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

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Abstract

Traditional computable general equilibrium (CGE) models based on the Armington assumption fail to capture the extensive margin of trade, and 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 the CGE model to capture the trade expansion and welfare effects of trade liberalization. Under the case of a global manufacturing tariff cut, the estimated gains in welfare and exports are more than double those obtained from a standard Armington CGE model. Sensitivity analysis indicates that model results are sensitive to the shape parameters of firm productivity distribution, suggesting the need for further empirical work to estimate the degree of firm heterogeneity.

JEL Classification: C68, F12, F17

Contents

1. INTRODUCTION

Computable general equilibrium (CGE) models have been used extensively in trade policy analysis. Though they shed considerable light on the static welfare effects and structural adjustment of trade reform around the world, they fail to capture some important features of modern international trade.[1] The most striking 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 expands 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 importance of the extensive margin for international trade. Empirical studies show that larger countries trade not only larger volumes, but also a wider variety of goods. Using data on shipments by 126 exporting countries to 59 importing countries in 5,000 product categories, Hummels and Klenow (2005) find that the extensive margin accounts for 60% of the increase of exports of larger economies, and about one third of that of the same countries. Eaton, Kortum and Kramarz (2004) examine 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 across destinations. The extensive margin is also a crucial force behind trade expansion following liberalization. In a study of six different instances of liberalization, Kehoe and Ruhl (2003) find that trade in goods that were not traded earlier shows substantial growth following a decrease in trade barriers. A set of goods that accounted for only 10% percent of trade before the liberalization may come to account for 40% following it.

The absence of the extensive margin makes trade CGE models incapable of explaining the rapid world trade growth since the 1960s, leading to a quantitative puzzle of why modest decreases in tariffs generate a large expansion of trade (Bergoeing and Kehoe, 2001; Yi, 2003). For example, Kehoe (2005) uses data on actual changes in trade flows among Canada, the United States, and Mexico between 1988 and 1999 to evaluate 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 the extensive margin in Armington-type CGE models also results in the well-known "stuck on zero trade" problem (Kuiper and van Tongeren, 2006). The Armington specification has the effect of locking in pre-existing trade patterns and prevents the models from generating large changes in trade in sectors with little or no trade. Under this specification, if a country's imports of a given 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.

The Armington model typically specifies a constant elasticity of substitution (CES) utility function over the home and import goods, and explains the trade pattern by the relative prices of goods produced in different regions and the fixed Armington taste (share) parameters. These fixed taste parameters, usually obtained from the calibration using observed trade flows, are essentially a black box to the model. There is no economic theory underlying the choice of these parameters. As argued by Hillberry et al. (2005), just like error terms in econometric models, the Armington taste parameters serve the role of containing the unexplained variance in the bilateral trade flows in CGE models. There "error terms" tend to be large. Hillberry et al. (2005) examine the trade patterns of 50 commodities and find that

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

the economic behavior modeled by the Armington model explains less than 20% of the variation in bilateral trade flows. Thus, in Armington-type CGE models, the trade patterns are largely determined by the fixed taste parameters, but these parameters are not explained by the model.

There have been some efforts toward incorporating the extensive trade margin into standard CGE models. Some keep the CES-based Armington structure, but seek to endogenize the Armington taste parameters. The MONASH and USAGE models developed by Monash University conduct "historical simulations" to estimate the historical trends in the movement of productivity and taste, and use them to update related parameters in the baseline forecasts (Dixon and Rimmer, 2002; 2003). Kuiper and van Tongeren (2006) propose an exogenous alteration of the Armingtion taste parameters based on separately estimated econometric gravity equations. Some CGE modelers opt for more general function forms in place of CES functions to model import demand. For example, Robinson et al (1993) and Weyerbrock (1998) use the AIDS function (Almost Ideal Demand System) while van der Mensbrugghe (2005) uses an extended CES function with minimum demand shifters a la LES (Linear Expenditure System) to capture the non-unitary income effects for import demand.

The recent trade theory incorporating firm-level heterogeneity offers an additional possibility for introducing the extensive margin into CGE models in a theoretically coherent way. In the models by Bernard, Eaton, Jensen and Kortum (2003), Melitz (2003), and Yeaple (2005), the patterns of trade are determined by variations in a number of factors, such as market size, number of firms, technology and trade barriers, rather than the fixed "taste" parameters. These models introduce the extensive margin as a result of the firms' self-selection to export markets. They emphasize the interaction of trade costs and productivity differences across firms operating in imperfectly competitive industries. The existence of trade costs induces only the 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 productive non-exporting firms are forced to exit because of the increased import competition in domestic markets. Empirical evidence has largely supported the predictions by these new firm-heterogeneity trade models.[2]

One 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 originate from the reallocation of economic activity across firms within an industry, as low productivity firms exit and high productivity exporting firms expand their market shares following the trade liberalization. The productivity effects of trade liberalization are key factors for understanding the impact of trade liberalization, but are often missed in CGE models.[3]

The introduction of the extensive trade margin in CGE models has important implications for evaluating the welfare effects of trade liberalization. In CGE models with differentiation of national products, the simulated welfare changes of trade liberalization are dominated by the terms-of-trade effects associated with 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 an export expansion is based more significantly on the extensive

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[2] Chaney (2006) estimates the distorted gravity equations based on a simplified version of the Melitz (2003) model, and finds strong support for it in both sectoral trade data and the stylized facts on firm-level trade. Bernard, Jensen and Schott (2006) use 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 entry into export markets in that sector. The existing exports expand as trade costs decline. Moreover, industry aggregate productivity and within-plant productivity rises 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).

margin or high quality, such adverse terms-of-trade effects are no longer a necessary consequence.

In order to improve the ability of applied trade models to describe the facts of trade, this paper attempts to incorporate recent developments in heterogeneous-firm trade models into a global CGE model. Specifically, a firm heterogeneity global CGE model based on Melitz (2003) is used, and experimental simulations are carried out to illustrate its features. The remainder of the paper is organized as follows: the next section presents the Melitz (2003) model. Section 3 discusses the specifications 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 a standard Armington-type CGE model. Section 5 is a sensitivity analysis. The final section offers conclusions.

