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. In equilibrium more productive firms show higher investment in innovation. 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 competition 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 more efficient, more innovative firms, thereby raising aggregate innovation and productivity growth. 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 0.5 percent, reduces firms surviving probability by 2.3 percent and increases growth by 33.8 percent; more than two thirds 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 and the most productive non-exporter firms to become exporters; 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 stimulating 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 differ 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. The oligopolistic market structure and the innovation by incumbents feature are borrowed from static trade models with endogenous market structure (e.g. Neary, 2003 and 2009) and from multi-country growth models with representative firms such as Peretto (2003) and Licandro and Navas (2008).

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. 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 more productive surviving firms, which are also those innovating at a higher pace. 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 *dynamic selection effect*. 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. Both effects are decreasing in the level of product market competition of the economy before trade liberalization: in highly competitive economies (large number of firms) trade liberalization has only negligible effects on innovation, and there exist a threshold level of competition above which trade has no effects on innovation. Incremental trade liberalization (reduction in the iceberg trade cost) has similar effects.

All these results are obtained assuming that the number of firms in each industry is exogenous. It is plausible that trade can produce a selection effect within narrowly defined oligopolistic industries as well. In a simplified version of the baseline model we endogenize the number of firms per sector and show that not only our basic results are confirmed but the effect of trade on innovation is even stronger when selection takes place both between and within industries. Similarly we show that our results are robust to the introduction of sunk export costs leading to the partition of the space of producing firms between exporters and non-exporters.

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 effects on both first and second moments of the productivity distribution. A 10 percent reduction in trade costs increases the aggregate growth rate by about 27 percent through the selection effect and by an additional 6 percent through the direct effect. Moreover, trade liberalization increases the variance of the firm-level growth rate and of firm sales by 3.5 and 3.2 percent respectively.

This paper is related to the emerging literature studying the joint selection and innovation effect of trade openness. 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 distinguishing feature of our model is that we study the interactions between trade, firm

[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.

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 non-homothetic 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). It is worth noticing that 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 to be counterfactual.[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. Finally, although our stylized economy features a rich and complex structure (oligopoly, firm heterogeneity, growth), the baseline version of the model is highly tractable and all results are obtained analytically, with no special assumption on either preferences or firms productivity distribution.

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.

[5]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)

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 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.

[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.

2.2 Households

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

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

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

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

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]

[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

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

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

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

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 $x_t = n q_t$. 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, $z e^{gt} = \tilde{z}_t^{\hat{\eta}}$, with $\hat{\eta} = \eta \frac{\alpha}{1-\alpha}$, and g is the growth rate of productivity as defined below. Average detrended productivity is

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

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

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.

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 $\hat{z}$,

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

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,

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

meaning that the growth rate of productivity is the same for all 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

[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), depend on the state z of direct competitors at least $\hat{\eta} = 1$.

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

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

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 $(z_{\min}, \infty)$, $0 \le z_{\min} < \infty$. 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 $z \ge z^*$, 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

[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 $1-(1+\eta)\theta < 0$.

[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.

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 (), Poschke () and Gabler and Licandro ()...

2.5 Stationary Equilibrium

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

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

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

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

Since $\int_{z^*}^{\infty} \mu\left(z\right) dz = \int_{z^*}^{\infty} z/\bar{z}\ \mu\left(z\right) dz = 1$, 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 givee 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,*

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

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 on z^*. A similar assumption is imposed by Melitz (2003). Assumption (b) makes the profit function (13) increasing on 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 (**??**) 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 competition effect and a selection effect. Let describe first the *direct competition 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. Resources are reallocated from exiting firms to the higher productivity surviving firms which, as shown in (**??**), innovate at a higher pace. Therefore this selection effect leads to higher innovation and growth. 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.

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.[11]

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

[11] 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.

