Armington Meets Melitz: Introducing Firm Heterogeneity in Global CGE Model of Trade

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Abstract

Traditional CGE models with Armington assumption fail to capture the extensive margin of trade, thereby underestimate the trade and welfare effects of trade opening. To address this problem, this paper introduces the Melitz (2003) theoretical framework with firm heterogeneity and fixed exporting costs into a global CGE model. Some illustrative simulations show that the introduction of firm heterogeneity improves the ability of CGE model to capture the trade expansion and welfare effects of trade liberalization. Under the case of global manufacturing tariff cut, the estimated gains in welfare and exports are more than double of that obtained from standard Armington CGE model. Sensitivity analysis also indicates that model results are sensitive to the shape parameters of firm productivity distribution, suggesting the need of further empirical work to estimate the degree of firm heterogeneity.

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1. Introduction

Computable General Equilibrium (CGE) models have been used extensively in trade policy analysis. Despite shedding considerable light on static welfare effects and structural adjustment of trade reform around the world, however, CGE models fail to capture some important features in modern international trade[1]. The most striking one is the extensive margin, i.e. the number of exporting firms and traded goods. In the standard CGE model with Armington's (1969) national product differentiation, trade is expanded purely at the intensive margin: each exporter increases the size of its exports, but there is no change in the set of exporters. However, recent research has revealed the significant importance of the extensive margin for international trade. Empirical studies show that larger countries trade not only bigger size, but also wider variety of goods. Using data on shipment by 126 exporting countries to 59 importing countries in 5,000 product categories, Hummels and Klenow (2005) find that the extensive margin account for 60% of the greater of exports of larger economies, and about one third of the greater imports of the same countries. Eaton, Kortum and Kramarz (2004) examine the firm-level export data of French firms and conclude that the number of exporting firms, rather than the amount exported by each firm, determines the variation in French exports across destinations. Extensive margin is also a crucial force to drive the trade expansion following trade liberalizations. In a study of six different trade liberalizations, Kehoe and Ruhl (2003) find that trade in goods that were not before traded shows substantial growth following a decrease in trade barriers. The set of goods that accounted for only 10% percent of trade before the liberalization may account for 40% of trade following the liberalization.

The absence of extensive margin makes the trade CGE models incapable to explain the fast world trade growth since 1960s, leading to the quantitative puzzle of why modest decreases in tariffs generate strong expansion in trade (Bergoeing and Kehoe, 2001; Yi, 2003). For example, Kehoe (2005) uses data on actual changes in trade flows among Canada, the US and Mexico between 1988 and 1999 to evaluate

[1] See Devarajan and Robinson (2005) on the influence of CGE models on trade policy and Kehoe (2005) for a critical review of

the performance of three CGE models that were used in the early 1990s to estimate the impacts of NAFTA. He finds that these models dramatically underestimated the impact of NAFTA on the volume of regional trade, especially for Mexico. Mexico's regional trade relative to GDP increased by over 1,000% in many sectors between 1988 and 1999, while the CGE models predicted changes in trade relative to GDP of less than 50% in most sectors.

The absence of extensive margin in Armington-type CGE models also results in the well-known "stuck on zero trade" problem (Abler, 2006; Kuiper and van Tongeren, 2006). As Kehoe (2005) argued, the Armington specification has the effect of locking in pre-existing trade patterns and prevented the models from generating large changes in trade in sectors where little or no trade. Under this specification, a country's imports of a product from another country are zero initially they will always be zero, even after significant reductions of trade barriers. If imports are nonzero but small they will remain small even if there are large changes in prices. This "stuck on zero trade" problem makes CGE models especially inappropriate for the least developed countries which usually have limited trade with the rest of the world.

Extensive trade margin has important implication for evaluating the welfare effects of trade liberalization. In CGE models with national products differentiation, the simulated welfare changes of trade liberalization are dominated by the terms-of-trade effects associated with the intensive export growth, i.e. expanding export quantity but lower export price of each variety (Brown, 1987). However, as mentioned by Hummels and Klenow (2005), if export expansion is based more on extensive margin or high quality, such adverse terms-of-trade effects are no longer a necessary consequence.

Recently, a number of new heterogeneous-firm models of international trade by Bernard, Eaton, Jensen and Kortum (2003), Melitz (2003), and Yeaple (2005) have introduced the extensive margin as a result of the firms' self-selection to export markets. They emphasis the interaction of trade costs and

CGE analysis of NAFTA.

productivity differences across firms operating in imperfectly competitive industries. The existence of trade costs induce only most productive firms to self-select into export markets. When trade costs decrease, new firms with lower productivity enter the export markets in response to the potential higher profits. On the other hand, the least productivity non-exporting firms are forced to exit because of the increased import competition in domestic markets. Empirical evidences have largely supported the predictions by the new firm-heterogeneity trade models[2].

An attractive feature of the new firm-heterogeneity trade models is that they provide an explicit microeconomic channel through which trade liberalization boosts aggregate productivity. Under these models, productivity gains via the reallocation of economic activity across firms within industry, as low productivity firms would exit and high productivity exporting firms would expand their market shares following the trade liberalization. The productivity effects of trade liberalization are key factors to understand the impact of trade liberalization, but, are often missed in most CGE models[3].

In order to improve the ability of applied trade models to describe the trade facts, this paper attempts to incorporate the recent development in heterogeneous-firm trade models into a global CGE model. Specially, I implement a firm heterogeneity global CGE model based on Melitz (2003), and carry out experimental simulations to illustrate its features. The reminder of the paper is organized as follows: the next section presents the Melitz(2003) model. Section 3 discusses the specification of the heterogeneous firm CGE model and its calibration. Section 4 presents the simulation results of trade liberalization using the new CGE model, and compares them to those obtained from standard Armington-type CGE model. Section 5 conducts sensitivity analysis. The final section offers conclusions.

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[2] Chaney (2006) estimates the distorted gravity equations based on a simplified version of Melitz (2003) model, and found strong support for it in both sectoral trade data and the stylized facts on firm-level trade. Bernard, Jensen and Schott (2006) use the firm level US manufacturing data to examine the effects of changing trade costs on firms' entry and exit behavior and changes in average productivity. They find that lowering trade costs in a sector increases the probability of firm death or entering export markets in that sector. The existing exports would expand as trade costs decline. Moreover, industry aggregate productivity and within-plant productivity rise as trade costs fall.

[3] Some CGE models incorporate ad hoc assumptions about trade-productivity externalities, such as linking productivity to export performance or imported intermediate and capital goods. See, for example, de Melo and Robinson (1992), Lewis, Robinson and Wang (1995) and World Bank (2001).

