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Trade, Firm Selection, and Innovation: the Competition Channel

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Trade, firm selection, and innovation: the competition channel*

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Abstract

The availability of rich firm-level data sets has recently led researchers to uncover an interesting set of empirical findings on the effects of trade liberalization. First, trade openness forces the least productive firms to exit the market. Secondly, it induces surviving firms to increase their innovation efforts. Thirdly, together with the selection and the innovation effect, trade liberalization seems to increase the degree of product market competition. This paper presents a theoretical model aimed at providing a coherent interpretation of these empirical findings. We introduce firm heterogeneity into an innovation-driven growth model. Incumbent firms operating in oligopolistic industries perform cost-reducing innovation in order to increase their future productivity. The oligopolistic structure implies that markups are endogenously determined by the number of firms competing in same product line. Trade liberalization leads to an higher number of firms, lower markups, and higher quantity produced by each firm. We show that this has standard *direct effect* on innovation thats does not depend on firm heterogeneity, and a new dynamic *selection effect* affecting productivity in the short and in the long-run: lower markups force less efficient firms out of the market and reallocates resources towards surviving firms, thereby their market shares and incentive to innovate. This selection effect of trade is decreasing in the level of product market competition and, as a consequence, trade liberalization has negligible effects on innovation in highly competitive economies. In a version of the model calibrated to match US aggregate and firm-level statistics we find that a 10 percent reduction in variable trade costs reduces the markups by 1.15 percent, reduces firms surviving probability by 10 percent and increases growth by about 13 percent; more than 90 percent of the total effect on growth can be attributed to the reallocation of market shares toward more productive firms (selection effect).

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1 Introduction

An interesting set of empirical regularities has recently emerged from a large numbers of studies using firm-level data. First, empirical evidence has established that large and persistent productivity differences exist among firms within the same industry (e.g. Bartelsman and Doms, 2000). The availability of micro data has also allowed researchers to assess the importance of firm heterogeneity in understanding international trade and its effect on productivity. A number of papers have shown that trade liberalization induces the least productive firms to exit the market, freeing market shares that are reallocated to surviving firms; this *selection effect* increases the aggregate productivity level (see e.g. Pavcnik, 2002, Topalova, 2004, and Tybout, 2003 for a survey).

A second line of research has focused on the role of firm heterogeneity in shaping the effects of trade liberalization on *innovation* activities affecting the growth rate of productivity. Bustos (2008) shows that a regional trade agreement, Mercosur, has selected highly productive firms into exporting and affected positively a broad set of measures of innovation (computers and software, technology transfers, R&D, and patents).[1] Bloom, Draca, and Van Reenen (2009) study the effect of Chinese import penetration on innovation in European countries. They find evidence of both the selection and the innovation effect of trade: on the one hand Chinese competition decreases employment and firm's chances of survival, and this effect is stronger for low-tech than for high-tech firms. On the other hand, surviving firms tend to innovate more (patenting and R&D) and upgrade their technology (IT intensity). Leeiva and Trefler (2008) find that tariff cuts mandated by the Canada-US Free Trade Agreement increase productivity heavily for lower productivity plants, while productivity gains for high productivity plants are negligible. They also show that plants experiencing higher productivity gains are those investing more strongly in innovation and technology upgrading.[2]

A third piece of evidence shows that trade liberalization has *pro-competitive* effects that can potentially lead to more selection and more innovation. Bugamelli, Fabiani, and Sette (2008) using Italian firm-level manufacturing data find that import competition from China has reduced prices and markups in the period 1990-2004. Griffith, Harrison, and Simpson (2008) have studied the effects of trade integration reforms carried out under the EU Single Market

[1] Focusing on innovation has the advantage of identifying one specific channel through which improvements in productivity take place. Other studies have instead estimated productivity as a residual in the production function, with the consequence that together with technological differences, residuals captures also other differences such as market power, factor market distortion, and change in the product mix. (see i.e. Foster, Haltowanger, and Syverson, 2008, Hsieh and Klenow, 2008, and Bernard, Redding, and Schott, 2008).

[2] Several papers have investigated the related but slighlty different question of whether the exporter status implies a higher investment in innovation or technology upgrading: this has been called the *learning by exporting* mechanism. The evidence is mixed: early papers, such as Clerides, Lach, and Tybout (1998) and Bernard and Jensen (1999) do not find any evidence in favor of this mechanism. Recent studies have instead found evidence that firms improve their productitivy subsequent to entry (e.g. Delgado, Farinas, and Ruano, 2002, De Loecker, 2006, Van Biesebroek, 2005, see Lopez, 2005, for a survey). The basic difference between these studies and those discussed in the main text is that the former focus on productivity and the latter on innovation. Once exception is Criuscolo, Haskel, and Slaugther (2008) which finds that expoters and multinational firms have higher productivity because they both innovate more and learn from foreign technologies. The other difference is that Bustos (2008), Bloom et al (2008), and Llleiva and Trefler (2008) focus on trade liberalization and not on export status.

Programme (SMP) and found that these reforms have increased product market competition (measured as average markups) and stimulated innovation (R&D expenditures). Chen, Imbs and Scott (2008) using micro data on EU manufacturing for the period 1989-99, estimate the Ottaviano and Melitz (2008) model and show that trade openness reduces average prices and markups, while raising productivity through firm selection.

This paper presents a theoretical model aimed at providing a coherent interpretation of these empirical findings. More precisely, we set up a model in which trade liberalization has pro-competitive effects (reduces markups) leading to firm selection and to more innovation. We introduce a dynamic industry model with heterogeneous firms into a model of growth with innovation by incumbents. There are two goods in the economy, an homogeneous good produced under constant returns, and a continuum of differentiated goods produced with a variable and a fixed quantity of the homogeneous good. Each variety of the differentiated good is produced by a given number of firms with the same technology, while productivity differs across varieties. Thus, as in Hopenhayn (1992) and Melitz (2003) firms are heterogeneous in their productivity. In addition to this now standard environment the model features a dynamic innovation activity performed in-house by firms and aimed at increasing productivity. The market structure for differentiated goods is oligopolistic, thus both the optimal quantity produced and the level of innovation result from the strategic interaction among firms. We assume in the economy there is a continuum of good each produced by with a different productivity and by an finite number of oligopolistic firms. The oligopolistic market structure and the innovation by incumbents feature are borrowed from static trade models with endogenous market structure (e.g. Neary, 2009 and 2010, Eckel and Neary, 2010) and from multi-country growth models with representative firms (e.g. Peretto, 2003 and Licandro and Navas 2008) respectively.

The open economy features two symmetric countries engaging in costly trade (iceberg type). In order to simplify the analysis in the benchmark version of the model, we assume that there are no entry costs into the export market, implying that all operating firms export, and we take the number of oligopolistic producer as given. The fixed production costs and the heterogeneous firms structure determine the cutoff productivity level below which firms cannot profitably produce. When the economies move from autarky to trade they experience an increase in product market competition because the number of firms producing each variety doubles. This yields a reduction in the markup and a decrease in the inefficiency of oligopolistic markets, ultimately leading to an expansion of the quantity produced by each firm. Moreover, a decline in the markup raises the productivity cutoff and forces the least productive firms out of the market. This selection effect reallocates resources from exiting firms to surviving firms, thus increasing the average size of operating firms. Since innovation is cost-reducing the trade-induced increase in the market size increases firms' incentive to innovate. Thus, trade-induced firm selection increases not only the 'level' of aggregate productivity (as in Melitz, 2003) but also aggregate innovation, thus affecting the 'growth rate' of productivity as well. We call this new mechanism the *selection effect* of competition. Secondly, the pro-competitive effect of trade has also a *direct effect* on innovation related to the increase in the quantity produced by more intense product market competition: since innovation is cost reducing, the marginal benefit from a reduction in costs is increasing with the quantity produced. Incremental trade liberalization (reduction in the iceberg trade cost) has similar effects. The direct effect can be obtained even in a model with representative firms, while the selection effect is the new channel that we highlight and it hinges on the presence of heterogeneous firms.

All these results are obtained assuming that the number of firms producing each good is exogenous and that there are no fixed export costs. In an extended version of the model we remove this assumptions and show that the main mechanisms behind our results are still at work in this more complex economy. Finally, we provide a quantitative evaluation of our results by calibrating the baseline model to match salient firm-level and aggregate statistics of the US economy. The model shows a sufficiently good fit of the data, and a reduction in trade costs has quantitatively relevant direct and selection effects on innovation. Precisely, a 10 percent reduction in trade costs increases the aggregate growth rate by about 11 percent, a big share of which (96 percent) comes from selection and the rest from the direct effect. Extensive sensitivity analysis show that this growth decomposition is fairly robust to changes in parameters value, with the selection effect systematically accounting for more than 90 percent of the overall growth effect of trade. This suggests that the selection channel, which represents the main innovation of our paper is quantitatively relevant.

This paper is related to the emerging literature studying the joint selection and innovation effect of trade liberalization. A first line of research introduces a one-step technological upgrading choice into an heterogeneous firm framework. Examples are Yeaple (2005), Costantini and Melitz (2007), Bustos (2007), Navas and Sala (2007), Vannoorenberge (2008). In all these papers innovation is a one-shot decision and, with exception of Costantini and Melitz, the model economy is static. Our paper is more closely related to a second stream of research that introduces innovation as a continuous process in dynamic models of trade and productivity growth. Baldwin and Robert-Nicoud (2008) and Gustaffson and Segerstrom (2008) explore the effects of trade liberalization on innovation and growth in models of expanding variety (Romer, 1990) with heterogeneous firms. They show that the effect of trade-induced firm selection on innovation and growth depends on the form of (international) knowledge spillovers characterizing the innovation technology. Atkeson and Burnstein (2007) set up a model of process and product innovation with firm heterogeneity and show that trade has positive effects on process innovation that can be offset by negative effects on product innovation.[3]

Although differing in the type of innovation or in the specific form of innovation technology they analyze, all these papers adopt a monopolistically competitive market structure.[4] The key

[3] Benedetti Fasil (2009) sets up a model featuring both product and process innovation and finds positive effects of trade liberalization on both types of innovation. Klette and Kortum (2004) and Mortensen and Lentz (2008) introduce a dynamic industry model with heterogeneous firms into a quality ladder growth model (Grossman and Helpman, 1991). They limit the analysis to the interaction between firm heterogeneity and creative destruction in closed economy, without exploring the effects of trade. Haruyama and Zhao (2008) explore the interaction between trade liberalization, selection and creative destruction in a quality ladder model of growth.

[4] One exeption is Van Long, Raff, and Stahler (2008) that features an oligopolistic market structure, but innovation is not a continuos process and the model is static.

distinguishing feature of our model is that we study the interactions between trade, firm heterogeneity and innovation in an dynamic oligopolistic environment. In this framework the market structure is endogenous and responds to changes in trade costs, thereby representing the ideal environment to analyze the effects of trade on product market competition (the third stylized fact discussed above). Melitz and Ottaviano (2008) show that under a particular form of preferences it is possible to obtain endogenous markups in the monopolistic competitive framework. In line with our result, they find that trade liberalization produces a pro-competitive effect (lower markups) and triggers the selection of the least productive firms out of the market.[5] Our model differs from that of Melitz and Ottaviano not only for the different source of endogenous markups but also because in their model there is no innovation activity aimed at improving productivity, therefore they cannot study the implications of firm heterogeneity and endogenous markups for innovation. Bernard, Jensen, Eaton, and Kortum (2003), set up a Ricardian model with Bertrand competition among firms and obtain markups responding endogenously to trade liberalization. We complement their analysis by introducing innovation and deriving endogenous markups from Cournot competition.