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

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

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 $\theta_{\tau=1}\equiv\left(2n-1+\alpha\right)/2n$ when $\tau=1$, the polar case of no iceberg trade costs; the autarky value $\theta=\left(n-1+\alpha\right)/n$ is reached when $\tau=n/\left(n+\alpha-1\right)$, 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

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

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

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

which, as shown in the appendix, yields

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

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

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

which is equal in all aspects to (MC) except for the markup, with θ_τ instead of θ. Equations (EC$^{\text{T}}$) and (MC$^{\text{T}}$) 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. The proof is similar to that in the closed economy, and we omit it for brevity. ■

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$^{\text{T}}$) and (EC$^{\text{T}}$) 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

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

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. 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$^{\text{T}}$) we can see that trade liberalization increases the productivity threshold $\tilde{z}^*$, thus forcing some firms out of the market. This *selection effect* triggers a reallocation of resources from exiting firms to the more productive firms, which are also those innovating at a faster pace. Thus, the selection effect produced by trade liberalization not only raises the level of productivity as in Melitz (2003) but also its growth rate.

As stated before, there is a another more standard channel through which trade-induced increases in competition affects growth. Trade reduces the level of oligopolistic inefficiency in the differentiated goods sector, thus raising the quantity produced of each variety. Since 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; this is the *direct competition effect*. This channel does not rely on the presence of heterogeneous firms and, as shown by Licandro and Navas (2007), it operates also in a model with a representative firm. The selection effect instead can be obtained only in an heterogeneous firms framework.

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 4 *The effect of trade liberalization on selection and growth is decreasing in the number of firms*

Proof. See appendix. ■

The intuition behind this result is that for countries with high levels of product market competition, opening up the economy, or implementing a further trade liberalization, does not have a large effect on the already low markup rates.

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.

A good question to ask is what would happen if we introduce innovation into the Melitz model and whether it would lead to different results. Trade induced selection would affect innovation similarly in the two models, but our oligopolistic setup yields an additional result that cannot be obtained in the monopolistic competitive framework used by Melitz. In the Melitz 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 trade reduces markups which forces less productive firms to exit.

Finally, it is worth mentioning that Melitz and Ottaviano (2007) endogenize markups by assuming an a non-homothetic structure of preferences that makes them dependent on the number of firms (varieties), thus introducing a selection effect working through trade-induced increases in product market competition. But this transmission channel is obtained by using special preferences in the monopolistic competitive framework, while in our paper it is produced by the oligopolistic interaction among firms.

5 Quantitative analysis [UNDER REVISION]

In this section we explore the quantitative relevance of our mechanism. 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 trade costs τ on the innovation rate. Precisely, we quantitatively evaluate the effect of trade liberalization on innovation due to the *direct competition 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. We also investigate the quantitative effect of a reduction in τ on the second moments of the productivity distribution, namely of the variance of the growth rate and of firm sales. 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. This is consistent with evidence on firm size distribution (see e.g. Luttmer, 2007)

5.1 Calibration

We have 12 parameters to calibrate $\alpha, \tau, \delta, \beta, \lambda, n, L, \rho, \eta, A, \kappa, z_{\min}$. We calibrate 8 parameters externally: the discount factor ρ is equal to the interest rate in steady state, thus we calibrate it to 0.03 as in the business cycle literature. For the preferences parameter α we refer to the international business cycle literature which provides estimates of the elasticity of substitution in the range $0.2 - 3.5$ (see i.e. Backus, Kehoe and Kidland, 1994, Heatcote and Perri, 2004, and Ruhl, 2008). Since the prohibitive trade cost is $n/(n + \alpha - 1)$ we have to stick to low values of α and n for the prohibitive tariff not to be too low and therefore not leaving much room for comparative statics on it. We choose a value of α yielding an elasticity of substitution in the range of the above estimates that allows a sufficiently high prohibitive trade cost: precisely we set $\alpha = 0.1$, which leads to an elasticity of substitution $\sigma = 1.1$. 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 use a 20 percent markup (in the range of estimates in Basu,1994) to back out the number of firms (the integer part of it) using the markup equation (18) and the calibrated values of α, and τ. Using these values we obtain $n = 3$. The choice of n and α leads to a sufficiently high prohibitive trade cost, $\bar{\tau} = 1.42$.

