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ONE MODEL TO RULE THEM ALL?
THE IMPORTANCE OF FIRM HETEROGENEITY
IN CGE MODELING OF THE GAINS FROM TRADE

Zeynep Akgul

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CENTER FOR GLOBAL TRADE ANALYSIS, PURDUE UNIVERSITY

AND

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500 E Street SW

Washington, DC 20436

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ABSTRACT

There are many different types of Computable General Equilibrium (CGE) models that vary in their underlying industrial organization. Prominent examples include the Armington, Krugman, and Melitz-based CGE models that differ in whether they include imperfect competition, scale economies, and heterogeneity in productivity of firms within industries. There is an ongoing debate about which type of CGE model is more suitable for modeling the impact of trade policy. The question of whether the differences in underlying microeconomic theory in Armington, Krugman, and Melitz-based CGE models leads to different macroeconomic predictions, in particular those on the gains from trade, is critically important. The answer remains elusive since important information is scattered across technical and theory-intensive studies. This paper addresses this question by surveying the theoretical literature along with recent advances in related CGE implementations. One branch of the literature suggests that the market structure does not make a difference and the predictions about the gains from trade from Armington, Krugman, and Melitz-based models are, for the most part, equivalent. In contrast, other studies argue that the models are not equivalent when model assumptions are relaxed to incorporate more of the behaviors of real economies. In the light of the review, we discuss that welfare equivalence across Armington, Krugman, and Melitz models breaks as one departs from the assumptions of stylized models. We conclude that the incorporation of multiple factors and sectors as well as tradable intermediate inputs enhances the economic relevance of models, alters their general equilibrium properties, allows different welfare components to be operative, and breaks the remarkable welfare equivalence findings. As such, when one deviates from the stylized setting, welfare predictions of the Melitz model become more pronounced compared to the rest by capturing new sources of gains from trade.

Zeynep Akgul

Center for Global Trade Analysis, Purdue University

Office of Economics, Research Division

zakgul@purdue.edu

1. Introduction

Firm behavior has become the main focus of research in international trade as academic researchers have gained increasing access to firm-level information in recent years. Empirical findings show that exporters tend to produce more, pay higher wages and are more productive than non-exporters (Bernard and Jensen, 1995, 1999). The heterogeneous nature of firms has motivated new theoretical models of trade to explain the coexistence of exporters and non-exporters within the same industry. One of the seminal works in this literature is the firm heterogeneity model developed by Melitz (2003). By relaxing the traditional definition of representative firms and endogenizing the adjustment in the number of exporters, Melitz (2003) provides a tractable firm heterogeneity model which discerns that only the most productive firms can profitably export since only they can overcome the substantial fixed costs of exporting. Moreover, the model also predicts that trade liberalization increases total factor productivity due to compositional changes within the industry as the most productive firms expand into export markets, less productive firms only serve the domestic market, and the least productive firms contract and even exit. As such, trade grows not only along the intensive margin with existing exporters trading more, but also along the extensive margin with new sets of exporters entering the market. By capturing additional trade-induced microeconomic mechanisms, the Melitz model offers novel economic insights and provides a more comprehensive toolkit for trade policy analysis than previously available.

Incorporation of firm heterogeneity into trade models is a significant step towards enabling rich and quantitatively accurate policy analysis of economies. Nevertheless, firm heterogeneity in Computable General Equilibrium (CGE) models has been relatively unexplored until recently with only a few studies present such as Zhai (2008), Balistreri and Rutherford (2013), Dixon, Jerie, and Rimmer (2016), and Akgul, Villoria, and Hertel (2016).[1] The CGE literature and policy applications in this area have been dominated by more traditional models that are based on the Armington (1969) assumption of national product differentiation or the monopolistic competition model of Krugman (1980). However, the traditional models are often criticized for failing to capture important mechanisms such as the extensive

[1] Ongoing studies include Itakura and Oyamada (2016) and Bekkers and Francois (2016).

margin of trade and trade-induced productivity gains, leading to significant shortcomings in explaining the effects of economic integration. There is, in fact, an ongoing debate on whether failure to account for these additional mechanisms results in underestimation of changes in welfare. This debate is related to a broader discussion about the macroeconomic implications of trade liberalization and which trade model is best for quantifying these implications.

With new trade models, the discussion of whether and in what ways trade benefits economies has been revisited as new sources of gains from trade come into play. Should the new insights in models with firm heterogeneity change our interpretation and understanding of the aggregate welfare gains from trade? Are the welfare gains from trade different, in fact higher, under the Melitz (2003) model compared to Armington (1969) or Krugman (1980)? Do the new micro-level mechanisms alter the macro-level outcomes of trade policies? Do models with firm heterogeneity render the other traditional formulations obsolete? Ultimately, is there one trade model to rule them all?

Some of these questions were initially addressed by Arkolakis et al. (2008) and later more exhaustively explored by Arkolakis, Costinot, and Rodriguez-Clare (2012). The main premise of both studies is that reductions in trade costs generate equivalent changes in gains from trade across the different market structures of these alternative models. In fact, they show that aggregate welfare gains from trade of a particular class of trade models can be summarized by two statistics: the domestic trade share (the domestic producers' share of the market) and the trade elasticity. Even though the micro-level implications of these trade models differ, their welfare predictions may be the same once they are calibrated to the same domestic trade share and trade elasticity. They conclude that gains from trade under Melitz are not that different from the more traditional Armington and Krugman models after all.

In the literature that follows Arkolakis, Costinot, and Rodriguez-Clare (2012), it has become a stylized fact that Armington, Krugman and Melitz models have the same macroeconomic consequences, though they are based on different underlying microeconomic mechanisms. This conclusion has triggered a new line of work in the firm heterogeneity literature that compares the aggregate welfare implications of these models to evaluate whether there is welfare equivalence among the models. There is growing evidence that the welfare equivalence observed in stylized versions of Armington, Krugman and Melitz models with particular restrictions breaks when one deviates from the stylized setting by relaxing model assumptions (Balistreri, Hillberry, and Rutherford, 2010, 2011; Costinot and Rodriguez-Clare, 2014; Melitz and Redding, 2015; Caliendo and Parro, 2015).

In this paper, we provide a critical review of the welfare debate in the firm heterogeneity literature and provide an understanding of the current advancements in related CGE models. While there is now a body of extensive research on the welfare effects of trade with firm heterogeneity, detailed reviews of this literature is rare. The main premise of the debate remains elusive since important information is scattered across the relatively technical and theory-intensive studies. By putting aside the theoretical derivations, this paper investigates why conclusions about the impact of firm heterogeneity on welfare vary substantially in the literature. In this manner, this paper is concerned with the welfare equivalence debate and the comparison of Armington, Krugman, and Melitz models in the CGE context. We aim to discuss the findings in the literature and summarize this debate in a way that is more accessible to the trade policy community.

In this paper, we point out that incorporation of multiple factors of production, multiple sectors, intermediate input trade, and different productivity distributions into the trade models do generate differences in the welfare results across models. Switching across models alters the economic relevance and the general equilibrium properties of models, allows different welfare components to be operative, and breaks the remarkable welfare equivalence findings. Welfare predictions of the Melitz model deviate from the traditional models by capturing new sources of gains from trade such as extensive margin effects due to new varieties, productivity effects due to firm selection and compositional changes in the industry, and scale effects due to intermediate input trade. These new sources of gains from trade in Melitz may be inoperative or offset when the models are stylized. However, as the models reflect more of the economies by relaxing assumptions, they become operative and may lead to more pronounced welfare predictions under Melitz. In addition to model assumptions, the method adopted to compare models and the type of trade policy instrument that is used in quantifying the effect of economic integration also affect the welfare predictions of models. As a result, there are many factors that can change conclusions about welfare equivalence. Finally, as much as welfare is one of the most discussed metrics of a trade policy effect, it should not be the basic criterion for selecting the appropriate type of CGE model in a trade policy analysis. The criterion should instead be whether the new trade theory is a good fit for the problem of interest.

The remainder of this paper is organized as follows. We begin our appraisal in Section 2 with a review of the new channels of gains from trade under the Melitz model. In Section 3, we discuss the welfare equivalence across models and the implications of relaxing some of the modeling assumptions. In Section 4, we move on to the recent developments in CGE models that feature firm heterogeneity and the welfare comparison across Armington, Krugman and Melitz specifications in those models. Section 5 concludes the paper.

2. New gains from trade under firm heterogeneity in the non-CGE literature

In Armington and Krugman-based trade models, welfare changes are often dominated by traditional sources of gains from trade such as the positive intensive margin effects due to increased export volumes of existing exporters and the negative terms of trade effects due to lower prices (Kancs, 2010). However, there are several nontraditional sources of gains from trade that are predicted by the firm heterogeneity model that do not arise in traditional models: (i) Love-of-variety and extensive margin effects due to the introduction of new varieties, (ii) firm selection and productivity effects due to the reallocation of market shares among firms within an industry, and (iii) pro-competitive effects due to reductions in markups. These additional sources of gains from trade may overshadow the consequences of the traditional sources on welfare, especially the adverse terms-of-trade effects. In this section we introduce each new source of gains from trade in the firm heterogeneity model and discuss their welfare implications.

