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JEL Codes : F10, F12, F41

**Keywords : trade liberalization, firm heterogeneity,
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Trade liberalization and heterogeneous within-firm productivity improvements

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Abstract

This paper develops an intra-industry model of trade with heterogeneous firms to investigate the impact of trade on the evolution of within firm productivity. The main contribution is to incorporate endogenous labor productivity gains. Heterogeneous firms have different incentives to invest in foreign technology which in turns enhances efficiency heterogeneously. Trade liberalization reduces the price of imported capital equipment and increases factor demands. These mechanisms introduce two novel results. First, aggregate productivity increases due to within-firm productivity improvements. Second, tariffs reduction has little impact on the extensive margin of trade in countries already highly open.

Keywords: trade liberalization, firm heterogeneity, endogenous productivity gains, extensive margin of trade.

JEL Classification: F10, F12 and F41

1 Introduction

Empirical works at the firm level have shown that trade policy shapes the evolution of firm productivity. This "within-firm" effect of trade, however, can not be reproduced by the wave of the recent heterogeneous firms' models. In these models, trade induces aggregate productivity improvements as a consequence of the exit of the least productive firms and the reallocation of market shares towards the most productive ones. This "between-firm" effect of trade is in line with stylized facts provided by firm-level data. Nonetheless, the understanding of the effect of trade on productivity calls for further analysis on the mechanisms explaining firm's productivity improvements.

This paper investigates the relationship between trade liberalization, technology investment and productivity gains at the firm level. We focus on developing economies, usually characterized as highly dependent on foreign technology. We propose an extension of Melitz (2003) incorporating endogenous labor productivity gains determined by an initial investment in technologies embodied in imported capital goods. While we assume an exogenous initial distribution of productivity levels, we allow for further modifications of the initial level as a consequence of firms' decisions. The main contributions of this paper to the existing literature can be resumed as follows. Firstly, the model allows for endogenous productivity gains. Thereby, it explains how trade policy shapes the incentives of firms to undertake investments to enhance their productivity gains, a topic that has received fewer attention in the existing theoretical literature of trade with heterogeneous firms. Secondly, the model sheds some new light on the impact of trade liberalization on the intensive (volume of exports) and the extensive margin of trade (number of new exporters). Actually, firms' productivity improvements are themselves heterogeneous. Initial productivity matters and self-selection mechanisms are emphasized. The result is that gains of trade are concentrated on a reduced number of exporters.

Several empirical works have studied the impact of trade integration on industry productivity evolution. One of their contributions is to understand whether trade liberalization influences aggregate productivity and by which mechanisms. By decomposing

aggregate productivity (see Olley and Pakes, 1996; Foster, Haltiwanger and Krizan, 1998), these studies have stressed three main channels : (1) Resources reallocation towards most productive firms (between-firm channel), (2) Net entry and (3) Improvements of firms' efficiency (within-firm channel). In general, these works use plant panel data to carry out study cases of countries which have experienced trade reforms. Results vary across countries and industries.

Pavcnik (2002) investigates the impact of trade liberalization on firm productivity in Chile (1979-1986). In her aggregate productivity decomposition, a major role is played by the reallocation process of inputs and production towards most productive firms. Bernard and Jensen (2001) estimate the determinants of aggregate productivity at the industry level in the US (1983-1992) and find similar results. In both studies, productivity improvements at the industry level are mainly explained by the between-firm channel.

On the other hand, other empirical works highlight the explanatory power of within-firm productivity improvements and the net-entry of more productive firms: Aw, Chung and Roberts (2000) on Taiwan (1986-1991); Treffer (2000) on Canada, De Loecker and Konings (2005) on Slovenia (1994-2000), Bergoeing, Hernando and Repetto (2006) on Chile (1979-2001) and Bas and Ledezma (2007) on Chile (1979-1999). These studies confirm that firm productivity evolves over the time and that this evolution is a key factor to explain aggregate levels.

Interestingly, concerning recent empirical works on Chile, one notes that the sample periods are larger than the one used by Pavcnik (2002). Using different estimates of firm productivity, both Bergoeing, Hernando and Repetto (2006) and Bas and Ledezma (2007) find that between 1979 and 1986 aggregate productivity is mostly explained by the reallocation process. Nevertheless, these studies show that the evolution of within-firm productivity plays an important role from 1986 to 1998, the same period in which Chile experienced stable macroeconomic growth. This result is illustrated by Figure 1.a. It depicts the ratio of the weighted average labor productivity to the simple average (un-weighted). While the former reflects average productivity gains arising from reallocation

of resources, the latter relates to within-firm productivity improvements. In Figure 1.b., we overlap the histogram of plant productivity of 1987 with the one of 1995, a period of within-firm productivity gains. First, we observe that distribution remains highly asymmetric. Since we only observe those firms that remain in the market, the reduction in the percentage at the lowest productivity levels reflects the exit of least productive ones (both histograms start at zero). Second, it is important to note that productivity improvements concern a much reduced number of plants (histogram for 1995 in gray). Thus, productivity improvements at the firm level are heterogeneous and concern just a few firms.

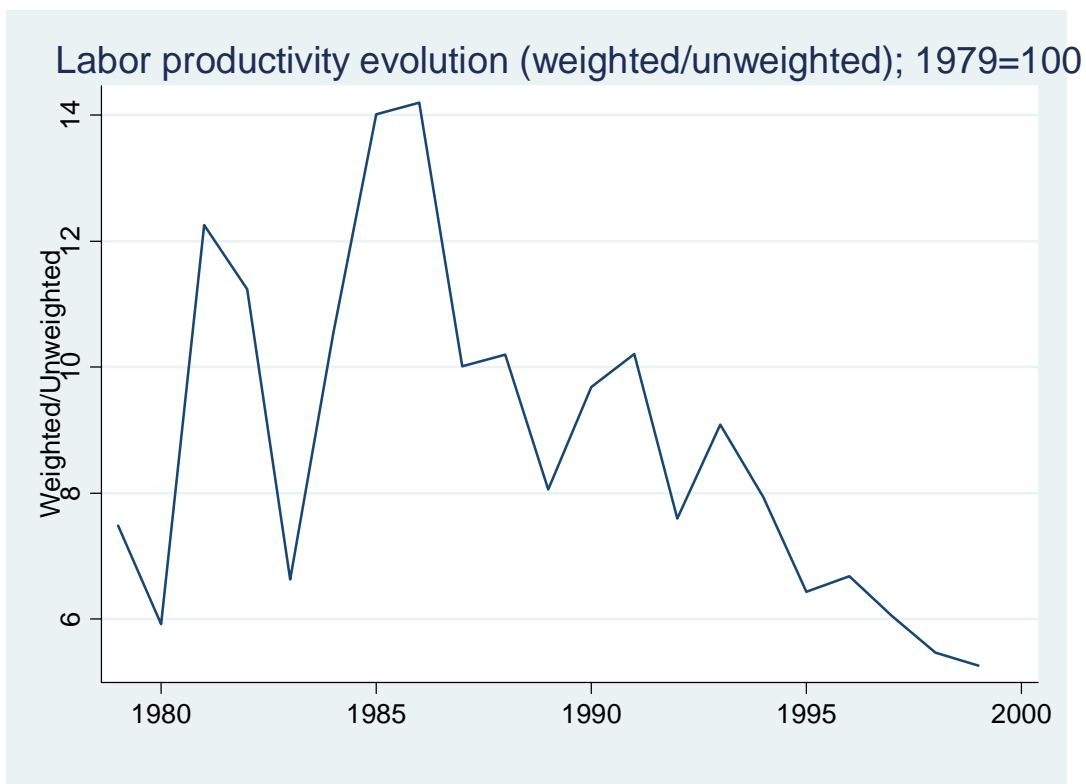


Figure 1.a. Source: Bas and Ledezma (2007)