2. The Melitz Model

The Melitz model is a dynamic industry model that incorporates the firm productivity heterogeneity in Krugman (1979) monopolistic competition framework, and it focuses on steady state equilibrium only. The original Melitz (2003) model considers a world of symmetric countries, one factor (labor) and one industry, but it can be easily extended to the setting of asymmetric countries[4]. In each country the industry is populated by a continuum of firms differentiated by the varieties they produce and their productivity. Firms face uncertainties about their future productivity when making an irreversible costly investment decision to entry the domestic market. Post-entry, firms produce with different productivity level. In addition to the sunk entry costs, firms face fixed production cost, resulting in increasing return to scale of production. The fixed production costs lead to exit of inefficient firms whose productivities are lower than a threshold level, as they do not expect to earn positive profits in the future. On the demand side, the agents are assumed to have Dixit-Stiglitz preference over the continuum of varieties. As each firm is a monopolist for the variety it produces, it set the price of its product at a constant markup over its marginal cost.

There is also fixed cost and variable cost associated with the exporting activities. But the decision to export occurs after the firms observe their productivity. Firm enters export markets if and only if the net profits generated from its exports in a given country are sufficient to cover the fixed exporting costs. The zero cutoff profit conditions in domestic and exporting markets define the productivity thresholds for firm's entering domestic and exports markets, and in turn determine the equilibrium distribution of non-exporting firms and exporting firms, as well as their average productivities. Usually, the combination of fixed export cost and variable export cost ensures that the exporting productivity threshold is higher than that for production for domestic market, i.e. only a small fraction of firms with high productivity engages in exports markets. These exporting firms supply for both domestic and export markets.

[4] See Helpman, Melitz and Yeaple (2004) and Falvey, Greenway and Yu (2006) for extension of Melitz model to asymmetric countries.

The remaining of this section describes detailed specification of the model. For notational simplicity, the region subscript *i* is omitted in what follows if this does not lead to confusion.

(1) Demand

There are *R* countries in the world. In each country, the representative consumer maximizes utility from consumption over a continuum of goods *Ω*. The utility *U,* or the aggregate good *Q*, is described by CES function,

$$U = Q = \left(\int_{\omega \in \Omega} q(\omega)^{\frac{\sigma - 1}{\sigma}} \right)^{\frac{\sigma}{\sigma - 1}} \tag{1}$$

where q_{ω} is the quantity of consumption of good *ω*, *σ* is the substitution elasticity across goods. The dual price index of utility *P* is defined over the prices of each good, p_{ω},

$$P = \left(\int_{\omega \in \Omega} p(\omega)^{1 - \sigma} \right)^{\frac{1}{1 - \sigma}} \tag{2}$$

And the demand for each good is

$$q(\omega) = Q \left(\frac{P}{p(\omega)} \right)^{\sigma} \tag{3}$$

(2) Production and trade

There is a continuum of firms in each country, each with different productivity *φ* and producing a different variety *ω*. Production involves a fixed and variable cost, and requires only factor, labor. Trade is assumed costly. A firm must pay a fixed cost to export. In addition, there are variable trade costs, which take the form of iceberg transportation cost whereby only a fraction $1/\tau_{ij}$ arrives for shipping one unit of good from country *i* to *j* (τ_{ij} =1 for i=j). Thus, for a firm with productivity *φ*, the cost of producing *q* units of good *ω* and selling them to country *j* is:

$$c(q_{ij}) = W_i\left(\frac{q_{ij}}{\varphi} + f_{Tij}\right) \tag{4}$$

where W_i is the wage rate and serves as numeraire. f_{Tii} is fixed production input and f_{Tij} is fix input to sell good from country *i* to country *j* (i≠j). The fixed costs are assumed to be same for all firms.

Firms are price setter. Given the demand function is isoelastic, the optimal pricing rule for firm is to charge a constant markup over marginal cost:

$$p_{ij}(\varphi) = \frac{\sigma}{\sigma-1}\frac{\tau_{ij}W_i}{\varphi} \tag{5}$$

The profits firm φ in country *i* obtains from selling in domestic market (π_{ii}) and exporting to country *j* (π_{ij}) are given by (6).

$$\pi_{ij}(\varphi) = q_{ij}(\varphi)p_{ij}(\varphi) - c(q_{ij}(\varphi)\cdot\tau_{ij}) = \frac{(P_jQ_j)P_j^{\sigma-1}}{\sigma}\left(\frac{\sigma-1}{\sigma}\frac{\varphi}{\tau_{ij}W_i}\right)^{\sigma-1} - f_{Tij}W_i \tag{6}$$

(3) Entry and exit of firms

The distribution of firms across different productivity level is a result of entry and exit of firms. Prior to entry, firms are identical. To enter the industry, firm must incur a sunk entry cost of f_E effective labor units. After entry, firms draw their productivity, φ, from a ex-ante distribution $g(\varphi)$ with support over $(0,+\infty)$. The productivity of a firm remains fixed thereafter. However, firm will not produce if it expected profits are non positive. Thus any firm whose productivity is lower than a threshold φ^* chooses to exit without even starting production. The condition defining the threshold is the zero cutoff profit condition:

$$\varphi_{ii}^{*}=\frac{\sigma}{(\sigma-1)}\frac{W_i^{\frac{\sigma}{\sigma-1}}}{P_i}\left(\frac{f_{Tii}\sigma}{P_iQ_i}\right)^{\frac{1}{\sigma-1}} \tag{7}$$

Similarly, a firm will choose to export to a given country if and only if net profits generated by the exports are sufficient to cover the fixed exporting costs. The productivity threshold for the least productive firm in country *i* able to export to country *j* is:

$$\varphi_{ij}^{*}=\frac{\sigma\tau_{ij}}{(\sigma-1)}\frac{W_i^{\frac{\sigma}{\sigma-1}}}{P_j}\left(\frac{f_{Tij}\sigma}{P_jQ_j}\right)^{\frac{1}{\sigma-1}}, \quad j\neq i \tag{8}$$

The condition $\varphi_i^* < \varphi_{ij}^*$ is assumed hold for any $j\neq i$ to ensure the partitioning of firms by export status. The firms with productivity levels between φ_i^* and the lowest exporting productivity threshold ($\min\varphi_{ij}^*, j\in R,\ j\neq i$) only produce for their domestic markets. The other firms vary in their exporting partners, depending on their productivity levels and the threshold φ_{ij}^* in specific exporting market.

