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Asymmetric trade liberalization, sector heterogeneity and innovation[*]

Antonio Navas Ruiz[**]

Abstract

Innovation, mark-ups and the degree of trade openness vary substantially across sectors. This paper builds a multi-sector endogenous growth model to study the influence that asymmetric trade liberalization and sectorial differences in the degree of product market competition has on the effect of trade openness on R&D investments at a firm level. I find that differences in the degree of competition generate large differences on firm innovative response to trade liberalization. A movement from autarky to free trade promotes innovation and productivity growth in those sectors which are initially less competitive. However, when the initial tariff level is common across sectors, a homogeneous tariff reduction promotes innovation in those sectors which are initially more competitive. The paper suggests that trade liberalization could be a source of industry productivity divergence: firms that are located in industries with greater exposure to foreign trade, invest a greater amount in R&D contributing to industry productivity growth. Finally the paper finds that these asymmetries generate important reallocative effects that contribute to enlarge these differences.

Keywords: Sectorial productivity, international trade, innovation.

JEL classification: F12, O43.

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1 Introduction

A recent body of literature on both theoretical and empirical grounds has studied the influence of trade openness and trade liberalization policies on productivity growth. These papers explore the extent to which a larger degree of trade openness affects the rate of an industry's technological change and ultimately the evolution of TFP. To address this question, some researches have relied on endogenous growth models with imperfect competition and product or proccess innovation (Rivera-Batiz and Romer (1991a)), Rivera-Batiz and Romer (1991b)), Segerstrom, Anant and Dinopoulos (1990). Peretto (2005), Navas and Licandro(2011)), and other recent contributions have used firm heterogeneity and industrial dynamics (Atkenson and Burstein (2010), Navas and Sala (2010), Long, Raff and Stahler (2011), Vannorenberghe (2008), Ederignton and Mc Calman (2007), Impulliti and Licandro (2011), Gustafsson and Segerstrom (2008), Baldwin and Nicoud (2008)).

A common feature that is shared by all of these models is that a firm's investment in innovation depends on the competition it faces in the market among other forces. Therefore, trade influences innovation and productivity growth through an increase in competition. The effect of this channel on innovation depends on several assumptions regarding the nature of innovation and the market structure. Rivera-Batiz and Romer (1991b) find that an increase in competition has a negative effect on innovation because of the assumption of monopolistic competition and product innovation. (Peretto (2005), Navas and Licandro (2011)) find that trade promotes technological change by increasing competition in local markets under the assumptions of oligopolistic competition and proccess innovation rather than monopolistic competition and product innovation. The more recent generation of models shows that in either a static framework (Navas and Sala (2010), Long, Raff and Stahler (2011) etc..) or a dynamic context (Atkenson and Burstein (2010), Impulliti and Licandro (2010)) the introduction of firm heterogeneity adds a new dimension to think about how trade affects innovation through competition. Trade openness promotes technological change through the selection effect: Intensifying competition from abroad forces less efficient firms out of an industry, and liberates productive resources that can be used by the most efficient firms to produce and innovate.

These papers focus on the representative sector case, hence differences among sectors and the interactions that could emerge because of these differences are not explored. Empirical evidence suggests that industries are certainly not homogenous in two dimensions that are relevant to the innovation investment decisions of firms: product market competition and trade openness. Several papers document substantial variation in mark-ups across sectors, which is typically considered as a proxy for the degree of competition (Griffith, Harrison and Simpson (2010), Eslava, Haltiwanger and Kugler (2009)). For example, Epifani and Gancia (2011), report that in the US manufacturing sector at a four-digit level of disaggregation, mark-ups vary from 1% (in the first quintile of the distribution) to 60%. These authors observe that mark-ups vary also across countries (mark-ups are larger in poor countries) and over time. The degree of trade openness varies substantially across industries and recent evidence indicates that tariff reductions following a deep process of trade liberalization are asymmetric across sectors. Bustos (2010) documents the proccesses of trade liberalization in Brazil and Argentina during the 90s. Despite the substantial variation in initial tariff levels across sectors, bilateral tariffs between the two countries were eliminated after their admission to MERCOSUR at the beginning of the 1990s. Eslava, Haltiwanger and Kugler (2009) review the proccess of trade liberalization in Colombia during the late 1980s. The trade reforms that were undertaken in this contry during the second half of that decade, reduced both the average tariff rate and the dispersion of tariffs across sectors, suggesting that the process was not symmetric across industries. Similar proccesses have been documented in detail for other countries including the Chinese import experience of the European Union (Bloom, Draca and Van Reenen (2010)), or the Chilean experience (Pavnick (2002)).

This paper builds a multi-sector endogenous growth model with oligopolistic competition and private R&D investments to study the effects of trade openness and trade liberalization policies on innovation and productivity growth at the industry level. The aim of this paper is to introduce asymmetries across sectors in the degrees of product market competition and the degree of trade openness to address several important questions. This paper explores, the consequences of the implementation of a particular homogeneous trade policy in an environment in which industries differ in the degree of product market competition. This exercise enable us to isolate the contribution of sectorial differences in product market competition to the relationship between trade and innovation. In this exercise, we consider alternative trade liberalization policies, (i.e. a movement from autarky to free trade, a tariff reduction or an increase in the number of trade partners). Similarly, in a second exercise, we investigate whether asymmetries in the proccess of trade liberalization across sectors generate steady state differences in industry productivity growth in otherwise identical industries. In this case, we isolate the contribution of asymmetric exposure to foreign trade in the evolution of an industry's TFP.

The model is based on the work of Navas and Licandro (2011), who explore the effect of trade liberalization on innovation and growth through its effect on competition in an oligopolistic general equilibrium model (OLGE). The model emphasises the role of increased competition that results from improved access to foreign markets on firm decisions to innovate. There exists a continuum of industries, each of which produces a differentiated product: within each industry, n firms compete á la Cournot and undertake proccess innovation to improve the state of technology in the spirit of Neary (2005). The model predicts a positive relationship among innovation efforts, firm size and productivity growth. The model focuses on trade openness and trade liberalization policies across identical economies to better isolate the role played by competition. The paper shows that the total output that is produced by a firm increases with the degree of trade openness because firms face a more elastic residual demand. Given the complementarity between firm size and innovation efforts the former increases innovation and productivity growth.

This paper introduces exogenous differences in the degree of product market competition across industries: these differences could arise because the number of active firms differ across industries or because the elasticities of substitution across varieties differ. A movement from autarky to free trade in all sectors increases firm size, fim innovation efforts and productivity growth in industries which are initially less competitive. These increases occur because the increase in the perceived elasticity of substitution (our measure for product market competition) is non-linear, and is thus more important when the number of firms is initially low. In other words, in sectors in which entry is restricted, trade openness intensifies competition disproportionately: because firms in such sectors encounter a more elastic demand they decide to increase production and innovation. However, when we consider the effect of a reduction in tariffs in sectors with initially identical tariff levels but different degrees of competition, we find that the largest gains from trade are obtained in sectors which are initially more competitive. This result occurs because sectors with a uniform tariff level and a larger number of firms, will be closer to an autarkic situation (prohibitive trade costs), and will thus be less open to foreign markets. A homogeneous tariff reduction causes a greate increase in competition in sectors that are relatively closer to autarky (prohibitive trade costs). Consequently, a tariff reduction leads to a greater enhancement in innovation and productivity growth in initially more competitive industries. Similar results are obtained for differences in the elasticity of substitution.[1]

Additionally, we find that asymmetries in the trade liberalization proccess generate asymmetries in innovation, firm size and productivity growth in otherwise identical industries. More precisely, industries that are open to foreign trade suffer from greater competition. This is associated with a larger perceived elasticity of demand what induces firms to increase the quantity that they produce. Consequently, firms increase their innovation effort more, having a positive impact on productivity growth. These results are robust to other means of trade liberalization such as an asymmetric tariff cut, or an increase in the number of trade partners.

This paper adopts a general equilibrium perspective when considering the impact of trade openness and trade liberalization. By adopting this perspective, we found that sectors that are not exposed to foreign trade or have smaller tariff reductions than other sectors, suffer from a reduction in innovation efforts, firm size and productivity growth. This result is obtained because the sectors that are more exposed to foreign competition have a larger reduction of mark-ups that causes demand to shift to these products and thus causes a greater increase in production and innovation in these industries. The increase in labour demand from these industries causes increases in real wages and reduces the profitability of firms that are located in autarkic or less open sectors. Consequently, as profitability declines, innovation efforts and productivity growth decreases. This general equilibrium effect is relevant and its importance decreases smoothly according to the number of industries that we consider.

Although, this paper is related to a voluminous literature that examines the effects of trade openness and trade liberalization on innovation and growth, to the best of my knowledge, this paper is the first research to study the role of asymmetric trade liberalization in a context in which sectorial differences in market power arise. Two relatively close papers in the area are Impulliti and Licandro (2010) and Ederignton and Mc Calman (2007). The first paper introduces firm heterogeneity into the oligopolistic competition model of Navas and Licandro(2011) to disentangle the effects of trade openness on industry productivity growth that are derived from selection from the effecs that are derived from a pure increase in competition. As each variety is produced by an oligopoly in which all firms have the same level of productivity, the results of this paper could be also interpreted in terms of industry heterogeneity in which fixed operational costs determines the mass of industries that are active at a particular point in time. By intensifying competition, trade openness reduces profitability and thus causes less efficient industries to leave the market. Although this model shares the framework with the current paper, the source of heterogeneity across industries is initial productivity and other variables such as market power or trade openness are identical across industries.

Ederignton and Mc Calman (2007) explore the effect of trade liberalization on the rate of technology adoption in a small open economy. This paper finds that unilateral trade liberalization

[1] A movement from autarky to free trade has a larger effect on innovation and productivity growth, when the elasticity of substitution across products is lower, whereas in the context of tariff reductions, a larger effect is expected in industries that offer very similar products.

is likely to delay the adoption date for the median firm. This effect depends on several industrial characteristics and the effect is stronger in, for example, more competitive industries (low entry costs, large domestic markets). Our paper differs in several dimensions. First, they use partial equilibrium whereas we use general equilibrium: hence, they fail to address the interactions across sectors that emerge in a general equilibrium framework. Second, by using monopolistic competition they ignore the strategic interaction among firms that becomes a crucial element in our model. Finally, these authors focus on unilateral trade liberalization policies in a small open economy. In contrast, we explore the effects of bilateral trade policies in an international oligopolistic context.

