8	−1.7	0.6
Number of operating firms	−11.6	434.5	−9.5	23.9
Average output per firm	3.3	−30.2	2.1	2.5
Average productivity per firm	1.6	−31.3	0.4	−2.5
Industry fix costs	0.8	−13.6	0.7	0.6
Fix costs per unit	10.4	−76.8	6.7	0.0
Industry variable costs	−12.1	362.0	−6.8	−7.1
Variable costs per unit	−3.8	23.8	−1.5	0.5
Total output sold	−8.7	273.2	−5.4	−3.9

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[11] We use the filtering approach discussed in Britz et al. (2016) to remove first very small transactions from the global SAM to improve solution behavior.

Table 4
Export volumes by region for “motor vehicle” [% change].

Regions	EU	US	ROW
World	5.5	20.8	0.0
EU	2.8	218.4	7.3
US	273.2		−5.4
ROW	−9.1	−11.1	−3.2

Table 5
Total export volumes by region [% change].

Regions	*MLZ_base*			*ARM*		
	EU	US	ROW	EU	US	ROW
World	3.9	19.4	−0.4	1.4	10.4	−1.0
EU	−3.6	114.5	−2.6	−4.6	77.7	−2.0
US	110.7		−2.1	74.4		−9.4
ROW	−1.0	0.6	0.7	−0.3	−2.9	1.1

The expansion in exports combined with in average less productive firms involved in trade increases the overall input demand in the economy which in turn bids up factor and other intermediate prices. As a first order impact, production costs increase and let profits on other trade links decline. In the EU domestic market, that induces some low productive firms to exit, the number of operating firms drops by −3.7%. As firms with low productivity, output and production factors are reallocated towards higher-productivity and larger firms, average productivity of firms operating in the EU domestic market rises by 2.4%. That, in turn, leads to an ultimate drop in variable costs per unit of −1.8%. These changes result in an increase in average output per firm of 4%. The increase in average firm output compensates for the decrease in the number of firms operating in the domestic market. Consequently, domestic sales increase by 0.2%, along with lower offer prices of −3.5%, reflecting the increased competition with US imports at lower border protection and the reduced export costs to the US.

Table 3 reports changes for export flows and domestic sales of motor vehicles from the US. Note first the impact on the US-EU link: following the reduction in border protection and trade cost, less productive firms find it profitable to enter. Thus, the number of operating firm on the US-EU link increases by factor 4.38. That, in turn, lowers the average productivity on that link, such that the average firm price and output increase. Still, US exports to the EU increase considerably by factor 2.73, which reflects removal of tariffs and bilateral trade costs plus increased willingness to pay due to a higher number of varieties. Export expansion ultimately negatively affects the output sold in the domestic market by −8.7%. In summary, the total industry sale of the US of motor vehicles decreases significantly by −3.9%.

A summary of export flows for the “motor vehicle” sector provides Table 4. As the ad-valorem equivalent estimates of the expected changes in existing NTMs between the EU and US are quite high (see Table A3), EU exports to the US for motor vehicle industry increase by 218% while US exports to the EU increase by 273%. The percentage changes are comparable as the productivity of EU and US firms operating on the bilateral trade links is similar (not shown in the table) and reflects that both countries are subject to similar reduction in NTMs (see Table A3). Nonetheless, the reason that US exports to the EU experience slightly higher changes reflects mainly higher tariffs by the EU compared to the US (not shown in the table).

4.2. *Impacts on trade, welfare, and GDP: Melitz vs. Armington structure*

Table 5 shows simulated changes in the volume of total export flows, measured in constant million US$, comparing the *MLZ_base* case with 22 Melitz sectors and 35 Armington ones to an Armington only configuration in *ARM*. Exports of the EU to the US increase by 114% under the Melitz configuration compared to 77% under the Armington one. Similar, the US exports to the EU raise by 110% with Melitz sectors compared to 74% with competitive sectors, only. Comparable relative differences in trade flows are reported by Hosoe (2017) for a simulation of Brexit in a CGE model with some Melitz sectors where he finds almost 60% higher trade impacts compared to a configuration based solely on Armington.

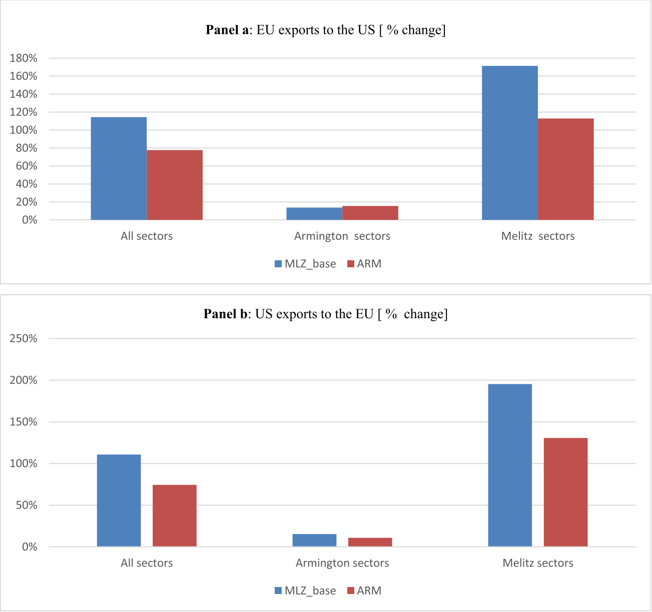

Fig. 1. Export follows between the US and EU.

Looking into sectoral export trade flows - differentiated by the manufacturing sectors captured in the Melitz model and the remaining ones in Fig. 1 – underlines that manufacturing sectors dominate the overall impact independent of the model configuration. The larger simulated exports if they are depicted based on the Melitz model thus also drives economy-wide differences. However, under the Melitz configuration, the remaining competitive sectors expand somewhat less compared to a pure Armington configuration, reflecting competition between sectors in input markets.