The surviving firms are assumed to face a "death" shock, which occurs with probability δ. Thus the value of a firm is equal to the stream of future profits discounted by the probability of death if it draws a productivity above the zero-profit productivity cutoff level, or equal to zero if it draws a productivity below the cutoff level.

$$v_i(\varphi)=\sum_{j\in R}\max\{0,\pi_{ij}(\varphi)/\delta\} \tag{9}$$

The number of new entrants in each period is determined by the free entry condition and the general equilibrium. The free entry condition requires the expected value of entering equals the sunk cost of entering, i.e.,

$$\int_{\varphi_i^*}^{\infty}v_i(\varphi)g(\varphi)d\varphi=W_if_{Ei} \tag{10}$$

And in steady state equilibrium, the mass of firms entering and producing must equal the mass of firms that die. Using M_e to denote the mass of new entrants and M to denote the mass of incumbents, the equilibrium condition is

$$\left(1-G(\varphi^*)\right)M_e = \delta M \tag{11}$$

where $G(\varphi)$ is the cumulative distribution function of $g(\varphi)$, and in 1-$G(\varphi^*)$ is the ex ante probability of successful entry in the industry.

(4) Firm Average

In equilibrium, the weighted average productivity level of the producing firms in country *i* is defined as a function of the cutoff level φ_i^*:

$$\tilde{\varphi}_{ii}\left(\varphi_{ii}^*\right) = \left[\frac{1}{1-G\left(\varphi_i^*\right)}\int_{\varphi_{ii}^*}^{\infty}\varphi^{\sigma-1}g\left(\varphi\right)d\varphi\right]^{1/(\sigma-1)} \tag{12}$$

where the weights reflect the relative output shares of firms with different productivity level. Similarly, the weighted average productivity levels of the firms in country *i* exporting to country *j* are:

$$\tilde{\varphi}_{ij}\left(\varphi_{ij}^*\right) = \left[\frac{1}{1-G\left(\varphi_{ij}^*\right)}\int_{\varphi_{ij}^*}^{\infty}\varphi^{\sigma-1}g\left(\varphi\right)d\varphi\right]^{1/(\sigma-1)} \tag{13}$$

These average productivities completely summarize the information in the distribution of productivity levels for all aggregate variables. Therefore, the aggregate price in country *j* and total profits earned by firms in country *i* can be expressed as follows:

$$P_j = \left(\sum_{i\in R} M_i \left(1-G(\tilde{\varphi}_{ij})\right)/\left(1-G(\tilde{\varphi}_{ii})\right)\left[p_{ij}\left(\tilde{\varphi}_{ij}\right)\right]^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{14}$$

$$Q_j = \left(\sum_{i\in R} M_i \left(1-G(\tilde{\varphi}_{ij})\right)/\left(1-G(\tilde{\varphi}_{ii})\right)\left[q_{ij}\left(\tilde{\varphi}_{ij}\right)\right]^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{15}$$

$$\Pi_i = \sum_{j \in R} M_i \left(1 - G(\tilde{\varphi}_{ij})\right) / \left(1 - G(\tilde{\varphi}_{ii})\right) \pi_{ij}\left(\tilde{\varphi}_{ij}\right) \tag{16}$$

5) Equilibrium

In each country, the representative consumer supplies L units of labor. The equilibrium in labor market requires that:

$$L_i = L_{Pi} + L_{Ei} = \sum_j q_{ij}\left(\tilde{\varphi}_{ij}\right) / \tilde{\varphi}_{ij} + \sum_{j \in R} M_i \left(1 - G(\tilde{\varphi}_{ij})\right) / \left(1 - G(\tilde{\varphi}_{ii})\right) f_{Tij} + M_e f_{Ei} \tag{17}$$

where L_p is the labor input for production and L_e is that used in investment by new entrants.

The representative consumer receives labor income and profits, and spends on consumption Q and irreversible investment f_E. As the free entry ensures that total profits are exhausted by the aggregate investment sunk costs of new entrants, i.e., $L_{Ei} = M_e f_{Ei} = \frac{\delta M}{\left(1 - G(\varphi_{ii}^*)\right)} f_{Ei} = \Pi$, the budget constraint of consumer is $W \cdot L = P \cdot Q$. This budget constraint also determines the equilibrium in goods market in each country.

6) Properties of the equilibrium

Some properties of the equilibrium of the model are worthy mentioning. First, trade opening leads to reallocation of market shares and profits among firms. Falling trade costs increases the profits of exporting firms and lowers the exporting productivity threshold. As a result, new and less productive firms enter the export markets. Moreover, reduction of trade costs enables existing exporting firms to increase their sales to foreign markets. In domestic market, more competition from increased imports results in domestic firms losing a portion of their domestic markets. One the other hand, the expansion of existing high productivity firms for exports and the entry of new firms increase labor demand, driving up real wage. Reduced profits and rising costs make the less productive firms unable to survive, forcing them to exit. As a result, the most productive firms increase their market shares and profits, while the least productivity firms shrink or exit. Thus, trade opening leads to larger inequalities between firms.

Second, because of the intra-industry resource reallocation, trade liberalization will unambiguously increase aggregate productivity in all trading economies. The reallocation of market shares towards exporting firms can boost the aggregate productivity as exporting firms are more productive. The entry of new exporters may also increase average productivity if the new entrants are more productive than the average productivity level. Average productivity in importing country is also enhanced because of the exit of the least productive non-exporting firms.

Third, trade liberalization always generates a welfare gain in the model. The magnitude of the gain is determined by the interaction of three factors: the decreased number of domestic firms, the increased number of foreign exporters and the increased average productivity of domestic firms. The less number of domestic firms supplied to domestic markets causes negative variety effect for domestic consumers. But this effect is typically dominated by the increased number of new foreign exporters, thereby domestic consumers still enjoy greater product variety. If a larger number of domestic firms are replaced by foreign firms and product variety impacts negatively on welfare, the positive contribution of aggregate productivity gain would more than offset the loss in variety. The net welfare gain from trade liberalization is always positive[5].

3. A Global CGE Model with Heterogeneous Firms

I now turn to a specific global CGE model with heterogeneous firms. The CGE model consists of 12 regions, 14 sectors and 5 production factors. Within the 14 sectors, agriculture and energy sectors produces homogeneous products. In each of these two sectors, there is a representative firm operated under constant return to scale technology. The other manufacturing and services sectors produce differentiated products. In these sectors, the production and trade structures of the CGE model closely

[5] See appendix of Melitz (2003) for the proof.

follow the Melitz model in section 2, but abstract from its dynamic parts, similar to Chaney (2006). The CGE model assumes no free entry condition, no sunk entry costs and no uncertainty about productivity before entry. Different from Melitz (2003), the CGE model characterizes not the steady state equilibrium, but a static equilibrium.