In addition, few theoretical papers have explored differences in the degree of product market competition and trade asymmetries when analyzing the impact of trade on aggregate outcomes. One exception is the detailed study of Epifani and Gancia (2011) who outline the importance of existing mark-up differences across sectors, across countries and over time, which causes a misallocation of production factors. As all goods are assumed to enter the utility function symmetrically, the Pareto-efficient solution assigns the production factors equally across sectors. Asymmetric trade liberalization creates welfare losses because it generates or amplifies the dispersion of sectorial mark-ups and thus contributes to larger misallocations across sectors. Their paper studies the importance of resource misallocation induced by trade in a static framework and its implications for welfare. The current study complements this research, as it outlines the importance of these asymmetries in a dynamic context by studying its consequences for innovation and growth.

The paper considers exogenous differences in competition across sectors. The model is suitable for analysing the consequences of trade liberalization on productivity growth over a medium-term horizon , or for situations in which entry is purely restrictive for institutional reasons. My research agenda includes endogenising these differences in competition and will be developed in the near future.

2 The model

Consider an economy that is populated by a continuum of consumers of measure L, with instantaneous logarithmic preferences defined over two final consumption goods X_t and Y_t,

$$\int_0^\infty e^{-\rho t}(\beta \ln C_t^x + (1-\beta)\ln C_t^y)dt, \quad \rho > 0,$$

where C_t^x, C_t^y denote respectively the consumption baskets of good X and good Y. Good Y is an homogeneous good.[2] Good X is a differentiated good that takes the following functional form.

$$C_t^x = \prod_{j=1}^{N} (c_{jt})^{\phi_j}\ , \ 0 < \phi_j < 1, \text{ and } \sum_{j=1}^{N} \phi_j = 1.$$

[2] The existence of a traditional good allows for the reallocation of labor to the R&D sector without necessarily reducing the labor that is assigned to the composite good sector. A similar result would hold under the assumption of elastic labor supply as in the work of Aghion et al. (2001). Although the relationship between trade and employment is interesting is not an issue in this paper.

Here a Cobb-Douglas subutility function between the different varieties has been assumed with the parameter ϕ_j controlling for the weights of each of these goods in a consumer's budget. Each of these varieties consists on a continuum of subvarieties that are aggregated following the standard CES functional form:

$$c_{jt}^{x} = \left(\int_{0}^{1} c_{ijt}^{\alpha_j} di \right)^{\frac{1}{\alpha_j}}, \quad 0 \leq \alpha_j < 1$$

,where the parameter α_j controls for the elasticity of substitution across varieties. The structure of our economy distinguishes between industries and subindustries where we have assumed a unitary elasticity of substitution across industries. As we allow permanent industrial differences in productivity growth to affect aggregate TFP growth rate, this preference structure is the only compatible with a Balanced Growth Path in which labor allocation across sectors is constant (Ngai and Pissarides (2006)).[3]

Each variety is produced under Cournot competition[4] with a number of firms n_j which is exogenously given. Each firm produces according to the following technology:

$$q_{lijt} = z_{lijt} l_{lijt}^{x}, \tag{1}$$

where q_{lijt} denotes the quantity produced by firm l producing subvariety i in industry j at time t, and z_{lijt} denotes the firms' stock of knowledge. Firms can also undertake cost-reducing innovations using the following technology:

$$\dot{z}_{lijt} = T_{jt} \left(l_{lijt}^{z} \right)^{\gamma} z_{lijt}, \ \gamma \in (0,1), \tag{2}$$

, which depends on the firm's stock of knowledge (z_{lijt}), and the resources that are devoted to innovation. In this set-up the stock of knowledge is firm-specific and there are no technological spillovers among firms. This assumption is made, to perfectly isolate the contribution of the increase in competition that is derived from trade openness on innovation and productivity from other sources (international R&D spillovers). T_{jt} is a technological constant, that includes industry R&D productivity differences that are not attributable to the internal firm proccess of knowledge accumulation.

At any point in time firms in j decide the quantity to supply and the optimal allocation of workers for both, physical production and R&D, taking into consideration other firms' strategies.

[3] This assumption simplifies calculations at some expenses. We have explored the role of the elasticity of substitution across industries and considered a version of this model with an innovation function that presents decreasing returns to scale in the accumulation of knowledge as in the work of Jones (1995). The advantage of this framework is that the steady state productivity growth rate is identical across industries and therefore, the aggregate TFP growth rate is constant independently of the elasticity of substitution across products. In this situation trade may generate temporary differences in productivity growth across sectors but does not generate permanent differences. However, the model is able to generate permanent differences in productivity levels across industries. The qualitative results are identical to those presented further in the paper. Thus, the results that are presented here are robust to changes in the elasticity of substitution across the different varieties of the composite good X_t. (Available upon request).

[4] Under Cournot competition with firms offering homogeneous goods, the model yields tractable solutions. However, the results derived in this paper are qualitatively more general, and it allows for alternative market structures such as: Cournot competition with firms that offer imperfect substitutes and Bertrand competition with product differentiation. (Available upon request).

This game belongs to the family of differential games, or repeated games defined in continous time, in which past actions affect current payoffs. Two different concepts of Markov perfect Nash equilibria have been proposed in the literature, the open-loop and the closed-loop Nash equilibrium. In an open-loop Nash equilibrium a firm initially selects the optimal path of strategies taking other firms' path of strategies as given and the firm remains to this path forever. In this sense an open-loop Nash equilibrium is equivalent to a static Nash equilibrium in which the possible strategies are time paths of actions and the associated payoffs are infinite sums of payoffs. This paper focuses in open-loop Nash equilibria (OLNE), mainly because standard optimal control theory techniques can be applied in order to find this type of equilibria. In addition,Navas and Licandro(2011) shows that the OLNE equilibria in this game collapse into the CLNE (closed loop Nash equilibria) being the game perfect or time-consistent.

The following definition applies for each firm in the subvariety i of the industry j (we omit some notation for simplification). Let $a_l = [q_{lT,} l_{lT}^{z}]$, $\forall\ T \geq t$ be the strategy of firm l, where $[q_{lT,} l_{lT}^{z}]$ are the time-paths of output and R&D workers, and let us denote Ω_l, as the set of possible strategies of firm l in variety i in sector j. Let V_l be the value of firm l when the firm plays the strategy path a_l and the $n_j - 1$ firms in the market, $n_j \geqslant 2$, play strategies $a_{-l} = \left\{a_1, a_2, ...a_{l-1}, a_{l+1}....a_{n_j}\right\}$

Definition 1 *At time t,* $A_l = [a_l^*, a_{-l}^*]$ *is an open loop Nash equilibrium if,*

$$V_i\left[A_l\right] \geq V_i\left[A_l'\right] \geq 0,$$

where $A_l' = [a_l', a_{-l}^*]$, $\forall\ a_l' \neq a_{l,}^* \in \Omega_l, \forall_l$.

This condition implies that the optimal time path of strategies a_l^* maximises the value of firm l taking as given other firms' strategies, (a_{-l}^*), and that the value of the firm must be non-negative.

2.1 Solving for the autarkic equilibrium

Let E_{jt}^i denote the expenditure dedicated to consuming the variety j of the good i, and let E_t denote the expenditure that is devoted to consumption. Consumers solve the standard optimal control problem that is defined above. The optimal conditions are as follows

$$E_t^x = \beta E_t, \tag{3}$$
$$E_t^y = (1-\beta)\, E_t, \tag{4}$$
$$E_{jt}^x = \phi_j E_t^x, \tag{5}$$
$$\frac{\dot{E}_t}{E_t} = r_t - \rho, \tag{6}$$
$$p_{jt} = \frac{LE_{jt}^x}{x_{jt}}, \tag{7}$$
$$p_{ijt} = \left(\frac{LE_{ijt}^X}{P_{jt}x_{ijt}}\right)^{1-\alpha_j} P_{jt}, \tag{8}$$

and $P_{jt} = \left(\int_0^1 p_{ijt}^{\frac{\alpha_j}{\alpha_j - 1}}\, di\right)^{\frac{\alpha_j - 1}{\alpha_j}}$, is the standard aggregate price index.[5]

[5] This is the inverse of the standard demand function derived in a Dixit-Stiglitz framework:

Firm l in subvariety i of industry j solves the problem:

$$V_{ijs} = \max \int_s^\infty R_{s,t} \left((p_{ijt} - z_{lijt}^{-1}) q_{lijt} - l_{lijt}^z \right) dt, \qquad \text{s.t.} \tag{9}$$

$$\begin{aligned} p_{ijt} &= \left(\frac{LE_{jt}^X}{P_{jt} x_{ijt}} \right)^{1-\alpha_j} P_{jt} \\ x_{ijt} &= \sum_{l=1}^{n_j} q_{lijt} \\ \dot{z}_{lijt} &= T_{jt} (l_{lijt}^z)^\gamma z_{lijt}, \quad 0 < \gamma < 1 \\ z_{lij0} &> 0, \end{aligned}$$

where $R_{s,t} = e^{-\int_s^t r_\tau d\tau}$ is the usual market discount factor. We restrict the analysis to symmetric equilibria by assuming that the initial stock of knowledge is equal for all firms in the same sector i.e. $z_{lij0} = z_{ij0}, \forall\, l$. In addition, to ensure simplicity, we assume that the initial productivity is equal across all firms in the economy. Because we focus on symmetric equilibria we omit the subscript l for the sake of simplicity. Deriving first order conditions, rearranging terms and applying symmetry, we get:

$$q_{ijt} = \theta_j z_{ijt} l_{jt} E_{jt}^x, \tag{10}$$

$$1 = \gamma v_{ijt} T_{jt} (l_{ijt}^z)^{\gamma-1} z_{ijt}, \tag{11}$$

$$\frac{z_{ijt}^{-2} q_{ijt}}{v_{ijt}} + T_{jt} \left(l_{ijt}^z \right)^\gamma = \frac{-\dot{v}_{ij}}{v i_j} + r_t, \tag{12}$$

where v_{ijt} is the costate associated with variable z_j and $\theta_j \equiv \frac{n_j - 1 + \alpha_j}{n_j}$ is the inverse of the markup rate. We denote l_j as $\frac{L}{n_j}$.