2. THE MELITZ MODEL

The Melitz model is a dynamic industry model that incorporates firm productivity heterogeneity into the Krugman (1979) monopolistic competition framework, and 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 enter the domestic market. Following entry, firms produce with different productivity levels. In addition to the sunk entry costs, firms face fixed production costs, resulting in increasing returns to scale of production. The fixed production costs lead to the 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 sets the price of its product at a constant markup over its marginal cost.

There are also fixed costs and variable costs associated with the exporting activities. However, the decision to export occurs after the firms observe their productivity. A 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 entry into the domestic and exports markets, and in turn determine the equilibrium distribution of non-exporting firms and exporting firms, as well as their average productivities. Typically, the combination of fixed export costs and variable export costs ensures that the exporting productivity threshold is higher than that for production for the domestic market, i.e., only a small fraction of firms with high productivity engage in exports markets. These exporting firms supply both the domestic and export markets.

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

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

(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 the CES function,[5]

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

where q_ω is the quantity of consumption of good ω, and σ is the substitution elasticity across goods. The dual price index of utility P is defined over the prices of each good, p_ω,

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

And the demand for each good is

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

(2) Production and Trade

There is a continuum of firms in each country, each with a different productivity φ and producing a different variety ω.[6] Production entails fixed and variable costs, and requires only one factor, labor. Trade is assumed to be costly. A firm must pay a fixed cost in order to export. In addition, there are variable trade costs, which take the form of iceberg transportation costs whereby only a fraction $1/\tau_{ij}$ of each unit of good shipped from country i to j (τ_{ij} =1 for i=j) arrives. Thus, for a firm with productivity φ, the cost of producing q units of good ω and selling them to country j is:

$$c(q_{ij}, \varphi) = W_i \left(\frac{q_{ij} \tau_{ij}}{\varphi} + f_{ij} \right) \quad (4)$$

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

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

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

[5] This is the standard Spence-Dixit-Stiglitz preference function, which implies love of variety in utility. Some recent empirical investigations have lent support to the love of variety effects in international trade. See Broda and Weinstein (2006) and Ardelean (2007).

[6] Since there is a one-to-one correspondence between φ and ω, we will look at the distribution of φ instead of the distribution of ω below.

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

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

(3) Entry and Exit of Firms

The distribution of firms across different productivity levels is a result of the entry and exit of firms. Prior to entry, firms are identical. To enter the industry, a 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*(φ) with support over ($0,+\infty$). A firm's productivity remains fixed thereafter. However, a firm will not produce if its expected profits are non-positive. Thus any firm whose productivity is lower than a threshold φ^* will choose to exit without even starting production. Similarly, a firm will choose to export to a given country if and only if the net profits generated by the exports are sufficient to cover the fixed exporting costs. The condition defining the threshold is the zero cutoff profit condition:

$$\varphi_{ij}^* = \frac{\sigma\tau_{ij}}{(\sigma-1)}\frac{W_i^{\frac{\sigma}{\sigma-1}}}{P_j}\left(\frac{f_{ij}\sigma}{P_j Q_j}\right)^{\frac{1}{\sigma-1}} \tag{7}$$

where φ_{ii}^* is the productivity threshold for production and φ_{ij}^* is the productivity threshold for the least productive firm in country *i* able to export to country *j*. To ensure the partitioning of firms by export status, the condition $\varphi_{ii}^* < \varphi_{ij}^*$ is assumed to hold for any *j≠i*. Firms with productivity levels between φ_{ii}^* 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 an exogenous probability of death, δ.[7] 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.

$$v_i(\varphi) = \sum_{j \in R} \max\{0, \pi_{ij}(\varphi)/\delta\} \tag{8}$$

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 to equal the sunk cost of entering, i.e.,

[7] The death shocks that force firms to exit are assumed to be independent of firms' productivity. Natural disasters, new regulations and major changes in consumer tastes could be the causes of these shocks.

$$\int_{\varphi^*}^{\infty} v\,(\varphi) g(\varphi) d\varphi = W \cdot f_e \tag{9}$$

And in a 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

$$\left(1 - G(\varphi^*)\right) M_e = \delta M \tag{10}$$

where $G(\varphi)$ is the cumulative distribution function of $g(\varphi)$, and 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* as well as that for exporting firms is defined as a function of the cutoff levels, φ_{ij}^*:

$$\tilde{\varphi}_{ij}\left(\varphi_{ij}^*\right) = \left[\frac{1}{1 - G\left(\varphi_{ij}^*\right)} \int_{\varphi_{ij}^*}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi\right]^{1/(\sigma-1)} \tag{11}$$

where the weights reflect the relative output shares of firms with different productivity levels.[8]

These average productivities are also aggregate as they completely summarize the information in the distribution of productivity levels for all aggregate variables. The aggregate price and demand in country *j* and total profits earned by firms in country *i* can also be expressed as functions of these average productivities:

$$P_j = \left(\sum_{i \in R} M_i \left(1 - G(\tilde{\varphi}_{ij})\right) / \left(1 - G(\tilde{\varphi}_{ii})\right) \left[p_{ij}\left(\tilde{\varphi}_{ij}\right)\right]^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{12}$$

$$Q_j = \left(\sum_{i \in R} M_i \left(1 - G(\tilde{\varphi}_{ij})\right) / \left(1 - G(\tilde{\varphi}_{ii})\right) \left[q_{ij}\left(\tilde{\varphi}_{ij}\right)\right]^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{13}$$

$$\Pi_i = \sum_{j \in R} M_i \left(1 - G(\tilde{\varphi}_{ij})\right) / \left(1 - G(\tilde{\varphi}_{ii})\right) \pi_{ij}\left(\tilde{\varphi}_{ij}\right) \tag{14}$$

5) Equilibrium

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

$$L_i = L_{pi} + L_{ei} = \sum_{j} q_{ij}\left(\tilde{\varphi}_{ij}\right) / \tilde{\varphi}_{ij} + \sum_{j \in R} M_i \left(1 - G(\tilde{\varphi}_{ij})\right) / \left(1 - G(\tilde{\varphi}_{ii})\right) f_{ij} + M_e f_{ei} \tag{15}$$

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

[8] See footnote 9 of Melitz (2003).