2.1 Love-of-variety and extensive margin effects

Accounting for varieties of differentiated products in trade under monopolistic competition shows that trade cost reductions not only lead existing exporters to export more (intensive margin), but the set of exporters to expand as well (extensive margin). The extensive margin effects are found to be significant for welfare consequences. Feenstra and Kee (2008) estimate that the number of varieties exported by China has increased from 710 to 10315 between the years 1972 and 2001. Of course, more export varieties implies more import varieties. During the same years, the number of products available to US consumers via imports is estimated to have tripled, resulting in welfare gains to US consumers, equivalent to a 2.6% rise in US GDP (Broda and Weinstein, 2006).

The magnitude of extensive margin gains from trade depends on the effect of three sources: (i) increase in the number of imported varieties, (ii) decrease in the number of domestic varieties due to fiercer competition, and (iii) ambiguous change in the number of producers in the country. The net impact of variety on welfare depends on which one of these partial effects dominates.

As a result of trade openness, the set of traded varieties increases. With Dixit and Stiglitz (1977) preferences, consumers benefit from the access to slightly differentiated imported varieties both because they value product uniqueness and because prices are lower. This is often referred to as "love-of-variety." On the other hand, more imported varieties increases competition in the domestic market, and this can eliminate some domestically produced varieties.

In addition to these two effects, Baldwin and Forslid (2010) discuss an "anti-variety" effect. As the number of exporters and their profits increase, the industry becomes more profitable and new firms want to enter into the industry. However, trade induced entry is not guaranteed. The anti-variety effect arises when trade liberalization leads to a reduction in the total number of firms from a particular country and they can have negative welfare implications. Such negative welfare outcomes may be realized when iceberg trade cost reductions lead to increased demand for complementary goods (Balistreri, Hillberry, and Rutherford, 2010). If the demand increase is sufficient to reallocate factors towards complementary goods sector, then we may see firm exit which reduces overall welfare.

One important aspect in the welfare equivalence debate is whether an increase in variety actually translates into welfare gains. Feenstra (2010) argues that removal of iceberg costs in a one-factor/one-sector model of trade with heterogeneous firms leads to welfare gains of increased imported varieties that are just offset by the losses from reduced domestic varieties. Hence, in such a setting, there are no gains or losses from changes in varieties consumed. This result, however, breaks as one moves away from stylized settings. The variety effect leads to changes in welfare, when there are multiple factors and sectors (Balistreri, Hillberry, and Rutherford, 2010, 2011) (see Section 3.2) or when the Pareto distribution is truncated above (Feenstra, 2016) (see Section 3.1).

2.2 Firm selection and productivity effects

One of the unique mechanisms introduced by the Melitz model is the trade-induced productivity change. In particular, trade policy improves industry productivity by shifting market share away from low-productivity non-exporters towards high-productivity exporters.

With trade liberalization, firms self-select into markets such that firms with high productivity levels expand into foreign markets, while firms with low productivity levels contract and die. Trade liberalization benefits firms by increasing the size of the market, while at the same time it hurts them by intensifying competition (Melitz and Trefler, 2012). High-productivity firms benefit more from the increase in market size as they are competitive. On the other hand, low-productivity firms have a hard time with the increased competition, and they cannot take advantage of greater market size. The overall productivity in the industry increases as a result of the reallocation of resources from poor performers to better performers.

The productivity mechanism is also supported by empirical studies. For example, Bernard, Jensen, and Schott (2006) test whether a decrease in variable trade costs leads to aggregate industry productivity gains as predicted by the Melitz model. Their empirical results support the conclusion that reductions in trade costs increase overall productivity growth. Moreover, the industries with relatively high reductions in trade costs experience relatively high gains in overall productivity growth. They find that these gains are the result of a reallocation of market shares towards more productive firms.

Another example of this mechanism is in the context of Canada-US free trade agreement, where Trefler (2004) finds that trade liberalization forced the low-productivity non-exporters to exit while it induced a substantial growth in average industry productivity through market share reallocation to high-productivity exporters. In particular, he reports that the fall in the Canadian tariffs resulted in a 4.3% increase in the overall Canadian manufacturing productivity due to compositional changes within the industry. In addition to that, the fall in US tariffs generated further compositional changes that resulted in a 4.1% increase in the Canadian manufacturing productivity (Lileeva and Trefler, 2010). Melitz and Trefler (2012) report that the free trade agreement with the United States increased Canadian labor productivity by 13.8%, when the two productivity changes above are combined with within-plant productivity growth.

2.3 Markups and pro-competitive effects

The pro-competitive effects of trade are emphasized in Krugman (1979) and Feenstra (2010). Lower trade costs reduce markups charged by firms, and this further lowers consumer prices. While this is an additional source of gains from trade under monopolistic competition, it is absent in models with constant markup, including the Melitz model. This is due to the fact that the Melitz model is based on Dixit and Stiglitz (1977) preferences which assumes a CES demand with constant markups. In addition to the constant markups, the distribution of markups across firms is also fixed due to the assumption of unbounded Pareto distribution. The productivity distribution informs the markup distribution, where the most productive firms have zero cost and infinite markup rates, while the least productive producers have zero markup rates (Feenstra, 2014). As such, when the productivity distribution has no upper bound, neither does the markup distribution. Therefore, trade costs have no effect on the distribution of markups in such cases and trade liberalization does not result in pro-competitive gains from trade. However, when productivity has an upper bound, so does the markup distribution, in which case trade costs determine the highest markups in the market (Feenstra, 2014).

There are several extensions of the Melitz model that moves beyond Dixit and Stiglitz (1977) preferences. An example is by Melitz and Ottaviano (2008) who assume a linear demand system and examine the effects of trade liberalization on variable markups. Those extensions are not explored in this paper as we limit ourselves to the applications of Melitz (2003).

3. Welfare implications of relaxing assumptions

One of the current debates in the trade literature is that the net welfare effects of trade liberalization may be the same across different trade specifications as the additional sources of welfare gains from trade under new models may be offsetting (Arkolakis et al., 2008; Feenstra, 2010). For example, Arkolakis, Costinot, and Rodriguez-Clare (2012) discuss that, for a class of models, the mapping between trade data and welfare is independent of the market structure assumed. An implication of this is that even though the type of sources of gains from trade varies across models, the total size of the gains is the same.

The common features of the class of models for which the welfare equivalence result holds are: (i) Dixit and Stiglitz (1977) preferences, (ii) one factor of production, (iii) one sector, (iv) complete specialization, (v) and iceberg trade costs. Additionally, there are two critical macro-level restrictions: (i) CES import demand system and (ii) gravity equation. Arkolakis, Costinot, and Rodriguez-Clare (2012) show that under these assumptions, there exists a common estimator of the gains from trade that is summarized by two sufficient statistics: (i) the share of expenditure on domestic goods and (ii) a gravity-based estimator of the elasticity of imports with respect to variable trade costs, commonly called the trade elasticity. Specifically, the gains from trade depends on the share of expenditure on domestic goods (or equally one minus the share of expenditure on imports) raised to the negative power that depends on the trade elasticity.[2] Based on this formula, many of the theoretical trade models predict the same gains from trade. However, recent research show that this conclusion is not generalizable to all models and, in fact, welfare equivalence is sensitive to model assumptions (Balistreri, Hillberry, and Rutherford, 2010; Costinot and Rodriguez-Clare, 2014; Melitz and Redding, 2015; Balistreri and Tarr, 2016).

In the context of CGE analysis, the work by Balistreri, Hillberry, and Rutherford (2010) is one of the first responses to the claim of welfare equivalence. They argue that the equivalence result is sensitive to the alternative uses of factors of production. They show that welfare gains are no longer equal across models once a labor-leisure choice is introduced in a one-sector/one-factor model. Costinot and Rodriguez-Clare (2014) further explore the effect of incorporating multiple factors, multiple sectors and intermediate input trade into the model. They show that the Melitz model predicts higher welfare gains compared to Armington and Krugman when multiple sectors and intermediate input trade are included in the model. Melitz and Redding (2015) also argue that domestic trade share and trade elasticity are no longer sufficient statistics for quantifying welfare gains once model restrictions are relaxed such as transferring from unbounded Pareto distribution to truncated Pareto. Any deviation from the models discussed in Arkolakis, Costinot, and Rodriguez-Clare (2012) will naturally lead to deviations in welfare predictions. In fact, Arkolakis, Costinot, and Rodriguez-Clare (2012) also acknowledge that welfare equivalence may no longer holds when multiple factors, multiple sectors or intermediate input trade are incorporated into the models.

[2] The exponent is the inverse of one minus the elasticity of substitution if the underlying model is Krugman (1980), while it is minus the inverse of the Pareto shape parameter if the underlying model is Melitz (2003).

In the rest of this section, we discuss several essential assumptions that affect the welfare equivalence result and the consequences of relaxing those assumptions. We argue that the incorporation of multiple factors of production, multiple sectors, intermediate input trade, different productivity distributions and free firm entry into trade models breaks the welfare equivalence conclusion. Moreover, the method used to compare welfare change as well as the policy instrument used to simulate economic integration also generates different welfare predictions across models.

