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# Trade liberalisation and innovation under sector heterogeneity.*

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**Abstract**

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 of trade liberalisation on innovation and, by extension, on sector and aggregate productivity growth under sectoral heterogeneity. I find that differences in the degree of competition generate substantial differences in firms' innovative responses to trade liberalisation. A movement from autarky to free trade promotes innovation and productivity growth in those sectors which are initially less competitive. This result is robust to an alternative scenario in which the economy is open to trade, but the degree of trade openness is common across sectors. Finally the paper outlines the importance of reallocation effects within sectors and across sectors that are the result of differences in product market competition across sectors. A movement towards zero trade costs has a smaller effect on aggregate innovation when the sectors are heterogeneous in terms of competition.

Keywords: Sectoral productivity, international trade, innovation.

JEL CODES: F12, O43.

## 1 Introduction

A recent body of theoretical and empirical literature studies the influence of trade openness and trade liberalisation on productivity growth. These studies explore the extent to which a larger degree of trade openness affects the rate of a sector's technological change and ultimately the evolution of TFP. To address this question, some researchers have relied on endogenous growth models with imperfect competition and product or process innovation (Segerstrom et al.,(1990), Rivera-Batiz and Romer (1991a)), Rivera-Batiz and Romer (1991b), Peretto (2003), Licandro and Navas (2011)), and more recently, firm heterogeneity and industry dynamics (Ederington and Mc Calman (2007), Baldwin and Robert-Nicoud (2008), Gustafson and Segerstrom (2010), Atkeson and Burstein (2010), Navas and Sala (2007), Long et al. (2011), Impulliti and Licandro (2011)).

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 sectors are not homogenous in two dimensions that are relevant to a firm's investment decision to innovate: the degree of product market competition and the degree of trade openness.[1] The former is a key determinant

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[1] The former is measured using sector average mark-ups as standard in the literature. While the literature on economic growth has been focused on (exports+imports)/GDP as a measure of trade openness, Rodriguez and Rodrik (2000) suggests that this may not be the appropriate measure. Exports and imports are measuring how successful the country is in the international context. However, this could be the result of low trade barriers or other technological advantages. Following this critique we use sectoral trade costs measures provided by Bernard et al. (2006).

of innovation both in early endogenous growth models (Romer (1990), Grossman and Helpman (1991)), and more recent contributions (Aghion et al. (1997), Peretto (1999), Aghion et al. (2001), Aghion et al. (2005)). In addition, several papers argue that trade may increase innovation efforts precisely through an increase in competition.[2] The latter clearly affects how firms respond to trade liberalisation. Despite the relevance of these two dimensions, few papers have investigated the consequences of the existence of these two sources of heterogeneity for the effect that trade liberalisation has on innovation.

The fact that sectors differ greatly in the degree of product market competition within a country is a stylized fact well-documented in the data (Eslava et al. (2009), Griffith et al. (2010)). Epifani and Gancia (2011) report that in the US manufacturing sector at a four-digit level of disaggregation, mark-ups vary substantially across industries. The degree of trade openness varies substantially across sectors and this is the case even for developed economies. Using sectoral data obtained from Bernard et al. (2006), we observe that average trade costs faced by different US manufacturing sectors (3-digit NAICS code) during the period 1989-2005 varies considerably from 3% up to 18%. This difference is even larger if we consider a finer level of disaggregation.

The aim of this paper is to introduce sector heterogeneity in the degree of product market competition in a standard multi-sector endogenous growth model with private R&D investments, to see how trade affects innovation and productivity growth at both sectoral and aggregate level. The model is based on the framework developed in Licandro and Navas (2011) that explores the effect of trade liberalisation on innovation and growth in an oligopolistic general equilibrium model (OLGE) that incorporates process innovation by incumbent firms. I have focused on this particular framework because the empirical evidence suggests that this is the most relevant case. Doms and Bartelsman (2000) and Foster et al. (2001) provide empirical support that innovation by incumbents accounts for the largest proportion of sectoral productivity growth. Akcigit and Kerr (2010) using the US Census of Manufacturing firms, find that old and large firms undertake innovations whose main aim is to encourage productivity improvements, while new and small firms perform product innovation. Finally, by assuming oligopolistic competition, I allow firms to interact strategically.[3]

To analyse the impact of this source of sector heterogeneity, I consider the implementation of a common trade policy in an environment in which sectors differ in the degree of product market competition. This exercise enables us to isolate the contribution of sectoral differences in product market competition to the relationship between trade and innovation. In this exercise, I consider two alternative scenarios (restricted entry vs. free entry) and two alternative trade liberalisation policies: a movement from autarky to free trade and a movement from positive to zero trade costs. In the second policy I consider either an initial situation in which trade costs are common across sectors or an alternative scenario in which the degree of trade openness is common across sectors, as explained below. In the six scenarios, trade liberalisation affects innovation through a joint effect of an increase in market size and an increase in competition. However, the latter is different across sectors due to differences in the initial degree of competition. More precisely, when the countries move from autarky to free trade, the initially less competitive sectors experience a larger increase in innovation and by extension, sector productivity growth. This is the consequence of the fact that the increase in competition coming from foreign markets is tougher in sectors which are initially less competitive. Once the countries are opened to trade, a reduction in trade costs in sectors which start with the same level of trade barriers increases innovation and sector productivity growth in those sectors that are initially more competitive. This is the consequence of the fact that, for the same trade barrier, a sector which is initially more competitive is relatively more closed to foreign trade and a reduction in trade barriers intensifies competition more in those sectors. When I consider instead an alternative scenario in which all sectors start with the same degree of trade openness, I find that innovation increases more in the less

[2] The main mechanism through which trade has an impact on innovation in these papers is the increase in competition. This could come through different channels: an effect through direct changes in the profitability of R&D: (Peretto (2003), Licandro and Navas (2011)), Rivera-Batiz and Romer (1991b) etc, and an indirect effect through selection: competition allows only the most productive firms to survive. The reallocation of market shares and productive resources towards the incumbents contribute to increase innovation investments. That is the case of the recent contributions with firm heterogeneity (Atkeson and Burstein, 2010).

[3] In this paper firms compete a la Cournot. However, most of the results are robust in qualitative terms to alternative oligopolistic market structures like Bertrand with product differentiation. (These results are available on request).

competitive sectors. In the six cases, tougher competition increases firm size, promotes innovation and it generates a reallocation of productive resources across sectors. When I allow for free entry, considering that the initial level of trade openness is common across sectors, the same competition effect reduces mark-ups by more in the less competitive sectors. This generates a reallocation of market shares and productive resources towards incumbents that further contribute to innovation. Consequently, the level of competition that the sector faces initially becomes an important determinant of the final effect that trade liberalisation has on innovation. In Appendix 3, instead, an asymmetric trade liberalisation exercise is explored. I find that asymmetric trade liberalisation has a heterogenous impact at a sectoral level. More precisely, firms increase innovation efforts in those sectors that are relatively more open to foreign trade, contributing to a rise in sectoral TFP growth.

The introduction of sector heterogeneity in the level of competition in the study of the effects of trade on innovation and productivity growth reveals two important findings that are absent in a representative sector analysis. First, this heterogeneity generates important reallocation effects across sectors and across activities within a sector through general equilibrium effects. This has varied effects on sector productivity growth: in the case of restricted entry, a common trade liberalisation policy may induce a reduction in productivity growth in those sectors which are relatively more competitive or, as shown in Appendix 1, those ones more open to foreign trade. Second, and most important, the existence of these differences across sectors partially mitigates the benefits of trade. In an environment where sectors face identical trade barriers but differ in terms of competition, a movement towards free trade has a positive effect on aggregate productivity growth, although this effect would be larger if sectors were more homogeneous in terms of competition. Similarly, when sectors differ in trade barriers, a movement towards a common trade barrier has a positive effect on aggregate productivity growth. The existence of diminishing returns to scale associated with labour in R&D activities implies that when industries face different trade barriers there is relatively too much R&D investment in some industries and relatively too little in other industries. The movement towards a common trade barrier generates a reallocation of resources from industries that invest relatively too much (and consequently labour is relatively less productive) to industries that invest relatively too little (and consequently labour is relatively more productive). Therefore, this paper suggests that when industries differ in these trade barriers and competition due to institutional reasons, the removal of these institutional barriers helps the economy to enjoy fully the benefits of trade.

Although this paper is related to an extensive literature that examines the effects of trade openness and trade liberalisation on innovation and growth, to the best of my knowledge, this paper is the first to study the role of this source of heterogeneity across sectors in innovation and sector productivity growth. Two related papers in the area are Impulliti and Licandro (2011) and Ederington and Mc Calman (2007). The first paper introduces firm heterogeneity into the oligopolistic competition model of Licandro and Navas (2011) to disentangle the effects of trade openness on sector productivity growth that are derived from selection, from the effects that are derived from a pure increase in competition. Though their results could be interpreted in terms of sector heterogeneity, the only source of sector heterogeneity in their model is the initial productivity. The consequences of the presence of asymmetries in certain policy variables, like the degree of product market competition or the degree of trade openness, are not explored. Ederington and Mc Calman (2007) explore the effect of trade liberalisation on the rate of technology adoption in a small open economy. Their paper finds that unilateral trade liberalisation is likely to delay the adoption date for the median firm. This effect depends on several sectoral characteristics and the effect is stronger in, for example, more competitive sectors (low entry costs, large domestic markets). Their model uses a monopolistic competition model in partial equilibrium. Thus, neither the rich interaction across sectors that emerges in a general equilibrium context, nor the strategic interaction among firms, which are crucial elements in my model, are explored.

The rest of the paper is divided as follows. Section 2 presents the theoretical model both in autarky and trade under restricted entry. In Section 3, I discuss the main results of the counterfactual exercises under restricted entry. In Section 4 I introduce the more general case in which there is free entry and I discuss the counterfactual exercises associated with this case. Section 5 concludes.