The left hand side of condition (12) is the marginal gain of accumulating one additional unit of knowledge, and it can be separated into two parts: the first consists of the reduction in the marginal production costs, which are proportional to the quantity supplied, and the second one represents learning by doing in research. The benefit of a cost-reduction innovation depends on the quantity produced, as it determines the amount of resources that are saved as a result of such a reduction in production costs.

Given that the quantity that is produced determines innovation effort, the way in which quantities are determined is fundamental for innovation. This is shown in equation (10). In this model, an increase in the number of firms generates two different, opposite effects. First, the market share of each firm declines, as shown in the last term of condition (10), as $l_j = \frac{L}{n_j N}$. This is the *size effect* or the market share effect. Second, the markup $\frac{1}{\theta_j}$ depends positively on the *perceived elasticity of demand* which is positively associated to the number of firms and the elasticity of substitution

$x_{ijt} = \left(\frac{LE_{jt}^X}{P_{jt}} \right) \left(\frac{p_{ijt}}{P_{jt}} \right)^{\frac{1}{\alpha_j - 1}}$, across varieties.[6] An increase in competition, given by an increase in the number of firms or an increase in the degree of substitutability across products, increases the perceived elasticity of demand. The increase in the perceived elasticity of demand give incentives to firms to increase the quantity supplied. This effect is represented by the first term on the right hand side of (10). This is the *competition effect*.

The set of optimal strategies across varieties depends on their own stock of knowledge and industry characteristics. Because we have assumed that $z_{ij} = z_0 \; \forall \; i$, we will also have symmetric equilibria across all varieties within the same industry.

To complete the model, we must impose the market clearing conditions for all markets. In the case of the labor market:

$$\sum_{j=1}^{N} \int_{0}^{1} n_j \left(l_{jt}^{x} + l_{jt}^{z} \right) di + L_t^y = L. \tag{13}$$

Each final good market must satisfy that:

$$Lc_{ijt} = x_{ijt}$$

The financial market-clearing condition implies that the aggregate asset demand LA_t is equal to the stock market value of firms:

$$LA_t = \sum_{j=1}^{N} \int_{0}^{1} n_j V_{jt} di. \tag{14}$$

Finally, let us impose the market-clearing condition in sector Y:

$$LE_t^y = L_t^y. \tag{15}$$

2.2 Balanced growth path

A Balanced Growth Path (BGP) is an equilibrium path in which variables $l_{jt}^x, l_{jt}^z, L_t^x, L_t^z, L_t^y, r_t, E_t, E_t^x, E_t^y$ and q_t^y, are constant and $q_{jt}, x_{jt}, z_{jt}, v_{jt}$ and p_{jt} grow at a constant rate. Next we will show that a BGP exists and is unique.[7]

Because $q_{ijt} = q_{jt} \; \forall i$, it follows from (8) that $p_{ijt} = p_{jt}$, we obtain the following equation:

$$p_{jt} = \frac{LE_{ijt}^x}{x_{ijt}} \tag{16}$$

.

[6] To see this notice that the mark-up μ_j is given by: $\mu_j = \frac{1}{1-\tilde{\varepsilon}_j}$ where $\tilde{\varepsilon}_j$ is the inverse of the perceived elasticity of demand $\tilde{\varepsilon}_j = s_j \varepsilon_j$ where s_j is the market share of the firm and ε_j the inverse of the elasticity of demand $(1 - \alpha_j)$. An increase in n or an increase in α_j increases the perceived elasticity of demand.

[7] In Appendix B, we also show that the economy jumps to its BGP at the initial time, so there is no transitional dynamics.

Because, $x_{ijt} = n_j q_{jt}$, and $E^x_{ijt} = E^x_{kjt}$ $\forall$ i, k substituting these conditions and (10) in (16), we get:

$$p_{jt} = \frac{1}{\theta_j} (z_j)^{-1}. \tag{17}$$

In a symmetric equilibrium $Lp_{jt}c_{jt} = n_j p_{jt} q_{jt}$. Combining this with (17) we have that

$$\frac{n_j}{\theta_j} l^x_{jt} = \frac{n_k}{\theta_k} \frac{\phi_j}{\phi_k} l^x_{kt}$$

and then

$$\frac{l^x_{jt}}{l^x_{kt}} = \frac{\phi_j}{\phi_k} \frac{\theta_j}{\theta_k} \frac{n_k}{n_j}$$

The per firm labor demand that is dedicated to production activities is larger in sectors characterised by less competition. However the industry labor demand that is dedicated to production activities (i.e. $L^x_{jt} = n_j l^x_{jt}$) is larger for more competitive industries. As is standard under Cournot, firms in sectors that are associated with lower competition produce higher quantities, but the the total production of the sector is lower. [8] This implies that the per firm labor demand in the production sector is larger in those sectors that are less competitive.

Combining (2), (10), (11) and (12), under $\dot{l}^z_{jt} = 0$, we obtain the following equation

$$\gamma T_{jt} (l^z_j)^{\gamma-1} l^x_j = \rho. \quad j = 1, 2, ...N \tag{18}$$

and therefore

$$\gamma T_{jt} (l^z_j)^{\gamma-1} l^x_j = \gamma T_{kt} (l^z_k)^{\gamma-1} l^x_k \quad \forall\ j, k.$$

This is the consequence of the fact that consumers are indifferent among the different R&D investment opportunities in each sector. In steady state the arbitrage condition implies that the rate of return of innovation must be equal in all sectors, and equal to the discount rate. Then:

$$\frac{l^z_j}{l^z_k} = \left(\frac{T_{jt}}{T_{kt}} \frac{l^x_j}{l^x_k} \right)^{\frac{1}{1-\gamma}} \tag{19}$$

Condition (19) reveals the dual nature of our model as a result of a standard mechanism in oligopoly models. If we measure competition by measuring the elasticity of substitution across products, then we find that as markets become more competitive (products become more substitutable), each firm produces more and therefore innovates more. However, if we measure competition by measuring the number of competitors, as markets become more competitive, each firm

[8] Notice that total labor force that is dedicated to production activities in both sectors is given by: $\frac{n_j l^x_{jt}}{n_k l^x_{kt}} = \frac{\theta_j}{\theta_k} \frac{\phi_j}{\phi_k}$
An increase in the number of firms in sector j increases the allocation of labor to production activities in sector j. Then the aggregate allocation of labor to production activities depend on the degree of competition adjusted by size (that we will later call $\tilde{\theta}_j$).

produces less and therefore innovates less. According to this measure, lower degrees of product market competition are associated with greater per-firm resources devoted to R&D. The total industry R&D expenditure is given by the following:

$$\frac{n_j l_j^z}{n_k l_k^z} = \left(\frac{\theta_j}{\theta_k} \frac{\phi_j}{\phi_k} \frac{n_k}{n_j} \frac{T_{jt}}{T_{kt}} \right)^{\frac{1}{1-\gamma}} \frac{n_j}{n_k} = \left(\frac{n_j - 1 + \alpha_j}{n_k - 1 + \alpha_k} \frac{\phi_j}{\phi_k} \frac{T_{jt}}{T_{kt}} \right)^{\frac{1}{1-\gamma}} \left(\frac{n_k}{n_j} \right)^{\frac{\gamma+1}{1-\gamma}}$$

In this context, and for lower values of n_j, a larger number of firms within an industry is associated with a larger volume of resources devoted to R&D in that industry. [9]

To obtain an expression for the equilibrium allocation of workers across activities and sectors, we observe the following:

$$l_j^x = \frac{\rho}{\gamma T_{jt}} \left(l_j^z \right)^{1-\gamma},$$

A nice property of this model is that the steady state solution can be summarised in a single non-linear equation, as follows:

$$\left(\frac{(1-\beta) + \beta\tilde{\theta}}{\beta\tilde{\theta}_k} \right) \frac{\rho}{\gamma T_{kt}} \left(l_k^z \right)^{1-\gamma} + \left(\sum_{j \neq k}^{N} \left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k} \frac{T_{jt}}{T_{kt}} \right)^{\frac{1}{1-\gamma}} \left(\frac{n_k}{n_j} \right)^{\frac{\gamma}{1-\gamma}} + 1 \right) l_k^z = l_k \tag{20}$$

where $\tilde{\theta}$ is a size-weighted average of the degree of competition across sectors (i.e. $\sum_{j=1}^{N} . \tilde{\theta}_j$ where $\tilde{\theta}_j = \phi_j \theta_j$ is a measure of the degree of competition of sector j, weighted by the importance that sector j has in total expenditure in the manufacturing sector. For the spetial situation in which we have two type of industries this measure becomes $\tilde{\theta} = \phi\theta_1 + (1-\phi)\theta_2$.

The next proposition shows that the BGP exists and it is unique.

Proposition 2 *A BGP exists and it is unique*

Proof. Since $f(.)$ is monotonically increasing, and satisfies the limit conditions $\lim_{x \to 0} f(x) = 0$ and $\lim_{x \to l} f(x) > l_k$, existence and uniqueness is directly implied by the intermediate value theorem.

Notice that if $\beta = \frac{1}{2}, \phi_j = \phi_k$ and $\theta_j = \theta_k$ (i.e. $n_j = n_k$, $\alpha_j = \alpha_k$) the previous equation is equal to that derived inNavas and Licandro(2011) with N being the number of industries existing in the composite sector. ■

To explore the properties of the model, we observe figure (1) , which depicts the left and right hand sides of condition (20) for certain parameter values (discussed below).

[9] More precisely, taking the logs of the right hand side expression and differentiating with respect to n_j we ogtain:
$\frac{d \ln \frac{n_j l_j^z}{n_k l_k^z}}{d n_j} = \frac{1}{1-\gamma} \frac{1}{n_j - 1 + \alpha_j} - \frac{\gamma+1}{1-\gamma} \frac{1}{n_j}$
This is bigger than zero iff:
$\frac{1}{\theta_j} > 1 + \gamma$
Since γ is going to be very close to zero, this is going to be the case of a great part of all numerical exercises. In concrete this will be the case whenever
$n_j < \frac{(1-\alpha)(1+\gamma)}{\gamma}$

The LHS part of (20) is monotonically increasing and concave in the argument l_k^z. However, as we will discuss below, the value of γ and ρ suggested by the data are close to zero. Substituting these parameter values we obtain that LHS is nearly linear in this argument.

Notice that an increase in the degree of product market competition induced by an increase in α_k increases the per firm resources dedicated to innovation in industry k. This is clearly shown in figure 2. The increase in α_k causes an increase in θ_k and moves the LHS to the right (the LHS is monotonically decreasing in θ_k). When firms face a more elastic-demand they increase the quantity supplied in the market. The increase in firm-size translates into greater innovation efforts and stimulate plant and industry productivity growth.