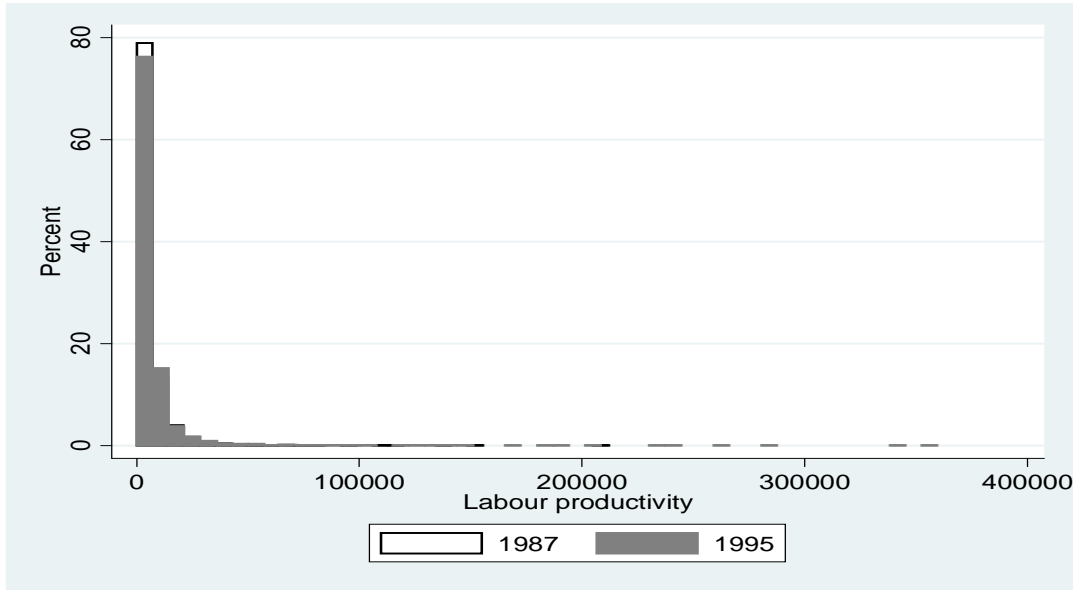


Figure 1.b. Histogram of labor productivity

On the theoretical ground, after the pioneer works of Melitz (2003) and Bernard, Eaton, Jensen and Kortum (2003), several trade models have been developed based on a microeconomic setup with heterogeneous productivity levels across firms. This theoretical framework is able to reproduce the between-firm effect of aggregate productivity improvements. The reduction of trade frictions enhances aggregate productivity through two mechanisms. The increase in real wages and foreign competition leads to a reduction of domestic market shares of all firms and, thereby, the exit of the least productive ones. Consequently, there is also a reallocation process of resources towards the most productive firms, namely exporters. The second channel is characterized by the raise in market shares of exporters due to the increase in foreign demand.

An interesting contribution is the one of Baldwin and Robert-Nicoud (2008), which incorporates an innovative sector in the Melitz's model to explain the effects of trade on aggregate productivity growth. They combine the framework of heterogeneous firms with the endogenous growth theory. Dynamic effects are introduced thanks to knowledge spillovers associated to the production of successful varieties. In their model, trade liberalization has two opposite effects on economic growth. The positive effect is based

on the reduction of the marginal cost of innovation. Nevertheless, the selection of the most productive firms in the domestic market, generated by trade openness, increases the expected cost of production of new varieties and reduces the growth rate. The impact of trade on aggregate productivity is different depending on whether one focuses on static or dynamic effects. After trade liberalization, industry productivity raises in level but the growth rate might decrease.

A key assumption of these models is that productivity at the firm level is exogenous. Therefore, they are not able to explain the evolution of industry productivity related to within-firm channels. Firm productivity is exogenously determined and it remains unchanged. This is a key issue motivating this paper. While several theoretical works have explained why only the most productive producers can export and how trade induces a market share reallocation process, the determinants of these productivity differentials have not received enough attention. We contribute to this issue by introducing an endogenous mechanism of productivity divergence across firms which is reinforced by trade liberalization.

In that sense our model is related to Yeaple (2005) who introduces a discrete technological choice. Firm heterogeneity arises endogenously from the allocation of heterogeneous skilled workers to different technologies. Homogeneous firms become heterogeneous due to the availability of more skilled workers. While Yeaple (2005) develops an explanation of firm heterogeneity, the static setup of his model does not allow for firms' decisions seeking to change their initial productivity. In this model, productivity improvements due to technology adoption are homogeneous. In this paper, we represent technological choice as a continuous decision of the initial level of capital investment, which contributes to improve the productivity of a homogenous labour factor. While we assume an initial level of heterogeneity, we endogenously explain the change in the distribution of firms' productivity.

The setup of our model is as follow. We keep the intra-industry monopolistic competition framework with (initially) heterogeneous firms and introduce an investment in

technology embodied in imported capital goods. Once firms have paid a fixed-sunk entry cost, their initial productivity level is revealed. Afterwards, depending on their profitability, firms have the possibility to improve even more their efficiency through capital investment. Since the initial level of productivity is heterogenous across firms, the productivity gains coming from capital-labor substitution are also heterogeneous across firms.

Trade policy is represented by fixed export costs and variable trade costs. The latter includes tariffs of imported capital goods. As usually, only most productive producers are able to pay the fixed export cost and to reach the foreign market. Trade liberalization affects firms' investment decisions on both the supply and the demand sides. On the supply side, a decrease in tariffs of imported capital goods implies a heterogeneous increase in capital-labor substitution. On the demand side, the reduction of variable trade costs enhances foreign demand of domestic producers. The anticipation of a greater demand also increases heterogeneously capital investment because producers know the impact of their investment on prices and profits. The role of monopolistic competition is crucial to create the demand channel. Firms not only set a mark-up over marginal costs, but they can also reduce their marginal costs depending on their productivity advantages relative to the economy. As in a Dixit-Stiglitz framework, each firm competes with the whole economy. Most productive firms boost up the average productivity of the economy and deter the least productive ones to undertake technology investments. At the end, trade liberalization is biased towards the initially high-productivity firms that become even more efficient after trade liberalization. This theoretical prediction is consistent with the empirical findings presented by Aw, Chung and Roberts (2000), Trefler (2004), De Loecker and Konings (2005), Bergoeing, Hernando and Repetto (2006) and Bas and Ledezma (2007).

Hence, both "between" and "within" mechanisms are present in this model to explain how the trade frictions reduction contributes positively to aggregate productivity. The between-firm effect works through the standard selection channel in the domestic market. The novel within-firm channel is interesting because productivity improvements are

heterogenous across firms. Indeed, the model predicts that only a small fraction of firms will become more efficient after a reduction of trade costs. Hence, the initial distribution of productivity is modified. Initially high-productive firms capture most of technological productivity improvements. This result explains why there is a minor change in the extensive margin of trade since gains from trade are concentrated in the most productive firms, those that more likely already export.