## 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 $X$ and $Y$ :

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

where $C^x, C^y$ denote the consumption baskets of goods $X$ and $Y$ respectively. Good $Y$ is an homogeneous good.[4] Good $X$ is a differentiated good that takes the following functional form.

$$C^x = \prod_{j=1}^{N} (c_j)^{\phi_j}, \; 0 < \phi_j < 1, \text{ and } \sum_{j=1}^{N} \phi_j = 1. \tag{1}$$

Here a Cobb-Douglas subutility function between the different varieties has been assumed with the parameter $\phi_j$ controlling for the weights of each of these goods in a consumer's budget. In each of these varieties there is a continuum of subvarieties of measure $Z$ that are aggregated following the standard CES functional form:

$$c_j^x = \left( \int_0^Z c_{ij}^{\alpha_j} di \right)^{\frac{1}{\alpha_j}}, \; 0 \leq \alpha_j < 1, \tag{2}$$

where the parameter $\alpha_j$ controls for the elasticity of substitution across varieties. The structure of our economy distinguishes between sectors (varieties) and subsectors (subvarieties) where we have assumed a unitary elasticity of substitution across sectors. This preference structure is needed to ensure the existence of a Balanced Growth Path in which labour allocation across sectors is constant in an environment in which differences in TFP growth rates across sectors may arise in the steady state (Ngai and Pissarides (2007)).[5] This is going to be the case in this paper.

Each subvariety is produced under Cournot competition[6] with a number of firms $n_j$ which is exogenously given.[7] Each firm produces according to the following technology:

$$q_{dij} = z_{dij} l_{dij}^x, \tag{3}$$

where $q_{dij}$ denotes the quantity produced by firm $d$ producing subvariety $i$ in sector $j$, $z_{dij}$ denotes the firm's stock of knowledge and $l_{dij}^x$ the firms' allocation of labour to production activities. Firms can also undertake cost-reducing innovations using the following technology:

$$\dot{z}_{dij} = B_j \left(l_{dij}^z\right)^\gamma z_{dij}, \; \gamma \in (0,1), \tag{4}$$

which depends on the firm's stock of knowledge ($z_{dij}$), the amount of labour that is devoted to innovation, $l_{dij}^z$, and $B_j$ which is a technological constant that includes differences in technological opportunities across

[4] 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 the focus in this paper.

[5] This assumption simplifies calculations. I have explored the role of the elasticity of substitution across sectors and considered a version of this model with an innovation function that presents decreasing returns to scale in the accumulation of knowledge as in Jones (1995). The advantage of such a framework is that the steady state productivity growth rate is identical across sectors and, therefore, the aggregate TFP growth rate is constant independent 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. The model is able to generate permanent differences in productivity levels across sectors although the qualitative results are identical to those presented further in the paper.

[6] Under Cournot competition with firms offering homogeneous goods, the model yields tractable solutions. However, as noted above, the results derived in this paper are qualitatively more general, and allow for alternative market structures like Bertrand with product differentiation.

[7] This assumption will be relaxed in a further section of the paper.

sectors. In this set-up, the stock of knowledge is firm-specific and there are no technological spillovers among firms. [8]

At any point in time, firms producing the subvariety $i$ decide the quantity to supply and the optimal allocation of workers for both physical production and R&D, taking into consideration other firms' strategies. This game belongs to the family of differential games, or repeated games defined in continuous 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 Nash equilibrium (OLNE) and the closed-loop Nash equilibrium (CLNE). In an OLNE, a firm initially selects the optimal path of strategies taking the other firms' path of strategies as given and the firm sticks to this path forever. In contrast, in a CLNE, the firm chooses at each point in time the set of strategies taking the other firms' strategies as given. In this sense, an OLNE 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. In this paper I focus on OLNE equilibria mainly for two reasons. Firstly, the literature has focused on OLNE, mainly because standard optimal control theory techniques can be applied in order to find this type of equilibria. Secondly, Licandro and Navas (2011) show that the OLNE equilibria in this game collapse into the CLNE being game perfect or time-consistent.

The following definition applies for each firm $d$ in the subvariety $i$ of sector $j$ (I omit the subindexes $i$ and $j$ for simplification). Let $a_d = [q_{dT,}l^{z}_{dT}]$ , $\forall\ T \geq t$ be the strategy of firm $d$, where $[q_{dT,}l^{z}_{dT}]$ are the time-paths of output and R&D workers, and let $\Omega_d$ be the set of possible strategies of firm $d$. Let $V_d$ be the value of firm $d$ when the firm plays the strategy path $a_d$ and the $n_j - 1$ firms in the market, $n_j \geqslant 2$, play strategies $a_{-d} = \left\{a_1, a_2, ....a_{d-1}, a_{d+1}....a_{n_j}\right\}$

**Definition 1** *At time $t$, $A_d = [a^*_d, a^*_{-d}]$ is an open loop Nash equilibrium if,*

$$V_d\,[A_d] \geq V_d\,[A'_d] \geq 0,$$

*where $A'_d = [a'_d, a^*_{-d}]$ , $\forall\ a'_d \neq a^*_{d,} \in \Omega_d$, $\forall .d.$*

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

### 2.1 Solving for the autarkic equilibrium

Let $E^i$ denote the expenditure that is devoted to consumption of the final goods $i = x, y$ and $E^x_j$ the expenditure dedicated to consumption of good $j$. Consumers solve the standard optimal control problem

[8] This assumption is made, to isolate the contribution of the increase in competition that is derived from trade openness on innovation and productivity from other sources (e.g. international R&D spillovers).

whose first order conditions are as follows:[9]

$$E^x = \beta E, \quad (5)$$

$$E^y = (1-\beta) E, \quad (6)$$

$$E_j^x = \phi_j E^x, \quad (7)$$

$$\frac{\dot{E}}{E} = r_t - \rho, \quad (8)$$

$$p_j = \frac{LE_j^x}{x_j}, \quad (9)$$

$$p_{ij} = \left(\frac{LE_j^x}{p_j x_{ij}}\right)^{1-\alpha_j} p_j, \quad (10)$$

where $E$ is total expenditure in consumption and $p_j = \left(\int_0^Z p_{ij}^{\frac{\alpha_j}{\alpha_j - 1}} di\right)^{\frac{\alpha_j - 1}{\alpha_j}}$, is the standard aggregate price index.[10] Firm $d$ in subvariety $i$ of sector $j$ solves the problem:

$$V_{dijs} = \max \int_s^\infty R_{s,t} \left((p_{ij} - z_{dij}^{-1}) q_{dij} - l_{dij}^z\right) dt, \quad (11)$$

$$\begin{aligned} s.t.\ p_{ij} &= \left(\frac{LE_j^x}{p_j x_{ij}}\right)^{1-\alpha_j} p_j \\ x_{ij} &= \sum_{d=1}^{n_j} q_{dij} \\ \dot{z}_{dij} &= B_j (l_{dij}^z)^\gamma z_{dij}, \quad 0 < \gamma < 1 \\ z_{dij0} &> 0, \end{aligned} \quad (12)$$

where $R_{s,t} = e^{-\int_s^t r_\tau d\tau}$ is the usual market discount factor. I 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. $z_{dij0} = z_{ij0}, \forall\ d$. In addition, to ensure simplicity, I assume that the initial productivity is equal across all firms in the economy. Because I focus on symmetric equilibria I omit the subscript $d$ for the sake of simplicity. Deriving first order conditions, rearranging terms and applying symmetry, I obtain:

$$q_{ij} = \theta_j z_{ij} l_j E_j^x, \quad (13)$$

$$1 = \gamma v_{ij} B_j (l_{ij}^z)^{\gamma - 1} z_{ij}, \quad (14)$$

$$\frac{z_{ij}^{-2} q_{ij}}{v_{ij}} + B_j \left(l_{ij}^z\right)^\gamma = \frac{-\dot{v}_{ij}}{v_{ij}} + r, \quad (15)$$

[9] The consumers solve the following optimal control problem:
$Max \quad U(C^x, C^y)$
s.t. conditions 1 and 2 and the budget constraint which is given by:
$\sum_{j=1}^{N} \int_0^1 p_{ij} c_{ij} di + C^y + \dot{S} = wL + rS$
$S$ are the only financial assets in this economy. These are shares of the existing firms. We are assuming that to finance new investments in R&D, firms are creating new shares. In equilibrium the value of these shares is equal to the expected discounted value of profits of all existing firms in the economy. Therefore, positive profits, which is going to be an equilibrium feature in the version of the model with an exogenous number of firms, are redistributed across consumers by means of these shares.

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

$x_{ij} = \left(\frac{LE_j^x}{p_j}\right) \left(\frac{p_{ij}}{p_j}\right)^{\frac{1}{\alpha_j - 1}}$.

where $v_{ij}$ is the costate variable associated with $z_{ij}$ and $\theta_j \equiv \frac{n_j-1+\alpha_j}{n_j}$ is the inverse of the markup rate. I denote $l_j$ as $\frac{L}{n_j Z}$ the market share of the firm.