We set the destruction rate $\delta = 0.24$ to match the US job destruction rate of 24% per year (Davis and Haltiwanger, 1999, table I). The share of the homogeneous good β is calibrated to match a 9 percent agriculture share of private industry (BEA NIPA). We set the population $L = 1.32$, which is the average US civil workforce 1990-2000 Bureau of Labor Statistics (2001) rescaled to obtain the best fit of the data. We normalize the minimum value of the productivity distribution $z_{\min}$ to 0.1, this is the only free parameter in the calibration and we will provide an extensive robustness check on it.

The remaining 4 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. In our model the correspondent moment is

$$\frac{R\&D}{GDP} = \frac{\eta\theta_\tau e\frac{L}{n} - \frac{\rho+\delta}{A}}{e(1+\beta)M}$$

where from (19) we can compute the aggregate (average) equilibrium R&D $h = \eta A\theta_\tau e_t\,(L/n)\,\tilde{z}_t - \rho - \delta$. The growth rate in open economy can be obtained from (**??**) with θ_τ replacing θ. The third targeted statistics is a standard deviation of firm growth of 0.35, which is found by Luttmer (2007) using US Census data. The standard deviation of firm growth in our model is

$$\sigma_z = \frac{\eta A\theta_\tau e\tilde{z}^* L}{(\kappa-1)n}\left[\frac{\kappa}{(\kappa-2)}\right]^{1/2},$$

where, since we are working with the equilibrium distribution, the bottom productivity level is $\tilde{z}^*$. Finally we use a statistics that is relevant to pin down the fixed operating costs λ, that is the average firm size of 19 workers found in Axtell (2001) for US firms in 1997 using Census data and considering only firms with at least one employee.[12] In our model the average firm

[12] 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.

size is

$$y_{avg} = \theta_\tau e \frac{L}{n} + \lambda.$$

Minimizing the quadratic distance between these statistics and their theoretical counterpart we obtain the following parameters: $A = 0.19$, $\eta = 0.096$, $\kappa = 2.52$, $\lambda = 2.76$. Table 1 below shows the model fit of the data.

[Table 1 ABOUT HERE]

The calibrated model matches the targeted statistics sufficiently well. The model produces acceptable values for some key non targeted statistics as well.

5.2 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 (??) as follows:

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

where the direct effect can be obtained keeping fixed the productivity threshold $\tilde{z}^*$, 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_d^τ is

$$g_\tau^d = \eta A \left(\frac{L}{n}\right) e \frac{d\theta_\tau}{d\tau} + \eta A \theta \left(\frac{L}{n}\right)(1+\eta) \frac{\frac{1}{M(z^{*T})} - \left(\lambda - \frac{\delta+\rho}{A}\right)\frac{n}{L}}{\left[\beta + (1+\eta)\,\theta_\tau\right]^2}. \tag{20}$$

where $d\theta_\tau/d\tau$ is derived in the appendix. The selection effect is thus obtained as a residual $g_\tau^* = g_\tau - g_\tau^d$.

Figure 3 shows the effect of a 10 percent reduction in trade cost τ from its benchmark value of 1.13 to 1.117, on some key first moments of productivity growth.

[Figure 3 about here]

The reduction in trade cost produces a small reduction in the markup, which declines by 0.003. Interestingly, although our calibrated model does not show a large pro-competitive effect, both the productivity cutoff and innovation are fairly sensitive to changes in the markup. In fact the productivity cutoff $\tilde{z}^{*T}$ rises by 34 percent, implying a reduction of the survival probability of entering firms, $1-F(\tilde{z}^{*T})$, by 2.3 percent. The growth rate of aggregate productivity increases by 33.8 percent from 0.022 to 0.029. Comparing these results with those obtained in empirical works which studied parts of the implications of our mechanism shows that the prediction of our stylized model are fairly close to the empirical evidence. Table 3 below summarizes the comparison. First we can see that the small pro-competitive effects of trade that we find are in line with empirical evidence: Chen, Imbs and Schott (2008) estimating the Melitz and Ottaviano (2008) model using European data find that a 10 percent increase in the import to production ratio lower the average markup by 0.01; Kee and Hoekman (2003) find that the a 10 percent increase in the import ratio lowers the markup by 0.014 in OECD countries. 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 21.4 percent increase in R&D, a 4 percent increase in IT intensity, and a 6 percent increase in patents in European countries.[13] They also find that the probability of firm survival reduces by 1.2 percent. Teshima (2009) using Mexican plant-level datasets finds that a 1 percent reduction in trade costs increases R&D by 8 percent.