3.1 Productivity distribution

The accurate measurement of the gains from trade crucially depends on the choice of productivity distribution. If the selected distribution does not fit well to the empirical distribution of firm sizes, the magnitude of the gains from trade may be measured incorrectly. Small departures from the standard distributional assumptions and even going beyond Pareto can generate substantial differences in welfare change.

While there is not a specific productivity distribution assumed in Melitz (2003), the established approach in the subsequent literature is to assume Pareto distribution of firm productivity in each country, following Chaney (2008). The Pareto distribution, $g(\varphi) = 1 - \varphi_{\min} / \varphi^{\gamma}$ with support $[\varphi_{\min}, \infty)$ and shape parameter γ_M , is commonly assumed because it is analytically tractable and empirically relevant. As a result of tractability, the task of deriving aggregate properties of the analytical model is simplified with Pareto distribution (Head and Mayer, 2014). Moreover, the Pareto distribution is stable to truncation from below. This stability implies that the right tail of the distribution, which is associated with high-productivity exporters, also follows the Pareto distribution (Chaney, 2008). Still another reason to select Pareto is that it provides a good fit for the observed distribution of firm sizes, especially for the right tail, such as for American firms (Axtell, 2001) and French firms (Eaton, Kortum, and Kramarz, 2011).

Despite its favorable properties, the Pareto distribution has been challenged in recent work for omitting small firms due to its poor performance in fitting the left-tail of export sales distribution (Head and Mayer, 2014; Sager and Timoshenko, 2016; Nigai, 2017). The empirical relevance of the Pareto distribution may not apply to small firms as there may be a minimum size threshold for Power Laws to provide a good fit for the data (di Giovanni et al. 2013). Nevertheless, matching the left-tail of the sales distribution has important implications on firm selection and therefore on welfare since the left-tail corresponds to the new entrants into the industry and the exit of low-productivity firms from the domestic market. The contribution of the extensive margin to trade and welfare in the Melitz model depends on the firms in the left-tail of the distribution. In extreme cases, the extensive margin effect of trade on welfare change may approach zero if larger incumbent firms are assumed to dominate the market and to have a substantial weight in prices and welfare compared to the small marginal firms (di Giovanni et al. 2013).

In addition to these issues, the traditional approach of assuming no-upper bound in Pareto distribution for productivity has also been criticized as it implies that there exists a firm with productivity that is high enough to cover even the highest fixed costs of exporting. In other words, no upper bound to productivity means that there is a positive mass of exporters for all country pairs (Head and Mayer, 2014), which is empirically incorrect.

Feenstra (2010) argues that with an unbounded Pareto distribution the only operating gains in the Melitz model will be the heterogeneity-led productivity gains because neither the extensive margin effects nor the pro-competitive effects will have welfare consequences. The gains from the expansion of imported varieties will be exactly offset by the loss in domestic varieties. Hence, there will be no welfare consequence of adjustment along the extensive margin. In addition, the Pareto distribution allows for a CES import demand function, which eliminates the pro-competitive gains from trade due to constant markups. Feenstra (2014, 2016) discusses that the gains from trade resulting from increased product variety can be restored once Pareto distribution is bounded from above.

Head, Mayer, and Thoenig (2014) consider alternative distributions for firm productivity such as the Log-normal distribution. They argue that Log-normal distribution has the advantage of providing a much better fit to the data than the Pareto distribution. In fact, they argue that while Pareto only approximates a good fit for the right tail of the distribution, Log-normal approximates a good fit for the complete distribution. Recently, however, both the Pareto and Log-normal distributions have been challenged on the grounds that neither distribution provides a good fit for the entire support such that using one of these distributions alone for the entire support results in sizable errors in estimates of the gains from trade (Nigai, 2017; Sager and Timoshenko, 2016). Specifically, while the Log-normal distribution performs better than Pareto in the left-tail, it performs worse in the right-tail. Therefore, Nigai (2017) suggests a mixed two-piece distribution which models the right-tail as Pareto and left-tail as Log-normal. His findings show that the two-piece distribution outperforms Pareto and Log-normal alone. As an alternative distribution, Sager and Timoshenko (2016) develop the Exponentially Modified Gaussian distribution and argue that it fits export sales data better than Pareto and Log-normal.

In summary, productivity distribution has important consequences for welfare. While the welfare equivalence may occur in stylized settings, deviation from the unbounded Pareto distribution leads to different welfare components to be operative and results in variation of welfare change across Armington, Krugman, and Melitz models.

3.2 Factors of production and sectors

The class of models that delivers equivalent welfare responses is also based on a stylized one-sector/one-factor setting with labor as the single factor. In a one-sector/one-factor setting, labor supply is inelastic. This distorts the firm entry/exit mechanism and eliminates the welfare implications of variety. However, as one moves away from this stylized setting and adds more factors and sectors into the model, the firm entry/exit condition becomes operative again. Due to these changes, the welfare equivalence no longer holds and there are additional sources of gains that are active under Melitz compared to Armington and Krugman models.

When labor is the single factor of production in the model and there are no competing activities for it, the factor supply is perfectly inelastic and cannot adjust to changes in trade costs (Feenstra, 2010; Balistreri, Hillberry, and Rutherford, 2010). Since labor supply does not respond, the free entry condition is satisfied through wage adjustments. Any change in entry costs are absorbed by changes in expected profits as wages respond, leaving the number of entrants in the industry unchanged (Balistreri, Hillberry, and Rutherford, 2010). In other words, there is no firm entry or exit in the industry. The implication of this no entry/exit in a one-factor/one-sector framework is that welfare predictions of Armington, Krugman, Melitz models are the same (Balistreri and Rutherford, 2013).

However, when factor supply is more elastic, the welfare predictions of these models may diverge as entry/exit into the industry becomes operative again. In this case, the free entry condition is satisfied by changes in the number of entrants since wage adjustments only partially absorb costs. As a result, labor will be drawn into the Melitz sector and new firms will enter the industry.

3.3 Intermediate inputs

A relatively unexplored source of gains from trade in models with firm heterogeneity is the scale effect associated with the decrease in costs due to intermediate input trade. Several studies have documented the importance of trade in intermediate inputs. In fact, trade in intermediate inputs constitutes the majority of international trade (Caliendo and Parro, 2015) and it has increased more than trade in final goods (Hummels, Ishii, and Yi, 2001). For example, in 1993, 72.8% of US imports from NAFTA members were intermediate goods, while the percentage is 64.6% for imports from non-member countries (Caliendo and Parro, 2015).

The high share of intermediate input trade indicates that there is a significant mismatch with the data when firm heterogeneity models do not include intermediate inputs. To understand why the empirical context is important for the welfare comparison, recall that domestic expenditure share is one of the two statistics that summarize the gains from trade in Arkolakis, Costinot, and Rodriguez-Clare (2012). The presence of imported intermediate inputs alters the domestic expenditure share substantially and thereby alters the magnitude of the gains from trade based on the welfare calculation in Arkolakis, Costinot, and Rodriguez-Clare (2012). As a result, the welfare conclusion in models that do not account for intermediate input trade may be empirically inaccurate. In fact, Arkolakis, Costinot, and Rodriguez-Clare (2012) state that the use of tradable intermediate inputs in production creates a feedback between input and output that amplifies the gains from trade even under perfect competition. The amplification is more pronounced under monopolistic competition with free entry. As such, welfare predictions of models may no longer be the same when intermediate input trade is incorporated.

The presence of intermediate input trade is a major driver in welfare change through its effects on firm scale (output per firm) and the number of firms in the industry. Lanclos and Hertel (1995) demonstrate the analytical mechanism between intermediate inputs and firm scale in monopolistically competitive industries. They show that the change in output per firm is driven by the change in the wedge between fixed and variable costs of production, where the presence of intermediate input trade significantly alters the outcome. They assume that fixed costs are attributed solely to primary factors, while variable costs are composed of intermediate inputs as well as primary factors. As such, due to intermediate inputs, fixed and variable costs change at a different rate in response to trade policy, and results in a much more pronounced change in firm scale and number of firms. This scale effect is one of the channels through which intermediate input trade affects welfare change.

The presence of intermediate input trade has other effects on welfare. For example, the extensive margin effects of trade are magnified when the entry/exit of new intermediate input varieties are incorporated into the model. This is due to the fact that the number of imported intermediate inputs increases with trade liberalization. In addition to the extensive margin effects, intermediate input trade also has a significant effect on prices. In fact, domestic prices decrease with trade due to increased number of intermediate input varieties and higher competition. Further reductions in prices are realized with trade-induced productivity growth and its implications on marginal costs. Low-productivity firms exit in the face of increased competition and the surviving high-productivity firms gain market share. This compositional change further reduces prices in the domestic market because the surviving firms have lower marginal costs. All these mechanisms create additional rounds of productivity, variety, and scale gains that are not captured in models that do not include intermediate input trade.