However, an increase in the degree of product market competition (measured as an increase in n_k) decreases the per firm resources dedicated to innovation in industy k. The main difference with respect to the experiment above is that when we increase n_k the direct effect appears, and moves the RHS down (figure 3). As is standard in the Cournot model, the direct effect is dominant; therefore an increase in the number of firms translates into a decrease in output per firm. As firm size decreases, firm level innovation efforts decreases. Note that we can not directly offer conclusions regarding the final effect in l_j^z based on 19 .

An increase in the degree of product market competition (measured as an increase in α_j) decreases the firm resources that are dedicated to innovation in industry k (Figure 4). The increase in α_j causes an increase in θ_j moving left hand side into the left. This reduces innovation efforts in industry k. As industries compete for labor, the increase in efficiency in industry j is associated with a reallocation of resources from the remainder of industries to industry j. Interestingly, this general equilibrium effect is shaped by the importance of industry j in the consumer's budget $\left(\phi_j\right)$. As ϕ_j approaches to zero, this effect will be negligible. However, the numerical results in the section below show that even for very low values of ϕ_j this effect is still quantitatively important.

Technological opportunities measured by the R&D's "TFP" (T_{jt}) also plays an interesting role in determining firms' innovation efforts in sector j. The increase in R&D productivity in sector j increases innovation efforts but is detrimental to other sectors.

Therefore, in autarky, the increase in product market competition produces an ambigous effect on innovation efforts and industry productivity growth. This ambiguity results from the different ways in which the degree of competition is measured. We will see in the next section that this ambiguity disappears in a global competitive environment. Moreover, asymmetries across industries generate a reallocation of resources that ultimately affects the industry both statically, through a change in the relative price of the goods and dynamically favoring industry productivity growth in some industries to the detriment of other industries. The size of the sectors also contributes to the relative importance of these effects.

2.3 Free trade

Consider that the economy is open to trade with M identical economies. To serve a foreign market, firms pay a transportation cost of the iceberg type (i.e firms need to ship $(1+\tau_j)$ units of the good

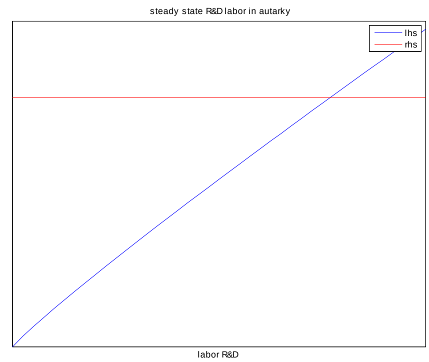


Figure 1: Steady State firm-employment in R&D industry k

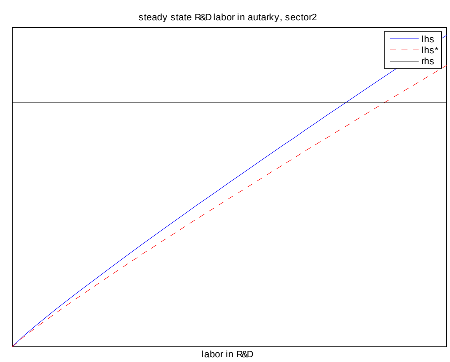


Figure 2: An increase in α_k.

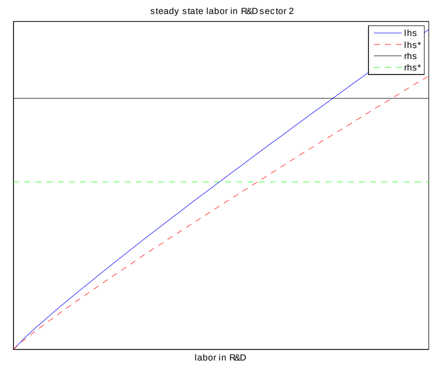


Figure 3: An increase in n_k

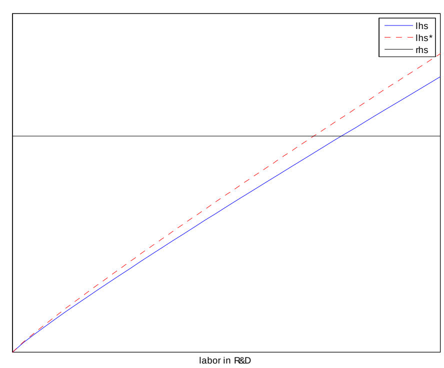


Figure 4: An increase in α_j.R&D labor in sector k.

to get one unit potentially sold abroad). Let denote with q_{lijt} the quantity that firm l producing subvariety i in sector j produces in its local market and q^{*m}_{lijt} denote the quantity that each firm l in in sector j supplies to country m. Since we assume that all countries are identical, we will again focus on symmetric equilibrium.

Firms solve

$$V_{is} = \max \int_s^\infty R_{s,t} \left[(p_{ijt} - z^{-1}_{lijt}) q_{lijt} + \sum_{m=1}^{M} (p^{*m}_{ijt} - z^{-1}_{lijt}(1+\tau_j)) q^{*m}_{lijt} - L^z_{lijt} \right] dt, \tag{21}$$

$$\begin{aligned} s.t. p_{ijt} &= \left(\frac{LE^X_{ijt}}{P_{jt} x_{ijt}} \right)^{1-\alpha_j} P_{jt} \\ p^{*m}_{ijt} &= \left(\frac{LE^X_{ijt}}{P^{*m}_{jt} x^*_{ijt}} \right)^{1-\alpha_j} P^{*m}_{jt} \\ x_{ijt} &= x^{*m}_{ijt} = \sum_{l=1}^{n_j} q_{lijt} + \sum_{m=1}^{M} \sum_{l=1}^{n_j} q^{*m}_{lijt} \\ \dot{z}_{lijt} &= T_{jt} (l^z_{lijt})^\gamma z_{lijt}, \quad 0 < \gamma < 1 \\ z_{lij0} &> 0, \end{aligned} \tag{22}$$

where q^{*m}_{lijt} is now the quantity that a local firm sends to the foreign market m. We can focus on a symmetric Nash equilibrium where q_{lijt} and q^{*m}_{lijt} are equal for all firms within the same sector in all countries but differ across sectors and across destinations (i.e, $.q_{lijt} = q_j$,$.q^{*m}_{lijt} = q^*_j$ $\forall\ l\ \epsilon\ n$,$\forall i$,$\forall\ m\ \epsilon\ M$,and $q_j \neq q^*_j$). We obtain the following first order conditions:

$$\left(\frac{LE_t}{n_j(q_j + Mq^*_j)P_{jt}} \right)^{1-\alpha} P_{jt} \left(1 - \frac{(1-\alpha_j)q_j}{n_j(q_j + Mq^*_j)} \right) = z_j^{-1} \tag{23}$$

$$\left(\frac{LE_t}{n_j(q_j + Mq^*_j)P_{jt}} \right)^{1-\alpha} P_{jt} \left(1 - \frac{(1-\alpha_j)q^*_j}{n_j(q_j + Mq^*_j)} \right) = z_j^{-1}(1+\tau_j) \tag{24}$$

$$1 = \gamma v_t T_{jt} (l^z_t)^{\gamma-1} z_{jt}, \quad j = 1,2 \tag{25}$$

$$\frac{z^{-2}_{jt} \left(q_{jt} + M(1+\tau_j) q^*_{jt} \right)}{v_{jt}} + \left(l^z_{jt} \right)^\gamma T_{jt} = \frac{-\dot{v}_j}{v_j} + r_t, \quad j = 1,2 \tag{26}$$

Firms consider the total volume of production when selecting the amount of resources to devote to R&D. Dividing (23) and (24) we obtain the following equation:

$$\frac{(n_j - 1 - \alpha_j)q_j + Mn_j q^*_j}{n_j q_j + (Mn_j - 1 - \alpha_j)q^*_j} = \frac{1}{1+\tau_j}$$

we simplify the equation as follows:

$$q_j^* = \frac{(1+\tau_j)(1-\alpha_j) - \tau_j n_j}{1-\alpha_j + M n_j \tau_j} q_j \tag{27}$$

(27) implies an interesting result. Manipulating (27) we deduce that if $\tau_j \geq \frac{1-\alpha_j}{n_j - 1 + \alpha_j}$, then $q_j^* = 0$. Unlike the monopolistic competition model where the CES preference structure ensures that all firms have positive trade flows independently of the trade cost, trade exists in this economy if and only if trade costs are not excessively high. This is the consequence of the fact that foreign goods and home goods are perfect substitutes. Therefore, a sufficient and necessary condition for foreign firms to survive in a local market is that the cost disadvantage that is introduced by transportation costs is not sufficiently large. [10] Substituting in 23, then we have that:

$$q_j = \frac{(n_j - 1 - \alpha_j) + M n_j \left(\frac{(1+\tau_j)(1-\alpha_j) - \tau_j n_j)}{1-\alpha_j + M n_j \tau_j} \right)}{n_j \left(1 + M \left(\frac{(1+\tau_j)(1-\alpha_j) - \tau_j n_j)}{1-\alpha_j + M n_j \tau_j} \right)\right)^2} z_j l_j E_t^x$$

We simplify the equation as follows:

$$q_j = \frac{((1+M)n_j - 1 + \alpha_j))(1 - \alpha_j + M \tau_j n_j)}{n_j (1-\alpha_j)(1 + M(1+\tau_j))^2} z_j l_j E_t^x$$

and substituting in 27

$$q_j^* = \frac{((1+M)n_j - 1 + \alpha_j)((1+\tau_j)(1-\alpha_j) - \tau_j n_j))}{n_j (1-\alpha_j)(1 + M(1+\tau_j))^2} z_j l_j E_t^x$$

and then, we can express total output per firm $q_T = q_j + M(1+\tau_j) q_j^*$
$q_T = \theta_j' z l_j E_{jt}^x$
where

$$\theta_j' = \frac{((1+M)n_j - 1 + \alpha_j)\left[(1 - M + 2M(1+\tau_j))(1-\alpha_j) + \tau_j^2 (1 - \alpha_j - n_j)\right]}{n_j (1-\alpha_j)(1 + M(1+\tau_j))^2} \tag{28}$$

θ_j' differs slightly from that defined in autarky because it is generally not the inverse of the mark-up but can still be used as a measure of competition.[11] It can be shown (see the appendix) that the steady state solution of the model can be summed up into the following equation:

[10] In this model, foreign firms serve the domestic market despite this disadvantage in costs. This feature is unique under Cournot competition and appears to be paradoxical, as foreign firms are more inefficient than domestic firms when serving a local market. However, foreign firms have a particular advantage over potential local entrants because they are incumbents. This could be because there are institutional or technological barriers that limit entry.