Summing up, to our knowledge the present paper is the first to provide a framework to interpret jointly the three stylized facts discussed above. The basic structure of the model is such that trade affects both firm selection and innovation through the *competition channel*, that is through its effect on the markup. The selection effect of trade operating through endogenous markups resulting from oligopolistic competition among firms is a novel contribution. Secondly, while the direct competition effect of trade on innovation is not new in the literature (see Peretto, 2003, and Licandro and Navas, 2007), the interaction between firm selection and innovation represents an original contribution of this paper.

2 The model

2.1 Economic environment

The economy is populated by a continuum of identical consumers of measure 1. Time is continuous and denoted by t, with initial time $t = 0$. The analysis is restricted to stationary equilibrium. Preferences of the representative consumer are

$$\int_0^\infty (\ln X_t + \beta \ln Y_t)\ \mathrm{e}^{-\rho t}\ \mathrm{d}t,$$

with discount factor $\rho > 0$. There are two types of goods: a homogeneous good, taken as the numeraire, and a differentiated good. Consumers are endowed with a unit flow of labor, which

[5] The presence of endogenous markups allows the selection effect to work through a channel different from that highlighted in Melitz (2003). In that paper, trade liberalization produces an increase in labor demand that bids up wages and forces low productivity firms to exit. In our paper, as in Melitz and Ottaviano (2008), the selection effect is produced by the reduction in markups brought about by trade liberalization. While there is evidence, as discussed above, that trade liberalization has increased product market competition, the trade-induced increase in average wages triggering firm selection in Melitz (2003) seems less in line with the data. For instance March CPS data show that both median and average US wages have stagnated in the last three decades, a period of progressive trade liberalization (see Acemoglu, 2002)

can be transformed into the homogeneous good at the rate one. It implies that at equilibrium wages are equal to unity. A fraction Y of the labor endowment is allocated to the production of the homogeneous good, which enters utility with weight β, $\beta > 0$.

The differentiated good X is produced by the mean of a continuum of varieties of endogenous mass M_t, $M_t \in [0, 1]$, according to

$$X_t = \left(\int_0^{M_t} x_{jt}^{\alpha} \, \mathrm{d}j \right)^{\frac{1}{\alpha}}, \tag{1}$$

where x_{jt} represents variety j, and $\frac{1}{1-\alpha}$ is the elasticity of substitution across varieties, with $\alpha \in (0, 1)$. Each variety in X is produced by n identical firms by transforming labor into this particular variety.[6] Firms face the same fixed production cost λ, $\lambda > 0$, but may have different productivities $\tilde{z}$. A firm with productivity $\tilde{z}_t$ has the following production technology (we omit index j)

$$\tilde{z}_t^{-\eta} q_t + \lambda = y_t, \tag{2}$$

where y represent inputs and q production. Variable costs are assumed to be decreasing on the firm's state of technology with $\eta > 0$.

Innovation activities are undertaken by incumbents according to the following technology

$$\dot{\tilde{z}}_t = A \hat{z}_t h_t, \tag{3}$$

where h represents labor allocated to R&D production and innovation efficiency is denoted by A, $A > 0$. An externality $\hat{z}$, which will be defined later, affects the productivity of the innovation technology. Let assume, for simplicity, that all firms producing the same good have the same initial productivity $\tilde{z}_0$, $\tilde{z}_0 > 0$.

Irrespective of their productivity, varieties exit the market at rate δ, $\delta > 0$. Exiting varieties are replaced by new varieties in order to the mass of operative varieties remain constant at steady state equilibrium.

2.2 Households

The representative household maximizes utility subject to its instantaneous budget constraint. The corresponding first order conditions are

$$Y = \beta E, \tag{4}$$

$$\frac{\dot{E}}{E} = r - \rho = 0, \tag{5}$$

$$p_{jt} = \frac{E}{X_t^{\alpha}} x_{jt}^{\alpha - 1}, \tag{6}$$

[6] Perfect substitution is implicitly assumed among the n goods belonging to a particular variety. For instance, in a more general framework, the degree of substitution across these n goods may be finite even if larger than the degree of substitution across varieties.

where r is the interest rate and p_{jt} is the price of good j. Total household expenditure on the composite good X is

$$E = \int_0^M p_{jt} x_{jt} \, \mathrm{d}j.$$

Because of log preferences, total spending in the homogeneous good is β times total spending in the differentiated good. Equation (5) is the standard Euler equation implying $r = \rho$ at the stationary equilibrium, and (6) is the inverse demand function for variety j, $j \in [0, 1]$. Variables Y, E, M are also constant at steady state (index t is then omitted to simplify notation).

2.3 Production and Innovation

Firms producing the same good behave non-cooperatively and maximize the present value of their net cash flow.

$$V_{is} = \int_s^\infty \pi_{it} R_t dt,$$

where R_t is the discount factor and $\pi_{it} = (p_{it} - \tilde{z}_{it}^{-\eta})q_{it} - h_{it} - \lambda$ is the profit. We solve this differential game focusing on Nash Equilibrium in open loop strategies. Let $a_i = (q_{it}, h_{it})$ for $t \geq s$ be a strategy for firm i. These strategies are time paths for quantity and R&D. In the open loop equilibrium we construct firms commit to time paths strategies for quantities and R&D, which induce time paths for productivity. At time s a vector of strategies $(a_1, ..., a_i, ..., a_n)$ is an equilibrium if

$$V_{is}(a_1, ..., a_i, ..., a_n) \geq V_i(a_1, ..., a_i', ..., a_n) \geq 0$$

where $(a_1, ..., a_i', ..., a_n)$ is the vector in which only firm i deviates from the equilibrium path of quantity and R&D. The first inequality states that firm i maximize its present value of its net cash flow, and the second condition requires this to be positive.[7]

The characterization of the open loop Nash equilibrium proceeds as follows: a firm producing a particular good solves at any time s the problem

$$V_s = \max_{(q_t, h_t)_{t=s}^\infty} \int_s^\infty \left[(p_t - \tilde{z}_t^{-\eta})q_t - h_t - \lambda \right] e^{-(\rho+\delta)(t-s)} \, dt, \qquad \text{st.} \tag{7}$$

[7] We choose the open loop equilibrium because it is easier to derive in closed form solution. The drawback of focusing on the open loop equilibriun is that it does not generally have the property of subgame perfection, as firms choose their optimal time-paths strategies at the initial time and stick to them forever. In closed loop and in feedback strategies, instead, firms do not pre-commit to any path and their strategies at any time depend on the whole past history. The Nash equilibrium in this case is strongly time-consistent and therefore sub-game perfect. Unfortunately, closed loop or feedback equilibria generally do not allow a closed form solution and often they do not allow a solution at all. The literature on differential games has uncovered classes of games in which the open loop equilibrium degenerates into a closed loop and therefore is subgame perfect (e.g. Reingaum, 1982 and Fershtman,1987). A sufficient condition for the open loop Nash equilibrium to be subgame perfect is that in the first order conditions for a firm the state variable of other firms do not appear. In our model this condition is violated because of the externality in the R&D technology leading to the FOC (9) below. Although, none of the basic results of this paper depend of this externality, removing it complicates the solution of the model substantially.

$$
\begin{aligned}
p_t &= \frac{E_t L}{X_t^{\alpha}}\, x_t^{\alpha-1} \\
x_t &= \hat{x}_t + q_t \\
\dot{\tilde{z}}_t &= A\, \hat{z}_t\, h_t \\
\tilde{z}_s &> 0,
\end{aligned}
$$

where $\delta > 0$ is the exogenous exit rate.

In a Cournot game a firm takes as given the path of its competitors' production $\hat{x}_t$, the path of its competitors' average productivity $\hat{z}_t$, as well as the path of the aggregates E_t and X_t. The first order conditions for the problem above are, where v_t is the costate variable,

$$
\tilde{z}_t^{-\eta} = \theta \underbrace{\frac{E_t L}{X_t^{\alpha}}\, x_t^{\alpha-1}}_{p_t}, \tag{8}
$$

$$
1 = v_t A \hat{z}_t, \tag{9}
$$

$$
\frac{-\eta \tilde{z}^{-\eta-1}}{v_t} q_t = \frac{-\dot{v}_t}{v_t} + \rho + \delta. \tag{10}
$$

From (8), firms charge a markup over marginal costs, with θ, $\theta \equiv (n-1+\alpha)/n$, being the inverse of the markup rate. This is the well known result in Cournot-type equilibrium that the markup depends on the perceived demand elasticity, which is a function of both the demand elasticity and the number of competitors.

Firms producing the same variety are assumed to face the same initial conditions, resulting on a symmetric equilibrium with $x_t = nq_t$. Substituting (8) on (1), as shown in the appendix, the demand for variable inputs becomes

$$
\tilde{z}_t^{-\eta} q_t = \theta e\, z/\bar{z} \tag{11}
$$

where e, $e = \frac{E}{nM}$, is expenditure per firm, z is a measure of detrended productivity, $ze^{gt} = \tilde{z}_t^{\hat{\eta}}$, with $\hat{\eta} = \eta \frac{\alpha}{1-\alpha}$, and g is the growth rate of productivity as defined below. Average detrended productivity is

$$
\bar{z} = \left(\frac{1}{M} \int_0^M z_j \, \mathrm{d}j \right)^{\frac{1}{\hat{\eta}}}.
$$

Notice that the amount of resources allocated to a firm in (11) is the product of average expenditures per firm, the inverse of the markup and the relative productivity of the variety the firm produces. When the environment becomes more competitive, θ increases, prices lower, produced quantities increase and firms demand more inputs.

The right hand side of equation (10) represents the return to R&D. After substituting v from (9), R&D returns become $A\eta(\hat{z}/\tilde{z})\tilde{z}^{-\eta}q$. Since R&D is addressed to reduce production costs, $z^{-\eta}q$, an increase in quantities makes innovation activities more profitable, inducing firms to innovative more.

Let now define the externality $\hat{z}$,

$$
\hat{z} = \frac{\bar{z}}{z}\, \tilde{z},
$$

where $\tilde{z}$ and z here are by definition productivity and detrended productivity of direct competitors, which at the symmetric equilibrium are equal to the productivity and the detrended productivity of the firm, respectively.[8] Under this assumption,

$$g \equiv \frac{\dot{\tilde{z}}}{\tilde{z}} = \eta A\theta e - \rho - \delta, \tag{12}$$

meaning that the growth rate of productivity is the same for all $\tilde{z}$. To obtain it, differentiate (9) and substitute the resulting $\dot{v}/v$ in (10), then substitute $v\hat{z}$ from (9) using the definition of $\hat{z}$.