4.2.1. *Effects on welfare, and real GDP*

Welfare impacts are measured based on the equivalent variation (EV) criterion (i.e., the additional income needed at benchmark prices to reach the same utility as under simulated income and prices). Global welfare increases by 253 billion US$ if manufacturing sectors are depicted by Melitz, more than double the 108 billion US$ found under the Armington configuration (Table 6). Higher welfare is associated with overall increased industry productivity due to firm entry and exit, reallocation of the production share among existing firms, and increases in the number of varieties on the trade links. Balistreri et al. (2011) also report considerably higher welfare gains compared to an Armington model.

Real GDP increases of 0.85% (EU) and 1.13% in (US) in *MLZ_base* compared to 0.36% (EU) and 0.77 (US) in *ARM*, reflecting these welfare gains. The impact on global real GDP follows a similar pattern.

Table 6
Impacts on welfare and real GDP.

Regions	Welfare [Billion US$]		Real GDP [% change]	
	MLZ_base	*ARM*	*MLZ_base*	*ARM*
World	253	108	0.40	0.17
EU	133	56	0.85	0.36
US	162	108	1.13	0.77
ROW	−43	−56	−0.12	−0.17

Table 7
Export volumes between the EU and US [% change].

	Exports of the EU to the US			Exports of the US to the EU		
	MLZ_VC	*MLZ_base*	*MLZ_FC*	*MLZ_VC*	*MLZ_base*	*MLZ_FC*
Number of operating firms	206.4	270.5	538.7	247.1	321.9	620.9
Average output per firm	−5.9	−26.7	−61.7	−10.4	−30.0	−62.8
Average productivity per firm	−16.5	−18.3	−28.6	−16.2	−18.0	−28.3
Total output sold	188.2	171.5	144.8	210.9	195.5	168.5

4.3. *Sensitivity analysis on allocating NTM costs*

4.3.1. *Trade impacts*

This section compares trade, welfare, and GDP impacts under different allocations to bilateral fixed and variable costs of trade of the same costs associated with NTMs. As indicated in Table 7, the number of operating firms increases under higher allocation shares to fixed cost. Their number on the EU-US link about doubles (206% in *MLZ_VC)* if fixed costs are unchanged, almost triples (270% in *MLZ-base)* if bilateral and variable cost of trade change by the same percentage change and increases by more than factor five (538% in *MLZ-FC*) if fixed costs of trade are allowed to be reduced by up to 50%. These results are in line with the theory of firm heterogeneity suggesting that reducing bilateral fixed cost of trade allows the less productive firm establishing new trade links, which results in an increase in traded varieties.

With new firms entering the trade link, the average output per firm on the trade link (i.e., the intensive margin of trade) will decrease across the different scenarios. As shown in Table 7, higher increases in the extensive margin of trade go along with larger decreases in the intensive margin of trade (i.e., the average output per firm on that trade link). The increases in extensive margin of trade of 206%, 270%, and 538% on the EU-US trade link discussed above are associated by reductions in intensive margin of trade in *MLZ_VC* (−5.9%), *MLZ_base* (−26.7%), and *MLZ_FC* (−61.7%), respectively. These results suggest that the intensive margin of trade is more elastic with respect to the bilateral variable cost of trade. This result are also in line with the theory suggesting that once firms are operating on a given bilateral trade, the bilateral variable costs of trade affect the intensity of trade. That matches Berthou and Fontagné (2015) which found in econometric analysis that 17% of the effect of variable trade costs is reflected in the number of products exported, and the rest of the effect is channeled through the intensive margin.

The net effect of the changes at the extensive and intensive margin reveals that allocating trade costs savings solely to bilateral variable costs leads to higher overall trade changes compared to allocating a higher share of the costs to fixed one.

The analysis of trade flows for Armington commodities, Melitz commodities and total export flows in response to the changes in bilateral variable and fixed cost of trade provides Fig. 2.

4.3.2. *Welfare and real GDP impact*

Increases in the number of operating firms and overall industry productivity are additional sources of welfare gains in the Melitz framework not found in an Armington one. As seen from Table 7, the number of operating firm will increase more significantly when more of the bilateral trade cost reductions are allocated to the bilateral fixed costs, which also implies a larger reduction in productivity for the average firm. However,

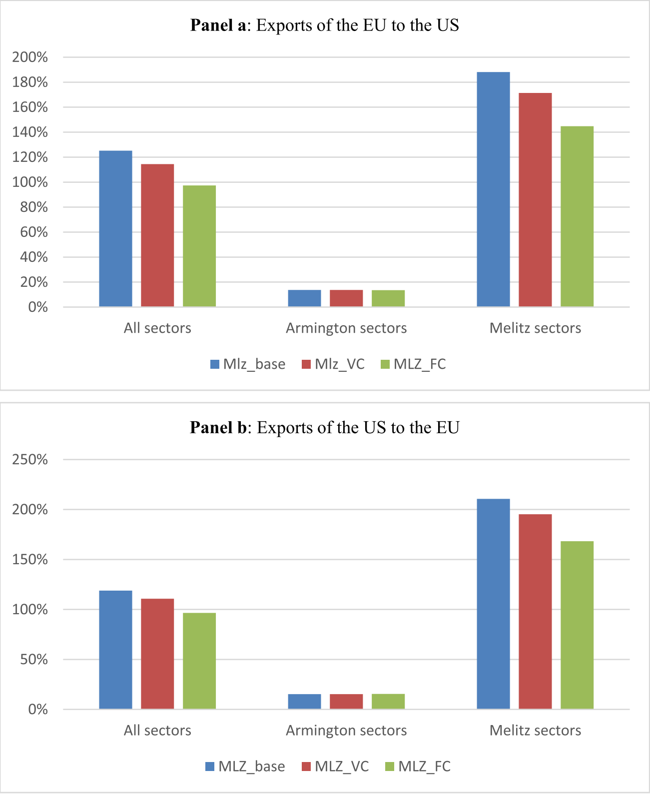

Fig. 2. Exports flows between the EU and US.