The left hand side of condition (15) is the marginal gain of accumulating one additional unit of knowledge. This increases with the quantity supplied 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 (13). In this model, an increase in the number of firms generates two different and opposing effects. First, the increase in the number of firms decreases the firm's residual demand since now a larger number of firms must serve the same mass of consumers. This decreases the firm's output, as shown in the last term of condition (13). This is the *size effect* or the market share effect. Second, the increase in the number of firms increases the perceived elasticity of demand. Since firms are facing a more elastic demand this provides an incentive for firms to increase the quantity supplied in the market which decreases the equilibrium price and the firms' mark-up. This effect is captured by the first element of equation (13). $\theta_j$ is the inverse of the mark-up, which depends positively on the number of firms $n_j$.[11] This is the *competition effect.*

Define $l_{ij}^f = l_{ij}^x + l_{ij}^z$, the firm's employment. To complete the model, I must impose the market clearing conditions for all markets. In the case of the labour market:

$$\sum_{j=1}^{N} \int_0^Z n_j l_{ij}^f di + L^y = L. \tag{16}$$

Each final good market must satisfy:

$$Lc_{ij} = x_{ij}$$

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

$$LS = \sum_{j=1}^{N} \int_0^Z n_j V_{ij} di. \tag{17}$$

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

$$LE^y = L^y. \tag{18}$$

Notice that the set of optimal strategies across varieties depends on the firm's initial stock of knowledge, which is assumed to be common across firms, varieties, and sectors. In the next set of results I omit the subscript $i$ for simplicity. A Balanced Growth Path in this economy is a situation when the variables $q_j, x_j, z_j, v_j$ and $p_j$ grow at a constant rate and the variables $l_j^x$, $l_j^z, l_j^f, L^x, L^z, L^y, r, E, E_j^x, E^x, E^y$ and $q^y$ are constant. In Appendix 1 we show that:

**Proposition 2** *A BGP for this economy exists and is unique*

**Proof.** See Appendix 1 (section 7.1) ■

More precisely, the growth rate of output either at a firm level $q_j$ or at a sectoral level $x_j$ is given by:

$$\frac{\dot{z}_j}{z_j} = B_j \left(l_j^z\right)^{\gamma}$$

[11] This positive relationship comes through the effect that $n_j$ has on the perceived elasticity of demand. To see this notice that the mark-up $\mu_j$ 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 $\varepsilon_j$ the inverse of the elasticity of demand $(1-\alpha_j)$. An increase in $n_j$ or an increase in $\alpha_j$ increases the perceived elasticity of demand.

so the sectoral growth rate of output is uniquely determined by the productivity of workers in the research sector $B_j$ and the per-firm labour allocation to research $l_j^z$. By considering equation (15) in steady state and the fact that the returns on innovation must be equal across sectors I obtain an expression for the allocation of R&D labour across sectors which is given by: [12]

$$\frac{l_j^z}{l_k^z} = \left(\frac{B_j}{B_k}\frac{l_j^x}{l_k^x}\right)^{\frac{1}{1-\gamma}} \tag{19}$$

This equation shows the complementarity between production and innovation activities in this set-up. In those sectors in which each firm produces more, each firm is going to dedicate relatively more labour to R&D. The labour in production activities is allocated across sectors according to the following condition:

$$\frac{l_j^x}{l_k^x} = \frac{\phi_j}{\phi_k}\frac{\theta_j}{\theta_k}\frac{n_k}{n_j} \tag{20}$$

Conditions (19) and (20) reveal how the increase in competition may affect firms' innovation efforts under this set-up. On the one hand the firm's labour demands for production and innovation activities are smaller in more competitive sectors through *the size effect.* This can be seen in the third term of the left hand side of condition (20). However, sectors with a larger number of firms have lower mark-ups and a larger $\theta$ through *the competition effect*. Consequently these sectors dedicate more resources to both production and innovation. This can be seen through the second element of the left hand side of condition (20). The net effect in both production and innovation is the combination of these two effects, the size and the competition effect.

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

$$\left(\frac{(1-\beta)+\beta\tilde{\theta}}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right) l_k^z = l_k \tag{21}$$

where $\tilde{\theta}$ is a size-weighted average of the degree of competition across sectors $\left(i.e. \sum_{j=1}^{N}\tilde{\theta}_j\right)$ 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. [13]

The following propositions discuss how labour in research and development and the sectoral TFP growth rate respond when either the elasticity of substitution or the number of firms change in just one sector. This distinction is interesting since the increase in the degree of substitutability across products in sector $k$, $\alpha_k$, affects innovation efforts only through *the competition effect*. A change in $\alpha_k$ only changes the perceived elasticity of demand through changes in the elasticity of substitution across varieties. This effect is entirely captured by the variable $\theta_k$. Analysing how innovation efforts respond to changes in these two variables allows us to compare how the competition and the size effects directly affect a firm's innovation efforts under this set-up. This is useful to understand the effects of trade openness on innovation. Finally, I analyse how changes in these parameters in one sector affect a firm's innovation effort in another sector. This outlines the importance of the reallocation effects across sectors that emerge when asymmetries are introduced.

**Proposition 3** *An increase in $\alpha_k$ increases the per-firm resources devoted to R&D in sector $k$.* $\left(\frac{\partial l_k^z}{\partial \alpha_k} > 0\right)$.

**Proof.** See Appendix 1. (section 7.2.1.) ∎

From this proposition, it follows that the competition effect positively affects innovation efforts. The increase in the perceived elasticity of demand increases a firm's labour demand for production and innovation activities. This increases firms' innovation efforts.

[12] Further details on how to derive the following results are provided in Appendix 1 (section 7.1)

[13] Details about the derivation of equation (21) are provided in Appendix 1 (section 7.1.).

**Proposition 4** *An increase in $n_k$ decreases the firm's R&D employment in sector $k$* $\left(\frac{\partial l_k^z}{\partial n_k} < 0\right)$.

**Proof.** See Appendix 1.(section 7.2.2). ■

However, the increase in the number of firms decreases the firm's R&D employment in sector $k$. The main difference with respect to the case above is that when we increase $n_k$ both the *competition effect* and the *size effect* are at work. This proposition not only suggests that the size effect decreases a firms' labour demand for production and innovation activities, it also implies that the size effect is the dominant one, as it is standard in the Cournot model. Therefore, an increase in the number of firms decreases firm size having a negative impact on innovation efforts.

**Proposition 5** *Consider a sector $h \neq k$. An increase in $\alpha_h$ decreases the per-firm resources devoted to R&D in sector $k$.* $\left(\frac{\partial l_k^z}{\partial \alpha_h} < 0,\right)$. *For the case of an increase in $n_h$, we have that:* $\frac{\partial l_k^z}{\partial n_h} < 0, if \ n_h < \frac{(1-\alpha_h)(1+\gamma)}{\gamma}$.

**Proof.** See Appendix 1.(section 7.2.3). ■

An increase in either the degree of substitutability across products or the number of firms in sector $h$ decreases the firm's resources that are allocated to innovation in sector $k$. In the case of $\alpha_h$, the effect is straightforward: the increase in $\alpha_h$ increases labour demand for production and research activities in sector $h$. This induces a labour reallocation from the other sectors to sector $h$. In the case of $n_h$, the effect is similar. In this case, the firm's labour demand decreases but the sector's increases provided that $n_h < \frac{(1-\alpha_h)(1+\gamma)}{\gamma}$.[14] This generates a reallocation effect from the other sectors to sector $h$. Interestingly, this general equilibrium effect is shaped by the importance of sector $h$ in the consumer's budget $(\phi_h)$. As $\phi_h$ approaches zero, this effect is negligible.

Therefore, in autarky, an increase in the number of firms produces a negative effect on innovation through the combination of both the competition and the size effect. In the next section I explore what happens when the economy opens to trade and we will see how this negative size effect is compensated by an increase in the market size of the firm. The introduction of asymmetries across sectors generates an interesting reallocation effect towards production and innovation in some sectors that ultimately affects the sector both statically, through a change in the quantity produced and dynamically favoring productivity growth in some sectors to the detriment of others.

## 2.2 Trade

Assume 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 to get one unit sold abroad). Let $q_{dij}$, be the quantity that firm $d$ producing subvariety $i$ in sector $j$ produces in its local market and $q_{dij}^{*m}$ denote the quantity that each firm $d$ in sector $j$ supplies to country $m$. Since I assume that all countries are identical, I focus again on symmetric equilibrium ( $q_{dij} = q_j$, $q_{dij}^{*m} = q_j^*$). Solving the open economy version of problem (11) I obtain the following first order conditions:

$$\left(\frac{LE_j^x}{n_j(q_j + Mq_j^*)p_j}\right)^{1-\alpha} p_j \left(1 - \frac{(1-\alpha_j)q_j}{n_j(q_j + Mq_j^*)}\right) = z_j^{-1} \tag{22}$$

$$\left(\frac{LE_j^x}{n_j(q_j + Mq_j^*)p_j}\right)^{1-\alpha} p_j \left(1 - \frac{(1-\alpha_j)q_j^*}{n_j(q_j + Mq_j^*)}\right) = z_j^{-1}(1+\tau_j) \tag{23}$$

$$1 = \gamma v_j B_j (l_j^z)^{\gamma-1} z_j, \quad j = 1,2 \tag{24}$$

$$\frac{z_j^{-2}\left(q_j + M(1+\tau_j)q_j^*\right)}{v_j} + \left(l_j^z\right)^{\gamma} B_j = \frac{-\dot{v}_j}{v_j} + r, \quad j = 1,2 \tag{25}$$

[14] To be precise, the industry $h$ labor demand for production activities increases with the number of firms $n_h$. However the labor demand for R&D activities increases with $n_h$ if $n_h < \frac{(1-\alpha_h)(1+\gamma)}{\gamma}$.

Firms consider the total volume of production when selecting the amount of resources to devote to R&D as can be seen in (25). Dividing (22) by (23) and rearranging terms, I obtain:

$$q_j^* = \frac{(1+\tau_j)(1-\alpha_j) - \tau_j n_j}{1-\alpha_j + M n_j \tau_j} q_j \tag{26}$$

(26) implies an interesting result. Manipulating (26) I deduce that if

$$\tau_j \geq \frac{1-\alpha_j}{n_j - 1 + \alpha_j} \tag{27}$$

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. A necessary and sufficient condition for foreign firms to survive in a local market is that the cost disadvantage that is introduced by transportation costs is not too large.[15] Substituting in (22), and rearranging terms yields:

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

and substituting in (26)

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

The firm's output $Q_j = q_j + M(1+\tau_j)q_j^*$ can be expressed as:

$$Q_j = \theta_j' z_j l_j E_j^x,$$

where

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

The steady state solution of the model can be summed up in an equation similar to the autarkic case. More precisely,

$$\left(\frac{(1-\beta)+\beta\tilde{\theta}'}{\beta\tilde{\theta}_k'}\right)\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j'}{\tilde{\theta}_k'}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_j}{n_k}\right)^{\frac{\gamma}{1-\gamma}}\right) l_k^z = l_k. \tag{29}$$

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 $\theta_j'$.