The particular assumption adopted for the externality $\hat{z}$ allows for the growth rates to be equal across varieties, offsetting the positive effect that the relative productivity has on the productivity growth rate. Remind that more productive firms produce more and have then larger incentives to do R&D. The externality has two components. Firstly, there is a standard *spillover effect* coming from the productivity of direct competitors, as represented by $\tilde{z}$ in the definition of $\hat{z}$. Second, there is a *catching-up effect* represented by the ratio $\bar{z}/z$, introduced to offset the positive effect of the relative productivity on R&D.

In a stationary equilibrium, firms grow all at the same rate, irrespective of the variety they produce. Consequently, their productivities grow at the same rate as the average productivity, meaning that their demand for variable inputs, as described by (11), is constant at a balance growth path. More important, in a stationary equilibrium productivity grows at the same rate for all varieties meaning that firms remain always in their initial position in the productivity distribution.

2.4 Exit

From the previous section, it can be easily shown that the cash flow is a linear function of the relative productivity $z/\bar{z}$

$$\pi(z/\bar{z}) = (1-\theta)\, ez/\bar{z} - \underbrace{\left(\eta\theta e - \frac{\rho+\delta}{A}\right) z/\bar{z}}_{h} - \lambda. \tag{13}$$

Produced quantities and R&D effort depend both on the distance from average productivity $z/\bar{z}$. In the following, we assume η small enough to $1-(1+\eta)\theta > 0$, a sufficient condition for profits positively depend on both e and z.[9] Let us denote by z^* the stationary cutoff productivity below which varieties exit the market. At a stationary state, the cutoff productivity makes firm's profits, then firm's value, equal to zero, implying

$$e = \frac{\frac{\lambda}{z^*/\bar{z}} - \frac{\rho+\delta}{A}}{1-(1+\eta)\theta}. \tag{EC}$$

[8] Notice that the externality $\hat{z} = z^{1-\hat{\eta}} e^{gt} \bar{z}$, which makes the first order condition for control h, equation (9), depends on the state z of direct competitors at least $\hat{\eta} = 1$.

[9] From the definition of $\hat{z}$, in order to the Cellini-Lambertini condition for the open loop equilibrium collapse in the closed loop, $\hat{\eta}$ has to be unity. It can be easily shown that $\hat{\eta} = 1$ implies that $1-(1+\eta)\theta < 0$.

We refer to it as the exit condition.[10]

Let us assume there is a mass of unit measure of potential varieties, of which M, $M \in [0,1]$, are operative. Let also assume that at any t non operative varieties draw a productivity z from the initial productivity distribution $\digamma(z)$, which is assumed to be continuous in $(z_{\min}, \infty)$, $0 \leq z_{\min} < \infty$. Let us denote by $\mu(z)$ the stationary density distribution defined on the z domain. The endogenous exit process related to the cutoff point z^* implies $\mu(z) = 0$ for all $z < z^*$. Since the equilibrium productivity growth rates are the same irrespective of z, in a stationary environment, surviving firms remain always at their initial position in the distribution $\digamma$. Consequently, the equilibrium distribution is $\mu(z) = f(z)/(1 - \digamma(z^*))$, for $z \geq z^*$, where f is the density associated to the entry distribution $\digamma$.

We can now write $\bar{z}$ as a function of z^*

$$\bar{z}(z^*) = \frac{1}{1 - \digamma(z^*)} \int_{z^*}^{\infty} z f(z) \, \mathrm{d}z. \tag{14}$$

Since varieties exit at the rate δ, stationarity requires

$$(1 - M)\,(1 - \digamma(z^*)) = \delta M. \tag{15}$$

This condition says that the exit flow, δM, equals the entry flow defined by the number of entrants, $1 - M$, times the probability of surviving, $1 - \digamma(z^*)$. Consequently, the mass of operative varieties (OV) is a function of the cutoff detrended productivity z^*,

$$M(z^*) = \frac{1 - \digamma(z^*)}{1 + \delta - \digamma(z^*)}. \tag{OV}$$

It is easy to see that $M(.)$ is decreasing, going from $1/(1+\delta)$ to zero.

Note that the entry distribution $\digamma$ is assumed to depend on detrended productivity z. This assumption is crucial for the economy to be growing at a stationary equilibrium. Incumbent firms are involved in R&D activities making their productivity grow at the endogenous rate g. This makes the distribution of incumbent firms move permanently to the right. By defining the entry distribution as a function of detrended productivity z, we allow the productivity of entrants be growing in average at the same rate as the economy. This is a form of technological spillover or learning-by-doing going from incumbents to new entrants, sustaining growth generated by incumbents innovation. A similar assumption has been previously used by Luttmer (2007), Poschke (2009) and Gabler and Licandro (2007).

2.5 Stationary Equilibrium

The market clearing condition for the homogeneous good can be written as

$$n \int_0^M (y_j + h_j) \, \mathrm{d}j + Y = n \int_0^M \left(\tilde{z}_j^{-\eta} q_j + h_j + \lambda \right) \, \mathrm{d}j + \beta E = 1.$$

[10] Notice that problem (7) does not explicitly include positive cash flow as a restriction. By doing so and then imposing the exit condition (EC), we implicitly forbid firms with $z < z^*$ to invest less than (12). If they were allowed to, they will optimally invest in R&D up to the point in which the cash flow would be zero. In such a case, firms with initial productivity smaller than the cutoff value will be growing at a rate smaller than g, moving to the left of the distribution and eventually exiting. Such an extension would make the problem unnecessarily cumbersome without affecting the main results.

The total endowment of the homogeneous good is allocated to composite good production and innovation, as well as homogeneous good consumption. The first equality comes after substitution of y from (2), and Y from (4).

Let change the integration domain from sectors $j \in [0,1]$ to productivity $z \in [z^*, \infty]$ and use (3), (11) and (12) to rewrite the market clearing condition as

$$\int_{z^*}^{\infty} \left((1+\eta)\ \theta e\ z/\bar{z} - \frac{\delta+\rho}{A} z/\bar{z} + \lambda \right)\ \mu(z)\ dz + \beta e = \frac{1}{nM}.$$

Since $\int_{z^*}^{\infty} \mu(z)\, dz = \int_{z^*}^{\infty} z/\bar{z}\ \mu(z)\, dz = 1$, after integrating over all sectors we obtain

$$e = \frac{\frac{L}{nM(z^*)} + \frac{\rho+\delta}{A} - \lambda}{\beta + (1+\eta)\theta}. \tag{MC}$$

The other equilibrium condition is give by the exit condition

$$e = \frac{\frac{\lambda}{z^*/\bar{z}(z^*)} - \frac{\rho+\delta}{A}}{1-(1+\eta)\theta} \tag{EC}$$

The following assumption on the distribution F will be useful for the next.

Assumption 1 *The entry distribution verifies, for all z,*

$$\frac{\bar{z}(z) - z}{\bar{z}(z)} \leq \frac{1-F(z)}{zf(z)}. \tag{a}$$

and the following parameter restrictions hold:

$$\lambda \bar{z}_e / z_{\min} > \frac{\rho+\delta}{A} \tag{b}$$

$$1+\eta < \frac{\mathcal{A}}{\theta} \tag{c}$$

where

$$\mathcal{A} = \frac{\frac{1+\delta}{n} + \frac{\rho+\delta}{A}(1+\beta) - \lambda\left(1+\beta\frac{\bar{z}_e}{z_{\min}}\right)}{\frac{(1+\delta)L}{n} + \lambda\left(\frac{\bar{z}_e}{z_{\min}} - 1\right)} \tag{16}$$

$\bar{z}_e$ is the average productivity at entry. Assumption (a) makes $z^*/\bar{z}(z^*)$ increasing on z^*, thus the (EC) curve decreasing in z^*. A similar assumption is imposed by Melitz (2003). Assumption (b) makes the profit function (13) increasing in e. Assumption (c) guarantees that the (EC) curves cuts the (MC) curves from above.

Proposition 1 *Under Assumption 1, there exits a unique interior solution (e, z^*) of (MC) and (EC)*

Proof. Since $M(.)$ is decreasing on z^*, the (MC) locus is increasing starting at

$$\frac{\frac{(1+\delta)L}{n} + \frac{\rho+\delta}{A} - \lambda}{\beta + (1+\eta)\theta},$$

when $z^* = z_{min}$, and going to infinity when z^* goes to infinity. Under Assumption 1(a), the (EC) locus is decreasing, starting at

$$\frac{\lambda \frac{\bar{z}_e}{z_{\min}} - \frac{\rho+\delta}{A}}{1-(1+\eta)\theta},$$

for $z^* = z_{min}$. It goes to $[\lambda - (\rho+\delta)/A] \, / \, [1-(1+\eta)\theta]$ when z^* goes to ∞. Operating on the definition of $\mathcal{A}$, it can be proved that assumption (b) implies $\mathcal{A} < 1$, which from Assumption 1(c) implies $1 + \eta < 1/\theta$. Under this last condition, it can be proved that Assumption 1(c) is sufficient for the intercept of the (EC) locus be larger than the intercept of the (MC) locus, which completes the proof. ■

Comment on the Pareto case, where the (EC) locus is constant. Figure 1 provides a graphical representation of the equilibrium.

[FIGURE 1 ABOUT HERE]

Proposition 2 *An increase in θ raises the productivity cutoff z^*, reduces the number of operative varieties $M(z^*)$, has an ambiguous effect on the labor resources allocated to the homogeneous sector e and increases the growth rate $(dg/d\theta > 0)$.*

Proof. Figure 1 shows the effect of an increase in the degree of competition (reduction in the markup $1/\theta$) on the equilibrium values of z^* and e. An increase in θ shifts both the (EC) and the (MC) curves to the right, thereby increasing the equilibrium productivity cutoff z^*. Depending on the relative strengths of the shift of the two curves e can increase or decrease, but the average growth rate g always increases. Intuitively, from (12) we know that the effect of a change in θ on g is determined by its effect on θe. Multiplying the market clearing condition (MC) by θ we can obtain θe as a function of θ and $M(z^*)$, and since in equilibrium $M(z^*)$ is decreasing in θ, we can conclude that θe is increasing in θ. ■

Two mechanisms contributes to increasing growth, a direct effect and a selection effect of competition. Let describe first the *direct effect*. In a Cournot equilibrium, an increase in competition reduces markups and allows for an increase in produced quantities. The increase in quantities is feasible since the homogeneous good becomes relatively more expensive (i.e. the relative efficiency of the differentiate sector increases), consumers' demand moves away from it towards the composite good and resources are reallocated from the homogeneous to the composite sector. Since the payoff of cost-reducing innovation is increasing in the quantity produced, the higher static efficiency associated to lower markups brought about by competition affects positively innovation and growth. This mechanism does not depend on firm heterogeneity: it is easy to check that assuming away the dependence of M on z^* by setting $M = 1$, the equilibrium growth rate derived from (MC) and (EC) becomes independent of the cutoff z^*, but still increasing in θ. This direct effect of competition on growth can in fact be found in representative firm models of growth with endogenous market structure (see e.g. Peretto, 2003, and Licandro and Navas, 2007).