(1) Demand

In each region of the model, the representative consumer receives income from the supply of production factors to the firms, dividends from the firms and lump-sum transfers from the government. They allocate their disposable income among the consumer goods and saving using the extended linear expenditure system, which is derived from maximizing a Stone-Geary utility function. The consumption/saving decision is completely static. Saving enters the utility function as a "good" and its price is set equal to the average price of consumer goods. Household demand for composite goods *s*, XAC^s, and saving, SAV^h, are specified as

$$XAC^s = Pop\theta^s + \mu^s Y^* / P^s \quad (18)$$

$$Y^* = YD - Pop\sum_s P^s\theta^s \quad (19)$$

$$SAV^h = YD - \sum_s P^s XAC^s \quad (20)$$

where θ^s denotes "subsistence" consumption, which is assumed to be zero for households savings. μ^s is the marginal budget share and Y^* is the supernumerary income.

Investment demand for composite good *s*, XAI^s, and government consumption for composite good *s*, XAG^s, are specified as fixed share Leontief function. The composite good *s* for region *j*, XA_j^s, is a CES aggregation of domestic goods and imports.

$$XA_j^s = \left(\sum_{i \in R} \left(\alpha_{ij}^s\right)^{1/\sigma^s} \left(XQ_{ij}^s\right)^{(\sigma^s - 1)/\sigma^s} \right)^{\sigma^s/(\sigma^s - 1)} \tag{21}$$

where XQ_{ij}^s is the quantity of good *s* produced in region *i* sold in the market of region *j*. The dual price index of composite good *s*, P_j^s, is defined over the aggregate prices of each supplier, PQ_{ij}^s

$$P_j^s = \left(\sum_{i \in N} \alpha_{ij}^s \left(PQ_{ij}^s\right)^{1-\sigma^s} \right)^{1/(1-\sigma^s)} \tag{22}$$

And the demand function generated from (21) is:

$$\frac{XQ_{ij}^s}{XA_j^s} = \alpha_{ij}^s \left(\frac{P_j^s}{PQ_{ij}^s} \right)^{\sigma^s} \tag{23}$$

In sectors with homogeneous goods, I follow the standard Armington assumption of national production differentiation, thus σ^s represents the substitution elasticity of good *s* among different regions in these sectors. The Armington share parameters α_{ij}^s in these sectors reflect the preference of consumers biasing for home or other regions' products. In sectors with differentiated goods, σ^s represents the substitution elasticity among variety of each firm and XQ_{ij}^s is the CES aggregate of the individual varieties that are produced in country *i* and sold in region *j*. In these sectors, Armington share parameters α_{ij}^s always equal to one, rendering that the pattern of bilateral trade flows in these sectors are totally determined by the relative prices of aggregated differentiated goods from each region, PQ_{ij}^s.

(2) Production and trade

Factor markets: There are five primary factors: capital, skilled labor, unskilled labor, agricultural land and natural resources for mining sector. Factor endowments are assumed to be fully employed. Land and natural resources are sector-specific but capital and labor are fully mobile across sectors. All primary factors are immobile across countries.

Production technology: In additional variable costs, firms in the differentiated goods sectors face fixed production and exporting costs. The fixed inputs of these firms are fixed combination of capital (f_{Kij}^{s}), labor (f_{Lij}^{s}) and intermediate inputs (f_{Xij}^{ts}). Thereby the fixed costs FC_{Tij} are defined as:

$$FC_{ij}^{s} = W_i f_{Lij}^{s} + R_i f_{Kij}^{s} + \sum_t P_i^t f_{Xij}^{ts} \tag{24}$$

where W_i, R_i, and P_i^t are wage rate, rental rate of capital and price of good t, respectively.

Marginal costs are modeled by a nesting of constant-elasticity-of-substitution (CES) functions. In the top level, the output XP^s is produced as a combination of aggregate intermediate demand and value added. In the second level, aggregate intermediate demand is split into each commodity according to Leontief technology. Value added is produced by capital-land bundle and aggregate labor. Finally, in the bottom level, aggregate labor is decomposed into unskilled and skill labor, and capital-land bundle is decomposed into capital and land (for agriculture sector) or natural resources (for mining sector). In each level of productions, there are a unit cost function that is dual to the CES aggregator function and demand functions for corresponding inputs. The top level unit cost function defines the marginal cost of sectoral output, MC^s.

Firm heterogeneity: In each region and sector the total mass of potential firms, N_i^s , is fixed. Firms are assumed to get a productivity draws φ from a Pareto distribution with low bound φ_{min} and shape parameter $\gamma > \sigma - 1$. Without loss of generality, the units of quantity can be chosen so that the low bound parameter φ_{min} equals unity. Then the density function $g(\varphi)$ and the cumulative distribution function $G(\varphi)$ are:

$$g(\varphi) = \gamma\varphi^{-\gamma-1}, \quad 1 - G(\varphi) = \varphi^{-\gamma}, \ \varphi \in [1, \infty) \tag{25}$$

γ is an inverse measure of the firm heterogeneity. The higher γ, the more homogeneous of the firms. Firms do not need to pay a sunk cost to participate the productivity draw. With the Pareto distribution, the average productivities for non-exporting firms in county i and firms in country *i* exporting to country j, $\tilde{\varphi}_{ij}^{s}$, can be expressed as:

$$\tilde{\varphi}_{ij}^{s} = \varphi_{ij}^{s*}\left(\frac{\gamma_i^s}{\gamma_i^s - \sigma^s + 1}\right)^{1/(\sigma^s - 1)} \tag{26}$$

The aggregate output in production function, XP_i^s, which is non-variety adjusted, is determined as follows:

$$XP_i^s = \sum_{j\in N}\left[N_i^s\left(1 - G(\varphi_{ij}^{s*})\right)\right]^{1/(1-\sigma^s)} \frac{XQ_{ij}^s}{\tau_{ij}^s \tilde{\varphi}_{ij}^s} \tag{27}$$

where $N_i^s\left(1 - G(\varphi_{ij}^{s*})\right)$ represents the total mass of firms in sector *s* and region *i* that sell in market *j*.

Pricing and cut-off productivity: The model assumes "large group" monopolistic competition under that the number of firms is arbitrarily large, such that the elasticity of demand for each firm's output is the substitution elasticity among varieties, σ^s. This results in fixed markup as in (5). Then the variety adjusted aggregate prices of domestic sale and exports can be defined as:

$$PQ_{ij}^s = \frac{\sigma^s}{\sigma^s - 1}\frac{(1 + t_{ij}^s)\tau_{ij}^s MC_i^s}{\tilde{\varphi}_{ij}^s}\left[N_i^s\left(1 - G(\varphi_{ij}^{s*})\right)\right]^{1/(1-\sigma^s)} \tag{28}$$

where t_{ij}^s is tariff rate, and τ_{ij}^s is ice-berg type variable trade cost.