In Appendix 1 (section 7.3), I show that $\theta_j' > \theta_j$. Consequently, trade has intensified competition. However, the negative impact that the increase in the number of competitors was having on production and innovation efforts is offset by the increase in the market size. Licandro and Navas (2011) reveal that a movement from autarky to free trade, or a trade liberalisation (understood as a decrease in trade 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. This comes through the positive effect that trade has on competition (i.e. *the competition effect).* The focus of this paper is to demonstrate how the situation changes when we allow for sectoral differences (in this context, differences in competition

[15] The fact that foreign firms are able to serve the foreign market at a higher cost even if the goods that domestic and foreign firms are producing are identical is not new in the literature and goes back to the seminal paper of Brander (1981). This phenomenon is known as cross-hauling and arises in this environment due to: 1. Firms offering homogeneous products are competing à la Cournot. 2. Short-run regulations that limit the entry of domestic firms (restricted entry). 3. In the case of free-entry, internal economies of scale.

| Parameter | Value | Source |
|---|---|---|
| $\rho$ | 0.0375 | World Bank Development Indicators |
| $\beta$ | 0.91 | World Bank Development Indicators |
| $\gamma$ | 0.08 | Ngai and Samaniego (2011) |
| $B$ | 0.020 | Calibrated internally |
| $L/Z$ | 23364 | US labor force from BLS |
| $\phi$ | 0.5 | Free |
| $\alpha$ | 0 | Free |
| $M$ | 1 | Free |

Table 1: Parameter choice under restricted entry

levels) or when we have a process of trade liberalisation that is not symmetric across sectors. I rely on numerical methods to demonstrate these results.

In the numerical analysis, I consider two different scenarios, one with restricted entry and another one with free entry. The first exercise allows us to identify the main forces determining the varied effect of trade openness on innovation in the more general case when I allow for free entry. Table 1 provides us with information regarding the sources of the values used for each parameter.[16] In the restricted entry scenario, I consider the case of two sectors without loss of generality. I also assume that $B_j$, is common across sectors. The latter provides a better picture of how differences in the two dimensions I explore affect innovation. From (15) in steady state I obtain:

$$B_j = \frac{n_j l_j^z}{n_j l_j^x} \frac{\rho}{\gamma} \left(l_j^z\right)^{-\gamma}$$

With $\gamma$ very close to zero, which is the case in this paper, the third term can be ignored, and this technological constant can be proxied as: $B = \frac{\rho}{\gamma}\frac{L_z}{L_x}$. To calibrate this parameter, I rely on the share of the sectoral labour force devoted to R&D activities provided by the National Science Foundation which is 4.43%.[17] This implies that the technological constant should take the value: $B = 0.020$.

The next section discuss in detail the results under the restricted entry scenario.

# 3 Results Under Restricted Entry

## 3.1 From Autarky to Free Trade

In this subsection I consider the case in which both sectors move from autarky to free trade but the sectors differ in the degree of product market competition. The number of firms in sector 1 is fixed at 2 for simplicity, while I let the number of firms in sector 2 vary. The results are reported in figure 1.

**INSERT FIGURE 1 HERE**

The horizontal axis in both panels represents the number of firms in sector 2. When there are no differences in competition (two firms in each sector), R&D employment increases by 6% as a consequence of trade openness. However, if sector 2 is more competitive, trade openness increases R&D employment to

[16] The following sources have been considered for the parameter values:

To obtain the value of $\beta$, I consider the manufacturing sector to be the differentiated sector of the economy. The World Development Indicators database reports that manufacturing represents 25% of total GDP for the US economy which implies a share of 91% of the total GDP net services. Services are excluded from our analysis due to the non-tradable nature of this component of GDP.

To obtain the value of $\gamma$ I rely on the previous work by Ngai and Samaniego (2011). In their paper, new knowledge is entirely produced using an intermediate research input with technology similar to my paper. 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 labour is therefore $\gamma = 0.6 \text{ x } 0.13 = 0.078$.

For the free parameters I have performed robustness checks which are available on request.

[17] That is around 1% of the total labor force in the US.

a greater extent in the less competitive sector. Moreover, if the differences in competition are large enough, the per-firm investment in R&D in sector 2 falls as a consequence of trade liberalisation. This result is the combination of two different effects: the competition effect and the general equilibrium effect; the increase in the perceived elasticity of demand is larger for sectors that are initially less competitive in autarky. This is a standard feature in oligopolistic competition models. This implies that trade intensifies competition to a greater degree in those sectors. As a result, firms increase the volume of production and the investment in research to a greater extent in those sectors. As the labour demand increases to a greater extent in the less competitive sector, general equilibrium effects induce a labour reallocation from the more competitive sector to the less competitive one.

## 3.2 From positive trade costs to Free Trade.

In this subsection, I consider the case in which the economy is already opened to international trade. In order to isolate how differences in competition are shaping the effects of trade liberalisation on innovation, I consider two initial situations: one in which sectors have common trade costs and another in which sectors start with the same level of trade openness. In both cases sectors move towards free trade. The results for the first case are represented in figure 2.

**INSERT FIGURE 2 HERE**

For this figure, I set the initial variable trade cost $\tau = 0.08$.[18] Panel A shows the variation in percentage points of R&D employment in sector 1 while panel B presents the same results for sector 2. Contrary to our previous case, the larger increase in R&D employment following trade liberalisation is in the more competitive sector. This apparently paradoxical result is the main consequence of two different results: first, the degree of trade openness in one sector depends on the number of firms in that sector and second the competition effect is stronger the relatively more closed the sector is to foreign trade. To understand this, it is useful to look at equation (27) which displays the upper-bound limit for trade costs. Above this threshold, firms cannot export. It depends on the number of firms in the sector, being smaller in the more competitive sectors.[19] Consider now a common trade barrier $\tau$ across both industries. For the most competitive sector, the common trade barrier is closer to the upper bound and consequently that sector is relatively more closed to foreign trade than the less competitive one. A movement to free trade has a stronger impact in the sector relatively more closed to foreign trade, or the most competitive sector. In this framework, having a common trade cost across sectors does not mean that these sectors are equally exposed to foreign trade.[20]

In a second scenario, I have controlled for this by considering that the initial trade cost in each sector is the one that ensures that both sectors have the same degree of trade openness. The results are reported in figure 3. As it can be observed, once sectors are equally exposed to foreign trade, moving to free trade increases innovation to a greater extent in the less competitive sector.

**INSERT FIGURE 3 HERE**

To assess the impact of asymmetric trade liberalisation, I consider an initial situation in which both sectors are identical. However, a trade policy will be implemented in sector 1 but will not be implemented in sector 2. R&D employment increases in the liberalised sector and decreases in the non-liberalised sector. Interestingly, the function is concave indicating that the effect is stronger when those sectors are relatively more closed to foreign trade. These results are provided in Appendix 3 (section 9.1.).

In the next section I show the extent to which these results are reinforced in a more general case in which there is free entry.

[18] The average across the industries used in the sample is 7.85%. The latter comes from an updated version of the database on trade barriers built in Bernard et al. (2006) (see next section for details). In the next section I use this database to pin down industrial measures of trade barriers.

[19] In the more competitive sectors, the residual demand faced by foreign firms is smaller and more elastic. Differences in the costs of serving the foreign market in these sectors reduce drastically the possibilities that a firm can export.

[20] Alternatively I can compute the degree of trade openness as (Exports+Imports)/GDP which for the same degree of trade barriers, is clearly decreasing in the number of firms. (See Appendix 1 (section 7.4))

# 4 Free Entry

## 4.1 Theory

The case of free entry brings a new interesting mechanism through which trade contributes to innovation: the "*selection effect*". The increase in competition from foreign markets reduces mark-ups and profits, and induces exit. The number of firms serving each market falls until the zero profit condition holds again. The market share of the newly inactive firms is reallocated towards the survivors and this provides additional incentives to engage in more innovation. The way in which I take into account the selection effect in this paper differs from current models of trade with firm heterogeneity. Since all firms are identical, the model does not provide a criterion to identify which firms remain inoperative. It may be also the case that the size of this selection effect differs substantially from a model with heterogeneous firms.[21]

To introduce free entry, I assume that each firm pays a per period fixed cost in terms of the numeraire. The two main modifications with respect to the above model are, firstly, the labour market condition:

$$\sum_{j=1}^{N} \int_{0}^{Z} n_j \left( l_{ij}^{f} + f_j \right) di + L^y = L. \tag{30}$$

and secondly the new zero profit condition which determines the mass of active firms per product. I focus on a symmetric equilibrium. Firstly, obtaining an expression for a firm's profits:

$$\Pi_{ijt} = p_{jt} q_{jt} - l_{jt}^{x} - l_{jt}^{z} - f_j = 0$$

Substituting the expression for a firms´ revenue, and rearranging terms yields:

$$\left( \frac{1-\theta_j}{\theta_j} \right) l_j^x = l_j^z + f_j. \tag{31}$$

Substituting (31) into (30) and rearranging terms, I obtain:

$$l_k^x = \beta \phi_k \theta_k l_k.$$

Substituting in the profit function, and rearranging terms I obtain:

$$\beta \left(1-\theta_j\right) \phi_j l_j - \left( \frac{\gamma}{\rho} B_j \beta \theta_j \phi_j l_j \right)^{\frac{1}{1-\gamma}} = f_j,$$

which is a non-linear equation in $n_j$. The case with trade is analogous with $\theta_j'$ instead of $\theta_j$.