The rest of the paper is organized as follows. In Section 2 the set-up of the model is presented. Section 3 develops the main results. Section 4 concludes.

2 The model

2.1 Households consumption

There are two countries: home h and foreign f . They represent two small open economies. Households allocate consumption between the set of available domestic varieties Ω_h and the imported one Ω_f^x . Both sets are endogenously determined by the entry and the exit of firms. Whether domestic varieties are exported or not depends on their profitability. Consumers' preferences across varieties are given by a standard CES utility function. All variables with an circle (\circ) represent the foreign market and all round brackets ($()$) are reserved to specify the arguments of functions. Let C_h be the aggregate CES index in the home country. Domestic preferences are then summarized by:

$$C_h = \left[\int_{i \in \Omega_h} d_h(i)^{\frac{\phi-1}{\phi}} di + \int_{i' \in \Omega_f^x} d_f(i')^{\frac{\phi-1}{\phi}} di' \right]^{\frac{\phi}{\phi-1}} \quad (1)$$

Where $d_h(i)$ and $d_f(i')$ are the consumption of home and foreign varieties, respectively. The elasticity of substitution, $\phi > 1$, is the same in both countries. Denoting $p_x(i)$ the price of variety (i) produced in country x and P_h the aggregate price in the home country, this formulation implies the following optimal inverse demand functions:

$$d_h(i) = \left[\frac{P_h}{p_h(i)} \right]^\phi C_h \quad (2)$$

$$d_f(i') = \left[\frac{P_h}{p_f^\circ(i') [1 + \tau] e} \right]^\phi C_h \quad (3)$$

Where e is the nominal exchange rate quoted in the home currency relative to the foreign one and τ the variable trade costs, modeled as "iceberg costs". Consequently, the CES price index is given by:

$$P_h = \left[\int_{i \in \Omega_h} p_h(i)^{1-\phi} di + \int_{i' \in \Omega_f^x} [p_f^\circ(i') [1 + \tau] e]^{1-\phi} di' \right]^{\frac{1}{1-\phi}} \quad (4)$$

2.2 Producers

Each firm i faces the following schedule. First it enters the market. To do so, before knowing its initial productivity level, $\alpha_h(i)$, the firm has to pay a start-up cost f_e . After paying this sunk entry cost, $\alpha_h(i)$ is revealed from a common distribution density $g(\alpha_h)$, with support $[0, \infty]$ and cumulative distribution $G(\alpha_h)$. Second, once the firm knows its initial productivity level, but still before production, it decides its investment in technology embodied in imported capital goods. This technology choice allows it to improve its initial level of productivity. Finally, due to the presence of a fixed production cost f paid at every period, the firm decides whether it stays or exits the market. It might be the case that, even if a firm invests to enhance its efficiency, the expected profitability is not high enough to produce. In that case, the firm exits the market. Otherwise it stays and produces with an improved productivity level until economic conditions change and its revenues become insufficient to pay the permanent fixed cost.

Firms enter the market if their expected value allows, at least, to pay the entry cost. Thus, they anticipate their expected discounted of profits. This also includes the expected

gains from investment. We then analyze each step of the schedule and solve the model in backward induction.

2.2.1 Technology

Producers compete within a monopolistic competition framework. When a firm is active in the market, it produces a specific variety by using labor with constant returns to scale. Focusing on the home country, the production function $Y_h(i)$ of producer i is given by:

$$Y_h(i) = A_h(i) l_h(i) \quad (5)$$

Labor productivity $A_h(i)$ depends on an initial investment in foreign technology $I_{h0}(i)$. This investment has a different impact depending on the initial productivity level of each firm $\alpha_h(i)$.

$$A_h(i) = \alpha_h(i) [I_{h0}(i)]^\lambda \quad (6)$$

Where $0 < \lambda < 1$. The technology choice of firm i is made once it knows its initial productivity level $\alpha_h(i)$ and before it starts producing. This initial investment represents a specific fixed technological cost incurred by the firm in order to improve its efficiency when it enters the market. If it decides to stay, the firm produces using only labor with constant returns to scale, but with an improved productivity level.

Thus, the firm's investment I_{h0} is a decision, which is endogenously determined in the model. Since this decision depends on the heterogeneity α_h , the level of investment will be heterogeneous across firms. Firms endowed with a higher initial productivity level, will be able to reinforce even more their efficiency through an "investment channel".

As we focus on developing economies, we think in technology as embodied in imported capital goods. The elasticity λ , which is homogeneous across firms, captures the extent to which labor productivity reacts to this type of technology in the industry. If $\lambda = 0$ one finds a Melitz-type model. If $\lambda > 0$ further decisions take place and, as we will see, the initial distribution of productivity is modified. In this sense, the model seeks to

understand the evolution of firm productivity in capital intensive industries.

One key assumption is that capital goods are supplied to both countries by the rest of the world in perfect competition. Implicitly, the model considers two small economies and a third country that represents the rest of the world. Since the investment is paid with profits, the trade balance condition between the two small economies does not take into account imported capital goods. Thus, we solve the model for the partial equilibrium between these two small economies.

2.2.2 Price setting and profits

As we mentioned, during production, firms behave as if they have constant returns on labor with a given level of productivity. Hence, first order conditions imply that firm set prices as a mark-up over marginal costs (wages over labor productivity):

$$p_h(i) = \frac{\phi}{[\phi - 1]} \frac{W_h}{A_h(i)} \quad (7)$$

Where W_h is the wage rate in the home country. The price of home goods sold in the foreign markets p_h° is higher due to variable trade costs (represented by τ).

$$p_h^\circ(i) = \frac{\phi}{[\phi - 1]} \frac{W_h}{A_h(i)} \frac{[1 + \tau]}{e} \quad (8)$$

Assumption 1: *Countries h and f are symmetric.*

We can now simplify our notation. Assumption 1 ensures equal wage rates (normalized to 1: $W_h = W_f = 1$) and equal aggregate prices ($P_h = eP_f^\circ = P$). Then, hereafter we drop country subscripts. Since heterogeneity is totally captured by α , we also drop firm subscripts and identify firms by α .

Firms' revenues can be divided into those earned from domestic sales r_d and those earned from export sales r_x . Using (7) and (6) the former can be written as:

$$r_d(I_0) = \left[\frac{P}{p(I_0)} \right]^{\phi-1} R \quad (9)$$

Where R is the aggregate revenue of the country ($R = PC$). We write revenues as a function of the initial investment in order to highlight the decision schedule. Using (8), export revenues are given by:

$$r_x(I_0) = r_d(I_0) [1 + \tau]^{1-\phi} \quad (10)$$

Total revenue $r(I_0)$ of a firm with initial productivity α depends on its export status:

$$\begin{aligned} r(I_0) &= r_d(I_0) && \text{if the firm does not export} \\ r(I_0) &= r_d(I_0) + r_x(I_0) = r_d(I_0) \left[1 + (1 + \tau)^{1-\phi} \right] && \text{if the firm exports} \end{aligned}$$

Similarly, profits can also be divided into domestic profits $\pi_d(I_0)$ and export profits $\pi_x(I_0)$:

$$\pi_d(I_0) = \frac{r_d(I_0)}{\phi} - \delta\psi(\tau) I_0 - f \quad (11)$$

Where f represents fixed production costs that are paid in every period. We assume that technology investment is paid with profits to the country supplying capital goods (the rest of the world). $\delta\psi(\tau) I_0$ is the amortized investment. $\psi(\tau) \equiv (1 + \tau)p_k e_w$ is the final price of imported capital in home currency. e_w is the nominal exchange rate between any of the two symmetric small economies and the rest of the world. The price of imported capital goods p_k is taken as given since both economies are supposed to be small enough to have any impact on world prices. Export profits $\pi_x(I_0) = \frac{r_x(I_0)}{\phi} - \delta f_x$ are then:

$$\pi_x(I_0) = \frac{r_d(I_0)}{\phi} (1 + \tau)^{1-\phi} - \delta f_x \quad (12)$$

Firms having a higher productivity, which depends on the initial technology investment, will charge a lower price, have a higher demand and earn higher profits than less productive ones.