The *selection effect* is instead specifically related to the heterogeneous firms structure of the model. The trade-induced reduction in the markup raises the productivity threshold above which firms can profitably produce, the cutoff z^*, thus forcing the least productive firms to exit the market. As a consequence, market shares are reallocated from exiting firms to the higher productivity surviving firms, thereby increasing their market size and their incentive to innovate. Therefore this selection effect leads to higher aggregate productivity level, as in Melitz (2003) and higher innovation and productivity growth.[11]

3 Open economy

Consider a world economy populated by two symmetric countries with the same technologies, preferences, and endowments as described in the previous section. We assume that trade costs are of the iceberg type: $\tau > 1$ units of goods must be shipped abroad for each unit finally consumed. Costs τ can represent transportation costs or trade barriers created by policy. For simplicity in the baseline model we do not assume entry costs in the export market, thus all surviving firms sell both to the domestic and foreign markets.[12]

3.1 Equilibrium characterization

Since the two countries are perfectly symmetric, we can focus on one of them. Let q_t and $\check{q}_t$ be the quantities produced for the domestic and the foreign markets, respectively. The firm solves a problem similar to that in closed economy (see appendix). The first order conditions are:

$$
\begin{aligned}
\tilde{z}_t^{-\eta} &= \left((\alpha-1)\frac{q_t}{x_t}+1\right)p_t \\
\tau\tilde{z}_t^{-\eta} &= \left((\alpha-1)\frac{\check{q}_t}{x_t}+1\right)p_t \\
1 &= v_t A\hat{z}_t, \\
\frac{\eta\tilde{z}_t^{-\eta-1}}{v_t}\left(q_t+\tau\check{q}_t\right) &= \frac{-\dot{v}_t}{v_t}+\rho+\delta.
\end{aligned}
$$

Notice that x represents here the total output offered in the domestic market by both local and foreign firms. By symmetry it is equal to the total supply in the foreign market. Firms face different marginal costs and set different markups for the domestic and foreign markets. In the appendix, we show that the first two conditions above yield the following demand for variable inputs

$$\tilde{z}_t^{-\eta}\left(q_t+\tau\check{q}_t\right)=\theta_\tau e\, z/\bar{z} \tag{17}$$

where $\tilde{z}$ and $\bar{z}$ are defined as in autarky and

$$\theta_\tau=\frac{2n-1+\alpha}{n\left(1+\tau\right)^2\left(1-\alpha\right)}\left[\tau^2\left(1-n-\alpha\right)+n\left(2\tau-1\right)+\left(1-\alpha\right)\right] \tag{18}$$

[11] Notice that in this model the direct competition effect of trade liberalization on innovation does not hold if we eliminate the homogeneous good, because no reallocation of market shares would be possible. While the selection effect produced by the presence of firm heterogeneity would still hold because reallocation takes place within varieties of the differentiated product.

[12] Our main goal is to explain the interaction between trade, selection and innovation, and for this purpose having firms partitioned by their export status is not necessary.

is the inverse of the average markup in the open economy. Notice that θ_τ is decreasing on variable trade costs τ, with θ_τ reaching its maximum value $\theta_{\tau=1} \equiv (2n-1+\alpha)/2n$ when $\tau = 1$, the polar case of no iceberg trade costs; the autarky value $\theta = (n-1+\alpha)/n$ is reached when $\tau = n/(n+\alpha-1)$, the alternative polar case where trade costs are prohibitive and economies do not have incentives to trade.

Using the last two first order conditions above and proceeding as in the closed economy, we find that the growth rate of productivity

$$\frac{\dot{\tilde{z}}}{\tilde{z}} = \eta A \theta_\tau e - \rho - \delta \tag{19}$$

takes the same functional form as in the closed economy. Consequently, opening to trade only affects equilibrium growth rates through changes in the markup.

As in the closed economy case, we focus on the characterization of the steady-state equilibrium. The productivity cutoff is determined solving the following equation

$$\pi(z^*/\bar{z}) = (1-\theta_\tau)\, e\, z^*/\bar{z} - \underbrace{\left(\eta\theta_\tau e - \frac{\rho+\delta}{A}\right) z^*/\bar{z}}_{h} - \lambda = 0.$$

which, as shown in the appendix, yields

$$e = \frac{\frac{\lambda}{z^*/\bar{z}(z^*)} - \frac{\rho+\delta}{A}}{1-(1+\eta)\,\theta_\tau}. \tag{EC$^{\mathrm{T}}$}$$

Since firms compensate their losses in local market shares by their new shares in the foreign market, profits are only affected by the change in the markup. Consequently, the exit condition has the same functional form as in (EC) except for the θ_τ.

The market clearing condition, proceeding as in the closed economy, becomes

$$e = \frac{\frac{L}{nM(z^*)} + \frac{\rho+\delta}{A} - \lambda}{\beta + (1+\eta)\,\theta_\tau}. \tag{MC$^{\mathrm{T}}$}$$

which is equal in all aspects to (MC) except for the markup, with θ_τ instead of θ. Equations (EC$^{\mathrm{T}}$) and (MC$^{\mathrm{T}}$) yield the equilibrium (e, z^*) in the open economy. The equilibrium growth is defined by (19).

Proposition 3 *Under Assumption 1 and for* $\tau \leq \bar{\tau} = \frac{n}{n+\alpha-1}$ *there exists a unique interior solution* $(e, \tilde{z}^*)$ *of (MC^T) and (EC^T).*

Proof. At $\bar{\tau} = n/(n+\alpha-1)$ the markups under trade and autarky are equal, $\theta_\tau = \theta$, and the prohibitive level of trade costs is reached. Thus, for $\tau \geq \bar{\tau}$ firms do not have incentives to export, and trade does not take place. For $\tau < \bar{\tau}$ the proof of the existence is similar to that in the closed economy, and we omit it for brevity. ■

3.2 Trade liberalization

Since (MC^{T}) and (EC^{T}) are formally equivalent to (MC) and (EC) apart from θ, we can apply proposition 2 to study the effects of trade liberalization. Trade openness does not affect market shares because the increase in the number of firms in the domestic market is offset by the access to the export market. The economy with costly trade is characterized by a level of product market competition higher than in autarky, $\theta_\tau > \theta$. A larger number of firms in the domestic market, raises product market competition, thus lowering the markup rate. From the definition of θ and the equilibrium value of θ_τ we obtain

$$\theta_\tau - \theta = \frac{\tau (1-\alpha)^2 - n(\tau-1)^2 (n+\alpha-1)}{n(1+\tau)^2 (1-\alpha)}. \tag{teta diff}$$

For $\tau < \bar{\tau}$ the markup under trade is lower, that is $\theta_\tau - \theta > 0$, and by differentiating the expression above it is easy to see that the distance between θ_τ and θ is decreasing in τ (see appendix). Hence, trade liberalization increases product market competition. When trade is completely free, $\tau = 1$, product market competition reaches its maximum level, $\theta_{\tau=1} \equiv (2n-1+\alpha)/2n$. Notice that $\theta_{\tau=1}$ has the same functional form as the inverse of the markup in autarky but with the number of firms doubled. Once established that trade reduces markups, from (EC^{T}) we can see that trade liberalization increases the productivity threshold $\tilde{z}^*$, thus forcing some firms out of the market. These results can be summarized in the following proposition.

Proposition 4 *Trade liberalization, both in the form of opening an economy in autarky to trade and incremental trade liberalization, produces a more competitive market with lower markups, higher productivity cutoff z^*, lower number of operative varieties $M(z^*)$, and a higher growth rate g.*

Similarly to the competition effect on growth in closed economy, the trade-induced competition effect in open economy can be decomposed in two components: a direct component that can be obtained also in an economy with representative firms, and selection component that depends on the presence of heterogeneous firms. The *direct effect* is related to the reduction of oligopolistic inefficiency in the differentiated goods sector produced by trade liberalization, which raises the quantity produced by each firm. As innovation is cost reducing, the marginal benefit from a reduction in costs is increasing with the quantity produced, therefore lower markups trigger higher investment in innovation. The *selection effect* works through exiting of less productive firms produced by the trade-induced reduction in the markup: the market shares of exiting firms are reallocated towards surviving firms, thus increasing their quantity produced and their incentive to innovate. Thus, the selection effect of trade liberalization not only raises the level of productivity as in Melitz (2003) but also its growth rate.

Notice that trade liberalization has an anti-variety effect, it reduces the number of produced and consumed varieties M. This is a consequence of the assumption that there is a perfect overlap between the varieties produced by the two economies. The standard pro-variety effect of trade (e.g. Krugman 1980) could be generated by introducing asymmetry in the set of goods produced by the two countries. However, a model with asymmetric countries would complicate the algebra substantially, without adding much to the main mechanism we want to highlight (the effect of trade-induced selection on innovation and growth).

Proposition 5 *The growth effect of moving from autarky to costly or free trade is decreasing in n. While the growth effect of incremental trade liberalization is increasing in n.*

As it can be easily seen from (teta diff) the distance between the trade and the closed economy markup is decreasing in n. This implies that opening up to trade is more beneficial, in terms of productivity gains, for less competitive countries. Differentiating the absolute value of (18) with respect to n we obtain

$$\frac{\partial\left(\left|\partial\theta^T/\partial\tau\right|\right)}{\partial n}=\frac{2(\tau-1)\left(2n-1+\alpha\right)}{n^2\left(1+\tau\right)^3}>0.$$

Hence, once a country has opened to trade, further reductions in trade costs produce larger productivity gains the lower the oligopolistic inefficiency in the domestic market. That is, more competitive domestic markets allow higher growth effects of incremental trade liberalization.

4 Discussion

The channel through which firms' selection operates in this paper is different from the one in Melitz (2003). In Melitz, selection happens through the effects of trade on the labor market: trade liberalization increases labor demand, this bids up wages and the cost of production, thus forcing the least productive firms to exit the market. In our framework, selection works through the effect of trade on product market competition: the reduction in the markup rate brought about by trade reduces profits and pushes the less productive firms out of the market. In Melitz this channel cannot operate because, under the assumption of monopolistic competition and CES preferences, a larger number of competitors does not affect the elasticity of demand. In our oligopolistic model the market structure is endogenous and trade affects the distribution of surviving firms by raising competition in the product market. The two papers are complementary in that the wage channel of firms selection can be easily introduced in our model by removing the homogeneous good and work with an economy endowed with labor.

Another interesting difference with Melitz is that in his model firm heterogeneity does not play any role when the economy moves from autarky to free trade (zero trade costs): the effects of trade are exactly those found in the representative version of the model (i.e. Krugman, 1980). Firm selection takes place only with incremental trade liberalization (positive trade costs). In our model instead, the oligopolistic structure implies that firm selection takes place under radical trade liberalization as well. This happens because opening up to trade reduces markups even in the extreme case of free trade: the markup increases from its autarky level $1/\theta\equiv n/\left(n-1+\alpha\right)$ to the free trade level $1/\theta_\tau\equiv 2n/\left(2n-1+\alpha\right)$.

Finally, Melitz and Ottaviano (2008) features a selection effect of trade through the competition channel similar to ours, but the source of the endogenous market structure is different: they endogenize markups in a monopolistic competitive environment assuming an a non-homothetic structure of preferences that makes markups dependent on the number of firms (varieties). While we operate under a general preference structure and markups are pinned down by the strategic interaction between oligopolistic producers.