In sectors producing homogeneous goods, the markup is zero and productivity is fixed and normalized to one. Their producer prices are simply equal to marginal costs.

$$PQ_{ij}^s = (1 + t_{ij}^s)\tau_{ij}^s MC_i^s \tag{29}$$

In sectors with heterogeneous firms, the productivity thresholds for market entry and exporting are:

$$\varphi_{ij}^{s*} = \frac{\sigma^s \tau_{ij}^s MC_i^s}{\left(\sigma^s - 1\right)}\left(\frac{P_j^s}{1 + t_{ij}^s}\right)^{\frac{\sigma^s}{1-\sigma^s}}\left(\frac{FC_{ij}^s \sigma^s}{XA_j}\right)^{\frac{1}{\sigma^s - 1}} \tag{30}$$

The total profits of firms in sector s and region i, Π_i^s, is the residual between the revenue from sales and all production and trading costs.

$$\begin{aligned}\Pi_i^s &= \sum_{j\in N}\left(PQ_{ij}^s XQ_{ij}^s \big/ (1+\tau_{ij}^s) - N_i^s\left(1-G(\varphi_{ij}^*)\right)FC_{ij}^s\right) - MC_i^s XP_i^s \\ &= \sum_{j\in N}\frac{PQ_{ij}^s XQ_{ij}^s}{(1+\tau_{ij}^s)}\frac{1}{\sigma^s}\frac{\sigma^s-1}{\gamma_i^s}\end{aligned} \quad (31)$$

(4)Closure

There are three closure rules — the net government balance, investment-savings, and the trade balance. I assume that changes in the government budget are automatically compensated by changes in marginal income tax rates. Government expenditures are exogenous in real terms.

Domestic investment is identically equal to the sum of domestic saving resources, i.e., household saving, government saving, and net foreign saving. As government saving is exogenous, changes in investment are determined by changes in the levels of household saving and foreign saving.

The final closure rule concerns the current account balance. In each region, either the foreign saving or real exchange rate can be fixed while the other is allowed to adjust providing alternative closure rules. When foreign saving set exogenously, the GDP price deflator for OECD economies taken as a group is chosen as the numéraire and the equilibrium is achieved through changing the relative price across region, i.e. the real exchange rate. Alternatively, the GDP price deflator in each region is fixed and the foreign saving is endogenous (subjecting to the constraint of the global balance) to maintain the trade balance. In the simulations conducted in section 4 and 5, I choose the foreign saving is fixed and the OECD GDP deflator is the numéraire.

(5)Calibration

The model is calibrated to the GTAP (version 6.2) global database. However, some information which are central to our model, such as the degree of returns to scale, the shape of productivity distribution, and the magnitude of the fixed and variable trade cost, are not available in the GTAP database. I set these parameters mainly based on the search of the relevant literature. Table 1 reports some major parameters used in the model. The markup ratios are set equal to 20%-25% for manufacturing sectors and 30% for services sectors. The choices of markup ratios, together with optimal pricing rule of monopolistic firms, imply that the substitution elasticity between differentiated varieties is 6.0 for manufacturing sectors and 5.0 for services sectors. Firm productivity is assumed to follow Pareto distribution. The shape parameters of the Pareto distribution are calibrated to match the assumed 50% profit ratio in total markup.

Table 1: Major Parameters in the Model

	Markup ratio	Substitution elasticity between varieties	Shape parameter in productivity distribution
Processing food	20%	6.0	10.0
Textile	20%	6.0	10.0
Apparels	20%	6.0	10.0
Chemical	25%	5.0	8.0
Material	25%	5.0	8.0
Electronics and electrical equipment	25%	5.0	8.0
Vehicles	25%	5.0	8.0
Machinery	25%	5.0	8.0
Other manufacturing	25%	5.0	8.0
Trade, transportation and communication	30%	4.3	6.7
Other services	30%	4.3	6.7

The base year producer price is normalized to 1 and the marginal cost is calculated from the markup ratio. I assume the mass of potential firms in each sector, N_i^s, is proportional to the sectoral output. As fixed production cost, fixed exporting costs and variable trade costs are not available, they are calibrated to the base year bilateral trade flows.

From the demand function in (23), and using the price function (28), average productivity function (26) and cut-off productivity function (30), we have the following gravity equation determining the bilateral trade flows:

$$PQ_{ij}^{s}XQ_{ij}^{s}=\left(P_{j}^{s}XA_{j}^{s}\right)^{\gamma_{i}^{s}/(\sigma^{s}-1)}N_{i}^{s}\left(\frac{P_{j}^{s}}{(1+t_{ij}^{s})\tau_{ij}^{s}MC_{i}^{s}}\frac{\sigma^{s}-1}{\sigma^{s}}\right)^{\gamma_{i}^{s}}\left(FC_{ij}^{s}(1+t_{ij})\sigma^{s}\right)^{1-\gamma_{i}^{s}/(\sigma^{s}-1)}\frac{\gamma_{i}^{s}}{\gamma_{i}^{s}-\sigma^{s}+1} \quad (32)$$

This equation reflects the combined effects of market size (P_jXA_j), stiffness of market competition (reflected in P_j), technology (MC_i), number of potential firms (N_i) and trade barriers (t_{ij}, τ_{ij}, and FC_{ij}) on bilateral trade patterns.