2.3 Technology choice: Initial investment

Using backward induction, firms set optimal prices taking I_0 as given (equations (7) and (8)) and decide the level of I_0 that maximizes the present value v of their domestic profits. Using δ as the time discounting factor.¹

$$v(I_0) = \frac{1}{\delta} \frac{r_d(I_0)}{\phi} - I_0 \psi(\tau) - f \quad (13)$$

The first order condition implies an optimal investment which depends on the initial productivity:

$$I_0(\alpha) = [P\alpha]^{\frac{\phi-1}{\beta}} \left\{ \frac{\lambda R}{\delta \psi(\tau)} \left[\frac{\phi-1}{\phi} \right]^\phi \right\}^{\frac{1}{\beta}} \quad (14)$$

Where $\beta \equiv 1 - \lambda(\phi - 1)$. We assume that $\frac{1}{(\phi-1)} > \lambda$ in order to ensure non-explosive returns of investment. The power $\frac{\phi-1}{\beta}$ gives the concavity of the effect of α on firm's investment. This term comes from the fact that, when maximizing the discounted value of profits flows, the effect of demand is taken into account twice. First, when setting their price, firms know that their demand is a decreasing function of their price relative to the aggregate one. This leads to the mark-up price rule. Second, when entering the market they also know that their demand can be enhanced by decreasing their marginal costs through the investment channel. As we will see this anticipation mechanism implies that the effect of the initial heterogeneity is not linear.

¹As in Melitz (2003), the time discounting parameter δ , represents also the exogenous probability of exit.

2.4 Thresholds of production and export status

Since there is a fixed production cost (paid in units of labor), there exists a marginal firm, α^* , whose domestic profits are equal to zero: $\pi_d(\alpha^*) = 0$. This is equivalent to state:

$$\frac{r_d^I(\alpha^*)}{\phi} = f \quad (15)$$

Where $r_d^I(\alpha) \equiv r_d(\alpha) - \delta I_0(\alpha) \psi(\tau)$ are domestic revenues net of amortization of initial investment in technology. The value α^* is the production cutoff. It defines the threshold corresponding to the minimum level of productivity that allows to produce. Some firms decide to exit the market because, even after investment, they are not profitable enough to pay the fixed production costs.

Similarly, the tractability condition implies that only those firms with operating profits that counterweight the fixed export costs δf_x , also paid in units of labor, will be able to export. Again, this defines a marginal firm, α_x^* , whose export profits are zero: $\pi_x(\alpha_x^*) = 0$

$$\frac{r_d(\alpha_x^*)}{\phi} (1 + \tau)^{1-\phi} = \delta f_x \quad (16)$$

From this condition we can derive the export cutoff α_x^* : the threshold corresponding to the minimum level of productivity which ensures just enough revenues to pay δf_x .

2.5 Aggregation

After applying trade balance condition for symmetric countries, the index price over the support of α leads to:

$$P^{1-\phi} = \int_{\alpha^*}^{\infty} Np(\alpha)^{1-\phi} \frac{g(\alpha)}{[1 - G(\alpha^*)]} d\alpha + \int_{\alpha_x^*}^{\infty} N_x [p(\alpha) [1 + \tau]]^{1-\phi} \frac{g(\alpha)}{[1 - G(\alpha_x^*)]} d\alpha \quad (17)$$

From the left to the right, the integrals represent domestic and imported varieties,

respectively. The assumption of symmetric countries implies that the characteristics of imported varieties are identical to those of exported ones. Thus, the number of exporters in both countries is the same $N_{hx} = N_{fx} = N_x$. The total number of varieties available for consumption in a country is then $N_T = N + N_x$. It is composed of N domestic varieties, including exported and non-exported goods, and N_x imported varieties.

The price index P takes into account that prices are a function of the random variable α . Consequently, the domestic component considers the distribution of α conditional on having entered the market $\frac{g(\alpha)}{1-G(\alpha^*)}$, and the import component the one conditional on having the export status $\frac{g(\alpha)}{1-G(\alpha_x^*)}$.

Trade balance accounting concerns two components: consumption goods and capital goods. The former are considered in the standard export-import balance accounting between the two symmetric countries and the latter in the amortization of the initial investment in capital, imported from the rest of the world and paid by revenues coming from sales. Since both components are supplied and paid independently their accounting can also be done independently. Hence, the index price takes only into account consumption goods. Using the assumption of symmetry and the standard results of CES demand formulation, one obtains directly the aboved-presented expression.

Plugging the optimal prices set by the firm into the price index we obtain:

$$P = \frac{\phi}{\phi-1} \left[\int_{\alpha^*}^{\infty} \frac{NA(\alpha)^{\phi-1}g(\alpha)}{[1-G(\alpha^*)]} d\alpha + (1+\tau)^{1-\phi} \int_{\alpha_x^*}^{\infty} \frac{N_x A(\alpha)^{\phi-1}g(\alpha)}{[1-G(\alpha_x^*)]} d\alpha \right]^{\frac{1}{1-\phi}}$$

Defining $\widetilde{A}_d^{\phi-1} \equiv \int_{\alpha^*}^{\infty} A(\alpha)^{\phi-1} \frac{g(\alpha)}{[1-G(\alpha^*)]} d\alpha$ and $\widetilde{A}_x^{\phi-1} \equiv \int_{\alpha_x^*}^{\infty} A(\alpha)^{\phi-1} \frac{g(\alpha)}{[1-G(\alpha_x^*)]} d\alpha$ we can express the average productivity and the price index as

$$\widetilde{A}_T^{\phi-1} = \frac{1}{N_T} \left[N \widetilde{A}_d^{\phi-1} + N_x (1+\tau)^{1-\phi} \widetilde{A}_x^{\phi-1} \right] \quad (18)$$

$$P = N_T^{\frac{1}{1-\phi}} \frac{\phi}{\phi-1} \frac{1}{\widetilde{A}_T} \quad (19)$$

This is the Melitz's (2003) aggregate price summarized by the average productivity \widetilde{A}_T . In our framework, productivity is determined by the optimal technology choice

(14), which depends on the index price. This leads to an externality of investment. Thanks to investment, the economy becomes more productive and the aggregate price P is reduced. As in this Dixit-Stiglitz framework each firm competes with the whole economy, the average productivity improvement induces firms to invest more in order to set a competitive price. However, firms do not take into account that their behavior determines the average productivity of the economy.