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

6) Properties of the equilibrium

Some properties of the equilibrium of the model are worthy mentioning.[9] First, trade opening leads to the reallocation of market shares and profits among firms. Falling trade costs increase the profits of exporting firms and lower the exporting productivity threshold. As a result, new and less productive firms enter the export markets. Moreover, a reduction of trade costs enables existing exporting firms to increase their sales to foreign markets. In the domestic market, more competition from increased imports results in domestic firms losing a portion of their domestic markets. On the other hand, the expansion of existing high productivity firms into exports and the entry of new firms increase labor demand, driving up the 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 unambiguously increases 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 countries 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 interactions between three factors: the decreased number of domestic firms, the increased number of foreign exporters and the increased average productivity of domestic firms. The reduced number of domestic firms supplying to domestic markets causes a negative variety effect for domestic consumers. But this effect is typically overpowered by the increased number of new foreign exporters, so that domestic consumers still enjoy greater product variety. If a large number of domestic firms are replaced by foreign firms, and product variety has a negative impact 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.

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, the agriculture and energy sectors produce homogeneous products. In each of these two sectors, there is a representative firm that operates under constant returns to scale technology. The other 12 manufacturing and services sectors produce differentiated products. In these sectors, the production and trade structures of the CGE model closely follow the Melitz model described in Section 2, but with two modifications. First, as in Chaney (2006), I abstract from the dynamic parts of the Melitz model by assuming no entry and exit of firms, no sunk entry costs and no uncertainty about productivity before entry. Thus the CGE model characterizes a static equilibrium rather than a steady-state

[9] See Melitz (2003) for detailed exploration and proof of these properties.

equilibrium. This abstraction is mainly due to the computational difficulties associated with multiple corner equilibria that the Melitz model may exhibit when it is extended to a multi-sector and asymmetric country setting and the intermediate inputs are explicitly considered. The centripetal forces arising from the self-reinforcing forward and backward linkages cause the multiple corner equilibria, and lead the model to behave more like a New Economic Geography model.[10] Second, the CGE model assumes no fixed production costs, but fixed domestic trading costs in sectors with heterogeneous firms. The presence of fixed trading costs leads to increasing returns to scale technology in these sectors. This assumption makes the model more easily compatible with the case when the number of exporting firms is larger than that of firms serving solely their domestic market. Although empirical evidence at the aggregate level strongly supports selection into export markets, there may be in some particular sectors with data pointing to the other direction.[11]

(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. The consumer allocates his disposable income among the consumer goods and savings using the extended linear expenditure system, which is derived from maximizing the Stone-Geary utility function.[12] The consumption/saving decision is completely static. Savings enter the utility function as a "good" and its price is set as equal to the average price of consumer goods.

Investment demand and government consumption are specified as a Leontief function. I assume that in each sector s a composite good Q_s is used for household consumption, investment, government consumption and intermediate input. The composite good is a CES aggregation of domestic goods and imports.

$$Q_j^s = \left(\sum_{i \in R} \left(\alpha_{ij}^s\right)^{1/\sigma^s} \left(Z_{ij}^s\right)^{(\sigma^s - 1)/\sigma^s} \right)^{\sigma^s/(\sigma^s - 1)} \qquad (16)$$

where Z_{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, $P_{r\,ij}^{\,s}$

$$P_j^s = \left(\sum_{i \in R} \alpha_{ij}^s \left(P_{r\,ij}^{\,s}\right)^{1-\sigma^s} \right)^{1/(1-\sigma^s)} \qquad (17)$$

And the demand function generated from (21) is:

[10] The centripetal forces and multiple equilibria are central themes of new economic geography models which analyze industry's location decisions in the context of imperfect competition and economies of scale. See Fujita et al (1999).

[11] See Bernard and Jensen (1999, 2004), Roberts and Tybout (1997) and Clerides *et al* (1998) for empirical evidence on selection into export markets. The electronic component sector in the People's Republic of China and some Southeast Asian countries may be good counterexamples for selection into export markets. As part of the global supply chain and regional production network, a large proportion of their products are exported and some of their firms are fully export-oriented.

[12] The modeling of household behavior follows the LINKAGE model. See van der Mensbrugghe (2005).

$$\frac{Z_{ij}^s}{Q_j^s} = \alpha_{ij}^s \left(\frac{P_j^s}{P_{r\,ij}^{\;s}} \right)^{\sigma^s} \tag{18}$$

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 varieties of each firm and Z_{ij}^s is the CES aggregate of the individual varieties that are produced in country *i* and sold in region *j*. In these sectors, the Armington share parameters α_{ij}^s always equal one, meaning that the pattern of bilateral trade flows in these sectors are totally determined by the relative prices of aggregated differentiated goods from each region, $P_{r\,ij}^{\;s}$.

(2) Production and trade

Factor markets: There are five primary factors: capital, skilled labor, unskilled labor, agricultural land and natural resources for the mining sector. It is assumed that factor endowments are 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: Production is modeled using a nesting of CES functions. At the top level, the output Xs is produced as a combination of aggregate intermediate demand and value added. At the second level, aggregate intermediate demand is split into each commodity according to Leontief technology. Value added is produced by a capital-land bundle and aggregate labor. Finally, at the bottom level, aggregate labor is decomposed into unskilled and skill labor, and the capital-land bundle is decomposed into capital and land (for the agriculture sector) or natural resources (for the mining sector). At each level of production, there is 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, Cs.

Firm heterogeneity: In each region and sector, the total mass of potential firms, N_i^s, is fixed. Firms are assumed to get productivity draws φ from a Pareto distribution with low bound φmin and shape parameter γ>σ-1.[13] Without a loss of generality, the units of quantity can be chosen so that the low bound parameter φmin equals unity. Then the density function g(φ) and the cumulative distribution function G(φ) are:

$$g(\varphi) = \gamma \varphi^{-\gamma-1}, \;\; 1 - G(\varphi) = \varphi^{-\gamma}, \;\; \varphi \in [1, \infty) \tag{19}$$

γ is an inverse measure of firm heterogeneity. The higher *γ*, the more homogeneous the firms are. Firms do not need to pay a sunk cost to participate in 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:

$$\tilde{\varphi}_{ij}^s = \varphi_{ij}^{s*} \left(\frac{\gamma_i^s}{\gamma_i^s - \sigma^s + 1} \right)^{1/(\sigma^s - 1)} \tag{20}$$

[13] The assumptionγ>σ-1 ensures that the size distribution of firms has a finite mean.

where φ_{ij}^{s*} is the productivity thresholds for firms in region *i* entering market *j*.