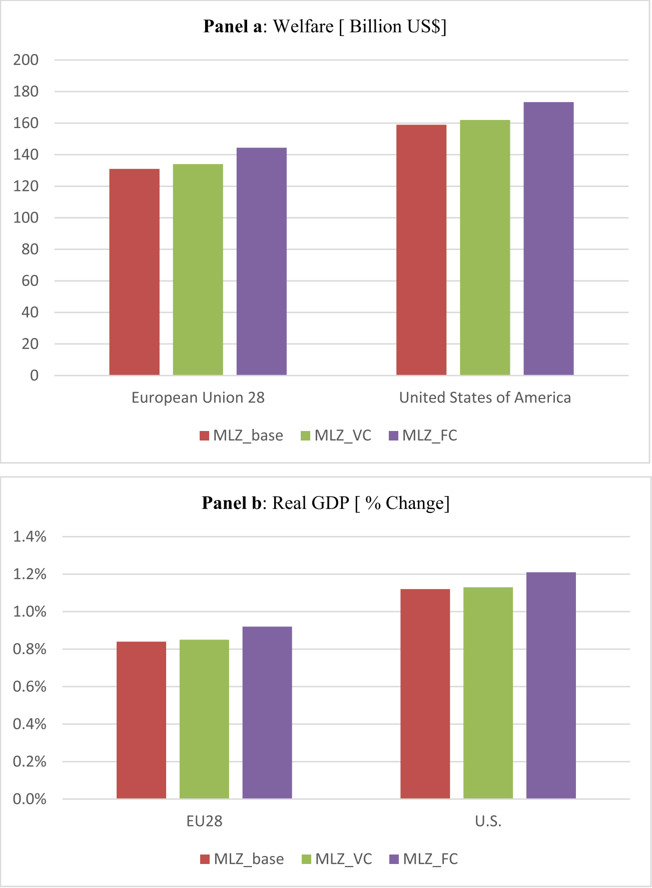

Fig. 3. Welfare and GDP effect under different imposition of NTMs.

in our example, that impact is typically offset in the different sectors by slightly larger productivity increases on the domestic trade link, while the remaining trade flows are hardly affected. The overall industry productivity, therefore, will increase which further boosts the welfare effect. The welfare impacts across regions are summarized in Panel a of Fig. 3. Both the EU and US are better off in all scenarios, but with larger differences: welfare increases are highest in *MLZ_FC* which mostly reduces bilateral fixed costs of trade and lowest in *MLZ_VC* s where fixed costs are not reduced at all. These findings also are reflected in real GDP impacts as illustrated in Panel b of Fig. 3.

5. Summary and conclusion

A vast body of literature supports with empirical evidence the Melitz (2003) model, which has led to different attempts to integrate it into existing CGEs. However, to our knowledge, a robust implementation allowing for dis-aggregated analysis with many sectors and regions is still missing. We, therefore, develop a Melitz module for the modular CGE modelling platform CGEBox (Britz, 2017) with a focus on numerical stability, building on Balistreri et al. (2011, 2013) and Akgul et al. (2016). We employ the module in an illustrative application to TTIP, considering besides the EU and US further eight global regions and treat 22 manufacturing of our total 57 sectors based on Melitz (2003). We compare key results to a configuration where all sectors follows the still dominant Armington assumption in CGE analysis. Our findings of sizeable larger trade and welfare impacts compared to an Armington configuration confirm the theoretical underpinnings and empirical findings of new trade theory.

Applying the Melitz extension is especially inviting for FTA impact assessments with their focus on bi-lateral trade impacts, not at least as the Melitz model allows to distinguish fixed and variable bilateral trade cost savings related to NTMs. We show with sensitivity analysis how allocating the overall estimated trade costs savings under TTIP differently to fixed and variable costs affects key results. As the theory suggests, fixed cost saving have a larger impact on increasing the number of operating firms on a trade link, while variable costs savings mainly increase traded quantities per firm. Overall, in our example, allocating a larger share of the cost savings to variable cost triggers larger trade generation effects, but lower welfare changes. The latter reflects the reduced welfare gains from love of variety linked to a lower increase in the number of operating firms.

Overall, the paper underlines again the advantages of the Melitz framework in empirical analysis. That holds especially in assessments of FTAs where NTMs are typically complex in nature and related cost savings large. Here, our robust open-source implementation of the Melitz model in a CGE is especially advantageous as it allows for a high sectoral resolution and thus detailed analysis of changes at the intensive and extensive margin of trade and related welfare changes.

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Appendix 1. Technical Appendix

Implementation of Melitz model into the standard GTAP model

We incorporate a module based on Melitz (2003) into the flexible and modular CGE model CGEBox (Britz, 2017). The actual implementation of the Melitz model into CGEBox draws largely on the empirical method by Balistreri et al. (2011, 2013) and Akgul et al. (2016) to introduce the Melitz (2003) model into an applied equilibrium model.

The Melitz framework focuses on intra-industry differentiation where each firm produces a single unique variety. However, data at the firm level are limited and applied equilibrium models work at aggregate levels. Fortunately, Melitz offers a numerical framework build around (marginal changes in) the average firm operating within a trade linkage. That average firm's productivity comprises all necessary information on the distribution of productivity levels of firms active in that link. That vastly eases the model's implementation by effectively eliminating any data needs at individual firm level as detailed below. Against a background of that definition of an average firm within each trade linkage, we now focus on the formulation of an empirically computable version of Melitz model and its linkages with the GTAP model.