After plugging (19) into (14) and the result into (6) and (18), we obtain:

$$\widetilde{A}_T = \frac{\kappa(\lambda, \tau)}{N_T} \widehat{\alpha} \quad (20)$$

Where the following definitions apply:

$$\begin{aligned} \kappa(\lambda, \tau) &\equiv \frac{\lambda R}{\delta \psi(\tau)} \left[\frac{\phi - 1}{\phi} \right] \\ \widehat{\alpha}^{\frac{\phi-1}{\beta}} &\equiv \frac{1}{N_T} \left[N \widehat{\alpha}_d^{\frac{\phi-1}{\beta}} + [1 + \tau]^{1-\phi} N_x \widehat{\alpha}_x^{\frac{\phi-1}{\beta}} \right] \\ \widehat{\alpha}_d^{\frac{\phi-1}{\beta}} &\equiv \frac{1}{[1 - G(\alpha^*)]} \int_{\alpha^*}^{\infty} \alpha^{\frac{\phi-1}{\beta}} g(\alpha) d\alpha \\ \widehat{\alpha}_x^{\frac{\phi-1}{\beta}} &\equiv \frac{1}{[1 - G(\alpha_x^*)]} \int_{\alpha_x^*}^{\infty} \alpha^{\frac{\phi-1}{\beta}} g(\alpha) d\alpha \end{aligned} \quad (21)$$

The average defined by $\widehat{\alpha}$ aggregates heterogeneity after taking into account optimal decisions of investment. Similarly, $\widehat{\alpha}_d$ and $\widehat{\alpha}_x$ are the domestic and export counterparts of $\widehat{\alpha}$. This average gives a measure of the reaction of labor productivity in the industry to the technology choice.

Proposition 1: *Firm's investment is a function of its (exogenous) initial heterogeneity α relative to the (endogenous) aggregate of the industry ($\widehat{\alpha}$). The investment function is given by:*

$$I(\alpha) = \frac{\kappa(\lambda, \tau)}{N_T} \left[\frac{\alpha}{\widehat{\alpha}} \right]^{\frac{\phi-1}{\beta}} \quad (22)$$

Proof: Plugging the global average productivity (20) into the optimal investment (14) gives (22). ■

Equation (22) gives further insights concerning the above-mentioned externality of investment. Since $\hat{\alpha}_d$ and $\hat{\alpha}_x$ are endogenously determined by productivity cutoffs, $\hat{\alpha}$ is modified by firms' decisions. Producers drawing a high initial productivity level will bias the initial distribution since they will concentrate most of investment gains. This occurs because firms anticipate the impact of their investment decisions on their demand. The decision of high productive firms will deter the least productive ones to undertake a large amount of investment because they compete with the average firm which has become more productive. As a consequence, firms' decisions are particularly sensitive to the expected relative advantages. As the average productivity gains are reinforced, the effectiveness of investment is reduced for firms with a low α . This induces the exit of the least productive firms and as a consequence an increase in $\hat{\alpha}$.

Proposition 2: *Global productivity \widetilde{A}_T can be summarized as the productivity of a representative firm which its initial productivity can be improved through the "investment channel" by a factor of $\hat{\alpha}$: $\widetilde{A}_T = A(\hat{\alpha})$. More generally, a firm with an initial level of heterogeneity α will obtain after investment decision a productivity level of :*

$$A(\alpha) = \alpha I(\alpha) = \alpha \frac{\kappa(\lambda)}{N_T} \left[\frac{\alpha}{\hat{\alpha}} \right]^{\frac{\phi-1}{\beta}} \quad (23)$$

Proof: Substitution of (22) into firm productivity (6) leads to equation (23). Evaluating (23) for $\alpha = \hat{\alpha}$ gives (20) ■

The optimal investment defines profits and revenues as functions of the exogenous initial productivity α . Plugging (22) into (9) gives:

$$r_d(\alpha) = \frac{1}{N_T} \left[\frac{\alpha}{\hat{\alpha}} \right]^{\frac{\phi-1}{\beta}} R \quad (24)$$

Export revenues and profits are pin down by $r_d(\alpha)$ (see equations (10) and (12)). The

industry can be aggregated using the weighted averages $\widehat{\alpha}$, $\widehat{\alpha}_d$ and $\widehat{\alpha}_x$. Average revenue \widetilde{r} (net of investment), stem from average revenues earned from domestic sales $r_d^I(\widehat{\alpha}_d)$ and from export sales $r_x(\widehat{\alpha}_x)$

$$\widetilde{r} = r_d^I(\widehat{\alpha}_d) + \rho_x r_x(\widehat{\alpha}_x) \quad (25)$$

A similar statement applies for average profits $\widetilde{\pi}$, which can be decomposed into domestic $\pi_d(\widehat{\alpha}_d)$ and export $\pi_x(\widehat{\alpha}_x)$ average profits.

$$\widetilde{\pi} = \pi_d(\widehat{\alpha}_d) + \rho_x \pi_x(\widehat{\alpha}_x) \quad (26)$$

Where the probability of exporting, $\rho_x = \frac{1-G(\alpha_x^*)}{1-G(\alpha^*)}$ is the probability of having an α higher than the export cutoff α_x^* , conditional on having entered the market. Applying (22), domestic revenues net of amortized investment $r_d^I(\alpha) = r_d(\alpha) - \delta I_0(\alpha)\psi$ can be expressed as:

$$r_d^I(\alpha) = \beta r_d(\alpha) \quad (27)$$

Hence, $r_d^I(\widehat{\alpha}_d) = \beta r_d(\widehat{\alpha}_d)$.

2.6 Macro Balance

In this subsection we analyze global conditions of stability and macroeconomic balance to close the model.

2.6.1 Entry-Exit

The first group of conditions relates to the entry-exit process. The mass of prospective entrants is unbounded, they decide to enter depending on the firm's value and before knowing their initial productivity level α . Hence, in order to decide whether they enter the market, firms calculate the expected value of the average profit flows $\widetilde{v} = \frac{[1-G(\alpha^*)]\widetilde{\pi}}{\delta}$

and compare it to the sunk entry cost f_e . As usual, firms enter the market until the expected value of firms \tilde{v} is equalized to the sunk entry cost. This equality ($\tilde{v} = f_e$) states the free entry condition (FE):

$$\tilde{\pi} = \frac{\delta f_e}{[1 - G(\alpha^*)]} \quad (\text{FE})$$

Among firms that enter the market N_e , only a fraction $\rho = 1 - G(\alpha^*)$ will decide to stay. These firms are those whose technical conditions allow enough revenues to pay the fixed costs of production. On the other hand, among active firms N , some of them will exit the market with an exogenous probability δ (the death shock of Melitz, 2003). The stability condition of entry and exit implies:

$$\delta N = N_e \rho \quad (28)$$

2.6.2 Labor Market and Global Accounting

The labor factor is inelastically supplied in perfect competition. Total labor L_T is composed of production workers L_p (including labor used to pay the fixed production and export costs) and also workers allocated to pay the sunk cost to enter the market L_e :

$$L_T = L_p + L_e \quad (29)$$

The N_e firms that enter the market incur a labor cost of start-up equal to

$$L_e = N_e f_e \quad (30)$$

The labor market clearing condition is ensured by the global accounting condition. Recalling that wage rate is normalized to 1:

$$L_p + N\tilde{\pi} = R \quad (31)$$

Using (30), the free entry condition (FE) and the stability condition (??) one easily obtains $L_e = N\tilde{\pi}$. Using (29) yields:

$$L_T = R \tag{32}$$

2.6.3 Number of Domestic Firms

Starting from the previous conditions we can express average revenues \tilde{r} as

$$\tilde{r} = \frac{R}{N} \tag{33}$$

We can write average profits as $\tilde{\pi} = \frac{\tilde{r}}{\phi} - f - \rho_x \delta f_x$. After multiplying both sides by N and rearranging terms, we obtain the aggregate revenue:

$$R = N\tilde{r} = N [\tilde{\pi} + f + \rho_x \delta f_x] \phi \tag{34}$$

Replacing R in labor market clearing condition (32) and applying the free entry condition (FE) one gets the number of active domestic firms:

$$N = \frac{L_T}{\left[\frac{\delta f_e}{\rho} + f + \rho_x \delta f_x \right] \phi} \tag{35}$$