5 Extension: fixed export costs and endogenous n

We now explore the implications of removing two basic assumptions from the baseline model: we allow costly entry in the production of each good, therefore endogenizing the number of firms per good n, and introduce a sunk cost of exporting which leads to an equilibrium in which only the most productive firms export.

Following Melitz (2003), let us assume exporting firms face not only a variable trade cost but also a fixed export cost λ_x.[13] Since the focus is on the effect of trade on the productivity threshold, we keep matters simple by removing R&D investment. Under this assumption, the equilibrium distribution is $\mu(z) = f(z)/(1 - F(z^*))$, as in the benchmark model. Otherwise, the equilibrium distribution would be endogenous and the problem much harder to solve.

In a model of two symmetric countries, the fundamental difference between exporters and non exporters is that the former face tougher competition. In fact, markets for non exporters behave as in autarky but markets for exporters behave as under costly trade. The only difference between them is the markup they face, $1/\theta$ for non exporters and $1/\theta_\tau$ for exporters, with θ and θ_τ as defined above. Under these assumptions, the exit condition becomes

$$(1-\theta)e = \frac{\lambda}{z^*}\left(\frac{1}{\bar{p}\theta}\right)^{\frac{\alpha}{1-\alpha}}, \tag{EC2}$$

where the $\bar{p}$ is

$$\bar{p} = \left(\theta^{\frac{\alpha}{1-\alpha}}\int_{z^*}^{z_x^*} z\mu(z)dz + \theta_\tau^{\frac{\alpha}{1-\alpha}}\int_{z_x^*}^{\infty} z\mu(z)dz\right)^{\frac{\alpha-1}{\alpha}},$$

and the productivity adjusted quantities for non exporters $\tilde{z}^{-\eta}q = e\theta^{\frac{1}{1-\alpha}}\ z\bar{p}^{\frac{\alpha}{1-\alpha}}$ and exporters $\tilde{z}^{-\eta}q_x = e\theta_\tau^{\frac{1}{1-\alpha}}\ z\bar{p}^{\frac{\alpha}{1-\alpha}}$ are derived in the appendix.[14] There is a similar, new condition for firms participating in international trade

$$(1-\theta_\tau)e = \frac{\lambda+\lambda_x}{z_x^*}\left(\frac{1}{\bar{p}\theta_\tau}\right)^{\frac{\alpha}{1-\alpha}}, \tag{XC}$$

where λ_x represents the fixed export cost and z_x^* the cutoff productivity for exporters. The difference between (EC2) and (XC) is double. Firstly, exporters pay both production fixed costs

[13] As in Melitz, this is equivalent to a sunk cost for entering the export market: since productivity is known to the firm when they decide whether to export or not, firms are indifferent on whether to pay a sunk export cost f_{ex} or its annualized value $\lambda_x \equiv f_{ex}/(\rho+\delta)$. Sunk export costs can be costs of setting distribution channels abroad, learning about foreign regulatory system, advertising etc.

[14] Notice that $\bar{p}$ is a geometric mean of varieties' prices. Notice that when $\theta_\tau = \theta$, trade is too costly and the economy remains in autarky with $\bar{p} = \tilde{z}^{\frac{\alpha-1}{\alpha}}/\theta$, where the z term represents the marginal cost of the average firm, as in the benchmark model.

and export fixed costs. Second, the markup charged by exporters is smaller, since markets facing international competition are more competitive.

Notice that in our framework, highly productive firms facing international competition may make smaller profits than less productive local firms facing no international competition. All varieties are here potentially tradable, but some are not traded because of the fixed cost of export. Firms producing the non traded varieties are protected from international competition by the export fixed cost and benefit from larger markups. In this sense, this model gives a rational to the fact that markets for traded goods are more competitive. By combining (EC) and (XC), we get a linear relation between z^* and z_x^*

$$\frac{z_x^*}{z^*} = \frac{1-\theta}{1-\theta_\tau}\left(\frac{\theta}{\theta_\tau}\right)^{\frac{\alpha}{1-\alpha}}\frac{\lambda+\lambda_x}{\lambda}. \tag{20}$$

Notice that the sign of $d(z_x^*/z^*)/d\theta_\tau$ is strictly positive, since it is equal to the sign of $\theta_\tau - \alpha$, and $\theta_\tau - \alpha > \theta - \alpha > 0$. On top of that, it is also easy to see that $z_x^* > z^*$ for any τ, since this is clearly true when $\theta_\tau = \theta$ and then, given that $d(z_x^*/z^*)/d\theta_\tau$ is positive, it has to be true for any other $\theta_\tau > \theta$ as well. Hence, no parameter restriction is needed to obtain the exporters non-exporters partition found in the data.[15]

So far we have assumed that the number n of firms producing a particular variety is exogenous. Here we extend the model to allow n to be pinned down by an entry condition. Firms entering the economy are assumed to pay a fixed entry cost $\phi > 0$ before they observe the productivity z of the good they will produce. Since profits are linear in productivity, free entry implies that the expected value of the firm must be equal to the entry cost

$$(1-F(z^*))\,\frac{\bar{\pi}}{(\rho+\delta)} = \phi,$$

where the average profit is given by

$$\bar{\pi} = \int_{z^*}^{z_x^*}\left[(1-\theta)e\theta^{\frac{\alpha}{1-\alpha}}\, z\bar{p}^{\frac{\alpha}{1-\alpha}} - \lambda\right]\mu(z)dz + \int_{z_x^*}^{\infty}\left[(1-\theta_\tau)e\theta_\tau^{\frac{\alpha}{1-\alpha}}\, z\bar{p}^{\frac{\alpha}{1-\alpha}} - \lambda - \lambda_x\right]\mu(z)dz \tag{21}$$

which yields the following expression for the free entry condition

$$(1-\bar{\theta})e = \lambda + \left(\frac{1-F(z_x^*)}{1-F(z^*)}\right)\lambda_x + \left(\frac{\rho+\delta}{1-F(z^*)}\right)\phi, \tag{FE}$$

where

$$\bar{\theta} = \theta\left(\bar{p}\theta\right)^{\frac{\alpha}{1-\alpha}}\int_{z^*}^{z_x^*} z\mu(z)dz + \theta_x\left(\bar{p}\theta_x\right)^{\frac{\alpha}{1-\alpha}}\int_{z_x^*}^{\infty} z\mu(z)dz,$$

is the average markup weighted by the varieties' contribution to the average price.

Finally, the market clearing condition has to take into account that some firms are exporters and some are non exporters:

$$\int_{z^*}^{z_x^*}\left[e\theta^{\frac{1}{1-\alpha}}\, z\bar{p}^{\frac{\alpha}{1-\alpha}} + \lambda\right]\mu(z)dz + \int_{z_x^*}^{\infty}\left[e\theta_\tau^{\frac{1}{1-\alpha}}\, z\bar{p}^{\frac{\alpha}{1-\alpha}} + \lambda + \lambda_x\right]\mu(z)dz + \beta e + \frac{1-M(z^*)}{M(z^*)}\phi = \frac{L}{nM(z^*)}$$

[15] There is robust evidence that more productive firms self-select into the export market. See for instance, Bernard and Jensen (1999) , Clerides, Lach, and Tybout (1998), and Aw, Chung, and Roberts (2000).

where $(1 - M(z^*))\,\phi/M(z^*)$ is the amount of resources devoted to entry. Using (15) and the definition of $\bar{\theta}$ the market clearing condition can be written as

$$(\beta + \bar{\theta})e = \frac{1}{nM(z^*)} - \left[\lambda + \left(\frac{1 - F(z_x^*)}{1 - F(z^*)}\right)\lambda_x + \frac{\delta}{1 - F(z^*)}\phi\right]. \tag{MC}$$

A stationary equilibrium for this economy is a vector $\{z^*, z_x^*, e, n\}$ solving the system (EC2)-(XC)-(FE)-(MC). Since the equilibrium system is fairly complex, we explore its properties numerically in the quantitative section below.

6 Quantitative analysis

In this section we explore the quantitative relevance of our mechanism, first using the baseline model, then the extension with endogenous n and fixed export costs. We calibrate the model's steady state to match salient aggregate and firm level statistics of the US economy, then perform a counterfactual exercise: we study the effects of a 10 percent reduction in the trade costs τ on the innovation rate. Precisely, we quantitatively evaluate the effect of trade liberalization on innovation due to the *direct effect,* for which firm heterogeneity doesn't matter, and the *selection effect,* which pushes growth through a reallocation of market shares toward more productive (more innovative) firms. Although the general analytical results presented above do not require assuming any particular productivity distribution, in order to perform our quantitative exercise we assume that the stationary distribution is Pareto with shape parameter κ, and scale $z_{\min}$. This is consistent with evidence on firm size distribution (e.g. Axtell, 2001, and Luttmer, 2007)

6.1 Baseline calibration

In the baseline model we have to calibrate 12 parameters to calibrate $\alpha, \tau, \delta, \beta, \lambda, n, L, \rho, \eta, A, \kappa, z_{\min}$. The discount factor ρ is equal to the interest rate in steady state, thus we calibrate it to 0.05 following in the business cycle literature. Anderson and Wincoop (2004) summarize the tariff and non tariff barriers using TRAINS (UNCTAD) data: for industrialized countries tariffs are on average 5% and non tariff barriers are on average 8%. We take the sum of these two costs and set $\tau = 1.13$. We set $1/\theta_\tau = 1.13$ to match a 13 percent markup which is in the range of estimates in Basu (1994). We use these values of τ and θ and choose $n = 6$ such that equation (18) yields $\alpha = 0.309$ and therefore an elasticity of substitution across varieties of 1.44 in the range of existing macroeconomic estimates obtained in the international business-cycle literature (e.g. Heatcote and Perri, 2004, and Ruhl, 2008, Imbs and Mejean, 2009). We set $\delta = 0.09$ to match the average enterprise death rate in manufacturing in the period 1998-2004 of 9 percent obtained using Census 2004 data.[16] We set the share of the homogeneous good $\beta = 0.34$ following Rauch (1999) classification of differentiated goods: the share of differentiated goods in the economy is found to be between 64.6 and 67.1 according to the aggregation scheme chosen, we choose

[16] For each year the death rates are computed follows: taking year 2000 as an example, the death rate is the ratio of the deaths of firms between March 2000 and March 2001 to the total number of firms in March 2000. Data can be downloaded at http://www.sba.gov/advo/research/data.html#ne, file data_uspdf.xls.

a value in this interval ($1-\beta = 0.66$). We normalize the minimum value of the productivity distribution $z_{\min}$ to 0.1, we will show that this normalization does not affect our quantitative results. Table 1 summarizes the calibration.