To see how our results change in the most general case (free entry), I undertake analogous counterfactual exercises to those presented in section 3.[22]

In this model, the existence of fixed operational costs is an important ingredient in determining the number of firms active in each sector. To the best of my knowledge there is no reliable data on fixed operational costs at a sector level. To proxy this parameter, I use an average of the fixed costs obtained from the World Bank Doing Business Database built initially by Djankov et al. (2002), which measures for each country, the cost of starting-up a business. For the case of the US it takes, on average, 6 procedures to start-up a business with a total cost of 6 working days and a monetary cost of 1% the country's per capita GDP. The total cost is consequently \$1146. Since in our model there is no exit, I assume that the entry cost

[21] To the best of my knowledge, there are only two relevant papers that incorporate the selection effect in an oligopolistic model with firm heterogeneity and innovation. The first is Impulliti and Licandro (2011). In their model, they have two selection effects: the selection effect within varieties, which is identical to the one in this model, and selection across varieties. Since in their model firms producing the same variety are identical, they also do not consider the effect of selection in an environment in which heterogenous firms produce the same variety. The other paper is Long et al.(2011) which incorporates a selection effect along the lines discussed above. Their model however is static, and this simplifies the analysis at some expense. In addition, they do not explore differences across sectors.

[22] As in the restricted entry case, the results for asymmetric trade liberalisation are provided in Appendix 3 (section 9.2).

is paid in a per period fixed cost of $f_j = rf^e$, so this gives us a fixed cost of \$43. In the calibration exercise, variation across sectors in the degree of product market competition comes from differences in technological opportunities ($B_j$) or trade costs across sectors ($\tau_j$). To pin down $B_j$, I pursue a similar strategy to the restricted entry case but I use sectoral data on the share of the labour force that was engaged in R&D activities in 2004 obtained from the National Science Foundation (NSF).[23] For the trade costs $\tau_j$, I have computed an average of trade costs for the period 1989-2005 using an upgraded version of the database constructed by Bernard et al. (2006).[24]

## 4.2 Results

To be consistent with the restricted entry case, I consider an economy with a common degree of trade openness but with differences in competition, these differences arising as a result of technological differences in R&D. Then I consider a movement towards free trade. Since the degree of trade openness is identical across sectors but sectors differ in the degree of product market competition, this exercise is the equivalent to the second exercise discussed in section 3.2.[25]

**INSERT FIGURE 4 HERE**

In panel A of figure 4 I show how the number of firms changes when the sectors move towards zero trade costs. Industries are less populated. The reduction in the number of firms, however, is stronger in the initially less competitive sectors. This result is a combination of the pro-competitive result of Cournot and the fact that the less competitive sectors start with a relatively higher level of trade costs (since, as discussed in the previous section, for the same level of trade costs they are relatively more open to free trade). The effect on the mark-up is negative but stronger in the initially more competitive sectors. The large fall in domestic firms that suffers the initially less competitive ones mitigates partially both the pro-competitive effect and the effect of the trade cost.

**INSERT FIGURE 5 HERE**

The movement towards free trade would bring a substantial reallocation of employment towards production and innovation, but this increase is not equally shared across all manufacturing sectors. More precisely the less competitive ones experience a larger increase in employment (Panel A in Figure 5). This reallocation is stronger in innovation activities, suggesting that within a firm there is a reallocation from production to innovation (Panel B). The former result is basically the consequence of the fact that the less competitive sectors suffer from a larger fall in trade barriers, a stronger pro-competitive effect but, above all, a larger fall in the number of surviving firms. This generates a reallocation of resources towards the incumbents.

Panel D in figure 5 suggests a very interesting result and this differs from the case with restricted entry. Almost all of the reallocation of labour that we have observed in the previous figure is not coming from a reallocation of labour across sectors but from a reallocation across activities within a sector. That is, in the less competitive sectors, the number of firms falls to a greater extent, and labour is reallocated towards the incumbent firms. The model also suggests that the change in trade costs generates a reallocation effect from production to innovation activities.

To see the importance of this asymmetry on the potential effects of trade on aggregate productivity growth, I have computed the increase in productivity growth that results from a movement from a common trade cost towards free trade when there are no differences in product market competition (being the technological constant common across sectors and equal to the average value). Compared to an initial situation

[23] I use a 3-digit level of disaggregation because this is the finest level for which the share of the labor force engaged in R&D activities across sectors is available. In Appendix 2, I provide additional information regarding how the model matches the data on markups.

[24] In that paper, the authors compute the value of duties and transportation costs for each of the 6-digit US manufacturing industries using the underlying product-level US import data compiled by Feenstra (1996). To obtain an aggregate measure of the trade costs for each of the 3-digit sectors, I take for each year a weighted average of the trade costs for each of the 6 digit products using the import shares as weights.

[25] An interesting exercise in which industries face a common trade barrier but they exhibit differences in the degree of product market competition, which is analogous also to the first exercise of section 3.2, is discussed in the Appendix 4.

in which industries differ in competition but share the same trade barrier, the increase in the aggregate productivity growth will be 0.0040 which is 5% larger than in the case of which we have asymmetries across sectors. Analogously I also obtain that in an environment in which there are differences in trade barriers across sectors, moving to a common trade cost (which is the average of the previous trade costs) increases the aggregate productivity growth by approximately 0.004 points. Although small, these exercises suggests that asymmetries across sectors due to differences in product market competition or trade costs limit the potential benefits of trade.

# 5 Conclusions

Empirical evidence suggests that there is substantial variation in mark-ups and trade barriers across sectors. In this paper, I explore how these two sources of heterogeneity affect the impact of trade liberalisation on innovation both at a sector and aggregate level. To do so, I consider a multi-sector endogenous growth model with oligopolistic competition in which incumbent firms undertake process innovation. Then, I consider either a movement from autarky or positive trade costs towards free trade in two alternative scenarios: restricted and free entry.

I find that a sector's degree of product market competition is a key determinant of the impact of trade on innovation. A movement from autarky to free trade increases innovation efforts in those sectors which are initially less competitive. This is the consequence of the fact that the increase in competition coming from foreign markets is tougher in sectors which are initially less competitive. This result is robust to an alternative scenario where sectors start with positive trade costs and the degree of trade openness is common across sectors. In all cases, tougher competition increases firm size and promotes innovation in those sectors and it generates a reallocation of productive resources towards these sectors. When I allow for free entry, the same competition effect reduces the mass of active firms by more in the less competitive sectors. This generates a reallocation of market shares and productive resources towards incumbents that further contributes to innovation. Interestingly, when the number of firms is endogenous, the reallocation of productive resources occurs across activities within the same sector, but there is little reallocation across sectors. I find also that an asymmetric trade liberalisation policy generates substantially different effects on innovation across sectors. Innovation increases in those sectors that reduce trade barriers and this is larger in those sectors that benefit from a larger reduction. This result is reinforced in the case of free entry, because the reduction in trade costs reduces the mass of active firms in the sector. Market shares and productive resources are reallocated towards the surviving firms which serve to increase firm size and innovation efforts.

The paper also outlines the importance of these differences in the impact that trade liberalisation has on aggregate productivity growth. The existence of these sources of heterogeneity either in the degree of trade openness or in the degree of product market competition limits the impact that trade has on innovation at an aggregate level. A movement towards a common trade cost could generate an increase in aggregate productivity growth. Similarly, when sectors start with identical trade barriers, a movement towards free trade has a stronger impact on aggregate productivity growth when sectors are more homogeneous in terms of competition.

This paper could be extended in two directions. The first could include firm heterogeneity and investigate how between-sector heterogeneity in these two dimensions and within-sector heterogeneity interplays on the effect that trade has on average productivity and innovation. The second could explore recent episodes of unilateral trade liberalisation policies in a model that allows for asymmetries across countries. Given that unilateral trade liberalisation policies have been increasing in the last decade (Baldwin (2010)), this seems to be a promising area for future research.

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# 7 Appendix 1 Mathematical Appendix

## 7.1 Balanced Growth Path

A Balanced Growth Path (BGP) is an equilibrium path in which variables $l_j^x, l_j^z, l_j^f, L^x, L^z, L^y, r, E, E_j^x, E^x, E^y$ and $q^y$, are constant and $q_j, x_j, z_j, v_j$ and $p_j$ grow at a constant rate. I will show that a BGP exists and is unique. Notice that $l_j^x, l_j^z, l_j^f, L^y$ are constant in BGP since they are upper and lower bounded from condition (16).

Symmetric equilibria imply that $q_{dij} = q_j,\ \forall i, d$. From (12), this implies that $x_{ij} = x_j = n_j q_j$. It follows from (10) that $p_{ij} = p_j$. Using this in (10), I obtain, $p_j = \frac{LE_j^x}{Zx_j} = \frac{LE_j^x}{Zn_j q_j}$. Substituting the last condition in (13), yields the following:

$$p_j = \frac{1}{\theta_j} (z_j)^{-1}. \tag{32}$$

Using (3) under symmetry, notice that

$$Zn_j p_j q_j = \frac{n_j}{\theta_j} Z l_j^x. \tag{33}$$

Using (9) and (7), I obtain :

$$\frac{n_j}{\theta_j} Z l_j^x = \frac{\phi_j}{\phi_k} \frac{n_k}{\theta_k} Z l_k^x$$

and then

$$\frac{l_j^x}{l_k^x} = \frac{\phi_j}{\phi_k} \frac{\theta_j}{\theta_k} \frac{n_k}{n_j} \tag{34}$$

Constant $E$ implies that $r = \rho$. Using this and combining (4), (13), (14) and (15), I obtain the following equation

$$\gamma B_j (l_j^z)^{\gamma-1} l_j^x = \gamma B_k (l_k^z)^{\gamma-1} l_k^x = \rho. \quad j,k = 1,2,...N. \tag{35}$$

To obtain an expression for the equilibrium allocation of workers across activities and sectors, note from (35) that:

$$l_j^x = \frac{\rho}{\gamma B_j} \left(l_j^z\right)^{1-\gamma} \tag{36}$$

Now let us obtain condition (21). Consider first, the labour market clearing condition under symmetry:

$$Z \left( \sum_{j=1}^{N} n_j l_j^f \right) + L^y = L. \tag{37}$$

From the production function I have that

$$l_j^x = z_j^{-1} q_j$$

and substituting (13) under symmetric equilibria I have that:

$$l_j^x = z_j^{-1} \theta_j z_j l_j E_j^x = \frac{\theta_j}{n_j} \phi_j \frac{LE^x}{Z} \tag{38}$$