Fixed trading costs: In addition to variable costs, firms in the sectors with heterogeneous firms face region-specific fixed costs for their domestic sales and exports. The fixed inputs of these firms are a fixed combination of capital (f_{Kij}^{s}), labor (f_{Lij}^{s}) and intermediate inputs (f_{Xij}^{ts}). Therefore, the expenditure of fixed trading costs, F_{ij}, is defined as:

$$F_{ij}^{s} = W_i f_{Lij}^{s} + R_i f_{Kij}^{s} + \sum_t P_i^t f_{Xij}^{ts} \qquad (21)$$

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

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

$$P_{r\,ij}^{\,s} = \frac{\sigma^s}{\sigma^s - 1} \frac{(1+t_{ij}^s)\tau_{ij}^s C_i^s}{\tilde{\varphi}_{ij}^s} \left[N_i^s\left(1 - G(\varphi_{ij}^{s*})\right)\right]^{1/(1-\sigma^s)} \qquad (22)$$

where t_{ij}^s is the tariff rate, and τ_{ij}^s is ice-berg type variable trade costs and $N_i^s\left(1 - G(\varphi_{ij}^{s*})\right)$ represents the total mass of firms in sector *s* and region *i* that sell in market *j* .

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.

$$P_{r\,ij}^{\,s} = (1+t_{ij}^s)\tau_{ij}^s C_i^s \qquad (23)$$

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

$$\varphi_{ij}^{s*} = \frac{\sigma^s \tau_{ij}^s C_i^s}{\left(\sigma^s - 1\right)} \left(\frac{P_j^s}{1+t_{ij}^s}\right)^{\frac{\sigma^s}{1-\sigma^s}} \left(\frac{F_{ij}^s \sigma^s}{Q_j^s}\right)^{\frac{1}{\sigma^s - 1}} \qquad (24)$$

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.

$$\begin{aligned} \Pi_i^s &= \sum_{j\in R}\left(P_{r\,ij}^{\,s} Z_{ij}^s \big/ (1+\tau_{ij}^s) - N_i^s\left(1 - G(\varphi_{ij}^*)\right) F_{ij}^s\right) - C_i^s X_i^s \\ &= \sum_{j\in R} \frac{P_{r\,ij}^{\,s} Z_{ij}^s}{(1+\tau_{ij}^s)} \frac{1}{\sigma^s} \frac{\sigma^s - 1}{\gamma_i^s} \end{aligned} \qquad (25)$$

(4) Equilibrium and Closure

The equilibrium of the good markets requires that the output, X_i^s, equal the sum of the demand from each markets, i.e.:

$$X_i^s = \begin{cases} \sum_{j \in R} \frac{z_{ij}^s}{\tau_{ij}^s}, & \text{for sectors with a representative firm} \\ \sum_{j \in R} \left[N_i^s \left(1 - G(\varphi_{ij}^{s*})\right)\right]^{1/(1-\sigma^s)} \frac{Z_{ij}^s}{\tau_{ij}^s \tilde{\varphi}_{ij}^s}, & \text{for sectors with heterogeneous firms} \end{cases} \quad (26)$$

Note that for sectors with heterogeneous firms, demand is adjusted by the Dixit-Stiglitz variety effects and the average productivity.

There are three closure rules: the net government balance, investment-savings, and 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 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 the real exchange rate can be fixed while the other is allowed to adjust, providing alternative closure rules. When foreign saving is set exogenously, the price index of global manufacturing exports is chosen as the numéraire and the equilibrium is achieved by changing the relative price across regions, i.e. the real exchange rate. Alternatively, the GDP price deflator in each region is fixed and foreign saving is endogenous (subject to the constraint of the global balance) to maintain the trade balance. In the simulations conducted in Sections 4 and 5, foreign savings is chosen to be fixed and the manufacturing export price index is the numéraire.

(5) Calibration

The model is calibrated to the GTAP global database (version 6.2). However, some of the information that is 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 costs, are not available in the GTAP database. I set these parameters based mainly based on a review of the relevant literature. Table 1 reports some major parameters used in the model. The markup ratios are set to 20%-25% for manufacturing sectors and 30% for services sectors. The choices of markup ratios, together with the optimal pricing rule for 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 a Pareto distribution. The shape parameters of the Pareto distribution are calibrated to match the profit ratio in total markup, which is estimated to be 64.5% based on French firm data by Arkolakis (2006). Assuming that all regions have access to same technology, the marginal costs C are set equal to unity in all regions for the calibration.

Table 1: Major Parameters in the Model

	Markup ratio	Substitution elasticity between varieties	Shape parameter in productivity distribution
Processing food	20%	6.0	7.75
Textile	20%	6.0	7.75
Apparels	20%	6.0	7.75
Material	20%	6.0	7.75
Chemical	25%	5.0	6.20
Electronics and electrical equipment	25%	5.0	6.20
Vehicles	25%	5.0	6.20
Machinery	25%	5.0	6.20
Other manufacturing	25%	5.0	6.20
Trade, transportation and communication	30%	4.3	5.17
Other services	30%	4.3	5.17

I assume the mass of potential firms in each sector, N_i^s, is proportional to the sectoral output. As fixed production costs, fixed exporting costs and variable trade costs are not available, they are calibrated to the base year's bilateral trade flows. From the demand function in (18), and using the price function (22), average productivity function (20) and cut-off productivity function (24), we have the following gravity equation determining the bilateral trade flows:

$$P_{r\,ij}^{s} Z_{ij}^{s} = \left(P_j^s Q_j^s\right)^{\gamma_i^s/(\sigma^s-1)} N_i^s \left(\frac{P_j^s}{(1+t_{ij}^s)\tau_{ij}^s C_i^s}\frac{\sigma^s-1}{\sigma^s}\right)^{\gamma_i^s} \left(F_{ij}^s(1+t_{ij})\sigma^s\right)^{1-\gamma_i^s/(\sigma^s-1)} \frac{\gamma_i^s}{\gamma_i^s-\sigma^s+1} \qquad (27)$$