Assume that a representative agent ‘*a*’ (private households, government, investors, intermediate inputs by the different firms) in region ‘r’ obtains utility $\mathrm{U}_{\mathrm{air}}$ from consumption of the range of differentiated varieties of product ‘i’ and considering the CES utility function as proposed by Dixit and Stiglitz (1997), the aggregate demand by each agent *a* for commodity i in region *r* $(\mathrm{Q}_{\mathrm{air}})$ which is equivalent to utility $(\mathrm{Q}_{\mathrm{air}} \equiv \mathrm{U}_{\mathrm{iar}})$ can be represented as:

$$Q_{air} = \left(\sum_{s} \int_{\omega \varepsilon \Omega_{isr}} \lambda_{aisr}^{\frac{1}{\sigma_{ir}}} Q_{aisr}(\omega)^{\frac{\sigma_{ir}-1}{\sigma_{ir}}} d\omega^{\frac{\sigma_{ir}}{\sigma_{ir}-1}} \right) \tag{A1}$$

where Ω_{isr} represents the set of products *i* sourced from region *s* to *r* and $\omega \ \varepsilon \ \Omega_{isr}$ index the varieties in the set Ω_{isr}. In this context, $Q_{aisr}(\omega)$ represents the demand quantity of commodity *i* for variety ω in region *r* by agent a which is sourced from region s, σ_i represents the constant elasticity of substitution for each commodity, and λ_{aisr} are preference weights (share parameters)[12] that reflect differences between origins not linked to diversity in varieties. Note that substitution elasticities might be differentiated by destination region *r*, but are uniform across agents in each region in our implementation.

The resulting CES unit expenditure function which is the dual price index on Dixit-Stiglitz composite demand in region r (P_{air}) is given by:

$$P_{air} = \left(\sum_{s} \int_{\omega \varepsilon \Omega_{isr}} \lambda_{aisr} \, PA_{aisr}(\omega)^{1-\sigma_{ir}} d\omega \right)^{\frac{1}{1-\sigma_{ir}}} \tag{A2}$$

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[12] The reader should note that the share parameters are absent in the original Melitz paper. We hence allow here a differentiation between products from different origins as in the Armington model in addition to the love of variety effect.

where $PA_{aisr}(\omega)$ is agent's *a* (purchase) price of product *i* for variety ω in region *r* sourced from region *s*. Using the aggregate price index in Melitz (2003) based on the definition of the average firm and considering that varieties do not differ in their marginal utility for the first unit, one can define the price index as equivalent to the dual price defined in Equation (A2)

$$P_{air} = \left(\sum_{s} \lambda_{aisr} \ N_{isr} \ \widetilde{PA}_{aisr}^{1-\sigma_{ir}} \right)^{\frac{1}{1-\sigma_{ir}}} \tag{A3}$$

where $\widetilde{PA}_{aisr}$ denotes the agent price inclusive of export, import and consumption taxes for the average firm, and N_{isr} refers to the number of firms operating on the trade link s-r. Equation (A3) generates the top level Armington price for each agent, replacing the Armington price aggregator in GTAP from the agents' domestic and import prices. Consistent with Melitz (2003), there is a one-to-one mapping among firms and varieties such that the number of firms is equal to the number of varieties on each trade linkage. In comparison to Equation (A2), which is based on the individual varieties, Equation (A3) summarizes the compositional change (i.e., change in the number of varieties), which goes along with an update of the average price. Again we assume the same substitution elasticities across agents.

The total (Q_{aisr}) and average per firm $(\tilde{Q}_{aisr})$ demand for the average variety by an agent to be shipped from s to r $(\tilde{Q}_{aisr})$ can be obtained by applying *Shephard's Lema* on the expenditure function:

$$Q_{aisr} = \tilde{Q}_{aisr} N_{isr} = \lambda_{aisr} N_{isr} Q_{air} \left(\frac{P_{air}}{\widetilde{PA}_{aisr}} \right)^{\sigma_{ir}} \tag{A4}$$

This equation replaces the equations determining the agent specific Armington demands for the domestic and imported good as well as the equations for bi-lateral import demand which are not agent specific in the GTAP standard model.

This reveals the main differences to a standard Armington composite: the share parameters vary with the number of operating firms (i.e., the number of varieties comprised in the bilateral trade bundles). As the agent demand for the average firm's output in region *s* in each industry *i* in region *r* (Q_{aisr}) depends on the aggregate regional demand for that industry Q_{air}, we need to determine this in equilibrium for each agent. In other word, we need to determine the demand for use of *i* as an intermediate input in each sector separately, and as final demand for household consumption, government consumption, investment, and for international transport margins. In the standard GTAP model, each agent has a specific preference function which determines the demand for each Armington commodity; the government and saving sector based CES preferences, while households use a CDE indirect demand function. The Armington demand for each agent and commodity is then decomposed into a domestic and import component in the first Armington nest. The second nest decomposes import demand by each region by origin, independent of the agent.

The implementation of the Melitz model thus simplifies the demand structure present in the standard GTAP model by aggregating the two Armington nests into a single one, however, note that the GTAP database does not yet differentiate in the SAM bi-lateral flows by agent. Therefore we use the same shares by origin to separate import demand for the different agents.

Assume that a small profit maximizing firm facing the constant elasticity of demand according to Equation (A4) for its variety and based on the assumption of the large group monopolistic competition, a firm will not consider its impact on the average price index and therefore follow the usual markup rule to translate their marginal cost of production (c_{is}) to the optimal price.