This implies that $Z l_j^x = \frac{\theta_j}{n_j} \phi_j LE^x$. This leads to,

$$L_j^x = \sum_{j=1}^{N} n_j Z l_j^x dj = \sum_{j=1}^{N} n_j \frac{\theta_j}{n_j} \phi_j LE^x = \tilde{\theta} LE^x$$

Since in steady state $l_j^x, l_j^z$ $L^y$ are constant. From (5), (6) and (18):

$$L^y = \frac{1-\beta}{\beta} LE^x \tag{39}$$

Notice that from (38) (the corresponding one to sector $k$):

$$LE^x = \frac{Z n_k}{\phi_k \theta_k} l_k^x = \frac{Z n_k}{\tilde{\theta}_k} \frac{\rho}{\gamma B_k} \left(l_k^z\right)^{1-\gamma} \tag{40}$$

where the last equality comes from substituting (36) in the previous equation. Then:

$$L^x + L^y = \left( \frac{\tilde{\theta} + \frac{1-\beta}{\beta}}{\tilde{\theta}_k} \right) Z n_k \frac{\rho}{\gamma B_k} \left(l_k^z\right)^{1-\gamma} = \left( \frac{\beta \tilde{\theta} + 1 - \beta}{\beta \tilde{\theta}_k} \right) Z n_k \frac{\rho}{\gamma B_k} \left(l_k^z\right)^{1-\gamma} \tag{41}$$

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

To get an expression for total labour in R&D I use (36) and (34) to obtain:

$$L^z = Z \left( \sum_{j=1}^{N} n_j l_j^z \right) = Z \left( \sum_{j \neq k}^{N} n_j \left( \frac{l_j^x}{l_k^x} \frac{B_j}{B_k} \right)^{\frac{1}{1-\gamma}} l_k^z + n_k l_k^z \right) = Z \left( \sum_{j \neq k}^{N} n_j \left( \frac{\tilde{\theta}_j}{\tilde{\theta}_k} \frac{n_k}{n_j} \frac{B_j}{B_k} \right)^{\frac{1}{1-\gamma}} + n_k \right) l_k^z$$

and working through this expression I get:

$$L^z = Z\left(\sum_{j=1}^{N}\frac{n_j}{n_k}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{n_k}{n_j}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\right)n_k l_k^z \tag{42}$$

Substituting (41) and (42) in (16) and dividing both sides by $Zn_k$ I get:

$$\left(\frac{(1-\beta)+\beta\left(\tilde{\theta}\right)}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}\left(l_k^z\right)^{1-\gamma}+\left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right)l_k^z = l_k$$

where $l_k = \frac{L}{Zn_k}$. Notice that $\frac{\dot{q}_j}{q_j} = \frac{\dot{x}_j}{x_j} = \frac{\dot{z}_j}{z_j} = B_j\left(l_j^z\right)^{-\gamma}$ and $\frac{\dot{p}_j}{p_j} = \frac{\dot{v}_j}{v_j} = -\frac{\dot{z}_j}{z_j}$.

The proof for the existence and uniqueness of the BGP is straightforward.

**Proof.** The BGP exists if a solution to equation (21) exists. This is due to the fact that all variables in steady state collapse to some function of $l_k^z$ and the parameters of the model. Denote the left hand side of (21) as $f(l_k^z)$. $f(l_k^z)$ is a continous function in the interval $[0, l_k]$. It is monotonically increasing in $l_k^z$ and satisfies the limit conditions $\lim_{l_k^z \to 0} f(l_k^z) = 0$ and $\lim_{l_k^z \to l} f(l_k^z) > l_k$. Existence and uniqueness is directly implied by the intermediate value theorem.

Notice that if $\beta = \frac{1}{2}, \phi_j = \phi_k$, $B_k = 1\ \forall\ k$, and $\theta_j = \theta_k$ (i.e. $n_j = n_k$, $\alpha_j = \alpha_k$), the previous equation is equal to that derived in Licandro and Navas (2011). ■

### 7.1.1 Trade (Equation 29)

In trade firms solve the following optimization problem:

$$V_{dijs} = \max \int_s^{\infty} R_{s,t}\left[(p_{ij} - z_{dij}^{-1})q_{dij} + \sum_{m=1}^{M}(p_{ij}^{*m} - z_{dij}^{-1}(1+\tau_j))q_{dij}^{*m} - l_{dij}^z\right]dt, \tag{43}$$

$$\begin{aligned}
s.t.\ p_{ij} &= \left(\frac{LE_j^x}{p_j x_{ij}}\right)^{1-\alpha_j} p_j \\
p_{ij}^{*m} &= \left(\frac{LE_j^x}{p_j^{*m} x_{ij}^*}\right)^{1-\alpha_j} p_j^{*m} \\
x_{ij} &= x_{ij}^{*m} = \sum_{d=1}^{n_j} q_{dij} + \sum_{m=1}^{M}\sum_{d=1}^{n_j} q_{dij}^{*m} \\
\dot{z}_{dij} &= B_j(l_{dij}^z)^{\gamma} z_{dij}, \quad 0 < \gamma < 1 \\
z_{dij0} &> 0,
\end{aligned} \tag{44}$$

Focusing on symmetric equilibrium, I obtain conditions (22-25) in the main paper. For obtaining the steady state of the model, I proceed as above, realizing that $l_j^x = z^{-1}(q_j + M(1+\tau_j)q_j^*)$

$$l_j^x = z_j^{-1}\theta_j' z_j l_j E_j^x = \frac{\theta_j'}{n_j}\phi_j\frac{LE^x}{Z} \tag{45}$$

so following the previous steps, replacing $\theta_j$ by $\theta_j'$ leads to the same expression.

## 7.2 Proof of propositions

### 7.2.1 Proof of proposition 3

**Proof.** Notice that:

$$\frac{\partial l_k^z}{\partial \alpha_k} = \frac{\partial l_k^z}{\partial \theta_k}\frac{\partial \theta_k}{\partial \alpha_k}$$

since the effects of $\alpha_k$ on $l_k^z$ are all coming through $\theta_k$. Notice that $\frac{\partial \theta_k}{\partial \alpha_k} > 0$. In order to show that $\frac{\partial l_k^z}{\partial \alpha_k} > 0$, we need to show that $\frac{\partial l_k^z}{\partial \theta_k} > 0$ Totally differentiating condition (21) and rearranging terms, we have that:

$$\frac{\partial l_k^z}{\partial \theta_k} = \frac{\left(\frac{1-\beta}{\beta \tilde{\theta}_k} + \sum_{j \neq k}^{N} \left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\right)\right)\left(\frac{1}{\theta_k}\right)\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma} + \left(\frac{1}{1-\gamma}\right)\sum_{j \neq k}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\left(\frac{1}{\theta_k}\right) l_k^z}{(1-\gamma)\left(\frac{\beta\tilde{\theta}+1-\beta}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}\left(l_k^z\right)^{-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right)} > 0. \blacksquare$$

### 7.2.2 Proof of Proposition 4

**Proof.** To show that $\frac{\partial l_k^z}{\partial n_k} < 0$, I totally differentiate condition (21) obtaining the following expression:

$$\frac{\partial l_k^z}{\partial n_k} = \frac{\frac{-L}{Z(n_k)^2} + \left(\frac{1-\beta}{\beta\tilde{\theta}_k} + \sum_{j \neq k}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\right)\right)\left(\frac{1}{\theta_k}\right)\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma}\frac{\partial \theta_k}{\partial n_k} - \sum_{j \neq k}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}} l_k^z\left[\frac{\gamma}{1-\gamma}\frac{1}{n_k} - \frac{1}{1-\gamma}\frac{1}{\theta_k}\frac{\partial \theta_k}{\partial n_k}\right]}{(1-\gamma)\left(\frac{\beta\tilde{\theta}+1-\beta}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}\left(l_k^z\right)^{-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right)}$$

Rearranging terms, I derive the following expression:

$$\frac{\partial l_k^z}{\partial n_k} = \frac{\frac{-L}{Z(n_k)^2} + \frac{\partial \theta_k}{\partial n_k}\frac{1}{\theta_k}\Psi + \frac{\gamma}{1-\gamma}\left(\frac{\partial \theta_k}{\partial n_k}\frac{1}{\theta_k} - \frac{1}{n_k}\right)\sum_{j \neq k}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}} l_k^z}{(1-\gamma)\left(\frac{\beta\tilde{\theta}+1-\beta}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}\left(l_k^z\right)^{-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right)}$$

where $\Psi = \left[\left(\frac{1-\beta}{\beta\tilde{\theta}_k} + \sum_{j \neq k}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\right)\right)\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma} + \sum_{j \neq k}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}} l_k^z\right]$.

Using condition (21) I have that:

$$\Psi = \frac{L}{Zn_k} - \frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma} - l_k^z \tag{46}$$

Substituting (46) in the equation above and rearranging terms, I have that:

$$\frac{\partial l_k^z}{\partial n_k} = \frac{\frac{L}{Z(n_k)}\left(\frac{\partial \theta_k}{\partial n_k}\frac{1}{\theta_k} - \frac{1}{n_k}\right) - \left(\frac{\partial \theta_k}{\partial n_k}\frac{1}{\theta_k}\right)\left(\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma} + l_k^z\right) + \frac{\gamma}{1-\gamma}\left(\frac{\partial \theta_k}{\partial n_k}\frac{1}{\theta_k} - \frac{1}{n_k}\right)\sum_{j \neq k}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}} l_k^z}{(1-\gamma)\left(\frac{\beta\tilde{\theta}+1-\beta}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}\left(l_k^z\right)^{-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right)}$$

This is negative iff $\left(\frac{\partial \theta_k}{\partial n_k}\frac{1}{\theta_k} - \frac{1}{n_k}\right) < 0$.This condition holds as:

$$\frac{\partial \theta_k}{\partial n_k} < \frac{\theta_k}{n_k}$$

$\frac{\partial \theta_k}{\partial n_k} = \frac{(1-\alpha_k)}{(n_k)^2}$ while $\frac{\theta_k}{n_k} = \frac{n_k - 1 + \alpha_k}{(n_k)^2}$. Rearranging terms, the last inequality implies that:

$$n_k > 2\left(1 - \alpha_k\right)$$

This is satisfied since we have assumed that $n_k \geq 2$. $\blacksquare$

### 7.2.3 Proof of Proposition 5

**Proof.** I first show that $\frac{\partial l_k^z}{\partial \alpha_h} < 0$.

As in the proof of proposition 2 $\frac{\partial l_k^z}{\partial \alpha_h} = \frac{\partial l_k^z}{\partial \theta_h}\frac{\partial \theta_h}{\partial \alpha_h}$ and since $\frac{\partial \theta_h}{\partial \alpha_h} > 0$, $\frac{\partial l_k^z}{\partial \alpha_h} < 0 \Leftrightarrow \frac{\partial l_k^z}{\partial \theta_h} < 0$.