By replacing the fixed export costs FC_{ij} with the share of exporting firms $\left(1-G(\varphi_{ij}^{s*})\right)$, (32) can be rewritten as:

$$PQ_{ij}^{s}XQ_{ij}^{s}=\left(P_{j}^{s}XA_{j}^{s}\right)N_{i}^{s}\left(\frac{P_{j}^{s}}{(1+t_{ij}^{s})\tau_{ij}^{s}MC_{i}^{s}}\frac{\sigma^{s}-1}{\sigma^{s}}\right)^{\sigma^{s}-1}\left(1-G(\varphi_{ij}^{s*})\right)^{1-(\sigma^{s}-1)/\gamma_{i}^{s}}\frac{\gamma_{i}^{s}}{\gamma_{i}^{s}-\sigma^{s}+1} \quad (33)$$

I assume a constant elasticity function between the share of exporting firms and variable trade cost, and the elasticity of the share of exporting firms with respect to variable trade cost is equal the shape parameter of firm productivity distribution, γ:

$$1-G(\varphi_{ij}^{s*})=\beta_{j}^{s}\left(\tau_{ij}^{s}\right)^{-\gamma_{i}^{s}} \quad (34)$$

This assumption leads to a unity elasticity of trade flows, $PQ_{ji}XQ_{ij}$, with respect to the share of exporting firms, S_{ij}.

$$\begin{aligned}PQ_{ij}^{s}XQ_{ij}^{s} &= \left(P_{j}^{s}XA_{j}^{s}\right)N_{i}^{s}\left(\frac{P_{j}^{s}}{(1+t_{ij}^{s})MC_{i}^{s}}\frac{\sigma^{s}-1}{\sigma^{s}}\right)^{\sigma^{s}-1}\left(\beta_{j}^{s}\right)^{(1-\sigma^{s})/\gamma_{i}^{s}}\left(1-G(\varphi_{ij}^{s*})\right)\frac{\gamma_{i}^{s}}{\gamma_{i}^{s}-\sigma^{s}+1} \\ &= \left(P_{j}^{s}XA_{j}^{s}\right)N_{i}^{s}\left(\frac{P_{j}^{s}}{(1+t_{ij}^{s})MC_{i}^{s}}\frac{\sigma^{s}-1}{\sigma^{s}}\right)^{\sigma^{s}-1}\left(\beta_{j}^{s}\right)^{1-(\sigma^{s}-1)/\gamma_{i}^{s}}\left(\tau_{ij}^{s}\right)^{-\gamma_{i}^{s}}\frac{\gamma_{i}^{s}}{\gamma_{i}^{s}-\sigma^{s}+1}\end{aligned} \quad (35)$$

I assume 80% of potential firms produce and sell at domestic market, and domestic trade incurs no costs, i.e. τ_{ii} equals 1. Thus from (35) the variable trade cost and share of exporting firms can be calculated using the base year trade flows and domestic sales data. Fixed production cost and fixed trade costs can then be derived from (30).

4. Simulations

To explore the properties of the firm-heterogeneity CGE model, I run several trade liberalization simulations and contrast the outcomes of the model to a benchmark standard Armington CGE model with homogeneous firms. The first simulation lowers global manufacturing tariff by 50%. The second simulation reduces variable trade costs τ_{ij}^{s} in manufacturing sectors by 5%. The third simulations cut fixed exporting costs in manufacturing sectors by 50%. Table 2 shows the welfare effects of these trade liberalization experiments. The results of first two simulations from a standard homogeneous firm CGE model are also reported in Table 2[6].

Table 2. Welfare effects of Trade Liberalization (EV, billion 2001 US$)

	50% tariffs cut		5% reduction in variable trade costs		50% reduction in fixed exporting costs
	Firm heterogeneity model	Armington model	Firm heterogeneity model	Armington model	Firm heterogeneity model
USA	2.9	4.6	32.9	44.8	64.9
EU	17.6	10.1	134.7	124.8	203.9
Australia&N. Zealand	2.3	1.1	5.3	4.8	8.7
Japan	18.1	7.7	13.3	13.6	24.2
NIEs	9.8	3.9	23.6	16.8	39.1
China	8.9	2.1	22.4	16.2	36.1
ASEAN	12.8	3.6	35.9	16.8	50.6
India	6.2	2.8	4.8	3.6	7.4
Rest of Asia	1.7	0.3	2.8	2.1	4.3
Latin America	2.0	0.3	30.3	24.0	53.5
Africa	3.4	1.4	10.9	8.5	17.3
Rest of the World	6.0	4.3	39.0	34.3	66.0
Total	91.6	42.2	356.0	310.4	576.0

The firm heterogeneity CGE model predicts a global welfare gain of $91.6 billion from the 50% global manufacturing tariff cut, more than double of the estimate came out from standard Armington CGE model. The difference of the two models in welfare results from simulation of variable trade costs reduction is less prominent. A 5% reduction in variable trade costs of manufacturing sectors would lead

[6] For the sake of comparability, I do not use the GTAP values of Armington elasticities in manufacturing and services sectors in the standard homogeneous firm CGE, but use the same values of the substitution elasticity between differentiated varieties in the firm heterogeneity model as shown in Table 1.

to $356.0 billion global welfare gains in firm heterogeneity model, in contrast to the estimate of $310.4 billion from Armington CGE model. However, it is important to mention here that tariff and iceberg trade costs are different in nature: tariff represents money transfer while iceberg trade costs actually burn up resources. As global manufacturing exports account for 16% of world GDP, a 5% reduction in their variable trade costs would bring a direct efficiency gain of 0.8% of world GDP. If this part is excluded, the indirect welfare gains of variable trade costs reduction would be US$105.7 billion for the firm heterogeneity model and US$60.2 billion for Armington CGE model, still showing a large difference between the two models. The results in Table 1 also suggest that the welfare effects of cutting fixed exporting costs are significant – a 50% cut in manufacturing fixed exporting costs brings five times larger gains than that arising from same percentage reduction in tariffs.

Compared with the standard Armington CGE mode with constant return to scale technology and homogeneous firms, the firm heterogeneity model introduces three additional channels through which the trade liberalization yields welfare gains. The first is the Dixit-Stiglitz "love-of-variety effect", i.e. the welfare gains from the entry of firms and associated increase in variety. Trade liberalization tends to increase the number of exporting firms and leads to greater product variety for domestic consumers if the losses in the number of domestic suppliers are more than offset by the number of new foreign exporters. The second channel is the productivity gains from intra-industry resource reallocation explained in section 2. This is a unique channel in firm heterogeneity model, as the productivity is taken as given in either Armington model or Krugman (1979) new trade model. The third channel is the scale effects. Increased import competition drives out the inefficient domestic producer and results in less producing firms. Due to increasing return to scale, average costs usually fall even they are partly offset by the increased fixed exporting costs associated with a larger number of exporting firms.

Table 3 and 4 report the changes of firm numbers and average productivity in aggregated manufacturing sector under the three trade liberalization simulations. As predicted by the theoretic model, trade liberalization leads to less domestic firms, but facilitates more firms engaging in exporting activities. In the tariff reduction simulation, regions with high initial tariff rates (Africa, India) experience larger decreases in the number of domestic firms. But their numbers of exporting firms also expand most due to their small numbers of exporting firms pre liberalization. The reduction of variable trade costs results in relatively even increase in exporting firms across all the regions. But its impact on the number of domestic firms is different. Regions more open to international trade or less competitive in manufacturing sectors would experience more decreases in their numbers of domestic firms. The impact of fixed exporting costs cut on the number of exporting firms is quite large. For most regions, their number of exporting firms would increase by 150-200%.