`[Table 3 about here]`

Using (20) we find that between 18 and 20 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 role of the reallocation of market shares between exiting and surviving firms in spurring growth, is quantitatively relevant. Bloom et al. (2009) instead find that the contribution of selection (between component) and of the direct effect (controlling for labor reallocation) of trade liberalization to increases in innovation is more balanced.

`[Table 3 about here]`

The exploration of the role of some key parameters in table 3 provides further insights on our results.[14] The increase in the number of firms n from 3 to 4 confirms the result in proposition 4, a larger number of firms reduces the overall effect of trade liberalization on growth; moreover the growth effect seems to be quantitatively very sensitive to n, because 1 additional firm reduces it from 33.8 percent to 20 percent. This result provides a new interpretation for the asymmetric effects of trade liberalization on productivity growth in countries of different sizes and stages of economic development. For instance, Pavcnik (2002) find that one-third of aggregate productivity gains from trade liberalization in Chile come from within-firms increase in productivity. Trefler (2004) finds that US-Canada Free Trade Agreement increased within-plant productivity by about 1.9 percent per average per year. On the other hand, for large countries like the US the effect of trade on within-firm productivity seems to be negligible, while most of the effect is found to be a one-shot reallocation across firms of different productivity (see e.g. Bernard and Jensen, 2006). Our result suggest a specific channel that can explain why large countries populated with a large number of firms will not experience the same pro-competitive effects of productivity then small developed and developing countries.

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

[14] This is not meant to be a robustness analysis of our results because under the specified parameters restrictions our basic findings have been analytically in proposition 1 and 2.

6 Extensions

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

6.1 Vertical entry

So far we have assumed that the number n of firms producing a particular variety is exogenous. In this section, we extend the model to allow n to be endogenous. Firms entering the economy are assumed to pay a fixed entry cost ϕ before they observe the productivity z of the variety they will produce. Since profits are linear on productivity, free entry implies that the value of the average firm have to be equal to the entry cost, which can be written in the following way

$$\pi(1) = [1-(1+\eta)\theta]\, e + \frac{\rho+\delta}{A} - \lambda = \frac{(\rho+\delta)\phi}{1-F(z^*)}. \tag{FE}$$

Combining it with the (EC) condition, we get the equilibrium cutoff productivity

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

which is in $(0,1)$. It is easy to see that for continuous distributions F the solution is unique. Under Assumption 1(a), the left hand side is increasing in z^*, starting at $z_{\min}/\bar{z}_e$, where $\bar{z}_e$ is the expected productivity at entry. The right hand side is decreasing on z^*, starting at $\frac{\lambda}{\lambda+(\rho+\delta)\phi}$, going to zero when z^* goes to infinity. Existence and unicity require the entry cost be no too large.

The stationary equilibrium for e and n derives from the market clearing (MC) and exit (EC) conditions after substituting z^* by the solution above. Let write again (MC) and (EC)

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

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

where $\theta(n) = \frac{n-1+\alpha}{n}$.