Totally differentiating condition (21) and rearranging terms I obtain:

$$\frac{\partial l_k^z}{\partial \theta_h} = \frac{-\left[\left(\frac{\phi_h}{\phi_k \theta_k}\right)\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma} + \left(\frac{1}{1-\gamma}\right)\left(\frac{\phi_h B_h}{\phi_k \theta_k B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_h}\right)^{\frac{\gamma}{1-\gamma}}(\theta_h)^{\frac{\gamma}{1-\gamma}} l_k^z\right]}{(1-\gamma)\left(\frac{\beta\tilde{\theta}+1-\beta}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}\left(l_k^z\right)^{-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right)} < 0.$$

Notice that the larger $\phi_h$, the stronger is this effect. This is because $\phi_h$ is a measure of the size of the sector. An increase in the degree of substitutability among varieties of the same sector, increases the demand for labour in that sector. The larger this sector is, the stronger is the increase in the demand, and consequently the stronger is the reallocation effect towards this sector.

To show that $\frac{\partial l_k^z}{\partial n_h} < 0$ we totally differentiate condition (21) considering that $\theta_h$ is a function of $n_h$ (Remember that $\frac{\partial \theta_h}{\partial n_h} > 0$). Rearranging terms I get,

$$\frac{\partial l_k^z}{\partial n_k} = \frac{-\left[\left(\frac{\phi_h}{\phi_k \theta_k}\right)\frac{\rho}{\gamma B_k}(l_k^z)^{1-\gamma}\frac{\partial \theta_h}{\partial n_h} + \left(\frac{1}{1-\gamma}\right)\left(\frac{\phi_h \theta_h B_h}{\phi_k \theta_k B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_h}\right)^{\frac{\gamma}{1-\gamma}} l_k^z \left[\frac{\partial \theta_h}{\partial n_h}\frac{1}{\theta_h} - \gamma \frac{1}{n_h}\right]\right]}{(1-\gamma)\left(\frac{\beta\tilde{\theta}+1-\beta}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma B_k}\left(l_k^z\right)^{-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{B_j}{B_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right)} < 0.$$

Notice that the latter is negative if $\left[\frac{\partial \theta_h}{\partial n_h}\frac{1}{\theta_h} - \gamma \frac{1}{n_h}\right] > 0$.

This will happen if $\frac{\partial \theta_h}{\partial n_h} > \gamma \frac{\theta_h}{n_h}$. Notice that $\frac{\partial \theta_h}{\partial n_h} = \frac{(1-\alpha_h)}{(n_h)^2}$. Substituting this in the previous condition I get

$$(1-\alpha_h) > \gamma \left(n_h - (1-\alpha_h)\right)$$

and this implies that:

$$n_h < \frac{(1-\alpha_h)(1+\gamma)}{\gamma}.$$

So $\frac{\partial l_k^z}{\partial n_h} < 0$ if $n_h < \frac{(1-\alpha_h)(1+\gamma)}{\gamma}$. Given that the data report a very low value for $\gamma$ this condition will hold throughout the paper. ■

## 7.3 Proof that $\theta_j' \geq \theta_j$

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

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

where $\triangle\theta = \theta_j' - \theta_j$

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 I 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 I can conclude that this expression is always positive, provided that exports are positive. It would be zero iff: $\tau_j = \tau_j^*,\ \ M = 0$. If $\tau_j = 0$, This expresssion reduces 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 the larger the number of trade partners the greater the increase in competition but it is concave in $M$ revealing that the increase in the number of trade partners has diminishing effects on competition. This expression is decreasing in $n_j$ and the elasticity of substitution $\alpha_j$ 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 sector productivity growth rate.

## 7.4 Free Entry

Notice that a firm's profits can be expressed as:

$$\Pi_{ijt} = \frac{1}{\theta_j}\left(z_{ijt}\right)^{-1} q_{ijt} - l_{ijt}^x - l_{ijt}^z - f_j$$

Rearranging terms, applying symmetry and the zero profit condition I obtain:

$$\left(\frac{1-\theta_j}{\theta_j}\right) l_j^x = l_j^z + f_j.$$

Substituting the last equation together with (39) and (40) in condition (30), I get:

$$Z\left(\sum_{j=1}^{N}\frac{n_j}{\theta_j}l_j^x+\left(\frac{1-\beta}{\beta}\right)\frac{n_k l_k^x}{\tilde{\theta}_k}\right)=L$$

Substituting equation (20) in the previous one and rearranging terms:

$$\frac{n_k l_k^x}{\beta\phi_k\theta_k}=L$$

Then:

$$l_k^x=\beta\phi_k\theta_k l_k$$

From (36):

$$l_k^z=\left(\frac{\gamma}{\rho}B_k l_k^x\right)^{\frac{1}{1-\gamma}}$$

Substituting the last two equations in the profit function it gives:

$$\beta\left(1-\theta_k\right)\phi_k l_k-\left(\frac{\gamma}{\rho}B_k\beta\theta_k\phi_k l_k\right)^{\frac{1}{1-\gamma}}=f_k, \forall\ k$$

## 7.5 The degree of Trade Openness

In the article I have explained that the main results regarding the effect of the initial degree of competition on the impact of trade on innovation hold when I consider a movement from positive to zero trade costs, keeping constant the degree of trade openness across sectors. This subsection aims to be precise on the way I have derived that result.

Let us denote $\lambda_j=\frac{(1+\tau_j)(1-\alpha_j)-\tau_j n_j}{1-\alpha_j+Mn_j\tau_j}$. A standard measure of the degree of trade openness in a certain sector is given by (Exports+Imports/GDP). Since trade balance is assumed our trade openness index of sector $j$ is given by: $TO_j=\frac{2n_j p_j q_j^*}{n_j p_j (q_j+q_j^*)}=\frac{2\lambda_j}{1+\lambda_j}$. Notice that $\frac{\partial TO_j}{\partial n_j}=\frac{\partial TO_j}{\partial\lambda_j}\frac{\partial\lambda_j}{\partial n_j}<0$ since $\frac{\partial TO_j}{\partial\lambda_j}>0$ and $\frac{\partial\lambda_j}{\partial n_j}<0$.

The model main equations remained unchanged, once I am able to express the value of $\theta_j$ in terms of $\lambda_j$. Consider without loss of generalisation that $M=1$.We can rewrite (22) and (23) as:

$$p_j\left(1-\frac{(1-\alpha_j)}{n_j(1+\lambda_j)}\right)=z_j^{-1} \tag{47}$$

$$p_j\left(1-\frac{(1-\alpha_j)\lambda_j}{n_j(1+\lambda_j)}\right)=z_j^{-1}(1+\tau_j) \tag{48}$$

and dividing (47) and (48) I have that:

$$\frac{n_j(1+\lambda_j)-(1-\alpha_j)}{n_j(1+\lambda_j)-(1-\alpha_j)\lambda_j}=\frac{1}{1+\tau_j}$$

Rearranging (47) and using (9) I obtain

$$q_j=\frac{n_j(1+\lambda_j)-(1-\alpha_j)}{n_j(1+\lambda_j)^2}z_j l_j E_j \tag{49}$$

and substituting (47), (48) and (49) in the definition of $\theta_j'$

$$\theta_j'=\frac{n_j(1+\lambda_j)^2-(1-\alpha_j)(1+\lambda_j^2)}{n_j(1+\lambda_j)^2}$$

Once you have $\theta_j'$ you can solve for all the relevant variables of the model. The case in Free Trade is analogous using as $\theta_j'$ the expression above.

# 8 Appendix 2 Notes on Calibration and Model Fit.

The calibration exercise provides us with a number of firms per product and consequently a measure of the product market competition in the sector. While the lack of information regarding $f_j$ could make the calibration exercise a little bit rough it is useful to see how the calibrated model fits the data. I have obtained measures of the average mark-ups for each 3-digit NAICS manufacturing sector using the NBER productivity Database by Bartelsman et al. (2000). This database contains information about the value of shipments, production costs and TFP measures for the US manufacturing sectors at a 6-digit level of disaggregation. To compute the mark-ups I have used the standard measure in the literature: $\mu = \frac{vship - prodc.}{prodc.}$.[26] To aggregate across sectors I have taken a weighted average for each year where I use the share of the value of shipments as weights. To compare the model with the data I have used an average over the whole sample period (1958-2009).

**INSERT FIGURE 6 HERE**

Figure 6 shows how the model fits the data. Panel A plots the actual versus estimated measure of product market competition. On average mark-ups are relatively well predicted by the model (the average mark-up predicted by the model was 18.75% while the average mark-up obtained in our sample was 18.96%). The standard deviation however reveals that in our model there is substantially less variation as compared to the real value (0.0151 vs 0.1055). The data suggests that the model does a relatively good job in matching the average but it only performs satisfactorily in terms of the variability. Although differences in trade costs and technological R&D differences are capturing important channels through which mark-ups vary across sectors, the fact that the fixed operational costs do not vary in our sample could be the main reason behind the small variability in mark-ups observed in the predicted data. Panel B shows how the model fits the share of the labour force engaged in R&D activities. In this case the model performs extraordinarily well both in average and in the variability.