This equation reflects the combined effects of market size (P_jQ_j), stiffness of market competition (reflected in P_j), technology (C_i), number of potential firms (N_i) and trade barriers (t_{ij}, τ_{ij}, and F_{ij}) on bilateral trade patterns. Replacing the variable export costs τ_{ij} with the share of exporting firms $\left(1-G(\varphi_{ij}^{s*})\right)$, (27) can be rewritten as:

$$P_{r\,ij}^{s} Z_{ij}^{s} = N_i^s\left(1-G(\varphi_{ij}^{s*})\right)\left(F_{ij}^s(1+t_{ij})\sigma^s\right)\frac{\gamma_i^s}{\gamma_i^s-\sigma^s+1} \qquad (28)$$

Based on the empirical findings in Hummels and Klenow (2005), I assume that the extensive margin accounts for 60% of the difference in export values across regions, i.e.

$$\left(\frac{P_{r\,ij}^{s} Z_{ij}^{s}}{P_{r\,jj}^{s} Z_{jj}^{s}}\right)^{0.6} = \frac{N_i^s\left(1-G(\varphi_{ij}^{s*})\right)}{N_j^s\left(1-G(\varphi_{jj}^{s*})\right)} \qquad (29)$$

Assuming that 60% of potential firms produce and sell in the domestic market, the shares of exporting firms can be calculated from (29) using the base year trade flows and domestic sales data. The fixed trading costs can also be derived from (28). Given that the shares of firms selling in each market are determined, one can solve their productivity thresholds from (19). I also assume that domestic trade incurs no iceberg costs, i.e. τ_{ii} equals 1. The iceberg trade costs τ_{ij} can thus be obtained from (24).

Zero-trade flows are frequently presented in international trade databases, including the GTAP database. Under an Armington trade structure, the share parameters α_{ij}^s are zero if there is no trade between their corresponding trading partners. However, for sectors with heterogeneous firms, the zero-trade flow is not allowed in the model because of: (i) the unity of import share parameters α_{ij}^s for all trade partners, and (ii) the infinity upper bound of firms' productivity distribution. To resolve this dilemma, I modify the benchmark trade data by assigning an arbitrary small value to initial zero-trade cells. This tiny base year trade value leads to very high calibrated fixed and variables trade costs for corresponding trade partners.

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 involves a lowering of the global manufacturing tariff by 50%. The second simulation involves a reduction in variable trade costs τ_{ij}^s in the manufacturing sectors by 5%. The third simulation involves a cut in fixed exporting costs in manufacturing sectors by 50%. Table 2 shows the welfare effects of these trade liberalization experiments. The results of the first two simulations from a standard homogeneous firm CGE model are also reported in Table 2.[14]

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

	50% tariff 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
US	3.5	4.4	32.8	44.8	44.3
EU	16.6	10.2	128.2	125.0	144.1
Australia & N. Zealand	2.2	1.1	5.0	4.8	5.5
Japan	15.6	7.6	11.7	13.4	13.3
NIEs	8.5	3.9	21.3	17.0	24.0
PRC	5.3	2.2	18.0	16.1	18.6
ASEAN	9.8	3.7	32.7	16.9	34.6
India	5.9	2.9	3.7	3.6	3.8
Rest of Asia	0.9	0.3	2.3	2.1	2.5
Latin America	0.2	0.3	27.0	24.0	32.9
Africa	1.8	1.4	9.7	8.6	9.7
Rest of the world	4.8	4.3	35.9	34.3	38.7
Total	75.0	42.2	328.3	310.6	372.0

The CGE model with firm heterogeneity predicts a global welfare gain of $75.0 billion from the 50% global manufacturing tariff cut, nearly double the estimate of the standard Armington CGE model. The difference between the two models results from the fact that simulation of the variable trade costs reduction is less prominent in the Armington model. A 5% reduction in variable trade costs in manufacturing sectors would lead to $328.3 billion in global welfare gains in the firm heterogeneity model, in contrast to an estimate of $310.6 billion from Armington CGE model. However, it is important to mention here that tariff and

[14] 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 and instead use the same values of the substitution elasticity between differentiated varieties in the firm heterogeneity model as shown in Table 1.

iceberg trade costs are different in nature: a tariff represents a money transfer while iceberg trade costs actually burn up resources. As global manufacturing exports account for 16% of world GDP, a 5% reduction in variable trade costs would bring a direct efficiency gain of 0.8% to world GDP. If this part is excluded, the indirect welfare gains of a reduction in variable trade are US$58.9 billion for the firm heterogeneity model and US$41.2 billion for Armington CGE model, still showing a relatively 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 an identical percentage reduction in tariffs.

Compared with the standard Armington CGE mode with constant returns to scale technology and homogeneous firms, the firm heterogeneity model introduces three additional channels through which 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 the associated increase in variety. Trade liberalization tends to lead to an increase in the number of exporting firms and 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 the firm heterogeneity model, as the productivity is taken as given in both the Armington model and Krugman (1979) new trade theory model. The third channel is scale effects. Increased import competition drives out inefficient domestic producers and results in a smaller number of producing firms. Due to increasing returns to scale, average costs usually fall even if they are partly offset by the increased fixed exporting costs associated with a larger number of exporting firms.[15]

Tables 3 and 4 report changes of firm numbers and average productivity in the aggregated manufacturing sector under the three trade liberalization simulations. As predicted by the theoretical model, trade liberalization leads to fewer domestic firms, but encourages more firms to engage 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. However, their numbers of exporting firms also expand most due to their small numbers of exporting firms prior to liberalization. The reduction of variable trade costs results in a relatively even increase in exporting firms across all the regions. But its impact on the number of domestic firms differs. Regions that are more open to international trade or less competitive in manufacturing sectors experience larger decreases in their numbers of domestic firms. The impact of a cut in fixed exporting costs on the number of exporting firms is quite large. For most regions, the number of exporting firms would increase by 110-155%.