There are several studies that demonstrate the difference in welfare predictions across models when intermediate input trade is explicitly modeled. Balistreri, Hillberry, and Rutherford (2011) report that a 50% reduction in tariffs results in a four times larger gains from trade in a multi-sector Melitz model with intermediate inputs compared to a multi-sector Armington model with intermediate inputs. Similarly, recent work by Costinot and Rodriguez-Clare (2014) shows that gains from trade in Melitz are systematically larger when intermediate inputs are accounted for using a uniform tariff cut scenario. This conclusion is echoed by recent studies by Caliendo et al. (2015) and Balistreri and Tarr (2016). In fact, Balistreri and Tarr (2016) find that even in a one-sector/one-factor model, the inclusion of intermediate input trade breaks the welfare equivalence across models.

3.4 Policy instruments

One of the criticisms of the welfare equivalence result is that it is based on reductions in only one type of policy instrument, namely the variable trade costs. These costs often take the form of iceberg trade costs, where a fraction of the shipment melts during transportation. When trade policy is modeled as iceberg costs in Arkolakis, Costinot, and Rodriguez-Clare (2012), the welfare predictions of the models are the same across models. However, this conclusion can change when one uses alternative policy instruments such as tariffs due to their different nature.

Iceberg costs represent the consumption of resources as products melt in transportation. In contrast, tariffs represent transfer of money between economic agents as they generate rents for the importing country. Hence a reduction in tariffs triggers a different microeconomic mechanism compared to a reduction in iceberg trade costs, which may lead to different welfare conclusions across models. Tariff reduction in multi-sector, multi-factor Melitz models are found to predict larger welfare gains than the traditional models (Zhai, 2008; Balistreri, Hillberry, and Rutherford, 2011; Balistreri and Tarr, 2016).

3.5 Model comparison

It is important to understand that comparing Armington, Krugman and Melitz models with respect to their welfare predictions is not simply a matter of applying the same shock to models with different market structures. Arkolakis, Costinot, and Rodriguez-Clare (2012) argue that an appropriate comparison should ensure that each model is calibrated such that the response to trade costs is equivalent across models. This means that models should be calibrated to the same observed trade share and the same trade elasticity with respect to variable trade costs under the Pareto distribution assumption. Once this calibration is done, Arkolakis, Costinot, and Rodriguez-Clare (2012) argue that, the welfare effects of trade cost reductions across various models are equivalent. Melitz and Redding (2013) refer to this approach as the “macro” approach as models are calibrated to match the same aggregate moments. This method ensures that models capture the key features of international trade data and strengthens their empirical relevance as the comparison occurs at the empirically-observed points (Melitz and Redding, 2013). This “macro” approach has been adopted by the subsequent literature.

It is important to note that calibrating the model to have equal reduced-form trade elasticity has implications for the structural parameters of the Melitz model. Specifically, adopting the “macro” approach alters the interpretation of the demand and supply parameters. As Chaney (2008) shows analytically, the gravity model implies different trade elasticities for different trade models. While in an Armington model the trade elasticity depends on the demand-side parameters, in a Melitz model, it depends on the supply-side parameters. Specifically, the trade elasticity in a traditional gravity model is equal to $\sigma_A - 1$ in Armington, while it is equal to γ_M in Melitz, where σ_A is the elasticity of substitution across varieties and γ_M is the shape parameter of the Pareto distribution that governs productivity heterogeneity in the industry (subscripts A and M stand for Armington and Melitz, respectively). In order to obtain the same trade elasticity in both models, one needs to impose the parameter restriction that $\gamma_M = \sigma_A - 1$. Note that for a well-defined Melitz model, the shape parameter has to satisfy the mathematical constraint $\gamma_M > \sigma_M - 1$. The equality condition together with the mathematical constraint implies that substitution elasticities differ across models. In particular, the Armington elasticity should be higher than the Melitz elasticity when the "macro" approach is adopted for model comparison, i.e. $\sigma_A > \sigma_M$ ($\gamma_M = \sigma_A - 1 > \sigma_M - 1$ implies $\sigma_A > \sigma_M$) (Melitz and Redding, 2013).

As a result, the "macro" approach of model comparison is carried out at the expense of flexibility in structural parameters. Melitz and Redding (2013) argue that this approach is quite restrictive because it changes the degree of firm heterogeneity and the degree of substitutability between varieties. For example, the constraints $\gamma_M > \sigma_M - 1$ and $\gamma_M = \sigma_A - 1$ lead to larger values of γ_M, which means that the productivity is assumed to be less-dispersed in the Melitz sector. This has an important effect on the size of the gains from trade. As argued in Melitz and Redding (2013), the proportional welfare gains from opening the closed economy to trade in a Melitz model with Pareto distribution is larger if the productivity is more-dispersed (smaller γ_M). Similarly, Head, Mayer, and Thoenig (2014) argue that smaller values for the shape parameter increase the welfare gains from trade.

In a current study, Balistreri and Tarr (2016) emphasize the effect of having two structural parameters in the Melitz model as opposed to the one parameter in Krugman and Armington on the gains from trade. They state that in order to match the trade responses between Melitz and Krugman, the substitution elasticity in the Krugman model is set at a level that is likely to generate smaller love of variety effects resulting in smaller overall welfare gains compared to Melitz.

As opposed to the "macro" approach, Melitz and Redding (2013) adopt a "micro" approach to compare models. They focus on a homogeneous firm model that is a special case of a heterogeneous firm model with a degenerate productivity distribution, where they keep all the structural parameters the same across models. They discuss that when the models differ only in their productivity distribution while all structural parameter values are the same across models as well as the trade costs, the two models have different aggregate welfare implications. In particular, the welfare effects are strictly higher in the heterogeneous firm model than in the homogeneous firm model. They report that the Melitz welfare gains from trade are greater because the endogenous productivity change from firm entry and exit provides additional welfare gains. They find that the only case where the results indicate equivalent welfare change between the two models is when the value of trade costs is calibrated accordingly. In summary, they argue that with the "macro" approach it is possible to obtain welfare equivalence by calibrating the domestic trade trade share and trade elasticity to be the same across models, which results in different substitution elasticities and different values of fixed and variable costs of trade across models. As opposed to these differences, the "micro" approach distinguishes models only with respect to the degree of firm heterogeneity in markets, which provides a way to obtain the isolated effect of firm heterogeneity on welfare.

Proper model calibration becomes more complicated as one moves into a multi-factor/multi-sector model, which casts further doubt on the generalizability of the "macro" comparison approach. Balistreri, Hillberry, and Rutherford (2010) note that matching the trade responses to policy shocks across models have implications for the pattern of trade in multiple products. In particular, by adjusting Armington elasticities one can match some of the Melitz model trade flows, but not all of them. The adjustment may in fact result in errors in other trade flows. In fact, Balistreri, Hillberry, and Rutherford (2011) note that there is no Armington elasticity in a setting with multiple-factors, multiple-sectors and rent-generating tariffs, that can generate the same bilateral trade response as in the Melitz model. In contrast, Dixon, Jerie, and Rimmer (2016) discuss that the two models will imply similar welfare effects if the Armington elasticity for a specific commodity is calibrated to deliver the same import response as in the Melitz model based on the same data. While this argument applies in their special setting where the effect of tariff increase is explored in a two-country, two-sector, and one-factor model, and implies welfare equivalence across models, it may not apply in a multi-factor environment.

In summary, the welfare equivalence conclusion depends on the approach adopted to compare the models. It is crucial to develop and adopt a comparison method that isolates the distinct features of each model, works in a multi-sector/multi-factor setting and at the same time allows for a more flexible parameter space. This is one of the important areas in the firm heterogeneity literature that grants further research.

4. Recent CGE models featuring firm heterogeneity

Where does the CGE literature stand with respect to model comparisons and welfare equivalence? In recent years, there have been a number of initiatives to incorporate firm heterogeneity into CGE models of trade. We focus on the models by Zhai (2008), Balistreri and Rutherford (2013), Dixon, Jerie, and Rimmer (2016) and Akgul, Villoria, and Hertel (2016). All of these models incorporate the core Melitz mechanisms such as markup prices, endogenous productivity thresholds and firm selection in markets in a similar fashion. However, there are a number of departures from the Melitz benchmark with respect to particular assumptions, such as the number of factors and sectors, the presence of intermediate input trade, and the modeling of fixed costs and firm entry and exit. These details in implementation differentiate each model and may contribute to varying welfare consequences.

A common feature of the CGE implementations is that they incorporate the Melitz model at the industry-level and do not rely on firm-level data. The current implementations are based on the behavior of the average firm following the definition in Melitz (2003). The productivity level of the average firm is determined by the weighted average of the productivity levels of active firms in the industry. As such, the average firm fully captures the firm-level information necessary for aggregate outcomes, as demonstrated in Melitz (2003).

4.1 Zhai (2008) and Petri, Plummer, and Zhai (2012a, b)

One of the first efforts to incorporate firm heterogeneity into a global CGE model of trade is Zhai (2008). He develops a multi-sector, multi-factor CGE model, where firm heterogeneity is modeled in several sectors. He explores trade liberalization scenarios and compares the welfare results to that of a benchmark Armington CGE model with homogeneous firms using the GAMS programming language. Among the 14 sectors in his model, manufacturing and services sectors are characterized by monopolistic competition and heterogeneous firms, while agriculture and energy sectors are characterized by perfect competition and traditional Armington assumptions.