Proposition 5 *Under Assumption 1 (b) and $\eta < \frac{1-\alpha}{\alpha}$, an interior equilibrium for n and e, $n \geq 1$, in (MC)-(EC) exits and is unique iff z^* is such that*

$$\mathcal{A}(1) \geq \mathcal{B}(1)$$

Proof. $\mathcal{A}(n)$ is decreasing on n, strictly positive at $n=1$ and going to a negative constant when n goes to ∞. $\mathcal{B}(n)$ is increasing on n, strictly positive for $n \in [1, \frac{(1+\eta)(1-\alpha)}{\eta})$ and strictly negative otherwise. Consequently, $\mathcal{A}(1) \geq \mathcal{B}(1)$ is necessary and sufficient for existence and unicity. ■

As shown below, a reduction in variable trade costs reduces both the markup and the number of firms, implying that trade openness has a pro-competitive effect on R&D even it is no so strong as in the baseline model. The open economy equilibrium can be obtained from (MC) and (EC) replacing $\theta(n)$ by the open economy markup $\theta_\tau(n)$, as defined in equation (18). A reduction on variable trade costs τ increases $\theta_\tau(n)$ for all n, shifting to the left both locus (MC) and (EC), thus leading to an equilibrium in which the number of firms n is lower. It's easy to see, that a lower number of firms requires a lower markup. To see that, substitute e from (MC) on (EC) and compute the sign of the derivative $dn/d\theta_\tau$, which is negative. Notice that in the benchmark model when going from autarky to free trade, the number of firms selling the same variety in the local market doubles, while with endogenous n the number of local producers reduces implying that the total number of firms selling in the local market increases, but less than double. Moreover, since, as shown in the appendix, $\theta_\tau(n)$ is decreasing in the variable trade cost τ, with a similar argument we can show that incremental trade liberalization leads to lower equilibrium number of firms and lower markups. Therefore, although the increase in competition brought about by trade liberalization does not produce reallocation across varieties, it reallocates resources toward surviving firms within each varieties.

Equation (AC) is fundamentally an arbitrage condition. A marginal firm with productivity z^* has the possibility of keeping running its old business or closing down and opening a new business. From linearity in the profit function, arbitrage reduces to comparing the difference in profits between the average and the marginal firm with the entry costs. Since the market structure does not change from one variety to another, markups and market shares do not affect the cutoff productivity, making changes in competition have no selection effect. Introducing sunk export cost leads to an equilibrium in which domestic and exporting firms face different market structures. Under this assumption, average and marginal firms face different markups making the selection effect work. This represents a generalization of the basic model in line with the evidence that only the most productive firms export while the others only sell in the domestic market.[15]

6.2 Exporters and non-exporters

Following Melitz (2003), let us assume exporting firms face not only a variable trade cost but also a fixed export cost.[16] This extension allows us to show how by introducing a simple form of markup heterogeneity across varieties we can obtain trade-induced firm selection in a model with endogenous n. 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 $\mu(z) = f(z)/(1 - F(z^*))$, as in the benchmark model. Otherwise, the equilibrium distribution would be endogenous and the problem much more difficult to solve.

In a model of two symmetric countries, the fundamental difference between exporters and

[15] Clerides, Lach and Tybout(1998), Bernard and Jensen (1999), and Aw, Chung and Roberts (2000) among others find evidence of self-selection of more productive firms into export.

[16] In our framework, it is equivalent to a sunk cost for entering the export market. These can be costs of setting distribution channels abroad, learning about foreign regulatory system, advertising etc.

non-exporters is that the formers face tougher competition. In facts, 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. As a consequence, the markups of the marginal firm and the average firm are different, making international trade affect selection.

Under these assumptions, the exit condition becomes

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

where the average price $\bar{p}$ is

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

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

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 (EC) and (XC) is double. Firstly, exporters pay both production fixed costs 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, differently from Melitz (2003), R&D activities make firm's local and foreign cash flows non separable. Consequently, for an exporter, is the average markup θ_τ that matters. Another remarkable difference of our framework is that 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 export fixed cost. Firms producing the non traded varieties are protected of international competition by the export fixed cost and benefit then 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^*

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

Notice that the sign of $\mathrm{d}(z_x^*/z^*)/\mathrm{d}\theta_\tau$ is strictly positive, since it is equal to the sign of $\theta_\tau - \alpha$, and $\theta_\tau - \alpha > \theta - \alpha > 0$. In top of that, it is also easy to see that $z_x^* > z^*$ for any τ, since it clearly arrives when $\theta_\tau = \theta$, and then it has to be true for any other $\theta_\tau > \theta$, from the sign of the derivative just above. A reduction on variable trade costs makes markets for traded goods more competitive, reducing benefits in particular of the marginal exporter. As a reaction, less varieties are traded. It's important to notice that reducing the fixed export cost has the opposite effect, since it has no effect on the profitability of the marginal traded variety, but it makes cheaper for the marginal non traded variety to be exported.