[15] To ensure that the new model generates additional gains from a trade expansion in comparison with the conventional model, I raise the Armington elasticities in the standard Armington CGE model by 33% and run the tariff reduction simulation. Compared to the Melitz CGE model, the Armington CGE model with high elasticities predicts a similar expansion in global real exports, but 23% lower global welfare gains. I am grateful to Peter Dixon for suggesting this simulation.

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	-2.2	-8.8	-9.4	6.4	22.8	151.3
EU	-3.0	-15.4	-16.6	3.5	16.9	129.0
Australia & N. Zealand	-7.2	-12.9	-13.9	24.5	24.4	146.1
Japan	-1.9	-5.7	-6.4	11.9	15.5	139.7
NIEs	-5.1	-14.1	-16.1	14.3	22.9	144.2
PRC	-6.5	-6.5	-7.1	24.7	19.1	143.4
ASEAN	-7.2	-6.7	-9.4	12.6	35.4	154.2
India	-15.8	-7.1	-7.9	56.1	18.8	128.9
Rest of Asia	-7.7	-6.8	-7.5	40.1	23.3	132.6
Latin America	-5.8	-7.7	-8.4	19.3	25.1	131.4
Africa	-17.7	-13.2	-13.9	32.5	24.0	110.7
Rest of the world	-7.3	-12.7	-14.0	11.6	23.8	128.7

Table 4 shows that the productivity gains from a 50% cut in manufacturing tariff are sizeable for Africa and India, whose average productivity of domestic suppliers in the manufacturing sector rise by 2.8% and 2.6%, respectively. The US, Japan and EU gain only modestly in productivity given their already low manufacturing tariffs. However, the sector-wide average productivity is also affected by the entry and output expansion of exporting firms. In the cases of Australia and New Zealand, the NIEs, ASEAN and Africa, because of the relatively high ratios of exporting firm in manufacturing sector, the new entrants into exports are less efficient and their entry causes smaller gains in the 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
US	0.3	1.3	1.4	0.6	2.0	-0.4
EU	0.5	2.2	2.3	0.8	1.3	-3.5
Australia & N. Zealand	1.1	2.0	2.1	0.0	1.2	-2.0
Japan	0.4	0.8	0.9	0.8	1.1	-1.6
NIEs	0.9	2.2	2.4	0.3	1.0	-4.1
PRC	1.0	0.9	1.0	1.2	1.0	-1.8
ASEAN	1.9	2.2	2.3	0.2	-1.0	-7.4
India	2.6	1.0	1.1	2.3	1.1	-0.7
Rest of Asia	1.2	1.0	1.1	0.7	0.8	-1.1
Latin America	0.8	1.0	1.1	0.9	1.0	-1.1
Africa	2.8	1.9	1.9	1.5	1.1	-1.4
Rest of the world	1.2	1.8	1.9	1.3	1.4	-1.8

The productivity gains for domestic suppliers from a 5% reduction of variable trade costs range from 0.8 (Japan) to 2.2 (EU, NIEs and ASEAN). This estimate is smaller than the 4.7% productivity increase obtained by Bernard, Eaton, Jensen and Kortum (2003) for the US, using 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 generates an average productivity gain of 2.13% for the EU countries.

A final issue that needs to be discussed is the trade effects of trade liberalization. Table 5 shows changes in real exports under the trade liberalization simulations, and again, contrasts them with the results from a standard Armington CGE model.[16] Generally, the trade expansion induced by trade liberalization is 40% stronger in the firm heterogeneity model than that in the 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 0.13, 2.5 and 0.1, 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**
US	5.1	4.0	17.1	12.3	9.0
EU	2.6	2.0	10.8	7.6	3.0
Australia & N. Zealand	7.5	5.8	9.7	6.6	4.6
Japan	10.4	7.5	13.5	9.3	5.7
NIEs	8.3	5.7	12.2	7.8	5.5
PRC	19.3	13.7	14.4	9.6	7.1
ASEAN	8.3	5.4	16.5	7.3	8.4
India	38.9	27.5	12.2	8.8	5.7
Rest of Asia	24.6	17.2	15.0	10.5	7.7
Latin America	12.4	9.5	15.5	11.2	9.4
Africa	14.2	11.0	8.5	5.9	4.3
Rest of the world	6.9	5.2	10.5	7.3	5.3
Total	6.8	5.0	12.7	8.6	5.4

5. SENSITIVITY ANALYSIS

A number of assumptions are made in the model calibration to determine the values of some important parameters, such as substitution elasticity between varieties σ^s, shape of parameter firms γ_i^s, fixed trade costs F_{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.

[16] Real exports are defined as the sum of each firm's exports, i.e. they are measured "at the factory gate" and are not augmented by variety effects.

(1) Substitution elasticity between varieties

Empirical estimates of industrial markup ratios usually range from 10%-20%,[17] implying a much higher substitution elasticity σ^s of 6-11 than that chosen 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 the 2,715 5-digit SITC sectors and 4.0 for the 256 3-digit SITC sectors. The more aggregated the sectors, the less substitutability there is between varieties. In view of the mixed empirical evidence about the substitution elasticities, I conduct sensitivity analysis simulations for both higher and lower values. In the higher (lower) elasticity simulation, markup ratios are 0.05 smaller (higher) than their benchmark values in Table 1, with 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 shows the welfare and trade effects of the three trade liberalization simulations under alternative substitution elasticity values. It finds that the trade expansion and welfare gains of a trade cost reduction are smaller when there is higher elasticity between varieties and larger when there are lower elasticity between varieties. The results also show that the effects of fixed trade cost reductions are very sensitive to the elasticity values. Under low (high) elasticity assumptions, the gain in global trade and welfare from fixed trade cost reduction is 70% higher (60% lower) than that obtained from benchmark assumptions of substitution elasticity. The impact of elasticity values on the effects of a tariff reduction is less significant, generally ranging from 4% to 9% for trade expansion and from 10% to 20% for welfare gains. The choice of different substitution elasticity values has only a modest impact on the effects of reducing variable trade costs.