[Table 1 about here]

The remaining four parameters $(A, \eta, \lambda, \kappa)$ are calibrated internally in order to match some steady-state moments produced by the model to key firm-level statistics: similarly to many calibrated models of firm dynamics we target the US economy, for which many firm level moments are available (see i.e. BEJK, 2003, Luttmer, 2007, Alessandria-Choi, 2007). We use four targets, the first two are the average growth rate of productivity and the R&D ratio of GDP. We use data from Corrado, Hulten and Sichel (2009) where US national account data have been revised to introduce investment in intangible capital, including R&D. Moreover, since there is no tangible capital in the model, all statistics used in the calibration must be adapted to the model economy. Precisely, the growth rate of labor productivity and the R&D ratio to GDP, are obtained by subtracting investment in tangible capital from total income in the data. After this adjustment, Corrado et al. data report an average growth of labor productivity of 1.9% a year in the period 1973-2003. Since in the model all investment is in R&D, the targeted statistics for the R&D ratio to GDP is the investment in intangible capital share of total income; after subtracting tangible capital this leads to an average of 13.5% over the period 1973-2003. As shown in the appendix, where a more detailed description of the calibration strategy can be found, these two statistics are useful for calibrating the technological parameters A and η.

Two firm-level statistics are used to calibrate the fixed operating costs λ and the Pareto shape coefficient κ: an average firm size of 21.8 workers found in Axtell (2001) for US firms in 1997 using Census data and considering only firms with at least one employee.[17] Secondly, Bernard, Jensen, Eaton, and Kortum (2003) using 1992 Census data find that a standard deviation of the productivity of US manufacturing firms of 0.75; we use this statistics to calibrate parameter κ. Solving the systems of equation matching the data with the corresponding moments in the model we find: $A = 12.47$, $\eta = 0.0119$, $\lambda = 1.507$, and $\kappa = 2.621$.

6.2 Counterfactuals

In this exercise we focus on quantifying the growth effect of a 10 percent reduction in the trade cost τ, breaking it down into the two growth channels of trade liberalization that we have in the model: the direct competition effect and the selection effect.

In order to decompose the total growth effect of trade liberalization we differentiate the equation (19) as follows:

$$g_\tau = \frac{dg}{d\tau} = \underbrace{\frac{dg}{d\theta_\tau}\frac{d\theta_\tau}{d\tau} + \frac{dg}{de(\bar{z}^*)}\frac{de(\bar{z}^*)}{d\tau}}_{\texttt{Direct effect}} + \underbrace{\frac{dg}{de(z^*)}\frac{de(z^*)}{dz^*}\frac{dz^*}{d\tau}}_{\texttt{Selection effect}}$$

[17] If we set the price of the homogeneous good to be the numeraire, using labor instead of units of the homogeneous good to produce the differentiated good does not change anything in the model and in the results.

where the direct effect can be obtained keeping fixed the productivity threshold z^*, therefore ignoring the cutoff condition and using the market clearing condition (MC^{T}) to obtain the effect of τ on expenditure e. The resulting direct effect g_τ^d is

$$g_\tau^d = \frac{\partial g}{\partial \tau}|_{z^*=\bar{z}^*} = \frac{\beta(1-\beta)\eta A e}{\beta + (1+\eta)\theta_\tau}\frac{d\theta_\tau}{d\tau}. \tag{22}$$

where $d\theta_\tau/d\tau$ is derived in the appendix. The selection effect is thus obtained as a residual $|g_\tau^*| = |g_\tau| - |g_\tau^d|$, where we take the absolute values because trade liberalization implies a reduction in τ.

Table 2 shows the effects of a 10 percent reduction in trade cost, from 13 percent to 11.7 percent, that implies a reduction of τ from its benchmark value of 1.13 to 1.117.

[Table 2 about here]

A 10 percent reduction in the trade cost produces a 1.15 percent reduction in the markup. Both the productivity cutoff and innovation are fairly sensitive to changes in the markup. In fact the productivity cutoff z^* rises by 4.21 percent, implying a reduction of the survival probability of entering firms, $1 - F(z^*)$, by 10.26 percent. The growth rate of aggregate productivity increases by 12.98 percent from 0.019 to 0.0214. Using (22) we find that only about 4 percent of the total increase in growth can be attributed to the direct effect, while the rest is produced by the selection effect. This suggests that the main mechanism highlighted in the paper, the reallocation of market shares from exiting to surviving firms, is quantitatively relevant. In table 2 we also show how doubling the benchmark value of parameters affects the results. As we can see, both the overall growth effect and the growth decomposition are very robust to parameters changes: the overall growth effect ranges between 0.129 and 0.233, and about 92 to 97 percent of it can be attributed to selection.[18]

In table 3 below we compare our results with the findings of a representative sample of empirical and quantitative works targeting similar questions. The scope of this comparison is twofold: first it shows that existing empirical analysis have only studied some but not all the testable implications of our model. Secondly, it shows that the quantitative predictions of our stylized model are fairly close to the existing empirical evidence.

[Table 3 about here]

Corcos, Del Gatto, Ottaviano and Mion (2007) estimate a version of the Melitz and Ottaviano (2008) model using firm level European data and find that a 5 percent reduction in trade costs reduces markups by 1.97 percent. Chen, Imbs and Schott (2008) estimating the Melitz and Ottaviano (2008) model using European manufacturing firm-level data find that a 10 percent increase in the import to production ratio lowers the average markup by 1 percent. The elasticity

[18] We also perfomed the opposite exercise of halving the benchmark parameters obtaining similar results which we do not report for brevity.

of the markup to trade costs in our benchmark model is in the range of these two results. Similarly, our findings are in line with some recent estimates of the trade-induced innovation and selection effects: Bloom, Draca, and Van Reenen (2009) for instance, find that a 10 percent increase in Chinese imports is associated with a 1.2 reduction in the probability of firm survival, a 21.4 percent increase in R&D.[19] They also find that the selection effect ("between" component) and of the direct effect (obtained controlling for labor reallocation) contribute equally to the increase in innovation produced by trading with China. Additional reduced form evidence is provided by Bustos (2010): using Argentinean firm-level data she finds that a 24 percent reduction in Brazil's tariff in the context of the MERCOSUR increased technology spending by Argentinean firms by an average 24 percent.[20] Finally, more methodologically closer to our quantitative exercise, Aw, Roberts, and Xu (2010) using Taiwanese data estimate a dynamic structural model of firm's decision to invest in R&D and to participate in the export market, with both activities affecting the dynamics of productivity. Their counterfactual exercise shows that a 5 percent reduction in the average tariff leads to a 5.3 percent increase in productivity in the long run (after 15 years).

Summarizing, table 3 provides us two insights: first, it shows that several studies using different data and methodologies seem to suggest that the elasticity of the markup to a reduction in trade costs is the interval between 0.1 and 0.4, and the elasticity of the investment in innovation to a reduction in trade costs roughly falls in the interval between 1 and 2. Secondly, it shows that none of the existing empirical works study the joint effect of trade on prices, firm survival, and innovation: our dynamic general equilibrium model provides a specific mechanism linking trade-induced competition, firm selection, and innovation, and allows us to pin down the role of firm heterogeneity in shaping the effects of trade on productivity growth (growth decomposition). Hence, the paper lays down a new set of testable implications providing a theoretical guideline for future empirical work.

6.3 Extensions

Next we solve the model with exporters and non exporters and endogenous n. In this second exercise we use the calibrated parameters to explore the qualitative properties of the extended model, that is we want to see how the number of firms n, the markups θ and θ_τ, and the two productivity cutoffs z^* and z_x^* are effected by trade liberalization. Since the focus here is not mainly quantitative we do not recalibrate all parameters but take those used in the benchmark model and calibrate the two new parameters as follows: the fixed cost of exporting λ_x is set equal to 4.5 in order to match a productivity advantage of exporters of 33 percent as found by Bernard et al. (2003) in Census 1992 US data. The sunk entry cost ϕ is set to 0.00309 to generate an equilibrium $n = 6$, the value used in the benchmark calibration, and consequently a markup for exporting firm of 13 percent as in the benchmark model. We then perform the same

[19] See Bloom et al (2009) table 2.

[20] Technology spending includes several innovation activities such as R&D, computers, softwares, patents, and technology transfer. Notice that in our model the innovation technology (3) and the growth equation (19) implies that changes in the innovation spending h maps one to one to changes in the growth rate of productivity g.

counterfactual exercise of reducing the trade cost by 10 percent. Figure 2 shows the results.

[Figure 2 about here]

There are three main results: first trade liberalization has a positive effect on n and a negative effect on the total number of firms nM. Second, both domestic and foreign markups are reduced, thus trade liberalization increases competition for both exporters and non-exporters. Thirdly, tougher competition makes both producing for the domestic market and exporting more difficult, thus increasing both the domestic and the exporting cutoff. Although we have simplified the model abstracting from innovation and growth, this simple comparative statics suggests that the economic mechanism behind the direct and selection effect of trade liberalization on innovation are still operative and are even stronger in the extended framework. The reallocation of market shares from exiting to surviving firms is now accompanied by an additional reallocation from firms exiting the export market to surviving exporters. Secondly, the reallocation of market shares from the homogeneous good sector to all firms producing differentiated goods is still active and is reinforced by the stronger increase in competition brought about by the increase in the number of firms n.

The key intuitions behind these results is that, as in the benchmark model, the reduction in trade costs reduces the markup of exporters, forcing the less productive among them to exit the market and the productivity cutoff z_x^* to increase. The benefit for firms to enter the market depends on the average profit which, as we can see in (21), is an average of domestic and export profits. From the baseline model we know that $\theta < \theta_\tau$, therefore the profits of exporters are always lower than those of non exporters. Since from (20) we know that the sign of $d(z_x^*/z^*)/d\theta_\tau$ is positive, a reduction in τ by increasing θ_τ increases the average profits for entering firms $\bar{\pi}$ in (21) and increases entry ultimately leading to a higher equilibrium number of firms. Moreover, trade-induced increase in competition produces a reallocation of resources from the homogeneous good to all varieties (exporters and non-exporters) in the differentiated good. This has an additional positive effect on the average profits and induces more entry. A larger n then reduces the domestic markup $1/\theta$, raises the domestic cutoff z^*, thus forcing the least productive domestic firms to exit. Finally, a higher n also strengthens the reduction in the export markup produced by trade liberalization, thus further increasing the export cutoff z_x^*.

The assumption that the two countries are perfectly symmetric, thus producing exactly the same varieties, is key for interpreting these results. A reduction in trade costs makes exporting more profitable and domestic firm intensify their presence in the foreign market and viceversa. This makes the export markets more competitive, reduces the export markups and induces the marginal exporters to exit the export market. Notice that although the exporting market is more competitive, there are more exporters per variety n/M and each exporter trades more. In fact, in figure 2 we can see that the total number of firms producing each good n and the average sales of exporters increase. These two predictions are in line with the empirical evidence on US firms.[21] Interestingly, although trade liberalization increases the level of competition

[21] Bernard, Jensen and Schott (2006) find that a reduction in trade costs increases the volume of export.

and reduces markups there is an indirect 'market-size' effect that increases average size, sales and profits. Similarly to Melitz and Ottaviano (2008) the endogenous market structure of our model implies that trade liberalization has a positive effect on quantity sold of each firms that outweights the direct competition effect on prices and markups and allow surviving firms to be bigger, sell more, and earn higher profits.