[11] More precisely, in this case: $p_j = \frac{1}{\theta_j'}(1 + \frac{\tau M q_j^*}{q_j + M q_j^*}) z^{-1}$ .Then θ_j' is the inverse of the mark-up in two extreme cases: Autarky: ($\tau_j = \frac{1-\alpha_j}{n_j - 1 + \alpha_j}$) or $M = 0$) and free trade (i.e. $\tau_j = 0$). In the first case, $q_j^* = 0$: thus the second element of the price equation is equal to one. In that case, $\theta_j' = \left(\frac{n_j - 1 + \alpha_j}{n_j}\right)$ when $\tau_j = \frac{1-\alpha_j}{n_j - 1 + \alpha_j}$ or $M = 0$. In the second case $\tau_j = 0$, and the second element of the price equation is also equal to one. In that case $\theta_j' = \left(\frac{(1+M)n_j - 1 + \alpha_j}{(1+M)n_j}\right)$.

$$\left(\frac{(1-\beta)+\beta\tilde{\theta}'}{\beta\tilde{\theta}'_k}\right)\frac{\rho}{\gamma T_{kt}}(l_k^z)^{1-\gamma}+\left(\sum_{j\neq k}^{N}\left(\frac{\tilde{\theta}'_j}{\tilde{\theta}'_k}\frac{T_{jt}}{T_{kt}}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_j}{n_k}\right)^{\frac{\gamma}{1-\gamma}}+1\right)l_k^z=l_k \tag{29}$$

where $\tilde{\theta}'_k=\phi_k\theta'_k$ and $\tilde{\theta}=\sum_{j=1}^{N}\phi_j\theta'_j$. This condition is analogous to the one in autarky but with the new value for the parameter θ'_j.

In the appendix we show that $\theta'_j>\theta_j$.Navas and Licandro(2011) also reveals that a movement from autarky to free trade, or a trade liberalization (understood as a decrease in transportation costs) increases employment in the R&D sector, and this increased employment has positive effects on innovation and productivity growth in a situation with perfect symmetry across sectors. The focus of this paper is to demonstrate how the situation changes when we allow for sectorial differences (in this context, differences in competition levels) or when we have a proccess of trade liberalization that is not symmetric across sectors. We rely on numerical methods to demonstrate these results.

3 Results I: From Autarky to Free trade

The aim of this section is to assess the importance of differences in exposure to foreign trade or in the the degree of product market competition on the effect of trade openness on innovation. It is not a pure calibration exercise as the experiment does not attempt to replicate a trade liberalization episode for a particular case. Rather we obtain plausible values for the structural parameters of the model and then employ several counterfactuals, to better understand how these dimensions affect the industrial response to foreign trade.

The structural parameters that we must fix in this section are ρ,γ,L,β, and T_{jt}. In steady state ρ, the consumer's discount factor, is equal to the real interest rate (logarithmic intertemporal preferences). We use the value that the business cycle literature traditionally assigns to this parameter, which is 0.03. The parameter β measures the weight of the differentiated sector in total expenditures. We exclude the production of services in our analysis because of the spetial characteristics of this sector.[12] We consider the manufacturing sector to be the differentiated sector of the economy. The World Development Indicators database from the World Bank computes the value added of the manufacturing sector as a percentage of GDP. Manufacturing represents 25% of the total GDP for the US economy which implies a share of 91% of the total GDP net services. This justifies a value for the parameter β of 0.91.

It remains to fix the parameters γ, L and T_{jt}. γ measures the degree of decreasing labor returns in the R&D sector. To obtain reasonable values for this parameter, we rely on the work of

[12] The Service sector accounted for 72% of the US GDP in 2011. However, most of the products that are included in this sector are non-tradable by nature. When examining the standard index of trade openness $\frac{(Exports+Imports)}{GDP}$ at the sectorial level we find that trade in services is responsible for just 8% of the value of the production of the sector. Conversely, trade in merchandise (manufacturing+agricultural goods) accounts for 73% of the value of the production of manufacture and agricultural goods in the US. Because we have not included a non-tradable sector in our economy it seems reasonable to exclude the service sector from the numerical analysis.

Ngai and Samaniego (2010) who explore the main determinants of differences in long run industry productivity growth rates. These authors use a richer but similar innovation function. In their paper, new knowledge is entirely produced using an intermediate research input. The elasticity of new knowledge to this intermediate research input is equal to 0.13. This research intemediate good is produced with physical capital and labor using a Cobb-Douglas technology. The Intermediate input's labor share is 0.6. The elasticity of R&D to research labor is therefore $\gamma = 0.6*0.13 = 0.078$. We will use the value $\gamma = 0.08$ and perform robustness checks for this parameter.

Because the aim of the paper is to distinguish the contributions of differences in the degree of trade openness and in the level of competition on the relationship between trade and innovation, this study leaves apart differences in other relevant dimensions, such as technological opportunities T_{jt} (i.e. $T_{jt} = T_t \; \forall \; j$). Note the following equation:

$$T_{jt} = \frac{n_j l_j^z}{n_j l j^x} \frac{\rho}{\gamma} \left(l_j^z \right)^{-\gamma}$$

With γ very closed to zero the third term can be ignored, and this technological constant can be proxied as follows: $T_t = \frac{L_z}{L_x} \frac{\rho}{\gamma}$. The Bureau of labor statistics reports that the average labor force that was dedicated to industrial activities in the US for the 2000-2010 period, was 20%. The NSF provides data on R&D employment and R&D expenditures for the US and selected countries. For the US we find that the number of researchers steadily increased from 1, 25 million in 2000 to 1.4 million in 2007. If we assume that the labor force in R&D activities was exclusively employed in manufacturing, this constitutes approximately 5% of the total labour force employed in manufacturing (that is, 1% of the total labor force aproximately) . Using these data we find that our technological constant should take the value: $T_t = 0,018$.[13] We will use this as a benchmark case in addition to some sensitivity analyses.

Because the population is identical to the work force, L, in our model, we proxy for this parameter by using the size of the US labour force. More precisely we assign a value of 153000 which was obtained from US labour workforce data for 2007 (provided by the Bureau of Labor Statistics, correctly rescaled to optimally fit the model). The parameters $M, \tau_j, \phi_j, \alpha_j$ are subject of interest in this paper therefore, in this section they will take a different rank of values depending on the counterfactual exercise run in each case. The initial value for τ_j will be discussed in the next section.

To perform the numerical exercises we assume that industries can be classified in two types, both of which have the same expenditure shares in the consumer budget. We denote industries as either Type I or Type II. In the first experiment both industries are equal in all dimensions and they move from autarky to free trade, with one or more identical trade partners. Given the parameter configuration, four is the maximum number of firms per industry, compatible with positive profits in equilibrium when the number of trade partners is equal to two. We restrict the analysis to two trade partners to ensure a certain amount of variability in the number of firms per industry.[14]

[13] More precisely $\left(\frac{1}{55}\right)$.

[14] The maximum number of firms per industry declines with the number of partners we trade. When we study the context of three trade partners, the maximum number of firms per industry is equal to three.

Trade openness increases R&D labour in both industries and enhances innovation and productivity growth. However, the gains in productivity decline according to the degree of competition that both economies enjoy in autarky. This result occurs because the increase in the number of competitors generates a non-linear increase in the perceived elasticity of demand which is stronger when the number of firms is initially low. Because all gains from trade in this model are derived from increased competition, the model shows that the gains from trade vanish as economies approach to perfect competition. As Epifani and Gancia (2011) document that mark-ups are systematically higher in less developed countries, the model suggests that free trade agreements among less developed countries (southern regional trade agreements), result in a larger increase in productivity growth than free trade agreements among developed economies. A similar result is obtained when we measure the degree of competition using the elasticity of substitution across varieties. In this case free trade has a larger effect on innovation and productivity growth when the degree of substitutability across products is small (i.e. consumers perceive that varieties in the same sector are starkly different).

Figure 5 also reveals an interesting result regarding the size of regional trade agreements. The dotted line in the graph reports the increase in R&D employment as a result of trade openness when the number of trade partners is two rather than one (the continous line). An increase in the number of trade partners enhances innovation and productivity growth in all countries. However, the increase in the R&D employment is lower when two economies open to a third partner than when both economies eliminate bilateral trade barriers; hence, opening to a third partner generates a smaller effect in terms of innovation and growth. The model states that an increase in the number of trade partners within a regional trade agreement does not always produce a significantly positive effect on innovation. As the trade block becomes larger, the degree of product market competition increases. This increase in competition has progressively smaller incremental effects on innovation. [15] The model suggests a size "limit" for the trade block; this limit depends on the autarkic degree of competition for each economy and is larger for initially less competitive economies. The model also suggest that trade agreements among less developed economies are potentially more benefitial than trade agreements between advanced and competitive economies.

The second set of results throughly examines the influence of asymmetric trade liberalization. In this exercise we discuss either a movement from autarky to free trade with only one economy or a change in the number of trade partners for just Type I industries. Type II industries remain closed to foreign trade. The results are reported in Table 1.

Table 1 shows the percentual variation in R&D employment for Type I and Type II industries respectively. As a consequence of trade liberalization R&D employment increases in the liberalized sector and decreases in the non-liberalized sector. The decrease in the R&D employment in the non-liberalized sector is a pure general equilibrium effect. Trade openness intesifies competition in the liberalized sector. The increase in competition reduces mark-ups, increases production per firm and thus promotes innovation. As labour demand increases in Type I industries, labor is reallocated to Type I industries. We can conclude that asymmetric trade liberalization positively contributes to industry productivity growth in the liberalized sectors and negatively affects non-liberalized

[15] For other parameter configurations, this result is clearer, as the maximum number of trade partners is larger than two. In this case if we consider a third regional partner, the maximum number of firms that is compatible with positive profits is three per country and we observe that adding a third trade partner produces a small increase in innovation efforts. (upon request).

sectors; therefore, it is a source of industry productivity divergence. This effect increases as the liberalized sector becomes more open (in terms of the number of trade partners). This result occurs because the reallocation effect increases with the improvement in efficiency in the liberalized sector. However, as a sector becomes more competitive, the effect becomes less important and becomes negligible for certain competition levels.