Cournot competition plays here a critical role. When exporting becomes profitable, local firms enter the foreign market reducing foreign firms profits. For the same argument, foreign firms enter the local market. A similar argument applies to marginal reductions in variable trade costs; by making easier to foreigners to access the local market, markups decline and then profits of the marginal exporter. Such a reduction on the incentives to export moves the z_x^* threshold up. This effect is different from the standard positive effect of variable trade costs reductions on trade participation. Contrary to our model, in the Krugman-Melitz framework trade entails the export of varieties which are not been produced in the foreign market. Exporters then benefit from an expansion of their market, making profits to increase.

The free entry condition (FE) becomes:

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

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 veriaties' contribution to the average price. Let multiple both sides of (EC) by the weight $(\bar{p}\theta)^{\alpha/(1-\alpha)}$ times $\int_{z^*}^{z_x^*} z\mu(z)dz$; do the same with (XC) but using the corresponding weight. Then, add both equations to get $(1-\bar{\theta})e$ on the left hand side and then substitute it in the (FE) condition to obtain

$$\lambda\int_{z^*}^{z_x^*}(z/z^*)\mu(z)dz + (\lambda+\lambda_x)\int_{z_x^*}^{\infty}(z/z_x^*)\mu(z)dz = \lambda + \left(\frac{1-F(z_x^*)}{1-F(z^*)}\right)\lambda_x + \left(\frac{\rho+\delta}{1-F(z^*)}\right)\phi. \tag{FE-XC-EC}$$

This is equivalent to the arbitrage condition (AC) in the section above.

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

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

Combining the two previous equation, the market clearing condition can be written as

$$(1+\beta)e = \frac{1}{nM(z^*)} + \frac{\rho\phi}{1-F(z^*)}. \tag{MC-FE}$$

[INTERPRET THIS CONDITION]

A stationary equilibrium for this economy is a $\{z^*, z_x^*, e, n\}$ solving the system (EC)-(XC)-(FE-(MC), after using the definitions for θ, θ_τ, $\bar{p}$ and $\bar{\theta}$. In the following section, we study the case where the entry distribution is Pareto.

6.2.1 Pareto distribution

Let assume the initial distribution is Pareto, $f(z) = \kappa\, z_{\min}^{\kappa}\, z^{-\kappa-1}$, with $\kappa > 1$. Notice that $\mu(z) = \kappa\, z^{*\kappa}\, z^{-\kappa-1}$, which does not depend on $z_{\min}$.

The (FE) condition becomes

$$\frac{\lambda}{\kappa-1} - \frac{\lambda\kappa}{\kappa-1}\left(\frac{z^*}{z_x^*}\right)^{\kappa-1} + \frac{\kappa\lambda+\lambda_x}{\kappa-1}\left(\frac{z^*}{z_x^*}\right)^{\kappa} = \phi\left(\rho+\delta\right)\left(\frac{z_{\min}}{z^*}\right)^{\kappa}, \tag{FE}$$

which relates z^*/z_x^* with $z^*/z_{\min}$. Notice that the right-hand-side is decreasing on $z^*/z_{\min}$. It is easy to see that the left-hand-side is increasing on z^*/z_x^* iff $z^*/z_x^* > \frac{(\kappa-1)\lambda}{\kappa\lambda+\lambda_x}$, which is in $(0,1)$.

As shown above, the (EC) and (XC) conditions collapse on

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

which relates z^*/z_x^* with n through the markups θ and θ_τ.