It is worth noticing that the positive effect of trade liberalization on the export cutoff z_x^* is different from that obtained in Melitz (2003). In that paper, as in Krugman (1980), trade entails the export of varieties which are not been produced in the foreign market, there is no overlap in varieties and, consequently, no direct competition between domestic and foreign goods. Therefore, opening up to trade or reducing trade costs implies that exporters benefit from an expansion of their market, yielding larger profits and reducing the threshold productivity for exporting. Our model can be extended to introduce the standard pro-variety effect of trade by removing the assumption that the varieties produced by the two countries are the same. As long as there is some overlap between domestic and foreign varieties, trade liberalization will reduce markups and make the domestic and the foreign markets more competitive (pro-competitive effect). The domestic cutoff will necessarily increase while the export cutoff could go up or down depending on how large is the overlap.

We conclude showing the sensitivity of the quantitative effects of trade liberalization on selection and innovation to changes in parameters values.

`[Table 4 about here]`

As we can see under all parameters specifications we obtain the same qualitative results. Quantitatively, it is worth noticing that the pro-competitive effect on both the domestic and the export market is lower with lower firm heterogeneity. Intuitively, a lower dispersion of firm productivity, higher κ, reduces the role of trade-induced selection in both markets, a role that would completely disappear as firms become more homogeneous. Changing the rest of parameters does not seem to change the quantitative results significantly.

7 Conclusion

In this paper we have built a rich but tractable model of trade with heterogeneous firms and cost-reducing innovation, in order to account for a set of findings recently emerged from empirical analyses of trade liberalization: i) pro-competitive effect, ii) the selection effects, and iii) the positive effect on innovation at the firm level. In our framework, the competition channel is at the roots of the selection and innovation effects of trade liberalization, as all other possible channels (pure market-size, international technology spillovers, terms of trade) have been excluded from the analysis. The endogenous market structure derives directly from Cournot competition

Bernard, Redding, and Schott (2010) find that the number of firms per product increases with a reduction in trade costs. Although they find that both the number of exporting firms and product increases, with the former incresing more than the latter. Below we discuss how our model can be extended to obtain the prediction that trade liberalization increases the number of products exported as well.

among firms. We have shown that trade liberalization reduces markups, thus forcing the less productive firms out of the market. This selection effect interacts with firms' innovation choice by redistributing resources towards the more productive firms and increasing their incentives to innovate, thereby increasing the aggregate long-run investment in innovation.

Calibrating the model to match US firm-level and aggregate statistics we show that the overall growth effect induced by a 10 percent reduction in trade cost is significant and, most importantly, we show that reallocation of resources across firms of different productivity levels accounts for more than 90 of the overall growth effect. This suggests that firm heterogeneity can play a substantial role in analyzing the innovation and growth effects of trade liberalization.

The innovation effect of trade highlighted in our model suggests the existence of a new channel of welfare gains from trade that has not been explored in the literature. To keep the model simple we have limited the analysis to the steady-state. A full understanding of the pro-competitive dynamic effects of trade requires the analysis of transitional dynamics, which we view as an interesting task for future research. Finally, studying two perfectly symmetric countries with an identical set of goods, does not allow us to obtain any pro-variety effects of trade. Introducing asymmetric countries is an important step for fully exploring the welfare effects of trade liberalization in our framework.

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A Equilibrium quantity

Here we derive the equilibrium productivity-adjusted quantity $\tilde{z}^{-\eta}q$ in (11). Rearranging (8) we obtain $x = \tilde{z}^{-\eta\frac{1}{1-\alpha}} \left(\theta EL/X^{\alpha}\right)^{\frac{1}{1-\alpha}}$ and substituting into (1) yields $X^{\alpha} = \left(M\bar{z}\right)^{1-\alpha}\left(\theta EL\right)^{\alpha}$ where

$$\bar{z} = \frac{1}{M}\int_0^M z_j^{\hat{\eta}} \,\mathrm{d}j.$$

with $\hat{\eta} = \eta/\left(1-\alpha\right)$ is the average productivity. Substituting this back into (8) we obtain $\tilde{z}^{-\eta} = \left(\theta EL/M\bar{z}\right)^{1-\alpha} x^{\alpha-1}$. Now putting this expression to the power $\alpha/(\alpha-1)$, and since under symmetry $x = nq$ we obtain

$$\tilde{z}^{-\eta}q = \theta e\; z/\bar{z}$$

where $e = LE/nM$ and z is a measure of detrended productivity, $ze^{gt} = \tilde{z}_t^{\hat{\eta}}$

B Firm problem in open economy

Each firm solves the following problem

$$\begin{aligned}
V_s \quad = \quad & \max_{\left(q_{D,t}^D, q_{D,t}^F, z_{D,t}\right)_s^{\infty}} \int_s^{\infty} \left[\left(p_{D,t} - \frac{1}{z_{D,t}^{\eta}}\right) q_{D,t}^D + \left(p_{F,t} - \frac{\tau}{z_{D,t}^{\eta}}\right) q_{D,t}^F - h_{D,t} - \lambda\right] e^{-\int_s^T (r_z+\delta)\,\mathrm{d}z}\,\mathrm{d}t \\
& \text{s.t.} \\
& p_{D,t} = \frac{E_{D,t}L}{X_{D,t}^{\alpha}}\, x_{D,t}^{\alpha-1} \qquad \text{and} \qquad p_{F,t} = \frac{E_{F,t}L}{X_{F,t}^{\alpha}}\, x_{F,t}^{\alpha-1} \\
& x_{D,t} = \hat{x}_{D,t}^D + q_{D,t}^D + x_{F,t}^D \quad \text{and} \quad x_{F,t} = \hat{x}_{D,t}^F + q_{D,t}^F + x_{F,t}^F \\
& \dot{z}_{D,t} = A\; \hat{z}_{D,t}h_{D,t} \\
& z_{D,s} > 0,
\end{aligned}$$

where $p_{j,t}$, $E_{j,t}$ and $X_{j,t}^{\alpha}$ are the domestic price, expenditure and total composite good respectively for country $j = D, F$, and q_i^j is the quantity sold from source country i to destination country j. Writing down the current value Hamiltonian and solving it yields the following first order conditions

$$\left[(\alpha-1)\,\frac{q_{D,t}^D}{x_{D,t}} + 1\right] p_{D,t} = \frac{1}{z_{D,t}^{\eta}} \tag{23}$$

$$\left[(\alpha-1)\,\frac{q_{D,t}^F}{x_{D,t}} + 1\right] p_{F,t} = \frac{\tau}{z_{D,t}^{\eta}} \tag{24}$$

$$1 = v_{D,t}A\hat{z}_{D,t}, \tag{25}$$

$$\frac{\eta z_{D,t}^{-\eta-1}}{v_{D,t}}\left(q_{D,t}^D + \tau q_{D,t}^F\right) = \frac{-\dot{v}_{D,t}}{v_{D,t}} + r_t + \delta, \tag{26}$$

Since the two countries are symmetric, $q_{D,t}^{D}=q_{F,t}^{F}\equiv q_t$, $q_{D,t}^{F}=q_{F,t}^{D}=\breve{q}_t$, $x_{D,t}=x_{F,t}\equiv x_t$, $E_{D,t}=E_{F,t}$, $X_{D,t}=X_{F,t}$, $p_{D,t}=p_{F,t}$. From (23) and (24) and using $q_t/x_t+\ \breve{q}_t/x_t=1/n$ yields

$$\left[(\alpha-1)\frac{q_t}{x_t}+1\right] = \frac{2n-1+\alpha}{n(1+\tau)}\equiv\theta_D \tag{27}$$

$$\left[(\alpha-1)\frac{\breve{q}_t}{x_t}+1\right] = \tau\frac{2n-1+\alpha}{n(1+\tau)}\equiv\theta_F=\tau\theta_D \tag{28}$$

which allows us to rewrite (23) and (24) as follows

$$\theta_D\frac{E_tL}{X_t^{\alpha}}\ x_t^{\alpha-1}=\frac{1}{\tilde{z}_t^{\eta}}\quad\text{and}\quad\tau\theta_D\frac{E_tL}{X_t^{\alpha}}\ x_t^{\alpha-1}=\frac{\tau}{\tilde{z}_t^{\eta}}.$$

Multiplying the above equations by q_t and $\breve{q}_t$ and summing up we obtain

$$\frac{q_t+\tau\breve{q}_t}{\tilde{z}_t^{\eta}}=n\left[\theta_D\frac{q_t}{x_t}+\tau\theta_D\frac{\breve{q}_t}{x_t}\right]\frac{E_tL}{n}\left(\frac{x_t}{X_t}\right)^{\alpha}.$$

Using $x_t=\{[1/\tilde{z}_t^{\eta}]\,(X_t^{\alpha}/\theta_DE_tL)\}^{\frac{1}{\alpha-1}}$, it is easy to prove that $(x_t/X_t)^{\alpha}=\tilde{z}_t$. From (27) and using $q_t/x_t+\ \breve{q}_t/x_t=1/n$ we obtain

$$\frac{q_t+\tau\breve{q}_t}{\tilde{z}_t^{\eta}}=\theta_{\tau}e_tzz_t \tag{29}$$

where

$$\theta_{\tau}=\frac{2n-1+\alpha}{n(1+\tau)^2(1-\alpha)}\left[\tau^2(1-n-\alpha)+n(2\tau-1)+1-\alpha\right]$$

is the inverse of the markup in the open economy.

C Exit in open economy

The productivity cutoff is determined solving the following equation

$$\pi_t(\tilde{z}^*)=\left(p_t-\frac{1}{\tilde{z}_t^{*\eta}}\right)q_t+\left(p_t-\frac{\tau}{\tilde{z}_t^{*\eta}}\right)\breve{q}_t-h_t-\lambda=0$$

Using $p_t=\frac{1}{\theta_Dz_{D,t}^{\eta}}$ and $h_t=\eta\theta_{\tau}e_t\tilde{z}_t-(\rho+\delta)/A$ obtained from (25) and (26) yields

$$\frac{1}{\theta_D}\frac{q_t+\breve{q}_t}{\tilde{z}_t^{*\eta}}-\left(\frac{q_t+\tau\breve{q}_t}{\tilde{z}_t^{*\eta}}\right)(1+\eta)+\frac{\rho+\delta}{A}-\lambda=0.$$

With the same procedure used to derive (29) we obtain

$$\frac{q_t+\breve{q}_t}{\tilde{z}_t^{*\eta}}=\theta_De_t\ z_t/\bar{z}_t$$

which, together with (29), yields

$$[1-(1+\eta)\theta_{\tau}]\,e_tz_t^*/\bar{z}_t+\frac{\rho+\delta}{A}-\lambda=0.$$

This expression is similar to (EC) except for the markup $1/\theta_{\tau}$ instead of $1/\theta$.