The third set of results studies the influence of a movement from autarky to free trade in industries that are characterized by different degrees of competition. In this case we focus on trade openness with just one trade partner. This allow us to consder six as the maximum number of firms compatible with positive profits in equilibrium. To study this effect, we consider that Type I industries remains with two firms without loss of generality, whereas the number of firms in Type II industries may vary from 2 to 6. We seek to determine the change in R&D employment per firm in each sector when both sectors are open to trade.

Table 2 shows the results for Type I and Type II industries, respectively. When both type of industries, have initially the same number of firms, R&D employment increases by 5%. However, if the initial number of firms in Type II industries increases, trade openness increases R&D employment in Type I industries and reduces R&D employment in Type II industries. Again, this result is the combination of the non-linear competition effect in Cournot and the reallocation of production factors induced by general equilibrium effects; the increase in the perceived elasticity of demand is larger for sectors that are less competitive in autarky. Because trade intensifies competition to a greater degree in those sectors, firms in those sectors increase the volume of production and the investment in research. As the demand for production factors increases to a greater extent in these industries, the production factors from the remainder sectors are reallocated towards those industries.

4 Results II: Trade liberalization policies.

This section explores partial trade liberalization experiments by considering a reduction in variable trade barriers. The structure of the section essentially follows that of the previous section: first we examine the effects of asymmetric trade liberalization in otherwise identical industries: second we examine a homogeneous trade policy in an heterogeneous industry environment.

To perform the numerical simulations, we must begin with an initial tariff rate. Anderson and Van Wincoop (2004) summarise tariff and non tariff barriers using TRAINS (UNCTAD) data: They find that the average tariff rate for industrialised countries is 5% whereas average non-tariff barriers are 8%. Although there are only tariff barriers in our model, we consider a tariff rate of 13% which is the sum of both. To ensure generality, we assume that both industries initially have identical number of firms and initial tariff. Next, we consider that Type II industries retains a tariff rate of 13% whereas type I industries could have a tariff rate between 0 and 13%.

Table 3 shows the variation in percentage points in per firm employment in R&D activities in both the liberalized industries (Type I) and the non-liberalized industries. Each line represents the results for a different initial degree of competition (number of firms) which becomes larger as the

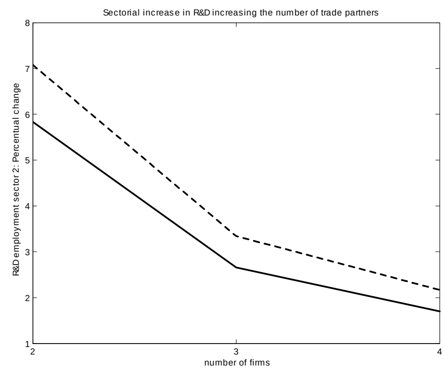


Figure 5: Symmetric case. Several trade partners.

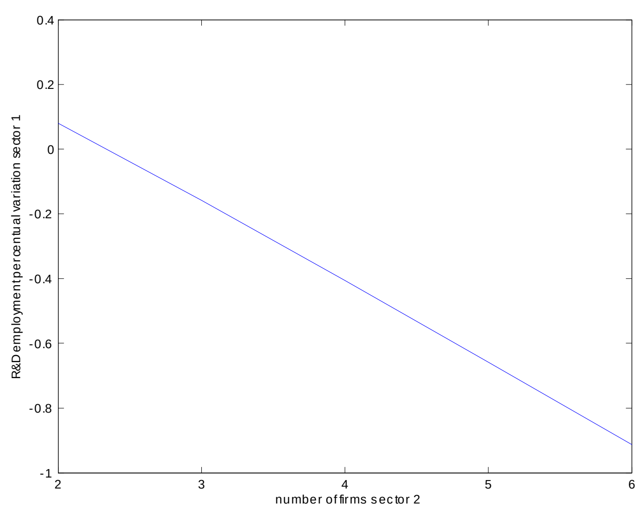


Figure 6: Symmetric Trade liberalization. Tariff reduction.

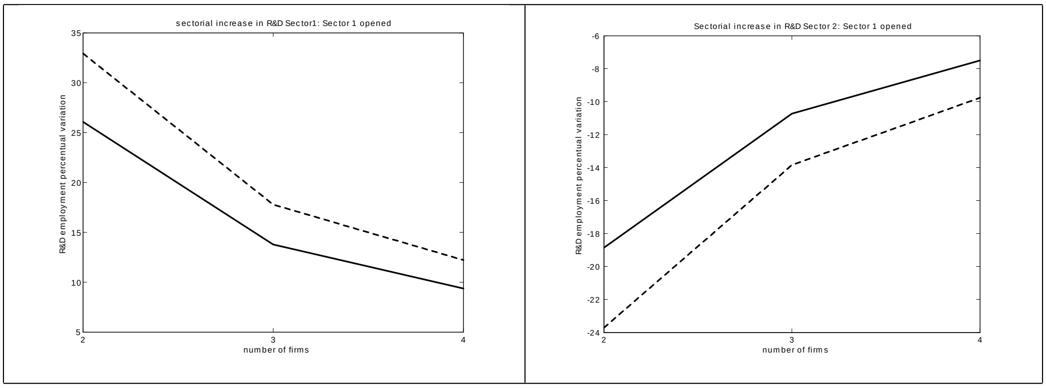


Table 1: Asymmetric trade liberalization

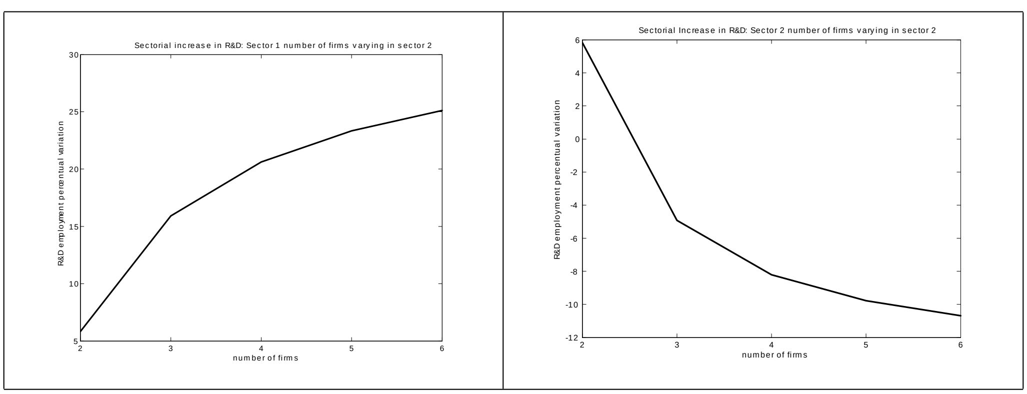
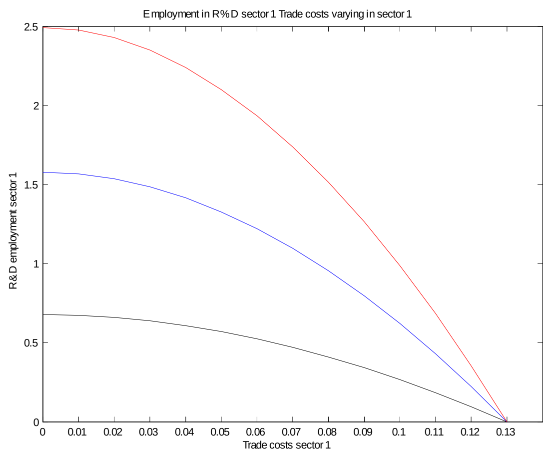
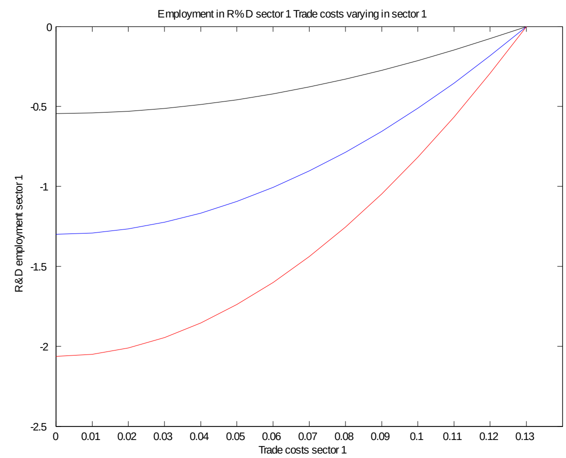


Table 2: Asymmetric trade liberalization

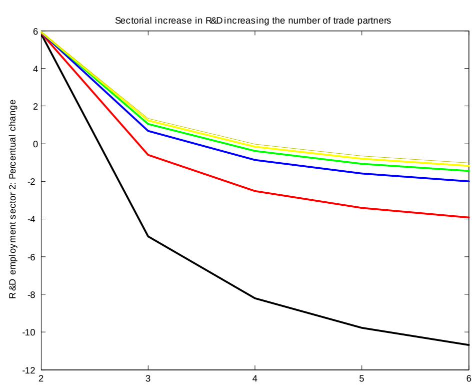


Asymmetric Trade Liberalization Sector 1



Asymmetric Trade Liberalization Sector 2.

Table 3: Asymmetric trade liberalization



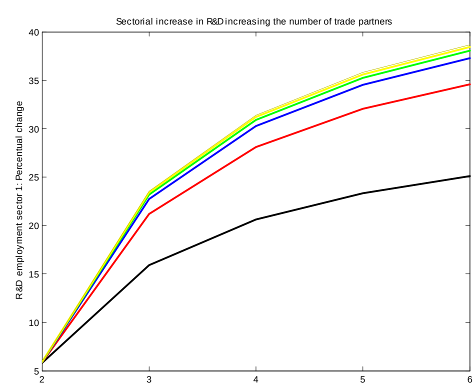


Table 4: Asymmetric trade liberalization

line moves to the right. The OY axis shows the variation in percentage points in R&D employment compared with the initial situation with 13% trade costs. The OX axis shows the different values that trade barriers can take. The largest increase in R&D employment per firm, is obtained when there are no trade barriers in Type I industries, and this increase varies from 0,7 (with two firms in each industry) to 2.5% (with six firms). Larger tariff reductions are associated with larger increases in R&D employment, although the function is concave. Trade liberalization enhances productivity growth in those industries which liberalize, but it has a non-linear effect. The effect is stronger when those industries are relatively more closed to foreign trade.