The (MC-FE) condition becomes

$$(1+\beta)e = \frac{1}{n}\left(1+\delta\left(\frac{z^*}{z_{\min}}\right)^{\kappa}\right) + \rho\phi\left(\frac{z^*}{z_{\min}}\right)^{\kappa}. \tag{MC-FE}$$

The average price can be written as

$$\bar{p}^{\frac{\alpha}{\alpha-1}} = \frac{\kappa}{\kappa-1}\left[\theta^{\frac{\alpha}{1-\alpha}} z^{*\kappa}\left(z^{*1-\kappa} - z_x^{*1-\kappa}\right) + \theta_\tau^{\frac{\alpha}{1-\alpha}} z_x^*\right]$$

Finally, take the (EC) condition, substitute the average price on it and combine with the (MC-FE) condition

$$(1-\theta)\left(\frac{1}{n}\left(1+\delta\left(\frac{z^*}{z_{\min}}\right)^{\kappa}\right) + \rho\phi\left(\frac{z^*}{z_{\min}}\right)^{\kappa}\right) = \frac{\kappa\lambda(1+\beta)}{\kappa-1}\left[1-\left(\frac{z_x^*}{z_*}\right)^{1-\kappa} + \left(\frac{\theta_\tau}{\theta}\right)^{\frac{\alpha}{1-\alpha}}\frac{z_x^*}{z_*}\right] \tag{21}$$

The average theta becomes

$$\bar{\theta} = \theta + (\theta_\tau - \theta)\left(\frac{\theta_\tau}{\bar{p}}\right)^{\frac{\alpha}{1-\alpha}}\frac{z_x^{*1-\kappa}}{\kappa-1}$$

After substitution of $\bar{p}$

$$\bar{\theta} = \frac{\theta^{\frac{\alpha}{1-\alpha}} + \frac{\theta_\tau}{\theta_\tau}\left(\theta_\tau^{\frac{\alpha}{1-\alpha}} - \theta^{\frac{\alpha}{1-\alpha}}\right)\left(\frac{z^*}{z_x^*}\right)^{\kappa-1}}{\theta^{\frac{\alpha}{1-\alpha}} + \left(\theta_\tau^{\frac{\alpha}{1-\alpha}} - \theta^{\frac{\alpha}{1-\alpha}}\right)\left(\frac{z^*}{z_x^*}\right)^{\kappa-1}}.$$

It can be shown that

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

TO BE COMPLETED FROM HERE

7 Welfare analysis

In this section we explore the effects of changes in trade costs on steady-state welfare.

To be completed...

8 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 (market-size, international technology spillovers, terms of trade) have been excluded from the analysis. The endogenous market structure derives directly from Cournot competition 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 (more innovative) firms, 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 and innovation intensity accounts for about 4/5 of the overall growth effect. This allows us to conclude that the 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 quantity in (). Rearranging (8) we obtain $x_t = z_t^{-\eta \frac{1}{1-\alpha}} (\theta EL/X^\alpha)^{\frac{1}{1-\alpha}}$ and substituting into (1) yields $X^\alpha = (M\bar{z})^{1-\alpha} (\theta EL)^\alpha$ where

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

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

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

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

B Firm problem in open economy

Each firm solves the following problem

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

where $p_{j,t}$, $E_{j,t}$ and $X^\alpha_{j,t}$ are the domestic price, expenditure and total composite good respectively for country $j=D,F$, and q^j_i 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

$$\left[(\alpha-1)\frac{q^D_{D,t}}{x_{D,t}}+1\right]p_{D,t}=\frac{1}{z^\eta_{D,t}} \tag{22}$$

$$\left[(\alpha-1)\frac{q^F_{D,t}}{x_{D,t}}+1\right]p_{F,t}=\frac{\tau}{z^\eta_{D,t}} \tag{23}$$

$$1=v_{D,t}A\hat{z}_{D,t}, \tag{24}$$

$$\frac{\eta z^{-\eta-1}_{D,t}}{v_{D,t}}\left(q^D_{D,t}+\tau q^F_{D,t}\right)=\frac{-\dot{v}_{D,t}}{v_{D,t}}+r_t+\delta, \tag{25}$$