D Non-linear effect of trade liberalization

Here we show that the competition effect of trade is decreasing in the number of firms n. This can be seen by differentiating θ^T with respect to τ

$$\frac{\partial \theta^T}{\partial \tau} = -\frac{2(\tau-1)(2n-1+\alpha)^2}{n(1+\tau)^3(1-\alpha)} \leq 0$$

Taking the absolute value and differentiating this with respect to n we find

$$\frac{\partial\left(\left|\partial \theta^T/\partial \tau\right|\right)}{\partial n} = \frac{2(\tau-1)(2n-1+\alpha)}{n^2(1+\tau)^3} > 0$$

E Calibration

Let us denote the set of externally calibrated parameters with Ω and solve the equilibrium system (EC)-(MC) to obtain e and z as functions of Ω and the four parameters that we have to calibrate, A, η, λ, κ. Let us call $\Theta = (A, \eta, \lambda, \kappa, z_{\min})$ the vector of parameters we calibrate internally. We then use the moments in the model corresponding to the statistics we want to match. The first moment is the average growth rate of production

$$g_q = \eta g(1-\beta) = \eta\left[\eta A \theta_\tau e(\Omega,\Theta) - \rho - \delta\right](1-\beta)$$

obtained from (19) and using the production function (2) and the fact that the share β of the economy does not innovate. Similarly the R&D share of income in our model the correspondent moment is

$$r = \frac{\eta\theta_\tau e(\Omega,\Theta) - \frac{\rho+\delta}{A}}{e(\Omega,\Theta)(1+\beta)nM}$$

where from (??) and the R&D technology we get the resources devoted to R&D by each firm $h(z) = gz/A\bar{z}$, thus average R&D is $h = \eta\theta_\tau e(\Omega,\Theta)z - (\rho+\delta)/A$. These two moments are relevant for the calibration of A and η, since they are technological parameters affecting the return to innovation. From (2) we obtain the average firm size

$$\bar{y} = \theta_\tau e(\Omega,\Theta) + \lambda$$

which is relevant in calibrating the fixed cost λ. Finally, relevant moments in calibrating the scale and shape parameters of the Pareto distribution of firm productivity, $z_{\min}$ and κ, are the standard deviation of firm productivity

$$std_z = \frac{z^*(\Omega,\Theta)\kappa^{\frac{1}{2}}}{(\kappa-1)(\kappa-2)^{\frac{1}{2}}}$$

where we can use (EC) and (MC) to express $z^*(\Omega,\Theta)$ as a function of parameters. Using the statistics discussed in the text, namely $g_q = 0.019$, $r = 13.5$, $\bar{y} = 21.8$ and $std_z = 0.75$, this system of equations is used to calibrate the vector of parameters $\Theta = (A, \eta, \lambda, \kappa)$.

F Equilibrium quantity for exporters and non-exporters

We want to derive the productivity adjusted quantities for non exporters $\tilde{z}^{-\eta}q$ and exporters $\tilde{z}^{-\eta}q_x$. Proceeding as in the benchmark model, from (8) we obtain $x = \tilde{z}^{-\eta\frac{1}{1-\alpha}}\left(\theta EL/X^{\alpha}\right)^{\frac{1}{1-\alpha}}$ and substituting into (1) yields $X^{\alpha} = (M)^{1-\alpha}(\theta EL)^{\alpha}\,\bar{p}^{-\alpha}$. Substituting this back into (8) we obtain $\tilde{z}^{-\eta} = (\theta EL/M\bar{z})^{1-\alpha}\,x_t^{\alpha-1}$. Now putting this expression to the power $\alpha/(\alpha-1)$, and since under symmetry $x = nq$ we obtain

$$\tilde{z}^{-\eta}q = e\theta^{\frac{1}{1-\alpha}}\ z\bar{p}^{\frac{\alpha}{1-\alpha}}$$

where $e = LE/nM$ and z is a measure of detrended productivity, $ze^{gt} = \tilde{z}_t^{\hat{\eta}}$. With the same procedure we obtain the productivity-adjusted quantity for the exporters

$$\tilde{z}^{-\eta}q_x = e\theta_{\tau}^{\frac{1}{1-\alpha}}\ z\bar{p}^{\frac{\alpha}{1-\alpha}}.$$

Using these two results we can easily determine the domestic cutoff condition (EC2) and the export cutoff condition (XC).

Table 1
SUMMARY OF CALIBRATION

parameter	value	moment	Source
α	0.309	Elasticity of sub/markup	Ruhl (2008)
τ	1.13	Trade cost	Anderson-Wicoop(2004)
δ	0.09	Enterprise death rate	US Census (2004)
β	0.34	Share non differentiated	Rauch (1999)
n	6	Elasticity of sub/markup	Basu (1994)
ρ	0.05	interest rate	Mehra-Prescott (2005)
A	12.47	R&D/GDP+Growth	CHS(2006)
η	0.0119	R&D/GDP+Growth	CHS (2006)
λ	1.507	avg. firm size	Axtell (2001)
κ	2.621	std. firm productivity	BJEK (2003)

Table 2
SENSITIVITY ANALYSIS: HALF THE BENCHMARK

		bench	$n = 12$	$\kappa = 5.24$	$\lambda = 3$	$\beta = 0.68$	$\delta = 0.18$	$\eta = 0.0218$
$1/\theta_\tau$	markup	-0.0115	-0.0252	-0.0115	-0.0115	-0.0115	-0.0115	-0.0115
z^*	cutoff	0.0421	0.0702	0.0206	0.0420	0.0418	0.0421	0.0471
$1 - F(z^*)$	survival	-0.1026	-0.1630	-0.1013	-0.1023	-0.1019	-0.1026	-0.1137
$\bar{y}$	size	0.1148	0.1965	0.1124	0.1148	0.1148	0.1147	0.1287
$\lvert g_\tau \rvert$	growth	0.1298	0.2334	0.1320	0.1265	0.1298	0.1345	0.1428
$\lvert g_\tau^d \rvert$	direct	4.2%	5.1	4.1	4.3	3.1	4	7.7
$\lvert g_\tau^* \rvert$	selection	95.8%	94.9	95.9	95.7	96.9	96	92.3

Benchmark: $n = 6$, $\kappa = 2.62$, $\lambda = 1.5017$, $\beta = 0.34$, $\delta = 0.09$, $\eta = 0.0109$

Table 3

Comparison with empirical evidence

Moments	model	CIS	CDMO	BDV	ARX	BUS
$1/\theta_\tau$	-0.0115	-0.01	-0.019			
$1-F(z^*)$	-0.1026			-0.012		
$\lvert g_\tau \rvert$	0.1298			0.24	0.053	0.24
$\lvert g_\tau^d \rvert$	4.2%			50%		
$\lvert g_\tau^* \rvert$	95.8%			50%		

Sources: Chen,et al.(2008), Corcos, et al (2007), Bloom,et al. (2009)

Aw, Roberts, Xu (2010), Bustos (2010)

Table 4

Sensitivity analysis: double the benchmark

		bench	$\lambda = 3$	$\beta = 0.68$	$\delta = 0.18$	ϕ =0.0061	$\delta = 0.18$	$\kappa = 5.24$
$1/\theta$	markup	-0.0115	-0.0004	-0.0005	-0.0002	-0.0005	-0.0115	-0.00007
$1/\theta_\tau$	cutoff	0.0421	-0.0109	-0.0103	-0.0128	-0.0082	0.0421	-0.0085
z^*	survival	-0.1026	0.0023	0.00288	0.0017	0.0023	-0.1026	0.00015
z_x^*	size	0.1148	0.0874	0.0817	0.1034	0.0609	0.1147	0.0645
n	growth	0.1298	0.0027	0.0036	0.0019	0.0030	0.1345	0.00039
nM	direct	4.2%	-0.0062	-0.0095	-0.0045	-0.0061	4	-0.00078
s_x	selection	95.8%	0.1567	0.1002	0.1501	0.0640	96	0.0644

Benchmark: $\kappa = 2.62, \lambda = 1.5017, \beta = 0.34, \delta = 0.09$,$\phi$= 0.00309

Figure 1. Steady state equilibrium

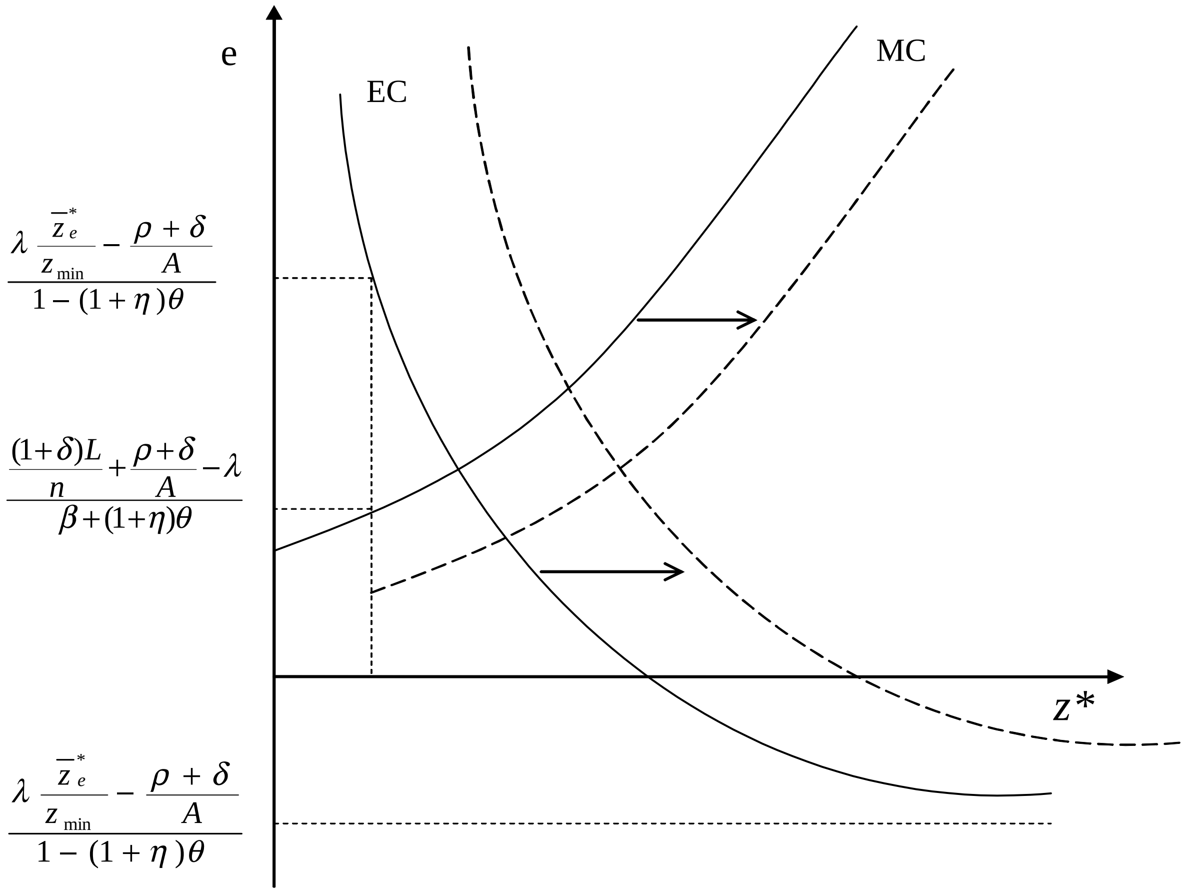

Figure 2. Trade liberalization