Firms in Melitz (2003) face different types of cost: sunk fixed cost of entry f^{ie}, fixed cost of operating on a trade linkage f_{isr} and marginal cost c_{is}. Let φ_{isr} indicate the firm's specific productivity, which measures the amount of "variable composite unit" needed per unit of output Q_{isr}. Accordingly, the marginal cost per unit is the amount of "composite input" required per unit $\left(\frac{1}{\varphi_{isr}}\right)$ times the unit cost of the "variable composite input" (c_{is}) in industry *i* of region *s*. Therefore, a firm wishing to supply Q_{isr} units from region *s* to *r* employs $\left(f_{isr} + \frac{Q_{isr}}{\varphi_{isr}}\right)$ units of "variable composite input." The structure of fixed costs and variable composite input demand is discussed in detail below. Let, τ_{isr} denote the iceberg cost of trade, which represent domestic production costs and not the international trade margins present in GTAP. Focusing on the average firm with a productivity $\tilde{\varphi}_{isr}$ operating within a trade linkage and solving the firm's profit maximization problem, the price charged by the average firm in region s to supply region r $\widetilde{PF}_{isr}$ (inclusive of domestic transport margin) is:

$$\widetilde{PF}_{isr} = \frac{\sigma_{ir}}{\sigma_{ir} - 1} \frac{\tau_{isr} \ c_{is}}{\tilde{\varphi}_{isr}} \tag{A5}$$

where $\frac{\sigma_{ir}}{\sigma_{ir}-1}$ represents the constant markup ratio in industry *i*, which reflects market power due to product differentiation into varieties. This newly introduced equation translates the variable per unit cost function for each sector and region into offer prices by the firms on each trade link including domestic sales. In the standard GTAP model, offer prices are not differentiated by destination and are equal to per unit cost corrected for output taxes.

The average price in Equation (A5) therefore depends on the price of variable composite input c_{is}, which is a function of the price of intermediates and primary factors. Given the assumption of constant return to scale and the way technology is presented in the standard GTAP model, the unit cost function for sector *i* in region $s \cdot c_{is}$ in GTAP is given by the Leontief composite of the value added bundle (CES aggregate of factors of production) and the aggregate of intermediate demand (Leontief aggregate of intermediate demands). In the CGEBox, *m_px*[13] is a macro defined as producer price, which constitute per unit costs corrected for production taxes. To be consistent with our Melitz formulation, the unit cost inclusive of production tax is directly introduced in the markup Equation (A5). It should be emphasized that the presence of fixed cost in the Melitz model is the source of increasing returns to scale in a monopolistically competitive industry: if firms expand production, the fixed cost can be distributed over a greater quantity of outputs such that per unit cost decreases.

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[13] http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_GUI.pdf.

While observed data on quantities traded and related prices allow identifying the necessary attributes of an average firm, additional information is needed to gain information about the marginal firm (i.e., the firm that earns zero profit). Obviously, the distance in productivity between the average and marginal firm reflects properties of the underlying distribution. We rely here on a Pareto Productivity distribution, which has analytical tractability.

Let M_s indicate the number of firms choosing to incur the fixed entry cost (i.e., total industry size), each individual firm receives its productivity φ draws from a Pareto distribution with Probability Density Function (PDF):

$$g(\varphi) = \frac{a}{\varphi}\left(\frac{b}{\varphi}\right)^{a} \tag{A6}$$

and Cumulative Distribution Function (CDF).

$$G(\varphi) = 1 - \left(\frac{b}{\varphi}\right)^{a} \tag{A7}$$

where b is the minimum productivity and a is a shape parameter. Lower values of the shape parameter imply higher productivity dispersion among firms. As discussed in Melitz (2003), $a > \sigma_{ir} - 1$ should be applied in order to ensure a finite average productivity level in the industry.

On each bilateral trade linkage, the given fixed bilateral trade cost, variable costs and demand define jointly a certain cut off productivity level (φ_{sr}^{*}) at which firms will receive zero profit. A firm with the productivity equal to that threshold level $(\varphi_{sr} = \varphi_{sr}^{*})$ will therefore face zero profits and act as the marginal firm from region s supplying r. Those firm whose productivity is above the threshold level $(\varphi_{sr} > \varphi_{sr}^{*})$ will receive a positive profit and will operate on the $s - r$ link and those firm with productivity that is below the threshold level $(\varphi_{sr} > \varphi_{sr}^{*})$ will not operate on the $s - r$ linkage. Focusing on the fixed operating cost f_{isr} in composite input units, the marginal firm on s-r linkage receives zero profit at:

$$c_{is} f_{isr} = \frac{r(\varphi_{isr}^{*})}{\sigma_{ir}} \tag{A8}$$

where $r(\varphi_{isr}^{*}) = p(\varphi_{isr}^{*})q(\varphi_{isr}^{*})$ denotes the revenue of marginal firm at the productivity equal to the cut off level $(\varphi_{isr} = \varphi_{isr}^{*})$.

The zero cut off productivity level in each bilateral market φ_{isr}^{*} can be obtained by solving Equation (A8). However, it is numerically easier to define this condition in terms of the average rather than the marginal firm. To do this, we define the productivity and revenue of the average firm relative to that of the marginal firm. Following Melitz (2003), average productivity is defined as the CES aggregation of productivities of all firms operating on a given trade link:

$$\tilde{\varphi}_{isr} = \left[\frac{1}{1 - G(\varphi_{isr}^{*})}\int_{\varphi_{isr}^{*}}^{\infty} \varphi_{isr}^{\sigma_{ir}-1} g(\varphi)\, d\varphi\right]^{\frac{1}{1-\sigma_{ir}}} \tag{A9}$$

If these productivities are Pareto distributed, we can write[14]:

$$\tilde{\varphi}_{isr} = \left[\frac{a}{(a + 1 - \sigma_{ir})}\right]^{\frac{1}{1-\sigma_{ir}}} * \varphi_{isr}^{*} \tag{A10}$$

Equation (A10) provides the relationship between the productivities of the average and marginal firm.