The theoretical underpinnings of Zhai (2008) follow the main microeconomic mechanisms of the Melitz model for the most part. In his implementation, the demand for differentiated goods is a CES aggregate of individual varieties and production is modeled as a CES nest of intermediate inputs and value-added. Firms in each monopolistically competitive industry produce unique varieties at different productivity levels, have monopoly power on their own distinctive products, and set product prices at a constant markup over marginal cost. Firms get their productivity draws from an unbounded Pareto distribution and face region-specific fixed costs for their domestic sales and exports. A portion of labor, capital and intermediate inputs are devoted to covering these fixed costs. The productivity thresholds for market entry in domestic and export markets depend on demand and prices at the importing region, bilateral fixed costs and substitutability across varieties. The average industry productivity is a function of bilateral productivity thresholds and structural parameters of the model, based on the Pareto distribution. The number of active firms in each bilateral market, then, is a function of the total mass of entrants into the industry and the associated productivity threshold to enter that market.

To illustrate the workings of the model, Zhai (2008) focuses on three simulations: (i) reducing global manufacturing tariffs by 50 percent, (ii) reducing variable trade costs in manufacturing by 5 percent and (iii) reducing fixed export costs in manufacturing by 50 percent. The simulations indicate that each of these policy changes leads to higher welfare gains under Melitz compared to Armington when the same substitution elasticities are used in both models. However, as discussed in detail in Section 3.2, to provide comparable experiments in the spirit of Arkolakis, Costinot, and Rodriguez-Clare (2012), Armington elasticities should be adjusted to equalize trade responses across models. This is addressed in Footnote 15, where Zhai (2008) explains that even when the tariff reduction simulation is repeated with higher Armington elasticities, the Melitz CGE model predicts *higher* global welfare gains compared to the Armington model. This result is at odds with the welfare equivalence reported in Arkolakis, Costinot, and Rodriguez-Clare (2012).

Why does Zhai's analysis deliver different insights into the welfare equivalence debate? First of all, this is a multi-sector/multi-factor implementation with intermediate input trade. These features make the model more complicated and closer to real economies, which in turn may deliver greater gains from trade in Melitz compared to Krugman and Armington depending on the trade policy as discussed in more detail in Section 3. In addition to these features, there are a number of simplifications made in this implementation which may be generating differences in welfare predictions across models.

For example, one of the significant assumptions in Zhai (2008) for aggregate outcomes is that the total mass of potential entrants in each monopolistically competitive sector is exogenous and fixed. In other words, there is no firm entry or exit into the industry, though there is adjustment in the number of firms participating in each national market. The mass of potential firms in each sector is calibrated to be proportional to current sectoral output. In addition, Zhai (2008) assumes that firms do not face fixed production costs or any sunk entry costs prior to entering into an industry. There is also no uncertainty about productivity before entry.

In Zhai's own words, his model abstracts from the dynamic parts of the Melitz model and should be interpreted as characterizing a “static equilibrium” as opposed to a “steady-state” equilibrium. He resorts to these strategic simplifications in order to avoid the possible computational difficulties, such as corner solutions, that may arise when multiple sectors are characterized by monopolistic competition and heterogeneous firms. Zhai (2008) argues that the multi-sector Melitz model with free entry/exit may behave like a New Geography Model such that the equilibrium may not be stable.[3]

It is important to note that the no firm entry/exit assumption has important implications for the extensive margin effects of trade on welfare. Based on this assumption, all of the trade adjustment in the extensive margin will be due to endogenous changes in the shares of firms that are active in each bilateral market. This corresponds to changes in the extensive margin due to competitive firm selection into specific markets. However, it is only part of the overall impact of extensive margin on welfare. As we discussed before, firm entry/exit into the industry is another component of how the extensive margin can affect welfare. This corresponds to the left tail of the productivity distribution, where new

[3] The literature on New Economic Geography discusses that centripetal forces that pull the economic activity together may give rise to computational difficulties due to multiple corner equilibria multiple corner equilibria. This is because these models generate a circular causation with backward and forward linkages, where producers benefit from scale economies by concentrating in regions and sectors with more varieties, and consumers concentrate in the same regions and sectors to have access to more varieties (Fujita, Krugman, and Venables, 1999). Numerical implementations of such models may also be associated with increased dimensionality and potential non-convexities (Balistreri and Rutherford, 2013).

firms enter the industry and low-productivity firms exit from the industry. Depending on the relative magnitudes, the welfare loss due to the decrease in the number of domestic varieties may offset the welfare gain due to the increase in the number of imported varieties, as discussed in Section 2.1. Therefore, the no firm entry/exit assumption may underestimate the impact of new entrants or the loss of domestic firms on welfare.

One of the fundamental criticisms of this implementation is that the no firm entry/exit assumption may lead to non-zero expected profits (Dixon, Jerie, and Rimmer, 2016; Balistreri and Tarr, 2016). In the Melitz model, all firms that are active in a bilateral market make positive profits. The only exception is the marginal firm which breaks even as its productivity equals the threshold level of productivity. Since all the other active firms have higher productivity levels than the marginal firm, it is expected that they make positive profits. Therefore, average firm profit is positive, which may lead to profit accumulation in the industry. The original Melitz model prevents potential profit accumulation with a free entry condition, where the present value of future average profit is offset by sunk entry costs. As such, any positive net value of entry will be exhausted by new firms entering into the industry and incurring sunk entry costs. If there is no free entry/exit and there are no sunk costs to enter the industry, how do potential firm profits clear? The absence of this mechanism may lead to profit accumulation in the industry which raises questions about the welfare predictions in Zhai (2008). As noted by Costinot and Rodriguez-Clare (2014), when there is only one sector in the model, the no firm entry/exit assumption does not have implications for the magnitude of gains from trade. However, when there are multiple sectors, such as in Zhai (2008), free entry/exit may generate home market effects, which then will have welfare consequences.

Zhai's model has been previously applied to the analysis of economic integration in studies such as the Association of Southeast Asian Nations (ASEAN) by Petri, Plummer, and Zhai (2012a) and the Trans-Pacific Partnership (TPP) by Petri, Plummer, and Zhai, (2012b). The TPP application has raised substantial interest. Since the template of the agreement was not available at the time of the study, they based their scenarios and policy shocks on the KORUS agreement. Their aggregation consists of 24 regions and 18 sectors, where manufacturing and private services are characterized by Melitz and the rest of the sectors follow the conventional perfect competition and Armington assumptions. As the template of the agreement made available later, Petri and Plummer (2016) have updated the TPP analysis with more recent data, based on a similar model. Their current aggregation covers 29 regions and 19 sectors, where, again, the manufacturing and services sectors are based on Melitz characteristics. Simulation results in both the 2012 and 2016 study predict high global welfare gains under firm heterogeneity.

One notable feature of the model used in these studies is the no firm entry/exit assumption of Zhai (2008). In both TPP applications, the authors assume that the total number of firms in Melitz sectors is exogenous and fixed, while they retain the mechanism of endogenous firm selection into bilateral markets. As discussed in detail above, this assumption may lead to higher welfare predictions under Melitz compared to Armington. Currently, we do not have enough information about how this potential profit accumulation issue is addressed in the later applications of Zhai's model. While it is tempting to conclude that this is driving the welfare results in these studies, we should not forget that there are many other factors at work here. The comprehensive policy scenarios that cover not only tariff removals but also reductions in non-tariff barriers, the incorporation of foreign direct investment and capital accumulation mechanism in the model and many other factors have to be accounted for in order to make a strong statement about the welfare equivalence debate.

4.2 Balistreri and Rutherford (2013)

The difference in theory and calibration across the Armington, Krugman and Melitz specifications is clearly demonstrated in Balistreri and Rutherford (2013). Their earlier work (Balistreri, Hillberry, and Rutherford, 2010) compares stylized versions of Armington and Melitz models and investigates the welfare equivalence conclusion in Arkolakis et al. (2008). They show that this conclusion is valid when a stylized model with one sector and one factor of production is assumed; however, it becomes fragile when a second sector is included into the model, which causes competition for factors of production (in this case, labor).

Balistreri, Hillberry, and Rutherford (2011) continue with a more detailed empirical implementation of the Melitz model. They apply the same framework to an aggregation with 12 regions, 7 aggregate sectors and 5 primary factors of production, with firm heterogeneity assumed in the manufacturing sector. They examine a number of policy scenarios to compare the Melitz results to that of the Armington benchmark. They first consider a 50% reduction in manufacturing tariffs which yields approximately four times larger welfare changes under Melitz compared to the Armington benchmark. Similarly, they experiment with 50% reduction in fixed trading costs and joint reduction in both tariffs and fixed costs. The Melitz model predicts higher welfare gains in all simulations. They find that the variety effects on consumption and prices, as well as the endogenous productivity changes in the Melitz model, lead to higher gains from trade compared to the Armington benchmark.