Another important feature of the model is that a larger initial degree of competition is associated with a larger effect of tariff reductions in Type I industries. Because this result appears to contradict previous results, we will elaborate further below.

Table 3 reveals that trade liberalization in Type I industries decreases per firm R&D employment in Type II industries. This is the consequence of the reallocation of production factors towards the libealized industries. However, the model suggests, that these reallocative effects are not so important in this context. This is the consequence of the fact that the average initial tariff rate for industrialized countries, is low, and therefore these countries are already open on average to international markets. Consequently, a reduction in tariffs of 5 percentual points, do not change competition enourmously in Type I industries and thus the allocation of employees across sectors.

The second experiment focuses on the effect of a homogenous trade policy in sectors that begin with different degrees of competition. The exercise considers a common 5% reduction in tariffs. Type I industries represent the less competitive sector with an initial number of firms equal to 2. The number of firms in Type II industries varies from 2 to 6. Because trade flows exist provided that $\tau^* < \frac{1-\alpha_j}{n_i-1+\alpha_j}$, six is the maximum number of firms that is compatible with positive trade flows and positive profits for a tariff rate of 13%.

Figure 6 shows the variation in percentage points of R&D employment in sector 1 while Figure 7 presents the same results for sector 2. Contrary to our previous observations, R&D employment declines in sector 1, when the number of firms in sector 2 increases. Paradoxically, the fall in R&D employment now occurs in the less competitive industries rather than in the most competitive industries as found in the section above. The general equilibrium effect favours the most competitive industries rather than the less competitive industries in this scenario.

To explain this result, it is useful to plot the change in θ after the tariff reduction across different initial degrees of competition as shown below. Figure 8 displays the value of θ under two different tariff levels, $\tau = 0.13$, and $\tau = 0.08$. When the initial number of firms in a sector increases the increase in teta is larger. For a homogeneous tariff reduction, the increase in competition that is associated with trade liberalization is larger in more competitive environments. The primary reason for this result lies in the upper bound tariff level τ^*. When $\tau = \tau^*$ the open economy collapses to the autarkic one. τ^* is decreasing with the number of firms. Thus for a given τ, a larger number of firms indicate that the industry is closer to an autarkic situation. Therefore, two industries with the same initial tariff rate will react differently to the same tariff reduction: the most competitive industry is relatively less open to trade, and the tariff reduction strongly intensifies competition in this industry.

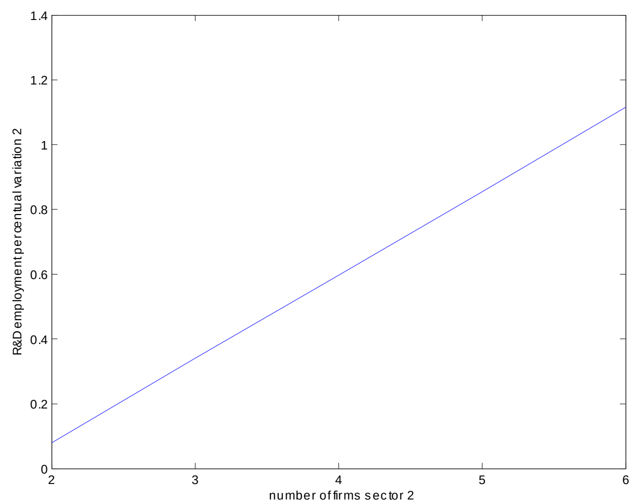


Figure 7: Symmetric Trade Liberalization. Tariff Reduction.

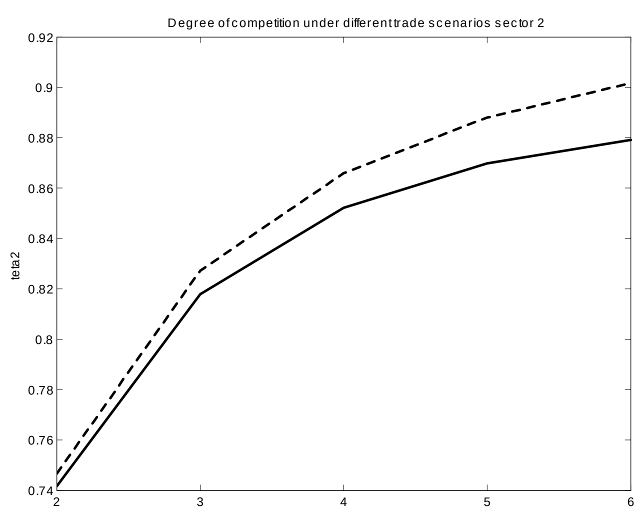


Figure 8: PMC across different tariff levels. Varying number of firms.

We can verify this property in Figure 8. With eight firms θ in autarky is 0.875 and in the open economy with no trade barriers is 0.9375. With $\tau = 0.13$, the value of θ is 0.8851. A 5% tariff reduction leads to $\theta = 0.9167$. The change in θ due to trade liberalization is considerable (3.57%). However, if we consider a situation with two firms, we observe that θ in autarky is 0.5 while in trade with a tariff of 13% is 0.7416. With no trade barriers, the value for θ will be 0.75. That is, this sector which is less competitive is already very open with a tariff of 13%. A 5% tariff cut leads to a $\theta = 0.7467$ or an increase in θ of 0.68%. This small increase in competition due to a 5% tariff cut is what it generates the results above.

5 Robustness

The results are qualitatively robust to changes in the parameters of interest (e.g. small changes in the degree of decreasing returns in innovation, active population size, the discount factor). One of the most interesting dimensions related to the robustness checks, is the manner in which the relative sizes of the opening industries affects the response of all industries to trade liberalization. The role of asymmetries across industries in the results may decrease as industries become less important for the entire economy (lower ϕ_j). To confirm the relevance of this effect, we have assumed that industries are identical in size, but the mass of industries can be classified into different groups where the number of groups varies from two, to forty. We conduct similar experiments in which we vary the dimension of interest in only one type of industry. As the number of industries increase, the relative importance of the reference type of industry decreases.

Table 4 shows the first set of results in which we consider homogeneous trade liberalization policies with differences in the degree of competition. As previously noted, we consider that Type I industries are less competitive, and that the remainder of industries are homogenous in terms of competition. The figure shows that when the less competitive industries are relatively smaller, the increase in R&D employment as a consequence of trade liberalization is larger in those industries. In contrast, when the most competitive industries are relatively larger, the decrease in R&D employment is smaller as a consequence of trade liberalization in those industries. This result occurs because as the number of industries increases the general equilibrium effect that induced by less competitive industries, is shared by a larger mass of industries. Consequently, the decline in R&D employment in each, becomes progressively lower the more numerous they are. It is significant that this general equilibrium effect vanishes relatively slowly. For example, when less competitive industries represents $\frac{1}{13}$ of the total output in the manufacturing sector, the decline in R&D employment in each of the rest of the remainder industries is 1%, which is not negligible. If there were 22 different type of industries (so the less competitive industries represents $\frac{1}{22}$ of the total output in the manufacturing industry), then the decline in R&D employment in each of the remainder industries will be of 0,40%. These results just show that these effects are important even if the less competitive industries represent a very small share of the industrial output.

The same experiment was conducted by considering trade liberalization as an undercut in tariffs. The very first set of results consider that Type I industries become more open while the remainder of the industries remain at a tariff rate of 13%. The results are shown in Table 5.

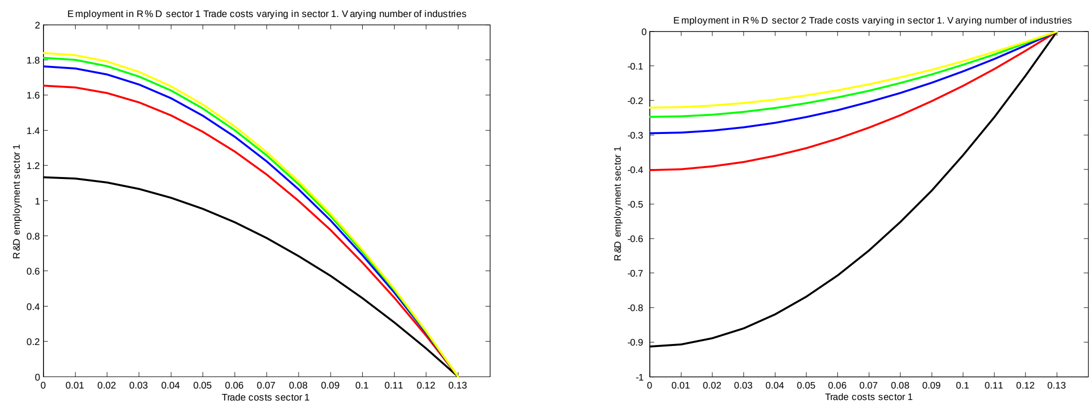


Table 5: Asymmetric trade liberalization

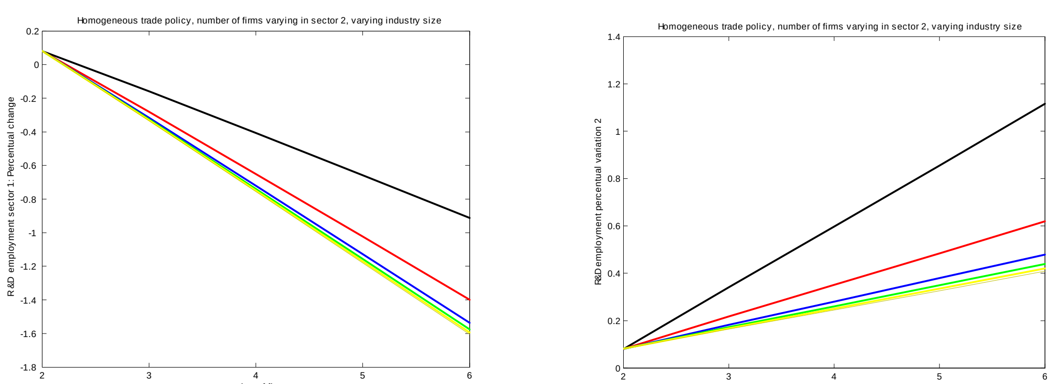


Table 6: Asymmetric trade liberalization

The results are generated with the initial number of firms in each industry set to three. The results are similar to table 5. However, the general equilibrium effect vanishes even more slowly in this case. When the opening industry represents $\frac{1}{22}$ of the manufacturing output, trade liberalization increases R&D employment in that sector by 1.8760 per cent whereas R&D employment declines in the remainder industries by 0.20%. When the opening industry was representing $\frac{1}{2}$ of the manufacturing output the fall in R&D was only 0.90 per cent. As the importance of the opening industry declines, the fall in R&D employment in the remainder of industries decreases relatively slowly.