Using optimal firm pricing according to Equation (A5) and given the input technology, the ratio of revenues of the firms with marginal productivity $r_{isr}(\varphi^{*})$ in relation to the revenue of the firm with the average productivity $r_{isr}(\tilde{\varphi})$ is defined as:

$$\frac{r_{isr}(\varphi^{*})}{r_{isr}(\tilde{\varphi})} = \left(\frac{\varphi^{*}}{\tilde{\varphi}}\right)^{\sigma_{ir}-1} \tag{A11}$$

Solving Equation (A10) for $\frac{\varphi^{*}}{\tilde{\varphi}}$, substituting it into (11), and then solving the resulting equation for $r_{isr}(\varphi^{*})$ and replacing its value in Equation (A8), defines a relation between the bilateral fixed cost at current composite input price (the LHS of (12) below), the average firms revenue $(\widetilde{PF}_{isr}\ \tilde{Q}_{isr})$, the shape parameter of the Pareto distribution of the productivities and the substitution elasticity of demand:

$$c_{is} f_{isr} = \frac{(a + 1 - \sigma_{ir})}{a\sigma_{ir}}\ \widetilde{PF}_{isr}\tilde{Q}_{isr} \tag{A12}$$

Note that average firm's sale in region s in each industry i to region r $(\tilde{Q}_{isr})$ at the equilibrium is composed of the demand for use of i by different agents.[15]

The optimal pricing in the markup Equation (A5) requires information on the average productivity on each bilateral trade link. In Melitz (2003), the

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[14] One could use industry specific shape parameter (a_i) given the availability of data at sectoral level. In this study we assume that all firms entering in different industries draw their productivity from the Pareto distribution function with same characteristics (i.e., same scale and shape parameter).

[15] $\tilde{Q}_{isr} = \sum_{a} \tilde{Q}_{aisr}$.

probability that a firm will operate is $1 - G(\varphi^{*}_{isr})$, which is equal to the fraction of operating firms over total number of firms choosing to draw their productivity $\left(\frac{N_{is}}{M_{is}}\right)$. Using the Pareto cumulative distribution function from Equation (A7) and inverting it we have:

$$\varphi^{*}_{isr} = \frac{b}{\left(\frac{N_{isr}}{M_{is}}\right)^{\frac{1}{a}}} \tag{A13}$$

Substituting Equation (A13) into Equation (A10) results in Equation (A14) introduced into the model.

$$\tilde{\varphi}_{isr} = b\left[\frac{a}{(a+1-\sigma_{ir})}\right]^{\frac{1}{1-\ \sigma_{ir}}} * \left(\frac{M_{is}}{N_{isr}}\right)^{-\frac{1}{a}} \tag{A14}$$

Next, the number of firms selecting to enter the market M_{is} is determined. Based on the free entry condition, the last firm that enters has expected profits over its life time, which just offset the sunk cost of entry. Industry entry of a firm requires a one-time payment of f^{ie}. A firm that enters a market faces a probability of δ to suffer a shock, which forces its exit in each future period. Therefore δM_{is} firms are lost in each period. Based on Melitz (2003), in a stationary equilibrium, the number of aggregate variables must remain constant over time, including industry size. This requires that the number of new entrants in every period is equal to the number of firms lost δM_{is} . Therefore, total entry cost is equal to $c_{is}\ \delta M_{is}\ f^{ie}$. Each firm faces the same expected share on that cost (i.e., $c_{ir}\ \delta f^{ie}$ if risk neutral behavior and no time discounting is assumed). The firm's expected share of entry costs must be equal to the flow of expected profit on the condition that firm will operate:

$$\tilde{\pi}_{isr} = \frac{\widetilde{PF}_{isr}\ \tilde{Q}_{isr}}{\sigma_{ir}} - c_{is}f_{isr} \tag{A15}$$

The probability that a firm will operate on the s-r trade linkage is given by the ratio of $\frac{M_{isr}}{N_{is}}\ G(\varphi^{*}_{isr}) = \frac{N_{is}}{M_{is}}$. Thus, the free entry condition ensures that the expected industry profits (i.e., the profits summed up over all potential bilateral trade links) is equal to the annualized flow of the fixed costs of entry

$$c_{is}\delta f^{ie} M_{\mathrm{is}} = \sum_{r} N_{isr}\widetilde{PF}_{isr}\ \tilde{Q}_{isr}\frac{\sigma_{ir}-1}{a\sigma_{ir}} \tag{A16}$$

where zero profit condition in Equation (A12) is used to replace the fixed operating cost $c_{is}f_{isr}$. With the number of entered firm established in Equation (A16), we now turn to total composite input demand of the industry Y,[16] which consists of three components: sunk entry costs of all entrants $(\delta M_{is}\, f^{ie})$, operating fixed cost $\left(\sum_{s} N_{isr}\ f_{isr}\right)$ on each trade linkage, and variable costs $\left(\sum_{r} N_{isr}\ \frac{\tau_{isr}\ \tilde{Q}_{isr}}{\tilde{\varphi}_{isr}}\right)$. Therefore, composite input demand is defined as:

$$Y_{is}\ = \delta M_{is}\, f^{ie} + \sum_{r} N_{isr}\ \left(f_{isr}\ + \frac{\tau_{isr}\ \tilde{Q}_{isr}}{\tilde{\varphi}_{isr}}\ \right) \tag{A17}$$

This equation replaces the output balance equation in the standard GTAP model which ensures that exports and domestic sales for each sector are equal to input composite demand. Table A1.1 summarizes the full set of Melitz equations, and shows the variables through which Melitz model is linked into the structure of the GTAP standard model.

Table A1.1
Equilibrium conditions.