After considering revenues net of investment, the expression defining the number of firms looks similar to the standard Melitz's framework. However, the outcome is different. In this model, the probabilities defined by ρ and ρ_x are determined by the cutoffs α_x^* and α^* , which at equilibrium are influenced by the endogenous investment decision.

2.7 Equilibrium

The equilibrium can be solved using the Free Entry condition (FE) once we have determined its left-hand-side: the average profits $\tilde{\pi}$. The latter can be related to the minimum level of initial productivity that allows enough revenues to stay in the market (the production cutoff α^* defined by equation (15)). This relationship is what Melitz (2003) calls

the Zero Cutoff Profit condition (ZCP). Hence, the equilibrium is jointly determined by both the FE condition (FE) and the ZCP condition. The intersection of both curves, gives α^* at equilibrium, which will then pin down the rest of endogenous variables of the model.

Starting from equation (26) we need to derive the ZCP in order to express $\tilde{\pi}$ as a function of the cutoff α^* . A convenient treatment is to exploit the aggregation properties of the model. To obtain the domestic average profit in (26), we start from the domestic average revenue (24). In order to simplify $\hat{\alpha}$, we express the ratio of the revenue of the representative domestic firm $\hat{\alpha}_d$ over the one earned by the cutoff firm α^* . Applying this to equation (27) gives:

$$r_d^I(\hat{\alpha}_d) = \left[\frac{\hat{\alpha}_d}{\alpha^*} \right]^{\frac{\phi-1}{\beta}} r_d^I(\alpha^*)$$

From equation (15) we know that operating profits of the production cutoff firm equals the fixed production cost: $\frac{r_d^I(\alpha^*)}{\phi} = f$. Hence, the domestic profits of the representative domestic firm $\pi_d(\hat{\alpha}_d) = \frac{r_d^I(\hat{\alpha}_d)}{\phi} - f$ can be written now as a function of the production cutoff α^* and the average $\hat{\alpha}_d$, which only depends on α^* . This leads to:

$$\pi_d(\hat{\alpha}_d) = \left\{ \left[\frac{\hat{\alpha}_d}{\alpha^*} \right]^{\frac{\phi-1}{\beta}} - 1 \right\} f$$

In the case of the average export revenues we proceed in a similar way. This time, we divide the export revenue of a representative exporter $\hat{\alpha}_x$ by the one earned by the export cutoff firm α_x^* . We also know that the export operating profits of the export cutoff firm equals the fixed cost to reach the foreign market: $\frac{r_x(\alpha_x^*)}{\phi} = \delta f_x$. Then, export profits of the representative exporter are give by:

$$\pi_x(\hat{\alpha}_x) = \left\{ \left[\frac{\hat{\alpha}_x}{\alpha_x^*} \right]^{\frac{\phi-1}{\beta}} - 1 \right\} \delta f_x$$

Therefore, the ZCP condition defines the average profit per firm as:

$$\tilde{\pi} = \left\{ \left[\frac{\hat{\alpha}_d}{\alpha^*} \right]^{\frac{\phi-1}{\beta}} - 1 \right\} f + \rho_x \left\{ \left[\frac{\hat{\alpha}_x}{\alpha_x^*} \right]^{\frac{\phi-1}{\beta}} - 1 \right\} \delta f_x \quad (\text{ZCP})$$

This condition is entirely determined by the production cutoff level. We know that $\hat{\alpha}_d = \hat{\alpha}_d(\alpha^*)$ and $\hat{\alpha}_x = \hat{\alpha}_x(\alpha_x^*)$. Thus, we just need to find $\alpha_x^* = \alpha_x^*(\alpha^*)$. In order to find this relationship, we plug the optimal investment (22) into equations (15) and (16). Then, we take the ratio of the resulting equations and we find:

$$\alpha_x^* = \alpha^* \gamma(\tau) \quad (36)$$

If $\gamma(\tau) \equiv [1 + \tau]^\beta \left[\frac{\beta \delta f_x}{f} \right]^{\frac{\beta}{\phi-1}} > 1$ there will be exported varieties at the equilibrium ($\alpha^* < \alpha_x^*$)². At the end, the ZCP condition depends only on α^* and the exogenous parameters. In order to get a closed solution we solve the model using a Pareto distribution for the initial productivity draws.

3 Analytical solution

Following Ghironi and Melitz (2005) and Melitz and Ottaviano (2005), we parametrize the productivity draws to get tractable solutions of the model.

Assumption 2: *Productivity draws are distributed according to a Pareto distribution $g(\varphi) = \frac{k\varphi_{\min}^k}{\varphi^{k+1}}$ with a lower bound $\varphi_{\min} = 1$ and a shape parameter $k > \frac{\phi-1}{\beta}$.*

When this shape parameter increases there is a reduction of the technological dispersion, which will be concentrated towards the lower bound. As usual, this distribution density requires $k > \frac{\phi-1}{\beta}$ in order to ensure finite means. The parameter $\alpha_{\min} = 1$ implies that the corresponding cumulative distribution function is given by $G(\alpha) = 1 - \left[\frac{1}{\alpha} \right]^k$.

²This occurs when $\delta f_x (2 - \phi) (1 + \tau)^{\phi-1} > f$

We can easily verify that $\rho = 1 - G(\alpha^*) = \alpha^{*-k}$ and $\rho_x = \frac{1-G(\alpha_x^*)}{1-G(\alpha^*)} = \left[\frac{\alpha^*}{\alpha_x^*}\right]^k$. After solving the integrals defining $\hat{\alpha}_d, \hat{\alpha}_x$ we obtain:

$$\hat{\alpha}_d = \alpha^* \eta \quad (37)$$

$$\hat{\alpha}_x = \alpha_x^* \eta \quad (38)$$

Where $\eta \equiv \left[\frac{-k\beta}{\phi-1-k\beta}\right]^{\frac{\beta}{\phi-1}}$

Proposition 3: *Under Assumption 2, there exists a unique equilibrium production cutoff α^* determined by the ZPC and FE conditions. This cutoff is given by:*

$$\alpha^* = \left[\frac{\left[\eta^{\frac{\phi-1}{\beta}} - 1 \right] \left[f + \delta f_x \gamma(\tau)^{-k} \right]}{\delta f_e} \right]^{\frac{1}{k}} \quad (39)$$

Proof. Equalizing the equations of average profit stated by the ZPC and the FE leads to the equilibrium production cutoff (39). ■