Table 3. Changes in Numbers of Firms (%)

	Domestic Firms			Exporting Firms		
	50% tariffs cut	5% reduction in variable trade costs	50% reduction in fixed exporting costs	50% tariffs cut	5% reduction in variable trade costs	50% reduction in fixed exporting costs
USA	-3.1	-10.9	-17.4	8.3	29.8	212.0
EU	-4.1	-19.3	-24.5	3.8	21.6	114.6
Australia&N. Zealand	-9.1	-16.3	-24.5	22.2	32.6	190.4
Japan	-2.9	-7.4	-12.0	15.5	20.4	169.5
NIEs	-7.0	-17.9	-26.0	17.4	30.2	186.0
China	-8.5	-8.3	-12.7	31.3	24.8	168.9
ASEAN	-10.1	-5.8	-11.8	16.0	47.0	185.2
India	-20.4	-9.1	-14.6	70.3	24.7	171.4
Rest of Asia	-10.7	-8.5	-13.3	54.6	33.2	154.5
Latin America	-7.9	-9.9	-15.6	25.7	32.8	210.9
Africa	-23.4	-16.7	-24.9	45.2	32.0	183.0
Rest of the World	-9.7	-16.2	-24.5	14.5	31.0	200.7

Table 4 indicates that the productivity gains from a 50% cut in manufacturing tariff are sizeable for Africa and India, whose average productivity of domestic suppliers in manufacturing sector rise by 2.9% and 2.6% respectively. The US, Japan and EU would gain only modestly in productivity given their already low manufacturing tariffs. However, the sector-wide average productivity is also impacted by the entry and output expansion of exporting firms. In the cases of Australia and New Zealand, NIEs, ASEAN and Africa, because of their relatively high ratios of exporting firm in manufacturing sector, the new entrants of exporting firms are less efficient and their entry causes smaller gains in average productivity of all producing firms relative to that of domestic suppliers. For the other regions, new exporting firms are more efficient than the industry average, and thus contribute to a further rise in sector-wide average productivity.

Table 4. Changes in Manufacturing Average Productivity (%)

	Domestic Suppliers			All Producing Firms		
	50% tariffs cut	5% reduction in variable trade costs	50% reduction in fixed exporting costs	50% tariffs cut	5% reduction in variable trade costs	50% reduction in fixed exporting costs
USA	0.4	1.3	2.1	0.6	2.3	1.2
EU	0.5	2.3	3.1	1.1	1.8	-0.8
Australia&N. Zealand	1.1	2.0	3.1	0.9	2.5	0.4
Japan	0.4	0.8	1.4	0.9	1.4	-0.2
NIEs	0.9	2.2	3.4	0.6	1.8	-2.1
China	1.0	1.0	1.5	1.3	1.4	-0.3
ASEAN	1.9	1.9	3.0	0.5	-0.2	-5.3
India	2.6	1.1	1.7	4.0	1.9	0.9
Rest of Asia	1.4	1.0	1.6	1.5	1.3	0.5
Latin America	0.9	1.1	1.7	1.4	1.7	0.1
Africa	2.9	1.9	2.9	2.7	2.2	0.0
Rest of the World	1.2	1.8	2.9	1.7	2.2	-0.5

The productivity gains for domestic suppliers from a 5% reduction of variable trade costs range from 0.8 (Japan) to 2.3 (EU). This estimate is smaller than the 4.7% productivity increase obtained by Bernard, Eaton, Jensen and Kortum (2003) for the US who use a probabilistic Ricardian model with Bertrand competition to consider the same percentage drop in world trade barriers. However, the result is more or less consistent with a recent study by Del Gatto, Mion and Ottaviano (2006), who calibrate a multi-country multi-sector firm heterogeneity model based on Melitz and Ottaviano (2005) to 11 EU countries and find that a 5% reduction in intra-EU trade costs would generate an average productivity gain of 2.13% for the EU countries.

One last thing need to be discussed is the trade effects of trade liberalization. Table 5 reports the changes in export values under the trade liberalization simulations, and again, contrasts them with the results from standard Armington CGE model. Generally, the trade expansion induced by trade liberalization is more than double in the firm heterogeneity model than that in Armington model. In the new model with its particular parameters, the elasticities of world trade with respect to overall tariff, variable trade costs and fixed exporting costs are 0.2, 4 and 0.6, respectively.

Table 5. Effects of Trade Liberalization on Exports Value (%)

	50% tariffs cut		5% reduction in variable trade costs		50% reduction in fixed exporting costs
	Firm heterogeneity model	Armington model	Firm heterogeneity model	Armington model	Firm heterogeneity model
USA	8.5	3.8	27.0	11.8	46.7
EU	4.3	2.0	17.9	8.1	21.8
Australia&N. Zealand	13.1	6.9	17.4	7.8	26.3
Japan	16.9	7.9	21.5	9.5	37.2
NIEs	13.9	6.1	20.0	7.9	31.2
China	28.8	12.8	23.0	10.0	35.6
ASEAN	14.5	5.7	25.7	7.4	34.0
India	53.8	23.6	20.4	9.5	32.3
Rest of Asia	38.0	15.4	24.5	10.6	34.2
Latin America	18.8	8.4	24.4	11.1	40.5
Africa	20.5	9.5	14.5	6.7	21.5
Rest of the World	9.7	4.6	17.5	7.8	28.2
Total	10.8	4.8	20.5	8.8	30.1

5. Sensitivity Analysis

A number of assumptions are made in model calibration to determine the values of some important parameters, like substitution elasticity between varieties σ^s, shape parameter firms γ_i^s, fixed trade costs FC_{ij}^s and variable trade costs τ_{ij}^s. In this section I check the robustness of the simulation results in the above section to alternative assumptions about these parameters.

(1) Substitution elasticity between varieties

Empirical estimates of industrial markup ratios usually range from 10%-20%[7], implying a much higher substitution elasticity σ^s of 6-11 than that I choose for model calibration in section 3. However, some direct estimates of substitution elasticity between product varieties suggest lower values. For example, Broda and Weinstein (2006) estimate the elasticity between (10-digit Harmonized System) varieties for the US and find an average of 6.6 for 2715 for 2715 5-digit SITC sectors and 4.0 for 256 3-digit SITC sectors. The more aggregated the sectors, the less substitutability between varieties. In views of the mixed empirical evidences about the substitution elasticities, I conduct sensitivity analysis simulations for both higher and lower values of them. In the higher (lower) elasticity simulation, markup ratios are 0.05 smaller (higher) than their benchmark values in Table 1, rending the elasticity values ranging from 5-7.7 (3.9-5.0). In the sensitivity analysis simulations, the shape parameter γ_i^s are kept same with that used in the benchmark simulations.