The same exercise has been performed for a situation with homogeneous tariff reductions with differences in the degree of competition. In this context we have decided to retain the assumption that Type I industries are less competitive to be consistent with the other exercises. Table 6 show the results. As we have noted above, the industries that are initially the most competitive benefit the most from trade liberalization in this context. As the size of the less competitive industries fall, the change in R&D employment is stronger in the smallest industry and is weaker in the most competitive and numerous industries. Interestingly, the general equilibrium effect falls smoothly with the decline in the size of the less competitive industry but remains quantitavely important even if the size is relatively small. [16]

6 Conclusions

Empirical evidence suggests that there is substantial variation in mark-ups, a proxy for the degree of product market competition, across industries. Moreover, recent episodes of trade liberalization are far away from being homogeneous across industries. This paper explores the effects of asymmetric trade liberalization on innovation in an economy with heterogeneous industries in terms of the number of competing firms or the elasticity of substitution across products. All sectors use a linear production technology and firms undertake proccess innovation to increase productivity when competing á la Cournot. When we open the economy we consider that the rest of the world is identical to this economy. Therefore, heterogeneity is observed across industries but not across countries.

To address these questions we have considered several types of trade liberalization policies (i.e. a movement from autarky to free trade, an increase in the number of trade partners and a tariff cut) and we have considered different scenarios in which local industries were either identical or different in terms of competition. The advantage of these exercises is that we can isolate the effect of asymmetric trade liberalization on industry productivity growth from the role played by industrial heterogeneity in that process.

We find that a movement from autarky to free trade increases innovation in industries that were initially less competitive. Conversely, a homogeneous tariff reduction enhances innovation in industries that were initially more competitive, provided that these industries begin with the same initial tariff level. This contradictory result is explained as follows: In the context of a uniform

[16] For example when the less competitive industries represent $(\frac{1}{38})$ of the total output of the manufacturing sector, the 5 percent tariff reduction still generates an increase of 0.20% in R&D employment in the remander industries.

initial tariff level, the most competitive industries are relatively less open to international trade. As the tariff reduction tends to foster innovation in those industries which are relatively more closed to foreign trade, the homogeneous tariff reduction benefits those industries that were initially more competitive.

When we consider the case of perfect symmetry across sectors, we discover that an increase in the number of trade partners increases firm size, innovation and growth, for the same reason that trade openness exert this effect: the increase in the number of trade partners intensifies competition from abroad and this effect provides firm with incentives to increase their production and investment in R&D. However, this effect declines with the number of trade partners; thus this result suggests a certain limit for trade blocks. This effect is observed because all gains from trade in this model are derived from increases in competition. When the number of trade partners is sufficiently large, economies belonging to a trade block are already close to perfect competition. The inclusion of a new economy does not alter as much the degree of competition and therefore innovation and productivity growth. This exercise suggests that if the model takes all relevant aspects of economic integration, then we should consider that trade blocks should have size limits. Increasing the number of trade partners beyond that limit, may be counterproductive for those economies if these policies have a positive implementation cost.

This paper could be extended in several directions. The first one, which is already in progress, considers a varying elasticity of substitution between the two final goods. This is important to determine whether the degree of intersectorial spillovers is highly dependent on this parameter. However as noted previously, this would oblige us to consider a model in which differences in productivity growth across sectors are not permanent. The second direction involves the consideration of free entry. This allow to observe in which direction the results are shaped by the effect of trade on the extensive margin. The third direction would include firm heterogeneity and investigate whether certain characteristics of an industry, such as the degree of productivity dispersion, may enhance or diminish the effects that of trade openness on R&D employment per firm.

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8 Appendix

8.1 Derivation of 20 and 29

8.1.1 Autarky (20)

Condition (29) comes from the labor market condition:

$$\sum_{j=1}^{N}\int_{0}^{1} n_{ij}l_{ijt}^{x}di+\sum_{j=1}^{N}\int_{0}^{1} n_{ij}l_{ijt}^{z}dj+L_{t}^{y}=L. \tag{30}$$

From the production function we have that

$$l_{ij}^{x}=z^{-1}q_{ij}$$

and substituting (10) then we have that:

$$l_{ij}^{x}=z^{-1}\theta_{j}zl_{j}E_{t}^{x}=\frac{\theta_{j}}{n_{j}}\phi_{j}LE_{t}^{x} \tag{31}$$

that under the symmetric equilibrium only depends on industry and not firm characteristics. Plugging the latter equation in the labor market clearing condition

$$L_{jt}^{x}=\int_{0}^{1} n_{j}l_{jt}^{x}dj=\int_{0}^{1} n_{j}\frac{\theta_{j}}{n_{j}}\phi_{j}LE_{t}^{x}dj=\tilde{\theta}_{j}LE_{t}^{x}$$

From (3), (4) and (15):

$$L_{t}^{y}=\frac{1-\beta}{\beta}LE_{t}^{x}$$

Notice that from (32):

$$LE_{t}^{x}=\frac{n_{k}}{\phi_{k}\theta_{k}}l_{k}^{x}=\frac{n_{k}}{\tilde{\theta}_{k}}\frac{\rho}{\gamma T_{kt}}\left(l_{k}^{z}\right)^{1-\gamma}$$

and then:

$$L_t^x + L_t^y = \left(\frac{\tilde{\theta} + \frac{1-\beta}{\beta}}{\tilde{\theta}_k} \right) n_k \frac{\rho}{\gamma T_{kt}} (l_k^z)^{1-\gamma} = \left(\frac{\beta\tilde{\theta} + 1 - \beta}{\beta\tilde{\theta}_k} \right) n_k \frac{\rho}{\gamma T_{kt}} (l_k^z)^{1-\gamma}$$

where $\tilde{\theta} = \sum_{j=1}^{N} \phi_j \theta_j$

To get an expression for total labor in R&D we use

$$L_t^z = \sum_{j \neq k}^{N} \int_0^1 n_j l_{jt}^z dj = n_k l_k^z + \sum_{j \neq k}^{N} n_j l_j^z = \sum_{j \neq k}^{N} n_j \left(\frac{l_j^x}{l_k^x} \frac{T_{jt}}{T_{kt}} \right)^{\frac{1}{1-\gamma}} + n_k l_k^z = \left(\sum_{j \neq k}^{N} n_j \left(\frac{\tilde{\theta}_j}{n_j} \frac{n_k}{\tilde{\theta}_k} \frac{T_{jt}}{T_{kt}} \right)^{\frac{1}{1-\gamma}} + n_k \right) l_k^z$$

and working through this expression we get:

$$L_t^z = \left(\sum_{j \neq k}^{N} \frac{n_j}{n_k} \left(\frac{\tilde{\theta}_j}{n_j} \frac{n_k}{\tilde{\theta}_k} \frac{T_{jt}}{T_{kt}} \right)^{\frac{1}{1-\gamma}} + 1 \right) n_k l_k^z$$

Substituting the previous expressions in (13) and dividing both sides by n_k we get:

$$\left(\frac{(1-\beta) + \beta \left(\tilde{\theta} \right)}{\beta \tilde{\theta}_k} \right) \frac{\rho}{\gamma T_{kt}} (l_{kt}^z)^{1-\gamma} + \left(\sum_{j \neq k}^{N} \left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k} \frac{T_{jt}}{T_{kt}} \right)^{\frac{1}{1-\gamma}} \left(\frac{n_k}{n_j} \right)^{\frac{\gamma}{1-\gamma}} + 1 \right) l_{kt}^z = l_j$$

8.1.2 Free trade (29)

For free trade we proceed as in the section above, realizing that $l_j^x = z^{-1}(q_j + (1+\tau_j) q_j^*)$

$$l_j^x = z^{-1} \theta_j' z l_j E_t^x = \frac{\theta_j'}{n_j} L E_t^x \tag{32}$$

so we just need to follow previous steps, replacing θ_j by θ_j' and we will arive to the same expression.

8.2 Proof that $\theta_j' \geq \theta_j$

The proof consists on showing that $\theta_j' - \theta_j = \triangle\theta \geq 0$.

From (28) and the definition of θ in the autarkic economy, the following expression is obtained.

$$\triangle\theta = \frac{((1+M)n_j - 1 + \alpha_j)\left[(1-M+2M(1+\tau_j))(1-\alpha_j) + M\tau_j^2(1-\alpha_j-n_j)\right]}{n_j(1-\alpha_j)(1+M(1+\tau_j))^2} - \frac{n_j - 1 + \alpha_j}{n_j}$$

Rearranging terms:

$$\triangle\theta = \frac{(1-\alpha_j)(1+M(1+\tau_j))[M((1+\tau_j)(1-\alpha_j)-\tau_j n_j)] + [M\tau_j((1-\alpha_j)+\tau_j(1-\alpha_j-n_j))]((1+M)n_j-1+\alpha_j)}{n_j(1-\alpha_j)(1+M(1+\tau_j))^2}$$

and manipulating the previous expression we get:

$$\triangle\theta = \frac{M((1+\tau_j)(1-\alpha_j)-\tau_j n_j)[(1-\alpha_j)(1-\tau_j+M(1+\tau_j))+\tau_j((1+M)n_j]}{n_j(1-\alpha_j)(1+M(1+\tau_j))^2}$$

Notice that the second element of the numerator is positive if exports are positive. The third term is always positive so we can conclude that this expression is always positive. It would be zero iff: $\tau_j = \tau_j^*$, $M = 0$. If $\tau_j = 0$, This expresssion is reduced to $\theta_j' - \theta_j = \frac{M(1-\alpha_j)}{n_j(1+M)}$. Notice that this expression is increasing in M which implies that larger the number of trade partners the further the increase in competition but it is concave in M revealing that the increase in the number of trade partners have less and less effects on competition. This expression is decreasing in n_j and the elasticity of substitution α_j reflecting that the larger the competition levels in autarky, the lower the increase in competition coming from trade openness, and therefore the lower is the industry productivity growth rate.