Proposition 4: *Under assumption 2, the production cutoff is a decreasing function of variable trade costs ($\frac{\partial \alpha^*}{\partial \tau} < 0$).*

Proof. From (39) we obtain: $\frac{\partial \alpha^*}{\partial \tau} = -\beta \alpha^{*1-k} \frac{\left[\eta^{\frac{\phi-1}{\beta}} - 1 \right] \delta f_x \gamma(\tau)^{-k}}{\delta f_e [1+\tau]}$. Since $\beta > 0$, as long as $\eta^{\frac{\phi-1}{\beta}} > 1$, we verify $\frac{\partial \alpha^*}{\partial \tau} < 0$. Note that $\eta^{\frac{\phi-1}{\beta}} = \frac{1}{1 - \frac{1}{k} \left[\frac{\phi-1}{\beta} \right]}$. Thus, if $k > \frac{\phi-1}{\beta}$, clearly $\eta^{\frac{\phi-1}{\beta}} > 1$. This is exactly what the condition restricting k states in order to get finite means. ■

Melitz (2003) explains this result as a general equilibrium consequence of the increase in the number of potential entrants. After a reduction of variable trade costs, export demand increases. The value of firms is higher in the new equilibrium, which implies a higher number of entrants. This in turn increases labor demands and also real wages $\frac{1}{P}$.

To be able to pay the fixed production cost, the marginal firm needs to be more productive than before.

In our model, the reduction of variable trade costs also enhances investment demand. As we saw, investment is more significant when the initial heterogeneity induces higher productivity gains from technology. The externality of investment reinforces the selection process. After a reduction of trade costs, investment remains low for initially-low-productive firms. Consequently, they end-up with a lower productivity relative to the economy. Therefore, these firms will be forced to exit the market after a reduction of trade frictions.

Proposition 5: *Under assumption 2, the export cutoff is an increasing function of variable trade costs: $\left(\frac{\partial \alpha_x^*}{\partial \tau} > 0\right)$.*

Proof. Applying (39) to the export cutoff equation (36) gives the cutoff α_x^* which verifies: $\frac{\partial \alpha_x^*}{\partial \tau} = \gamma \left[\frac{\partial \alpha^*}{\partial \tau} + \frac{\alpha^* \beta}{(1+\tau)} \right]$. Since $\frac{\partial \alpha^*}{\partial \tau} < 0$, we need to prove $\left| \frac{\partial \alpha_x^*}{\partial \tau} \right| < \left| \frac{\alpha^* \beta}{(1+\tau)} \right| \Leftrightarrow -\frac{\partial \alpha_x^*}{\partial \tau} < \frac{\alpha^* \beta}{(1+\tau)}$. After using $\frac{\partial \alpha^*}{\partial \tau}$ obtained in the proof of proposition 4, this condition is similar to state $\frac{1}{\left[\frac{f}{f_x \gamma^{-k}} + 1 \right]} < 1$. Since $\frac{f}{f_x \gamma^{-k}} > 0$, this proposition is unambiguously verified. ■

Since productivity $A(\alpha)$ increases monotonically with α , a reduction of variable trade costs will decrease the export cutoff productivity level. Hence, more firms are able to acquire the export status. On the demand side, variable trade costs reduction leads to a decrease in the price of home goods sold in the foreign market. This price reduction accounts for an increase in foreign demand, which in turn raises export profits. In this new equilibrium firms need a lower level of productivity to pay the fixed export costs and to sell in the foreign market.

Note that these properties $\left(\frac{\partial \alpha^*}{\partial \tau} < 0; \frac{\partial \alpha_x^*}{\partial \tau} > 0\right)$ imply directly that higher variable trade costs increases the ex-ante probability of staying in the market $\left(\frac{\partial \rho}{\partial \tau} > 0\right)$ and reduces the probability of exporting $\left(\frac{\partial \rho_x}{\partial \tau} < 0\right)$. Intuitively, if the reduction of trade costs increases the minimum level of productivity required to stay in the market, the probability of a successful entry is reduced. Similarly, if less costly trade induces a lower threshold of productivity to export, it also implies a higher probability to reach the foreign market.

4 The reduction of trade variable costs

4.1 Within-firm productivity

The standard results presented in the previous section are reinforced by the investment channel introduced in this model. The impact of trade liberalization can be separated into two channels whether one observes the supply or the demand effects of trade variable costs. The former is related to the reduction of the cost of capital equipment, while the latter is based on the anticipation of an increase in final goods and factor demands which induces capital-labor substitution. In this section we analyze these channels in more detail.

Consider firm productivity at equilibrium. Investment (22) applied to productivity (23), after global accounting states:

$$A(\alpha) = \alpha \left[\frac{\phi - 1}{\phi} \right] \left[\frac{L_T}{N_T(\tau)} \frac{\lambda}{\delta\psi(\tau)} \right] \left[\frac{\alpha}{\hat{\alpha}(\tau)} \right]^{\frac{\phi-1}{\beta}} \quad (40)$$

$N_T(\tau)$ highlights the dependency of the number of varieties on trade costs. The latter affects the probabilities of staying in the market and of exporting (see equation (35)). Applying the aggregation of heterogeneity for domestic (37) and exported (38) varieties to the global one (21) gives $\hat{\alpha}$ as function of τ . The reason is that this aggregation depends on the cutoffs of production and export, which are in turn determined by τ .

On the supply side, the effect of trade costs on the final capital price is captured by the final price of imported capital in home currency $\psi(\tau) = (1 + \tau)p_k^*e_w$. Clearly $A(\alpha)$ increases when ψ decreases and its impact (in absolute value) is higher for high values of initial productivity gains α . On the demand side, foreign consumption increases after a reduction of variable trade costs. The intuition is that firms anticipate a greater demand and, as a consequence, more requirement of labor. Hence, labor productivity gains become more profitable, which leads to a raise in investment demand. While the supply channel is homogeneous across firms, the demand channel depends on α . Thus, the latter generates

heterogeneous firms' productivity improvements.

We find these results with the help of numerical simulations. The parameters used are: $f_e = 15$, $\delta = 10\%$, $f_x = 20$, $f = 1$, $\phi = 1$, $\lambda = 2/3$, $k = 4$. This setting verifies both $k > \frac{\phi-1}{\beta}$ and the following condition $\gamma(\tau) \equiv [1 + \tau]^\beta \left[\frac{\beta \delta f_x}{f} \right]^{\frac{\beta}{\phi-1}} > 1$, ensuring exported varieties at equilibrium.

Result 1: *Firm productivity increases with the reduction of trade variable costs τ . The impact of τ on productivity gains is non-linear and it is more significant when α is higher.*

We illustrate this mechanism in Figure 2. It shows the plot of $A(\alpha)$ on τ for a high ($\alpha = 2$) and a low ($\alpha = 1$) levels of initial draws. In both cases a reduction of variable trade costs enhances labor productivity, but this improvement depends positively on the initial productivity level. Moreover, in the graph one clearly observes a steeper slope for the higher α .