Table 6. Welfare and Trade Effects of Manufacturing Tariff Reduction under Alternative σ^s

	Welfare (EV, bn US$)			Export Value (%)		
	Low value	**Benchmark value**	**High value**	**Low value**	**Benchmark value**	**High value**
USA	1.6	2.9	3.9	9.1	8.5	8.0
EU	18.2	17.6	16.3	4.4	4.3	4.1
Australia&N. Zealand	2.4	2.3	2.2	13.6	13.1	13.1
Japan	20.4	18.1	16.5	18.5	16.9	15.6
NIEs	11.6	9.8	8.1	15.0	13.9	13.0
China	11.3	8.9	7.0	31.6	28.8	26.6
ASEAN	15.9	12.8	10.5	16.8	14.5	13.1
India	6.9	6.2	6.9	57.1	53.8	52.1
Rest of Asia	2.2	1.7	1.4	42.8	38.0	34.4
Latin America	1.7	2.0	2.2	19.7	18.8	17.9
Africa	3.6	3.4	3.1	21.5	20.5	19.0
Rest of the World	6.3	6.0	6.3	10.2	9.7	9.3
Total	102.2	91.6	84.4	11.6	10.8	10.1

Table 6 shows the welfare and trade effects of the 50% manufacturing tariff cut simulations under alternative substitution elasticity values. Under low elasticity assumptions, the increase in global trade

[7] See, for example, Oliveira-Martins, Scarpetta and Pilat (1996).

and welfare would be 7%-11% higher than that obtained from benchmark assumptions of substitution elasticity, while under high elasticities, the global gains in trade and welfare are 6-8% smaller. This is consistent with the theoretic prediction that the substitution elasticity between varieties has a negative effect on the elasticity of trade flows with respect to tariff (see equation (32)), as a higher substitution elasticity makes the extensive margin less sensitive to changes in trade costs, damping the impacts of tariff on trade flows (Chaney, 2006). This property makes the firm heterogeneity CGE model distinctly different from Armington CGE model, in which an increase in Armington elasticity roughly causes the same magnitude of increase in the trade expansion and welfare.

(2) Shape parameter in Pareto productivity distribution

In firm heterogeneity model, the dispersion of firm productivity plays an important role in determining the impact of trade barriers on trade flows. Table 7 presents the simulation results of a 50% cut in global manufacturing tariffs obtained under the assumption that the shape parameters γ_i^s are 1/3 lower than their benchmark values in Table 1. It shows that the results are sensitive to the choice of productivity dispersion parameter. A 1/3 reduction in shape parameters leads to around 37% less global welfare gains and trade expansion. This sensitivity analysis simulation confirms that the shape parameter γ_i^s, rather than the substitution elasticity between varieties, is the key parameter governing the effects of trade liberalization in Melitz-type firm heterogeneity model.

Table 7. Welfare and Trade Effects of Manufacturing Tariff Reduction under Alternative γ_i^s

	Welfare (EV, bn US$)		Export Value (%)	
	1/3 lower	Benchmark	1/3 lower	Benchmark
USA	2.3	2.9	5.3	8.5
EU	13.7	17.6	2.8	4.3
Australia&N. Zealand	1.9	2.3	9.1	13.1
Japan	12.8	18.1	10.6	16.9
NIEs	7.5	9.8	9.3	13.9
China	3.9	8.9	18.3	28.8
ASEAN	8.8	12.8	9.2	14.5
India	2.7	6.2	32.5	53.8
Rest of Asia	0.6	1.7	22.2	38.0
Latin America	-0.5	2.0	11.6	18.8

Africa	1.2	3.4	12.8	20.5
Rest of the World	3.0	6.0	6.2	9.7
Total	57.8	91.6	6.8	10.8

(3)Fixed trade costs

The base year numbers of exporting firms and variable and fixed trade costs are calibrated based on the assumption of unity elasticity of trade flows with respect to the share of exporting firms. To explore the sensitivity of model results to the size of fixed trade costs, I assign a higher elasticity of trade flows with respect to the share of exporting firms in model calibration. This higher elasticity results that on average the base year numbers of exporting firms are 30% smaller than the benchmark values and the fixed trade costs are 180% higher. Table 8 reported the welfare effects of the three trade liberalization simulations under the new assumption about fixed trade costs. It shows that the results are essentially unchanged for the three simulations. This is not surprising because the policy shocks imposed in the three simulations are all expressed as percentage changes relative to their baseline levels.

Table 8. Welfare Effects of Trade Liberalization under Higher Fixed Trade Costs (EV, bn US$)

	Tariff Cut		Variables trade costs reduction		Fixed trade costs reduction	
	Higher Fixed Costs	Benchmark	Higher Fixed Costs	Benchmark	Higher Fixed Costs	Benchmark
USA	2.9	2.9	32.9	32.9	64.8	64.9
EU	17.6	17.6	134.7	134.7	205.1	203.9
Australia&N. Zealand	2.3	2.3	5.3	5.3	8.7	8.7
Japan	18.1	18.1	13.3	13.3	24.0	24.2
NIEs	9.8	9.8	23.6	23.6	39.0	39.1
China	9.0	8.9	22.4	22.4	36.1	36.1
ASEAN	12.8	12.8	36.0	35.9	50.8	50.6
India	6.2	6.2	4.8	4.8	7.3	7.4
Rest of Asia	1.7	1.7	2.8	2.8	4.3	4.3
Latin America	2.0	2.0	30.3	30.3	53.7	53.5
Africa	3.4	3.4	10.9	10.9	17.3	17.3
Rest of the World	6.1	6.0	39.0	39.0	66.0	66.0
Total	91.8	91.6	356.0	356.0	577.3	576.0

6. Conclusions

The recent models of international trade with heterogeneous firms have opened up a new way for empirical CGE models to better understand the effects of trade liberalization. This paper builds a multi-region, multi-sector global CGE model with firm heterogeneity, monopolistic competition and fixed trade costs *a la* Melitz(2003) and calibrates it to GTAP database. Some illustrative trade liberalization simulations using it demonstrate that introducing firm heterogeneity improves the ability of CGE model to capture the trade expansion and welfare effects of trade liberalization. However, the model results are sensitive to the shape parameters of firm productivity distribution. Future efforts need to be devoted to get better estimates for the degree of firm heterogeneity.

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