These findings are consistent with the theoretical prediction that the substitution elasticity between varieties has a negative effect on the elasticity of trade flows with respect to tariff and fixed trade costs (see equation (27)), as a higher substitution elasticity makes the extensive margin less sensitive to changes in trade barriers, damping the impacts of a trade cost reduction on trade flows (Chaney, 2006). This property makes the firm heterogeneity CGE model distinctly different from the Armington CGE model, in which an increase in Armington elasticity roughly leads to the same magnitude of increase in the trade expansion and welfare.

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

Table 6. Welfare and Trade Effects under Alternative σ^s

	Welfare (EV, bn US$)			Real exports (%)		
	Low value	Benchmark value	High value	Low value	Benchmark value	High value
Manufacturing tariff reduction						
US	2.8	3.5	3.9	5.4	5.1	4.8
EU	18.2	16.6	15.0	2.7	2.6	2.5
Australia & N. Zealand	2.3	2.2	2.0	7.8	7.5	7.1
Japan	17.3	15.6	14.1	11.1	10.4	9.8
NIEs	10.0	8.5	7.0	8.8	8.3	7.8
PRC	6.5	5.3	4.3	20.4	19.3	18.2
ASEAN	11.8	9.8	8.1	9.0	8.3	7.8
India	6.5	5.9	5.3	41.0	38.9	36.9
Rest of Asia	1.2	0.9	0.7	26.7	24.6	22.7
Latin America	-0.1	0.2	0.4	12.9	12.4	11.9
Africa	1.9	1.8	1.7	14.8	14.2	13.6
Rest of the world	4.7	4.8	4.8	7.2	6.9	6.6
Total	83.5	75.0	67.2	7.2	6.8	6.5
Variable trade cost reduction						
US	29.7	32.8	35.3	17.2	17.1	17.0
EU	128.0	128.2	128.3	10.8	10.8	10.8
Australia & N. Zealand	5.0	5.0	5.0	9.9	9.7	9.6
Japan	11.3	11.7	11.9	13.7	13.5	13.3
NIEs	22.3	21.3	20.5	12.4	12.2	12.0
PRC	18.1	18.0	17.8	14.5	14.4	14.2
ASEAN	39.4	32.7	28.3	19.7	16.5	14.6
India	3.6	3.7	3.8	12.3	12.2	12.1
Rest of Asia	2.3	2.3	2.2	15.5	15.0	14.7
Latin America	27.4	27.0	26.8	15.5	15.5	15.4
Africa	9.7	9.7	9.7	8.5	8.5	8.4
Rest of the world	35.5	35.9	36.2	10.6	10.5	10.4
Total	332.4	328.3	325.9	12.9	12.7	12.5
Fixed exporting cost reduction						
US	72.1	44.3	18.6	19.4	9.0	-1.0
EU	241.1	144.1	54.7	8.9	3.0	-3.3
Australia & N. Zealand	9.3	5.5	2.0	10.5	4.6	-1.3
Japan	24.3	13.3	4.1	15.3	5.7	-3.1
NIEs	42.1	24.0	8.6	13.0	5.5	-2.0
PRC	33.0	18.6	6.1	16.6	7.1	-1.8
ASEAN	60.9	34.6	12.0	18.2	8.4	-1.2
India	6.8	3.8	1.3	13.7	5.7	-1.7
Rest of Asia	4.3	2.5	0.8	17.7	7.7	-1.5
Latin America	55.9	32.9	13.1	19.3	9.4	0.1
Africa	16.6	9.7	3.4	9.0	4.3	-0.5
Rest of the world	65.7	38.7	14.3	11.4	5.3	-0.7
Total	632.2	372.0	139.2	12.9	5.4	-2.1

(2) Shape Parameter in the Pareto Productivity Distribution

In the 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 one-third higher than their benchmark values in Table 1. The results are sensitive to the choice of productivity dispersion parameter. A one-third increase in shape parameters leads to 40-50% higher global welfare gains and trade expansion under the simulation of tariff reduction. 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 the Melitz-type firm heterogeneity model.

Table 7. Welfare and Trade Effects under Higher γ_i^s

	50% tariff cut		Variable trade cost reduction		Fixed exporting cost reduction	
	Higher γ	Benchmark	Higher γ	Benchmark	Higher γ	Benchmark
Welfare (EV, bn US$)						
US	4.5	3.5	36.5	32.8	75.1	44.3
EU	21.3	16.6	139.7	128.2	236.6	144.1
Australia & N. Zealand	2.6	2.2	5.4	5.0	9.0	5.5
Japan	20.6	15.6	14.0	11.7	26.5	13.3
NIEs	10.6	8.5	24.0	21.3	42.1	24.0
PRC	10.0	5.3	22.0	18.0	37.6	18.6
ASEAN	13.0	9.8	41.6	32.7	58.7	34.6
India	11.2	5.9	5.0	3.7	8.2	3.8
Rest of Asia	1.8	0.9	2.9	2.3	4.5	2.5
Latin America	2.2	0.2	31.3	27.0	55.0	32.9
Africa	3.6	1.8	11.1	9.7	16.6	9.7
Rest of the world	8.5	4.8	40.0	35.9	66.4	38.7
Total	110.0	75.0	373.4	328.3	636.4	372.0
Real exports (%)						
USA	7.4	5.1	24.2	17.1	28.3	9.0
EU	3.6	2.6	15.5	10.8	15.6	3.0
Australia & N. Zealand	10.9	7.5	14.4	9.7	16.6	4.6
Japan	15.3	10.4	19.7	13.5	25.4	5.7
NIEs	11.7	8.3	17.2	12.2	20.7	5.5
PRC	28.2	19.3	20.7	14.4	26.2	7.1
ASEAN	11.8	8.3	27.1	16.5	25.4	8.4
India	58.8	38.9	17.8	12.2	21.7	5.7
Rest of Asia	37.3	24.6	22.3	15.0	25.4	7.7
Latin America	17.7	12.4	22.1	15.5	28.1	9.4
Africa	19.9	14.2	12.3	8.5	13.1	4.3
Rest of the world	9.7	6.9	15.3	10.5	17.3	5.3
Total	9.9	6.8	18.4	12.7	20.4	5.4