Balistreri and Rutherford (2013) focus on developing stylized versions of Armington, Krugman and Melitz CGE implementations separately. Unlike Zhai's implementation, in their model there is uncertainty about the productivity levels of firms prior to entering the industry. Firms incur sunk entry costs to have access to a productivity draw and enter the industry. In addition to sunk entry costs, firms face fixed production costs that result in increasing returns to scale in production and market specific fixed costs that restrict the number of firms active in each bilateral market. Firms also face an exogenous probability of death due to a negative shock such as a change in regulations or natural disaster. Most importantly, Balistreri and Rutherford (2013) incorporate firm entry/exit into their implementation.

There are seven core equations that are common to all of the Melitz CGE implementations in Balistreri, Hillberry, and Rutherford (2010,2011), and Balistreri and Rutherford (2013): (i) Dixit and Stiglitz (1977) preferences and demand facing the average firm, which is a function of relative prices and aggregate demand of the importer, (ii) CES price index which is an aggregation of individual prices, (iii) average firm price which is a constant markup over marginal cost, (iv) bilateral productivity thresholds to enter into domestic and export markets, which is determined by the marginal firm that breaks even, with its variable revenue from selling in that market exactly offsetting the fixed cost of exporting, (v) a free entry condition that determines the total number of entrants into the industry, with new firms entering until all operating profits are exhausted by the entry costs paid by new firms, (vi) the average productivity of active firms, which is proportional to the productivity threshold for market entry, and (vii) labor market clearing conditions that ensure that the supply of labor equals the demand for labor.

While the Melitz mechanisms, multiple sectors and free firm entry/exit condition in these CGE implementations offer many insights into trade, they also cause some difficulties in large-scale general equilibrium applications. There are several computational challenges associated with solving large-scale models with Melitz sectors. One of such challenges is the large dimensionality. Balistreri and Rutherford

(2013) point out that the dimensions of the Melitz model are much larger due to the bilateral equilibrium conditions present in the Melitz sectors. The bilateral equilibrium conditions and the associated variables are indexed by sector, by source country and by destination country. Therefore, the dimension of the model gets larger as the number of sectors and countries increases. This causes computational difficulties as the model should solve non-linear trade equilibrium together with region-specific non-linear entry conditions, bilateral markup prices and productivity. Another challenge is the possibility of encountering non-convexities in such models. Some of these non-convexities are due to the nature of monopolistic competition. As Balistreri and Rutherford (2013) mention in Footnote 9, these non-convexities are especially notable in industries that use a lot of their own output as intermediate inputs. In industries where the demand for own-input is large, adding love-of-variety, markup pricing and scale effects makes it difficult for the model to converge.

Balistreri, Hillberry, and Rutherford (2011) and Balistreri and Rutherford (2013) address these challenges by introducing a decomposition algorithm and by using an advanced Mixed Complementary Problem (MCP) solver in GAMS. Rather than solving the Melitz market structure and general equilibrium jointly, the decomposition algorithm divides the problem into two modules and tackles them separately. In the first module, they take the general equilibrium variables as given and solve a partial equilibrium model with the Melitz market structure. The solution yields estimates of sectoral variables under firm heterogeneity such as productivity, markup prices and firm production. In the second module, they use these sectoral estimates in an Armington general equilibrium model that does not include the Melitz market structure and they solve for the aggregate variables such as demand, input supply and wages. They then feed these aggregate variables back into the partial equilibrium model and recalibrate the sectoral variables with the Melitz market structure. The iteration between these modules continues until the aggregate variables used in the Melitz sectors and the GE module converges.

Despite its clear distinction between Melitz market effects and Armington general equilibrium effects, the decomposition algorithm is computationally demanding and may be impractical in trade policy analysis. Dixon, Jerie, and Rimmer (2016) argue that while resorting to this decomposition may be necessary when solving non-linear large-scale Melitz models in levels form using GAMS, it may not be necessary when using the GEMPACK software suite (Harrison and Pearson, 1996; Horridge, Pearson, and

Rutherford, 2013), which uses a linearized version of the behavioral equations and allows for substituting out the large-dimension variables. This is an approximation that improves the computation of the model with higher efficiency and without resort to the decomposition algorithm. Therefore, instead of remedying dimensionality issues, the decomposition algorithm is used as a tool to investigate the components of welfare change in Dixon, Jerie, and Rimmer (2016).

A recent study by Balistreri and Tarr (2016) clarifies how relaxing the assumptions in CGE applications of the Melitz model results in different welfare predictions across models. The systems of equations in Armington, Krugman, and Melitz implementations closely follow Balistreri and Rutherford (2013). Balistreri and Tarr (2016) begin with replicating the equivalence result in Arkolakis, Costinot, and Rodriguez-Clare (2012) based on a one-factor, one-sector stylized model with balanced trade and no intermediates. Results show that 10% global reduction in variable trade costs predict identical welfare effects across alternative market structures in this stylized framework. They then incorporate progressively more information into the Armington, Krugman, and Melitz models by adding intermediate input trade, more sectors and factors. They find that even in a one-sector, one-factor model, the inclusion of intermediate input trade alters the welfare conclusions. Their simulation results demonstrate that the Melitz structure generates greater welfare gains compared to Krugman and Armington. Further additions to the model, such as adding multiple sectors, magnify the difference in the welfare predictions across the models.

The welfare calculations in Balistreri and Tarr (2016) are based on Hicksian Equivalent Variation (EV), as opposed to the two sufficient statistics used in Arkolakis, Costinot, and Rodriguez-Clare (2012). Therefore, Balistreri and Tarr (2016) are able to track the mechanisms that generate the difference in welfare predictions of models. Adopting the “macro” comparison method, they match the trade responses across models by using higher values for substitution elasticity in Armington and Krugman than in Melitz. One notable distinction in this recent research is that the Melitz model is based on the seven core equations in Balistreri and Rutherford (2013) mentioned earlier and it does not incorporate the broader general equilibrium. Therefore, in this implementation, they do not have to resort to the decomposition algorithm to tackle the potential computational issues. They conclude that the welfare equivalence across models breaks with the incorporation of multiple sectors, multiple factors, and intermediate input trade.

4.3 Dixon, Jerie, and Rimmer (2016)

Balistreri and Rutherford (2013) demonstrated that, despite distinctions due to different theoretical underpinnings, Armington, Krugman, and Melitz specifications also share several common equations. Inspired by this unifying perspective, Dixon, Jerie, and Rimmer (2016) develop an encompassing model that can capture the similarities and differences across the three structural models. The resulting 10-equation system is referred to as the Armington-Krugman-Melitz Encompassing (AKME) model. Each individual model is obtained as a special case by sequentially relaxing assumptions in AKME.

This implementation is based on a multi-country setting with one heterogeneous sector (widgets). There are three types of costs in the Melitz module of AKME: (i) variable costs that are proportional to output, (ii) fixed setup costs to enter into the industry and, (iii) fixed export costs that are bilateral. Firms are heterogeneous with respect to their productivity levels and they produce slightly differentiated varieties in the monopolistically competitive industry. The authors develop a 10-equation system that describes production, pricing and trade as follows: (i) price is a constant markup over marginal cost, (ii) the CES price index is an aggregation of the individual prices of the domestic good and imports identified by source countries, (iii) CES demand is a function of relative prices and the aggregate demand of the importer, (iv) aggregate demand for varieties imported from the source country, which depends on the demand for an average variety and the number of varieties imported from the source, (v) bilateral productivity thresholds to enter into domestic and export markets that are determined by the marginal firm that breaks even because its variable revenue from selling in that market exactly offsets the fixed cost of exporting, (vi) a free entry condition that determines the total number of entrants into the industry, with new firms entering until all operating profits are exhausted by the entry costs paid by new firms, (vii) labor market clearing condition that ensures that the supply of labor equals the demand for labor, (viii) the number of exporters is determined by the productivity threshold to export and the total number of firms in the industry, (ix) the average productivity of active firms is proportional to the productivity threshold for market entry, and (x) the output of the marginal firm is proportional to the output of average firm based on Pareto distribution of firm productivity.

In their implementation, Dixon, Jerie, and Rimmer (2016) also present a detailed welfare decomposition based on the Balistreri and Rutherford (2013) decomposition algorithm. Dixon, Jerie, and Rimmer (2016) define welfare as the weighted average of the percentage changes in consumption of composite commodities in the destination country. They disaggregate the welfare results into five Armington components: the contribution of changes in (i) employment, (ii) tax-carrying flows (gains from trade by the consumer and producer surpluses due to difference between tax-inclusive and tax-exclusive prices), (iii) terms of trade, (iv) production technology, and (v) conversion technology (or preferences). Here we focus on the last two components since they are the contributions of the Melitz model.

The production technology effect is described as the contribution of improvements in sectoral productivity to welfare. If the sector can produce more output per unit of labor input, labor can be utilized by other sectors without reducing the sector's output. Therefore, higher sectoral productivity boosts welfare. The conversion technology (or preferences) is described as the contribution to welfare through the conversion of products from different sources into the composite good. This component captures the love-of-variety effect, where consumers attain higher levels of utility with the increasing availability of different varieties.