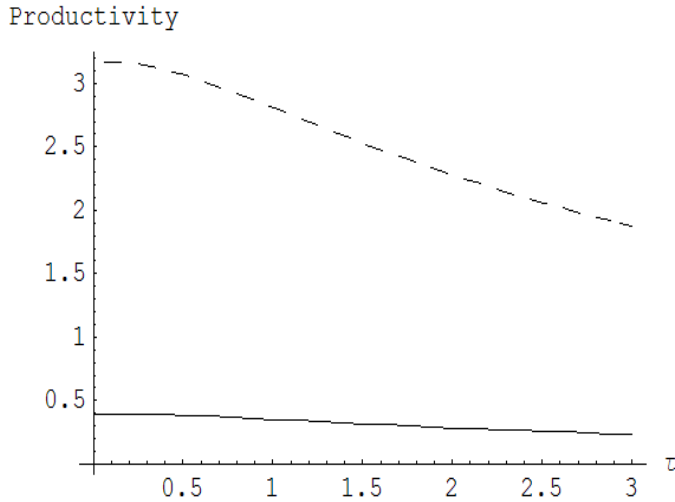


Figure 2

More interestingly, there is a change in the distribution of initial productivity levels. This result is illustrated in Figure 3. We plot both the initial productivity draws (dashed line) and the equilibrium-level of productivity after investment (solid line). Firms can decide to modify their initial productivity level by the means of technological investments, but these decisions depend on their initial profitability. Thus, technological improvements

are biased towards initially high-productive firms. In an heterogeneous firms model with fixed-exogenous productivity draws, the levels of firm productivity will be simply represented by α . This is the 45° dashed line³. The heterogeneous effect of investment is captured by the concavity of the productivity level at equilibrium (solid line). It might be the case that, as in Figure 3, the productivity level is even reduced. The fixed-exogenous productivity model can be seen as a model in which initial investment is homogenous and normalized to 1. Allowing for a continuous technology choice with investment externalities reinforces the effect of market selection. Firms drawing a low α will be deterred to undertake a significant level of investment.

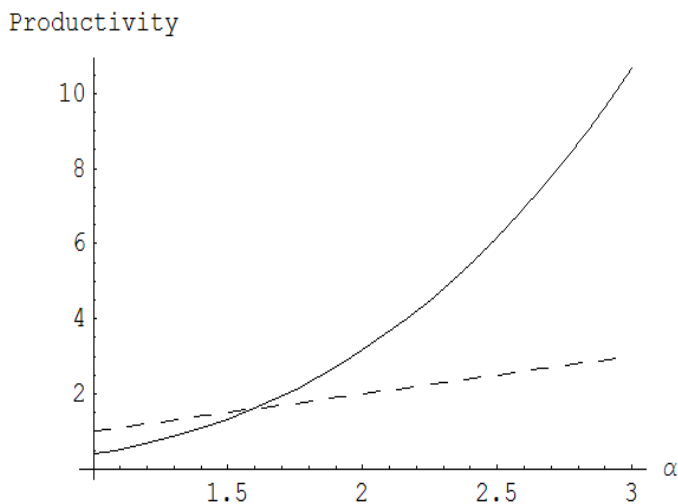


Figure 3

4.2 The intensive and the extensive margin of trade

One implication of the previous results is that trade liberalization, in countries highly dependant on imported technologies, improves mainly the volume of exports of initially high-productive firms. Namely those that already export before trade reform (intensive margin). Foreign demand (3), using the properties of aggregation $\tilde{A}_T = A(\hat{\alpha}(\tau))$, can be expressed at equilibrium as:

³Scales of axis are assymetric.

$$d_f = \alpha \left(\frac{\phi - 1}{\phi} \right) \left[\frac{\alpha}{\widehat{\alpha}(\tau)} \right]^{\frac{1}{\beta}} \frac{L_T}{N_T(\tau)} (1 + \tau)^{-\phi} A(\widehat{\alpha}(\tau))$$

We know that a fall of trade variable costs forces the least productive firms to exit the market. Thus, the average $\widehat{\alpha}(\tau)$ increases. We observe again differentiated effects of trade policy depending on the impact of foreign technology on labor productivity. A reduction of variable trade costs induces a positive income effect through an increase in the average productivity of the economy, which boosts up global consumption. However, the demand of each firm (in monopolistic competition) depends on their technology relative to the average of the economy (the by $\frac{\alpha}{\widehat{\alpha}(\tau)}$), the latter being endogenously determined. The initially high-productive firms will become even more efficient after trade liberalization and thereby they will enlarge their export demand.

Result 2: *A reduction of trade barriers has a higher impact on the intensive margin of trade (volume of exports) relative to the extensive one (number of new exporters).*

To illustrate this point, we simulate the relationship between foreign demand and initial productivity of firms, for two different levels of variable trade costs. Figure 4 plots foreign demand $d_f(\alpha)$ on α . In the plot, the economy changes from a iceberg cost level of 80% (solid line) to a one of 20% (dashed line). Foreign demand curve increases more for high levels of α , where the slope is steeper.

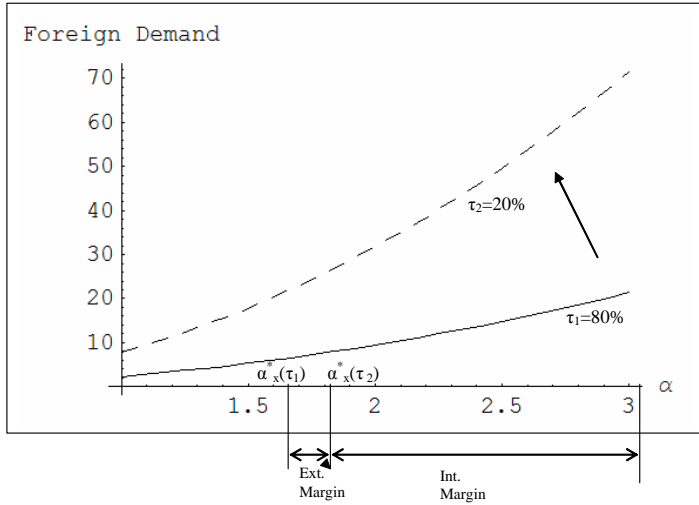


Figure 4.

While there is a huge increase in the intensive margin of trade, there is only a minor one in the extensive margin. Indeed, the reduction of the export threshold α_x^* is small. It will only allow for few firms to become exporters. Therefore, gains from trade are concentrated on continuing exporters.

5 Conclusion

This paper addresses the impact of trade on the evolution of within firm productivity gains in countries highly dependant on technologies embodied in imported capital equipment goods. We proposed an intra-industry trade model of heterogeneous firms which are able to change their initial efficiency level. The main contribution of this study is to introduce endogenous productivity gains determined by an initial investment in foreign technology.

The model proposed in this paper introduces several results consistent with the empirical findings of firm-level studies. Firstly, trade liberalization induces a profitability bias towards the initially more productive firms. These firms are able to improve easily their efficiency by foreign technology adoption after a reduction of trade variable costs.

Secondly, contrary to the standard vision that supports the idea of a tariffs reduction

in order to foster export diversification, this work argues that, in the case of a country highly dependant on foreign technology, trade variable costs reduction will have a minor impact on the extensive margin of trade.

Finally, the model is able to reproduce two important channels through which trade liberalization affects aggregate productivity growth. Besides the standard mechanism of selection and reallocation of resources (between- firm channel), the model also reproduces aggregate productivity gains related to improvements inside the firm (within-firm).

Further research should be oriented to analyze the specific pattern of the distribution of productivity levels at equilibrium and to compare it to firm level data. This can be made by the means of stochastic simulation. It seems clear for us that the link between trade and productivity asks for further research on stochastic dynamic issues.

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