(3) Fixed Trade Costs

The base year variable and fixed trade costs are calibrated based on the assumption that 60% of firms sell in the domestic market, and that the elasticity of the extensive margin with respect to trade flow is 0.6. To explore the sensitivity of the model results to the size of fixed trade costs, I conduct two sets of sensitivity analysis. The first set reduces the base year share of firms selling in the domestic market from 60% to 45%. This raises the base year fixed trading costs by one-third. As both the fixed domestic trading costs and fixed exporting costs are raised proportionally, the calibrated base year variable trade costs are not affected by the increase of fixed trade costs. The second set of simulations raises the elasticity of the extensive margin with respect to trade flow from 0.6 to 0.8, assuming that changes in the extensive margin account for 80% of the difference in export values across regions. Under this simulation set, the base year fixed domestic trading costs are the same as in the benchmark simulations, but both variable trade and fixed exporting costs are changed in calibration. Table 8 reports the welfare effects of the three trade liberalization simulations under the two alternative assumptions about fixed costs. 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. Despite the differences in calibrated base year fixed trading costs, the first-round effects of a tariff cut and trade cost reduction on trade are the same between the benchmark simulations and the sensitivity analysis. The slight differences reported in Table 8 are mainly due to the second-round effects on income distribution and expenditure pattern.

Table 8. Welfare and Trade Effects under Higher Fixed Trade Costs and Higher Elasticity of Extensive to Trade Flow

	Welfare (EV, bn US$)			Export value (%)		
	Higher fixed trade costs	Higher elasticity of extensive margin	Benchmark value	Higher fixed trade costs	Higher elasticity of extensive margin	Benchmark value
Manufacturing tariff reduction						
US	3.4	3.4	3.5	5.1	5.4	5.1
EU	16.6	16.6	16.6	2.6	2.7	2.6
Australia & N. Zealand	2.2	2.2	2.2	7.3	8.2	7.5
Japan	15.9	15.9	15.6	10.5	10.3	10.4
NIEs	8.4	8.4	8.5	8.3	7.8	8.3
PRC	5.3	5.3	5.3	19.3	18.6	19.3
ASEAN	9.8	9.8	9.8	8.3	7.3	8.3
India	5.9	5.9	5.9	39.0	38.7	38.9
Rest of Asia	0.9	0.9	0.9	24.6	23.3	24.6
Latin America	0.2	0.2	0.2	12.4	12.7	12.4
Africa	1.8	1.8	1.8	14.2	14.5	14.2
Rest of the world	4.8	4.8	4.8	6.9	6.9	6.9
Total	75.2	75.2	75.0	6.8	6.8	6.8
Variable trade cost reduction						
US	32.8	32.7	32.8	17.1	17.1	17.1
EU	128.2	128.2	128.2	10.8	10.8	10.8
Australia & N. Zealand	5.0	5.0	5.0	9.7	9.7	9.7
Japan	11.7	11.7	11.7	13.5	13.5	13.5
NIEs	21.3	21.3	21.3	12.2	12.2	12.2
PRC	18.0	18.0	18.0	14.4	14.4	14.4
ASEAN	32.7	32.7	32.7	16.5	16.5	16.5
India	3.7	3.7	3.7	12.2	12.2	12.2
Rest of Asia	2.3	2.3	2.3	15.0	15.0	15.0
Latin America	27.0	27.0	27.0	15.5	15.5	15.5
Africa	9.7	9.7	9.7	8.5	8.5	8.5
Rest of the world	35.9	35.9	35.9	10.5	10.5	10.5
Total	328.3	328.3	328.3	12.7	12.7	12.7
Fixed exporting cost reduction						
US	43.5	44.1	44.3	9.8	10.5	9.0
EU	144.9	143.8	144.1	3.1	3.0	3.0
Australia & N. Zealand	5.5	5.5	5.5	4.5	4.6	4.6
Japan	12.0	12.2	13.3	5.5	5.5	5.7
NIEs	23.6	23.7	24.0	5.4	5.4	5.5
PRC	18.5	18.5	18.6	7.3	7.2	7.1
ASEAN	35.7	33.8	34.6	9.1	8.1	8.4
India	3.9	4.0	3.8	5.7	5.7	5.7
Rest of Asia	2.5	2.5	2.5	7.9	7.9	7.7
Latin America	32.9	33.2	32.9	9.2	9.2	9.4
Africa	10.1	10.3	9.7	4.2	4.2	4.3
Rest of the world	39.2	39.6	38.7	5.3	5.3	5.3
Total	372.3	371.2	372.0	5.5	5.6	5.4

6. CONCLUSIONS

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 the GTAP database. Some illustrative trade liberalization simulations using it demonstrate that the introduction of firm heterogeneity improves the ability of the CGE model to capture the trade expansion and welfare effects of trade liberalization. However, the model results are sensitive to the shape parameters of the firm productivity distribution. Future efforts need to be devoted to obtaining better estimates for the degree of firm heterogeneity.

Some important limitations of this study should be mentioned. First, the aggregation of countries in the CGE model may lead to some biases in the calibration of trade costs. Unlike the Armington model, the elasticity of trade flows with respect to the total demand in the destination market is greater than one in the Melitz model. Thus, differences in market size play a larger role in determining the trade pattern in the Melitz CGE model than in the conventional CGE models. In this new model, the aggregation of some small economies to a single region, such as the rest-of-the-world region, may be problematic because this aggregate region is actually composed of numerous small, disjointed markets rather than a large integrated market (Balistreri *et al*, 2007). Second, given the assumption of no free entry and exit, the total mass of potential firms in each sector is fixed and any adjustment in the extensive margin is solely due to the changes in the shares of firms engaged in a specific market. Thus, the model's results may overestimate the changes in the shares of exporting firms following a policy shock and the associated changes in productivity, but underestimate the variety gains brought by new entrants. A better description of the dynamic of firm entry and exit will be important for improving the performance of the model. Finally, the model can be improved in the modeling of the trade and use of intermediate goods. Some micro evidence has shown that firms are heterogeneous in terms of the use of imported intermediate inputs, and that trade liberalization can boost trade through the increased extensive margin in importers of intermediate goods (Ramanarayanan, 2006). A more realistic model of firm behavior in the use of intermediate inputs would make the CGE model potentially useful in explaining the rise of vertical integration and the rapid expansion of trade in intermediate goods in recent two decades.

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