The workings of the AKME model is demonstrated by a tariff increase scenario using the GEMPACK software suite. Interestingly, simulation results indicate that there are cases where the new micro-mechanisms in the Melitz theory may not change the aggregate welfare outcome due to competing effects neutralizing each other. This is illustrated in the tariff increase scenario, where the contribution of conversion technology to welfare is positive, while the contribution of production technology is negative. Higher tariffs result in reduced productivity in the importer as low-productivity domestic producers expand and replace imports while high-productivity exporters contract. As a result, average industry productivity decreases and reduces welfare. That is why the production technology contribution to welfare is negative. On the other hand, higher tariffs lead to increased number of available varieties in the market, especially domestic varieties. The availability of new varieties benefits consumers and increases welfare. That is why the conversion technology contribution to welfare is positive. The unexpected result of this experiment is that these two effects offset each other in magnitude such that they do not contribute to the overall welfare outcome. As a result, the overall welfare change in the Melitz GE illustration is still driven by the conventional components of welfare, namely the terms of trade effect and tax-carrying flows, rendering the total welfare change not significantly different than what one would get in an Armington trade model. In the context of the welfare debate, this result is in line with the Arkolakis, Costinot, and Rodriguez-Clare (2012) welfare equivalence conclusion.

Dixon, Jerie, and Rimmer (2016) propose an explanation for the offsetting effect based on the Envelope Theorem. They state that the Melitz economy is an optimized market outcome that would be achieved by a cost-minimizing world-wide planner. In accordance with the Envelope Theorem, changes in production and conversion technology components of welfare generate only marginal shifts from the optimum. Therefore, they do not lead to significant welfare consequences. They assert that the welfare result may be a reflection of the Envelope Theorem based on the fact that the initial situation is optimal, where there are zero tariffs in the initial equilibrium. Furthermore, they show that the Melitz results can be obtained by an Armington model with extra shocks to productivity and preferences once the Armington elasticity is calibrated to match the trade responses in the Melitz model. Based on these finding, they interpret the Melitz model as providing a micro-theoretic foundation for an Armington implementation.

Despite their clear Melitz implementation and contributions to welfare decomposition and model comparison, it is important to note some caveats before generalizing the Dixon, Jerie, and Rimmer (2016) welfare equivalence conclusion. There are several assumptions in this implementation that may generate different welfare conclusions once relaxed. First of all, Dixon, Jerie, and Rimmer (2016) implement stylized versions of the Armington, Krugman and Melitz models. There is only one Melitz sector and one factor of production (labor) in the model. Moreover, there are no intermediate inputs in production or trade. As discussed extensively in Section 3, an extension of the AKME model based on any of these dimensions may alter the equivalence of the welfare predictions across the different market structures. Incorporation of more sectors and factors alter the response of firm entry and exit, and this is a significant factor in welfare response (Costinot and Rodriguez-Clare, 2014; Caliendo and Parro, 2015). The presence of imported intermediate inputs is another major driver in welfare change (Lanclos and Hertel, 1995). Notably, the incorporation of real-world complexities in quantitative CGE models is important and may generate divergence of welfare results across model specifications.

4.4 Akgul, Villoria, and Hertel (2016)

While firm heterogeneity is successfully implemented in CGE by the papers discussed above, these models are either stylized, thereby not policy-oriented, or they are not publicly available such as Zhai (2008) and Petri, Plummer, and Zhai (2012a, b). In order to improve the accessibility of firm heterogeneity models in policy-oriented work, Akgul, Villoria, and Hertel (2016) incorporate the Melitz structure into the standard GTAP model using the GEMPACK suite. The resulting GTAP Melitz framework is referred to as the GTAP-HET module.

The standard GTAP model is based on the Armington assumption of national product differentiation and the assumption of perfect competition. Representative firms produce identical products at constant returns to scale technology. Therefore, total factor productivity and the set of traded varieties are exogenously determined. With exogenous productivity, the Melitz mechanism of trade-induced productivity change is absent in the standard GTAP model, as is the extensive margin effect of trade. In their firm heterogeneity implementation, Akgul, Villoria, and Hertel (2016) endogenize sectoral productivity as well as the set of traded varieties in the standard GTAP model. On the demand side, they modify the CES demand function to capture love-of-variety via Dixit and Stiglitz (1977) preferences. On the supply side, they include new equations that determine markup prices, endogenous productivity thresholds in the domestic and export markets, average industry productivity, the number of active firms, and the number of new entrants. These new equations are mostly similar to the previous CGE implementations of the Melitz model.

A key feature of the GTAP-HET model is the incorporation of free firm entry and exit in the monopolistically competitive industries. This is accomplished by assuming that the zero profits condition holds at the industry level, and this determines the number of new entrants into the industry. The possibility of nonnegative profits attracts new firms into the industry. While all new entrants pay the fixed set-up costs to enter, not all of them earn profits, since only a portion of new entrants receive a productivity draw that allows them to profitably produce. The non-producers incur negative profits. Therefore, firm entry continues until expected positive profits are exhausted by the fixed set-up costs paid by non-producers. This mechanism determines the number of entrants and profit accumulation in the industry.

An additional feature of GTAP-HET is that it traces out the scale effect in the monopolistically competitive industry and links it to changes in the firms' costs. It is important to capture this mechanism in the model, because changes in the scale of production alter the welfare effects significantly. We come back to this issue in more detail below.

One of the important deviations of this implementation from other Melitz-based CGE models is its treatment of fixed costs. Akgul, Villoria, and Hertel (2016) assume that there are two types of fixed costs: (i) sector-specific fixed set-up costs that firms face prior to entering the industry to access the productivity draw, (ii) source and destination specific fixed trading costs that firms face when they want to enter the domestic market or the export markets. The standard GTAP data base does not report the information on fixed costs separately. Nor do other data sources provide data on fixed costs that cover multiple sectors and multiple countries. Instead, initial values of fixed set-up costs as well as fixed trading costs are calibrated to the GTAP data base.

In order to model and calibrate fixed costs, Akgul, Villoria, and Hertel (2016) assume that fixed costs are composed of value-added only, e.g. capital and labor in manufacturing sectors, in the spirit of Lanclos and Hertel (1995) and Swaminathan and Hertel (1996). Fixed costs are considered as marketing costs that are necessary to establish a product in the market. As such they reflect the rents for capital utilized in the research and development labs to develop a unique variety, or wages of lawyers providing the legal service to comply with the regulations of foreign markets. Based on this assumption, the value-added composite of each Melitz industry is split between fixed costs and variable costs. Therefore, a portion of factors is employed to cover fixed costs of market entry and the rest are employed to cover the variable costs of production. Primary factor intensities in the fixed and variable portion of value-added are assumed to be the same for simplification.

Unlike Zhai (2008), intermediate inputs are not used in fixed costs. However, tradable intermediates are used in the production of final goods. As such, variable costs include intermediate inputs as well as the value-added composite, while fixed costs only include value-added. This compositional difference creates a wedge between the fixed and variable costs which allows firms to benefit from higher scale of production leading to substantial scale effects in welfare. The divergence between fixed and variable costs deepens if there is a tariff on imported intermediate inputs (Lanclos and Hertel, 1995).

The current specification for fixed costs is selected based on its tractability and on the limited information available for the actual composition of fixed costs in industries. While the distinction between fixed and variable cost compositions highlights the significance of intermediate input trade on welfare change, it is straightforward to alter the fixed cost structure in the model as more industry-specific data becomes available.

Another feature of the GTAP-HET module is the detailed decomposition of welfare change. The existing welfare decomposition in the standard GTAP model is an Equivalent Variation calculation based on Huff and Hertel (2000), extended in GTAP-HET to incorporate new mechanisms under firm heterogeneity. There are four new channels through which trade liberalization induces welfare changes in GTAP-HET: (i) the productivity effect, (ii) the love-of-variety effect, (iii) the scale effect, and (iv) the fixed cost effect. These new channels are in addition to the more conventional components of welfare changes under the Armington framework, such as the terms of trade and allocative efficiency effects.

The productivity effect is the result of compositional changes within the industry. Trade induces reallocation of factors of production from less productive firms to more productive ones, leading to an overall productivity increase in the industry. This compositional gain in productivity is a positive contribution to regional welfare. The variety effect is a weighted average of the consumer gains from having access to new imported varieties and the consumer losses due to the exit of domestic varieties. The net contribution of variety to welfare depends on which of these components dominate. According to Kancs (2010), despite the lost domestic varieties following a tariff-cut, the overall impact is positive, because there are more imported varieties available. However, Akgul, Villoria, and Hertel (2016) find that the loss of domestic varieties may outweigh the gains from imported varieties when there is a preference bias towards domestic varieties. In fact, observed trade shares demonstrate that consumers prefer domestically produced varieties to imported varieties.

The two latter welfare components, namely scale and fixed cost effects, are a bit less obvious. The scale effect is the result of economies of scale in the monopolistically competitive industries. The presence of fixed costs and imported intermediate inputs creates a wedge between average total cost and average variable cost. With tariff cuts, this wedge deepens and results in higher output per firm. This expansion in firm scale spreads fixed costs across more output, generating significant additional gains from trade.