Equation	Equilibrium condition	Paired variable
(A3)	Sectoral Aggregation	P_{air} : Sectoral price index
(A4)	Firm-level demand	$\tilde{P}_{isr}$ Average firm price
(A5)	Firm-level Pricing	$\tilde{Q}_{isr}$: Average firm quantity
(A12)	Zero cut off condition	M_{is} Number of operating firms
(A14)	CES Weighted Average productivity	N_{is} : Average firm productivity
(A16)	Free entry condition	N_{isr} : Number of entered firm
(A17)	Factor market clearing condition	c_{is} : Sectoral composite input price

Production structure for sectors in the Melitz module

This section briefly introduces the production technology for the Melitz commodities which is based on Akgul et al. (2016). The main differences to the GTAP standard model are production function nestings specific to variable and fixed costs. The production nesting for variable and fixed cost is shown in Figure A1 where the total cost is the sum of variable and fixed costs, the latter is added up from fixed cost per firm which entered the industry and fixed cost on each trade link per firm operating on that link.

The variable cost nest uses both a value-added and an intermediate composite based on constant returns to scale (CRS) technology, and in the default case, the fixed cost nest only uses value-added. However, if the overall total cost share of value-added in a sector is small, also the fixed nests comprise a share of intermediate composite. This alternative is identified with the intermediate composite in brackets. The value added and intermediate bundles

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[16] Y corresponds to XP the GTAP in GAMs model.

are CES composite of primary factors of production and intermediate inputs, respectively. The total value added (not shown here) is the sum of value added used in both variable and fixed cost nestings. Similarly, the total use of intermediate commodities and primary factors (not shown here) are the sum of their use in fixed and variable cost nestings.

In the variable cost nests for the Melitz sectors, primary factors or intermediate inputs used are proportional to output, i.e. average output per firm on each trade link times firm operating on the link, summed up over all trade links, corrected for average productivity. On the other hand, the fixed cost nests reflect solely the number of firms which entered the industry and the trade links, and not average output per firm.

Each intermediate commodity used by a Melitz sector could be either a Melitz or Armington commodity, and the intermediate input bundle is a CES composite of these commodities, in the default configuration based on fixed input coefficients. For the Armington goods, we retain the standard GTAP model assumption of domestic and import distinction where imports are sourced at the border (not shown). There is no separate domestic and imports distinction for Melitz commodities, but only one aggregator with love-variety effects which comprises domestic sales and all bi-lateral imports.

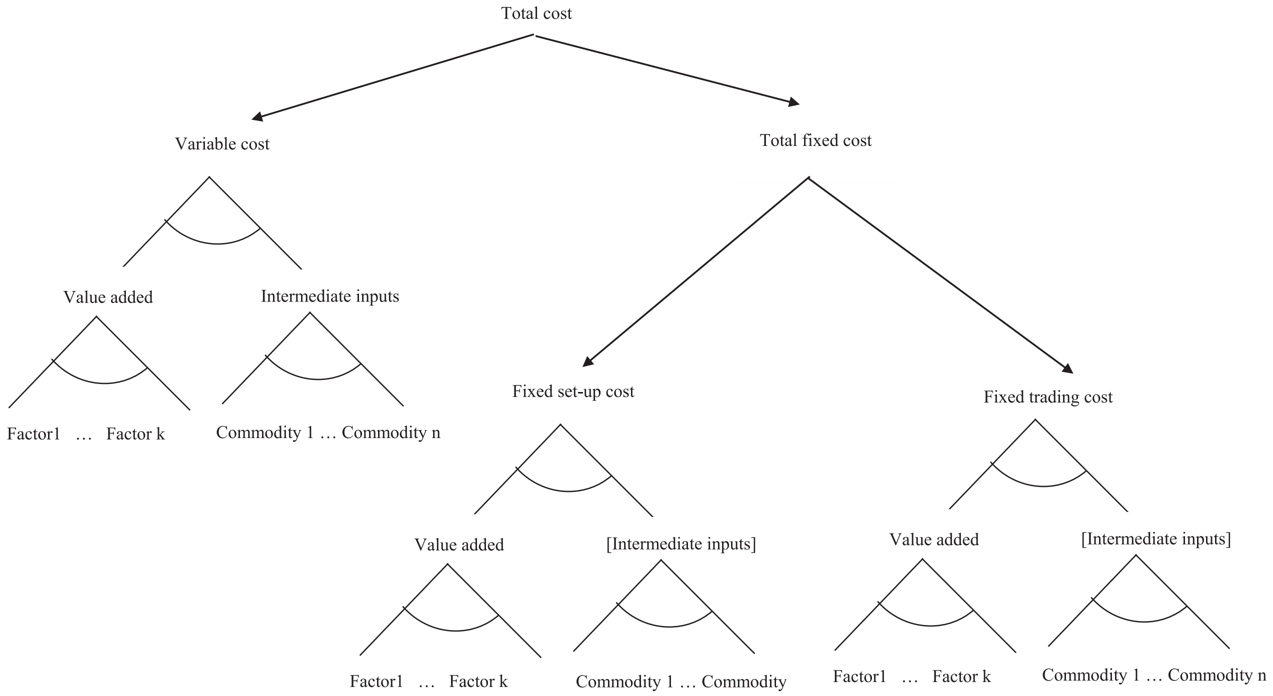

Fig. A.1. Production structure in Melitz sectors.

Comparison of the modelling framework with the existing frameworks

We compare our modelling framework with that of Balistreri et al. (2011, 2013) and Akgul et al. (2016) in Table A1.2. Balistreri et al. (2011) provide the basis of our implementation to which we add modifications introduced by Akgul et al. (2016) and ourselves. The second column of the table reports the original equation numbers found in these two papers. If Akgul et al. (2016) use the same equation layout as in Balistreri et al. (2011), we report only the number from Balistreri et al. (2011). The last column of the table presents the extensions of the model introduced by us.

Table A1.2
Comparison of the modelling framework with the existing frameworks.