Since the two countries are symmetric, $q^D_{D,t}=q^F_{F,t}\equiv q_t$, $q^F_{D,t}=q^D_{F,t}=\breve{q}_t$, $x_{D,t}=x_{F,t}\equiv x_t$, $E_{D,t}=E_{F,t}$, $X_{D,t}=X_{F,t}$, $p_{D,t}=p_{F,t}$. From (22) and (23) and using $q_t/x_t+\ \breve{q}_t/x_t=1/n$ yields

$$\left[(\alpha-1)\frac{q_t}{x_t}+1\right] = \frac{2n-1+\alpha}{n(1+\tau)}\equiv\theta_D \tag{26}$$

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

which allows us to rewrite (22) and (23) as follows

$$\theta_D\frac{E_tL}{X^\alpha_t}\,x^{\alpha-1}_t=\frac{1}{z^\eta_t}\quad\text{and}\quad\tau\theta_D\frac{E_tL}{X^\alpha_t}\,x^{\alpha-1}_t=\frac{\tau}{z^\eta_t}.$$

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

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

Using $x_t=\{[1/z^\eta_t]\,(X^\alpha_t/\theta_DE_tL)\}^{\frac{1}{\alpha-1}}$, it is easy to prove that $(x_t/X_t)^\alpha=\widetilde{z}_t$. From (26) and using $q_t/x_t+\ \breve{q}_t/x_t=1/n$ we obtain

$$\frac{q_t+\tau\breve{q}_t}{z^\eta_t}=\theta_\tau e_t\left(\frac{L}{n}\right)\widetilde{z}_t \tag{28}$$

where $e_t = E_t/M$ and

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

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 $p_t = \frac{1}{\theta_D z_{D,t}^{\eta}}$ and $h_t = \eta\theta_\tau e_t \tilde{z}_t - (\rho+\delta)/A$ obtained from (24) and (25) 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 (28) we obtain

$$\frac{q_t+\breve{q}_t}{\tilde{z}_t^{*\eta}} = \theta_D e_t\, \tilde{z}_t/\bar{z}_t$$

which, together with (28), yields

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

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_τ with respect to τ

$$\frac{\partial\theta_\tau}{\partial\tau} = -\frac{2(\tau-1)\left(2n-1+\alpha\right)^2}{n\left(1+\tau\right)^3\left(1-\alpha\right)} \le 0$$

Differentiating this with respect to n we find

$$\frac{\partial\left(\partial\theta_\tau/\partial\tau\right)}{\partial n} = -\frac{2(\tau-1)\left(2n-1+\alpha\right)}{n^2\left(1+\tau\right)^3} \le 0$$

TABLE 1
Model Fit

Moments	Data	Sources	Benchmark model
`Targeted`			
growth	0.019	CHS (2006)	0.022
R&D/GDP	0.135	CHS (2006)	0.12
Std. firm growth	0.35	Luttmer (2007)	0.337
avg. firm size	19	Axtell (2001)	18.8
`Non targeted`			
Std. of log sales	1.64	BJEK(2003)	0.93
Std. log productivity	0.75	BJEK(2003)	0.98(*check*)

TABLE 2
Comparison with empirical evidence

	model	CIS	KH	BDV	Tesh*
Markups	$-.005$	$-.01$	$-.014$		
$\tilde{z}^*$	.34				
$1 - F(\tilde{z}^*)$	$-.023$			$-.012$	
Growth	.338			.24($R\&D$)	.08
Direct effect	20%			50%	
Selection effect	80%			50%	

TABLE 3
Growth decomposition

	benchmark	$n = 4$	$L = 2.6$	$\kappa = 5$	$\lambda = 6$	$z_{\min}$
total	0.338	0.198	0.10	0.048	0.044	
direct	0.18	0.163	0.22	0.42	0.375	
selection	0.81	0.837	0.78	0.58	0.625	

Figure 1. Steady state equilibrium

Figure 2. Increasing the number of firms n

Figure 3. Trade liberalization