Finally, the fixed cost effect is the contribution of fixed cost payments to welfare. This is generally negative. While all potential firms that enter the industry have to pay initial fixed set-up costs, some of them will not has a high enough productivity draw to produce. The non-producers will be inactive in the market and therefore incur negative profits which then reduce regional welfare.

In order to illustrate the new mechanisms under firm heterogeneity, Akgul, Villoria, and Hertel (2016) present a stylized experiment based on a two sector (manufacturing and non-manufacturing), three region (USA, Japan, Rest of the World) aggregation. The manufacturing sector has monopolistic competition and firm heterogeneity, while the non-manufacturing sector has perfect competition and Armington assumption. The experiment focuses on the effects of reducing tariffs levied by Japan on imported US manufacturing goods and compares the welfare effects across the Melitz, Krugman and Armington market structures.

The model comparison is carried out by matching trade responses across models. This is slightly different than the method used in Arkolakis, Costinot, and Rodriguez-Clare (2012) and Dixon, Jerie, and Rimmer (2016), where parameters are calibrated to match the trade response across models. In Dixon, Jerie, and Rimmer (2016), this calibration yields higher elasticities in the Armington model compared to Melitz. However, in Akgul, Villoria, and Hertel (2016), the substitution elasticity is not calibrated to match trade responses. Instead, substitution elasticities are obtained by a gravity equation estimation using the shape parameter values in Spearot (2016). This empirical work yields higher elasticities in the Armington model compared to Melitz, similar to Dixon, Jerie, and Rimmer (2016). Additionally, Akgul, Villoria, and Hertel (2016) calibrate the tariff shock to match trade responses such that export flows from US to Japan in the post tariff-cut economy is the same across models. As such, a lower tariff cut under Melitz yields the same export flows as in Armington.

Simulation results in GTAP-HET show that Melitz specification predicts higher gains from trade in the US compared to Krugman and Armington specifications. This conclusion is mainly driven by the additional components of firm heterogeneity in the decomposition of changes in welfare. Productivity in the US manufacturing industry increases as a result of the exit of low-productivity non-exporters and the expansion of high-productivity exporters. Higher productivity increases welfare in the US. However, the positive productivity effect in welfare is partly offset by the negative fixed cost effect, which is the result of negative profits incurred by non-producers. Simulation results also show that the overall variety effect in welfare is negative. While the US consumers benefit from new imported varieties, they lose more from the loss of domestic varieties due to home market effects. Finally, the most striking contribution to welfare is observed by the scale effect. The expansion of firm output generates substantial increase in welfare which more than offsets the negative variety effect. Therefore, the overall welfare change is driven by the scale effect under the Melitz specification. On the other hand, the more traditional terms-of-trade effects continue to drive the welfare increase in the Armington and Krugman cases.

These results are at odds with the welfare equivalence conclusions in Arkolakis, Costinot, and Rodriguez-Clare (2012) and Dixon, Jerie, and Rimmer (2016). This difference is an example of the importance of additional micro-mechanisms of firm heterogeneity on welfare predictions of trade models. In fact, welfare differences across models can be magnified by the incorporation of intermediate input trade, multiple sectors, and multiple factors of production in the model.

This GTAP-HET implementation is currently limited by the fixed cost calibration procedure that imposes certain restrictions on model parameters. While the GTAP data base includes information on total value-added, the fixed and variable components of value-added are not separately reported. This lack of information is remedied by calibration of the fixed cost component and calculation of the variable cost component as a residual. The problem is complicated by the dependence of the initial value of fixed cost on model parameters. Certain combinations of parameters can lead to prohibitively high values of fixed cost and can result in negative variable value-added. To illustrate, fixed set-up costs are high in sectors where varieties are highly differentiated (small σ_M). Parameter dependence becomes a critical issue in extreme cases where substitution elasticity is sufficiently small to generate prohibitively high values of fixed set-up costs such that variable value-added becomes negative. In such cases, either the sector is misspecified as monopolistically competitive or the parameter values are not estimated properly. Similarly, the value of the shape parameter may also lead to negative values for variable value-added or fixed trading costs. In fact, depending on the aggregation, there is a feasible set of values for the shape and elasticity parameter values, such that the variable and fixed portions of the value-added in a given sector are positive. The feasible parameter set is difficult to determine analytically and a brutal-force search across the parameter space is often useful. However, this parametric analysis needs to be repeated for each new sectoral and regional aggregation, because the parameter values that generate positive values for the calibrated variable costs change with each aggregation.

In summary, each of the Melitz CGE model discussed in this paper takes a slightly different approach in their implementation with relative strengths and outstanding issues. Their different approaches help illuminate the welfare equivalence conclusion. The stylized implementation of Dixon, Jerie, and Rimmer (2016) gives rise to equivalent welfare change in Armington, Krugman, and Melitz CGE models, when "macro" approach of model comparison is adopted. However, broader implementations with multiple-sectors, multiple-factors and intermediate input trade result in differences in welfare change across models, with the new Melitz mechanisms generating more pronounced welfare change in Zhai (2008), Balistreri, Hillberry, and Rutherford (2010,2011), Balistreri and Rutherford (2013), and Akgul, Villoria, and Hertel (2016).

5. Concluding remarks

The prospects of enhanced explanatory power and strong support from current empirical data places firm heterogeneity in a prominent position in CGE research and applications. The field is without doubt in its infancy with only a few applied CGE models developed from the main theory and strong debates circling around welfare equivalence across models. In this paper we provide a review of the recent work on CGE models that incorporate firm heterogeneity. We discuss whether gains from trade vary across different market structures, and specifically whether Melitz models are better able to capture the gains from trade compared to models based on Armington and Krugman. Our goal is to make the recent welfare debate and the CGE contributions in the firm heterogeneity literature more accessible to the community.

In the light of recent literature, it has become clear that the concept of welfare equivalence amongst Armington, Krugman and Melitz models is fragile with respect to model assumptions. Research shows that when calibrated properly, the stylized one-sector/one-factor Melitz model with unbounded Pareto distribution may generate the same macroeconomic results as in Krugman and Armington. While stylized models are able to explain the main economic behaviors, they gloss over many important facets of the current global economy. In fact, as the assumptions are relaxed to reflect the complexities of real economies, the welfare equivalence across models no longer holds. In this paper, we point out that the incorporation of multiple factors of production, multiple sectors, intermediate input trade, and different productivity distributions into the trade models alters the general equilibrium properties of models, allows different welfare components to be operative. These additions not only enhance the economic relevance of the model, but also break the remarkable welfare equivalence findings.

We discuss that welfare gains from trade in the Melitz model deviates from that of the other models since the Melitz model captures new sources of gains from trade such as love-of-variety and extensive margin effects due to the introduction of new varieties, firm selection and productivity effects due to the reallocation of market shares among firms within an industry, and scale effects due to monopolistic competition and intermediate input trade. In addition to model assumptions, the method adopted to compare models and the type of trade policy instrument that is used in quantifying the effect of economic integration also affects the welfare predictions of models. In summary, there are many factors that may change conclusions about welfare equivalence across models.

The growing literature on firm heterogeneity has generated new economic insights for policy analysis. In the meantime, it also points out a number of empirical, theoretical, and computational challenges. In order to extend the reach of firm heterogeneity and enable its widespread use in CGE models for trade policy analysis, we should focus on overcoming several outstanding issues. First and foremost, it is necessary to adopt an appropriate method to compare models and to have a better understanding of the structural parameters. Since simulation results are sensitive to the comparison method and parameter values, it is paramount that we consolidate the understanding and enumeration of results obtained from numerical models.

Another important outstanding issue is the role of intermediate inputs and fixed costs in firm heterogeneity models. Clearly, our current knowledge about the magnitude of fixed costs is limited and the assumptions on modeling and calibrating fixed costs may alter the welfare predictions of the models. The same challenges apply to intermediate inputs. Even though trade in intermediate inputs has been explored extensively in earlier monopolistic competition literature, the research in the firm heterogeneity literature is insufficient. Proper modeling of intermediate inputs and fixed costs will improve the explanatory power of the models, constituting a rich vein for future research.

Finally, we should keep in mind that the presence of a relatively more realistic microeconomic foundation in the Melitz model does not make the traditional models obsolete. It merely indicates that there are features of the real economy that can be better captured with advances in theory and availability of new data. While welfare is one of the most discussed metrics of a policy effect, the basic criterion for selecting the appropriate type of CGE model in a trade policy analysis should not be whether the predicted gains from trade are larger when we use new trade theories. The criterion should instead be whether the new trade theory is a good fit for a given sector in a given economy and whether the predicted sources of gains from trade are more realistic compared to other trade theories. The Melitz model provides new insights about trade-induced changes in sectors where there is productivity heterogeneity, such as in particular manufacturing sectors. On the other hand, conventional models are more appropriate in sectors that produce more homogeneous products based on similar technologies, such as in agricultural sectors. As such, different contingencies call for different theoretical representation.

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