Equation	Comparison with literature	Modifications to the Equation
(A3)	Identical to Equation (6) in Balistreri et al. (2011)	We add preference weights (share parameters) to keep the same structure as in the Armington version of the equations. The number of firms operating in the benchmark is set to unity.
(A4)	Identical to Equation (5) in Akgul et al. (2016). Similar equation appears in previous studies, but Akgul et al. (2016) explicitly shows the number of firms operating.	
(A5)	Identical to Equation (23.14) in Balistreri and Rutherford (2013). Equation in similar form appear in the other studies, but partially with different imposition of iceberg cost and tariffs. The layout for the differentiation of variable and fixed cost follows Fig. 1 in Akgul et al. (2016).	1 We build on Akgul et al. (2016) by differentiating the composition of variable and fixed cost as discussed in this appendix under the headline "Production structure for sectors in the Melitz module". 2 A procedure improving numerical stability is introduced as discussed in Section 2.5 which allows removing the love of variety effect and price markup for intermediate demand for the domestic origin by the same sector.
(A12)	Identical to Equation (18) in Balistreri et al. (2011)	With changes according to 1. in Equation (A5), see above
(A14)	Identical to Equation (16) in Balistreri et al. (2011)	
(A16)	Identical to Equation (21) in Balistreri et al. (2011)	With changes according to 1. in Equation (A5), see above
(A17)	Identical to Equation (22) in Balistreri et al. (2011)	

Appendix 2. Supplementary Table

Table A2
Correspondence of GTAP Sectors to sectors with information on AVEs of NTMs.

No.	Code	GTAP and model sectors	Concordance of GTAP sectors and the sectors with information on AVEs of NTMs	Industry structure
1	PDR	Paddy rice	Primary agriculture	PC
2	WHT	Wheat	Primary agriculture	PC
3	GRO	Cereal grains nec	Primary agriculture	PC
4	V_F	Vegetables, fruit, nuts	Primary agriculture	PC
5	OSD	Oil seeds	Primary agriculture	PC
6	C_B	Sugar cane, sugar beet	Primary agriculture	PC
7	PFB	Plant-based fibers	Primary agriculture	P C
8	OCR	Crops nec	Primary agriculture	PC
9	CTL	Bovine cattle, sheep and goats, horses	Primary agriculture	PC
10	OAP	Animal products nec	Primary agriculture	PC
11	RMK	Raw milk	Primary agriculture	PC
12	WOL	Wool, silk-worm cocoons	Primary agriculture	PC
13	FRS	Forestry	Primary agriculture	PC
14	FSH	Fishing	Primary agriculture	PC
15	COA	Coal	Primary Energy	PC
16	OIL	Oil	Primary Energy	PC
17	GAS	Gas	Primary Energy	PC
18	OMN	Minerals nec	Primary Energy	PC
19	CMT	Bovine meat products	Processed foods	FH
20	OMT	Meat products nec	Processed foods	FH
21	VOL	Vegetable oils and fats	Processed foods	FH
22	MIL	Dairy products	Processed foods	FH
23	PCR	Processed rice	Processed foods	PC
24	SGR	Sugar	Processed foods	PC
25	OFD	Food products nec	Processed foods	FH
26	B_T	Beverages and tobacco products	Beverages and tobacco	FH
27	TEX	Textiles	Other manufactures	FH
28	WAP	Wearing apparel	Other manufactures	FH
29	LEA	Leather products	Other manufactures	FH
30	LUM	Wood products	Other manufactures	FH
31	PPP	Paper products, publishing	Other manufactures	FH
32	P_C	Petroleum, coal products	Petrochemicals	FH
33	CRP	Chemical, rubber, plastic products	Chemical and pharmaceuticals	FH
34	NMM	Mineral products nec	Other manufactures	FH
35	I_S	Ferrous metals	Metals and fabricated metals	FH
36	NFM	Metals nec	Metals and fabricated metals	FH
37	FMP	Metal products	Metals and fabricated metals	FH
38	MVH	Motor vehicles and parts	Motor vehicles	FH
39	OTN	Transport equipment nec	Other machinery	FH
40	ELE	Electronic equipment	Electrical machinery	FH
41	OME	Machinery and equipment nec	Other machinery	FH
42	OMF	Manufactures nec	Other manufactures	FH
43	ELY	Electricity	Public services	PC
44	GDT	Gas manufacture, distribution	Public services	PC
45	WTR	Water	Public services	PC
46	CNS	Construction	Construction	PC
47	TRD	Trade	Distribution	PC
48	OTP	Transport nec	Other transport	PC
49	WTP	Water transport	Maritime transport	PC
50	ATP	Air transport	Air transport	PC
51	CMN	Communication	Communications	PC
52	OFI	Financial services nec	Banking	PC
53	ISR	Insurance	Insurance	PC
54	OBS	Business services nec	Other business services	PC
55	ROS	Recreational and other services	Personal and recreational Services	PC
56	OSG	Public Administration, Defense, Education, Health	Public services	PC
57	DWE	Dwellings	Public services	PC

Notes: FH: Firm heterogeneity, PC: Perfect Competition (Armington).

Table A3
AVE % cost reductions.

	EU NTBs	US NTBS
Goods		
Primary agriculture	15.8	15.8
primary energy	16.1	16.1
Processed foods	33.8	33.8
Beverages and tobacco	42	42
Petrochemicals	24.2	24.2

(*continued on next page*)

Table A3 (*continued*)

	EU NTBs	US NTBS
Chemicals, pharmaceuticals	29.1	29.1
Metals, fabricated metals	16.7	16.7
Motor vehicles	19.3	19.3
Electrical machinery	1.8	1.8
Other machinery	6.2	6.2
Other manufactures	3.6	3.6
Services		
Construction	4.6	2.5
Air transport	12.5	5.5
Maritime	0.9	6.5
Other transport	14.9	0
Distribution	0.7	0
Communications	0.6	1.8
Banking	0	0
Insurance	0	0
Professional and business	17.7	21
Personal, recreational	14.4	2.5
Public services	*	*

Source: Egger et al. (2015).

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