# 9 Appendix 3 Asymmetric Trade Liberalisation

In this appendix I report the asymmetric trade liberalisation exercise. The aim of this exercise is to explore the consequences for innovation of the existence of asymmetries in trade barriers across sectors. As in the main paper, I distinguish two different scenarios, restricted entry and free entry.

## 9.1 Asymmetric Trade Liberalisation. Restricted Entry.

Consider an initial situation in which both sectors are exactly identical and start with the same value for the trade costs (i.e. $\tau = 0.08$). However, a trade policy is implemented in sector 1 but is not implemented in sector 2. What would be the effects for innovation of this policy?

**INSERT FIGURE 7 HERE**

Figure 7 shows the variation in percentage points in the firm's R&D-employment in both the liberalised sector (Sector 1) and the non-liberalised sector (Sector 2). R&D employment increases in the liberalised sector and decreases in the non-liberalised sector. The largest increase in R&D employment is obtained when there are no trade costs in sector 1, and this increase varies from 0.3 (with two firms in each sector) to almost 1% (with six firms). Larger trade cost reductions are associated with larger increases in R&D employment, although the function is concave. Trade liberalisation enhances productivity growth in those sectors which liberalise, but it has a non-linear effect. The effect is stronger when those sectors are relatively more closed to foreign trade. As we have discussed above, this is the consequence of the fact that the competition effect is stronger the more closed the sector is to foreign trade.

[26] where *vship* is the value of shipments and *prodc* are the production costs. In the production costs I have used labour costs (to which I have added an estimated cost of social security expenditure paid by the employer), materials (which include intermediate inputs and energy) and capital costs. For computing the capital costs I have used the capital stocks provided in the data. For the user cost of capital, I have considered the standard measure $r_t + \delta$, where $r_t$ is the long-term real interest rate and $\delta$ is the depreciation cost. For the latter I have distinguished between equipment (with a depreciation rate of 10%) and plant (with a depreciation rate of 5%). To compute the capital expenditures I have used the lagged value of the capital stock as suggested in Epifani and Gancia (2011).

## 9.2 Asymmetric Trade Liberalisation. Free Entry.

To make our results comparable to the previous subsection I compare a calibrated US economy with no technological differences in R&D but differences in trade barriers across sectors with a hypothetical identical economy that faces a common trade barrier across sectors. The latter is equal to the average trade barrier of the US manufacturing industries obtained from the data. With this counterfactual exercise I am measuring indirectly the consequences of asymmetric trade liberalisation by comparing a US economy in which there are only differences in trade barriers across manufacturing sectors with what the same economy would look like if trade costs were common across all manufacturing sectors.

**INSERT FIGURE 8 HERE**

Figure 8 shows how the degree of competition across sectors differs in both economies. The OX axis in both graphs measures the change in trade barriers with respect to the average. In panel A we observe the change in the domestic number of firms between both scenarios. In those industries where trade costs are above the average (bigger than zero in the OX axis), the number of firms is larger while the reverse happens in those sectors where trade costs are below the average (smaller than zero in the OX axis). This implies that in a hypothetical movement to a common trade cost, the number of firms would decline (increase) in those sectors whose trade costs are above (below) the average. However, markups would fall (increase) in those sectors whose trade costs are above (below) the average, as Panel B shows. This suggests that trade would intensify competition in those sectors that are affected by a decline in trade costs and tougher competition will simultaneously reduce the number of local firms in each sector and the markups. The effect is more intense the larger the trade cost change.

**INSERT FIGURE 9 HERE**

Figure 9 reveals that labour in production and R&D activities changes substantially across sectors. Panel A reveals that employment in these activities increases in those sectors that are affected by a decline in trade costs and the opposite happens in those sectors for which trade costs increase. The effect is also stronger the larger the change in trade costs.

The previous exercise also suggests that moving towards a unique trade cost increases aggregate productivity growth, although the impact is small.[27] In a scenario in which trade barriers vary across sectors, very protected sectors (with high trade barriers) invest too little in R&D and labour is relatively more productive in those sectors while sectors very exposed to foreign trade invest a lot in R&D and so labour is relatively unproductive in those sectors. A movement towards a common trade cost reallocates labour in R&D generating an increase in aggregate productivity growth. This suggests that asymmetries across sectors in trade barriers reduce the potential gains from trade. If these trade barriers are the result of policy outcomes, governments should try to minimize the differences among them to fully exploit the benefits from trade.

# 10 Appendix 4 Trade Liberalisation with differences in competition. Common trade costs. Free Entry

In this exercise I compare an economy with a common trade barrier (7.85%) but with differences in competition, these differences arising as a result of technological differences in R&D, with an identical one in which there are no trade costs. Since initial trade costs are identical across sectors but sectors differ in the degree of product market competition, this exercise is the equivalent to the first exercise with common trade costs but differences in competition exposed in section 3.2.

**INSERT FIGURE 10 HERE**

[27] Since the expenditure shares on the different goods are constant we can approximate aggregate productivity growth by $\frac{\dot{z}}{z} = \beta \sum_{j=1}^{N} \phi_j \frac{\dot{z}_j}{z_j}$. A movement to a common trade cost increases aggregate productivity growth by 0.004 percentage points. This tiny effect is due to the fact that the data suggests very low levels for $\gamma$. On average labor in R&D activities increases as a consequence of a common tariff policy by 0.40%.

In panel A of figure 10 I show how the number of firms changes. There is a reduction in the number of firms that is stronger in the initially more competitive sectors, or those relatively less open to foreign trade. Panel B shows that the decline in markups would be also stronger in those sectors which are initially more competitive, consistent with the conclusions obtained in section 3.2.

**INSERT FIGURE 11 HERE**

The movement towards free trade brings a substantial reallocation of employment towards production and innovation. This increase is more pronounced in the most competitive sectors. In addition, these sectors experience a larger increase in employment (Panel A in Figure 11).[28] Again, the reallocation is stronger in innovation activities (Panel B). Interestingly, the effect on the firm's TFP growth, though small is asymmetric across sectors favoring, however, those sectors which are initially less competitive (Panel C). The reason behind this result is the fact that the initially less competitive sectors are also the ones in which firms are more productive in R&D activities.

The previous reallocation effects across sectors also have an impact on sector productivity growth. Although the trade policy has brought productivity growth to all sectors, the increases are small but vary substantially across sectors (ranging from 0.0012 percentage points to 0.0067 percentage points). Aggregate productivity growth increases by 0.0038 points.

# 11 Figures

[28] That is the case of The Wood Product Manufacturing Industry whose labor force increases by 3.29%.

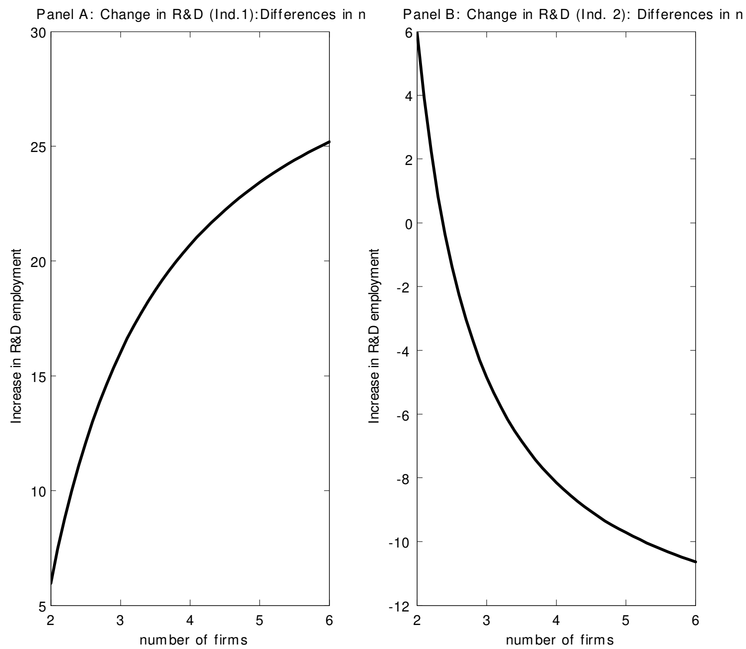


Figure 1: A movement from autarky to free trade with differences in the degree of competition across sectors (Restricted Entry). The number of firms in sector 1 is fixed at 2. OX axis in both graphs indicates the number of firms in sector 2. OY axis in each figure indicates the variation in per firm R&D labour in percentage points for sector 1 and sector 2 respectively.

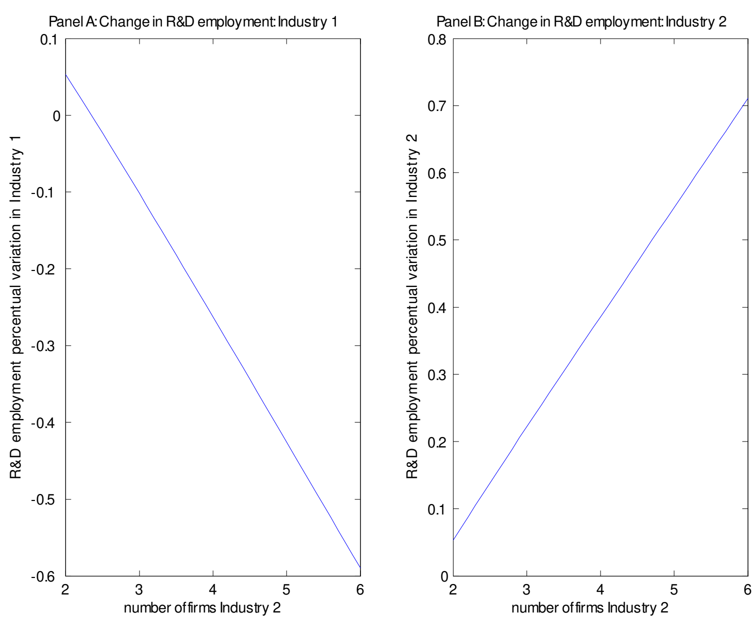


Figure 2: Trade Liberalisation Policy under differences in the degree of product market competition across sectors (Restricted Entry).

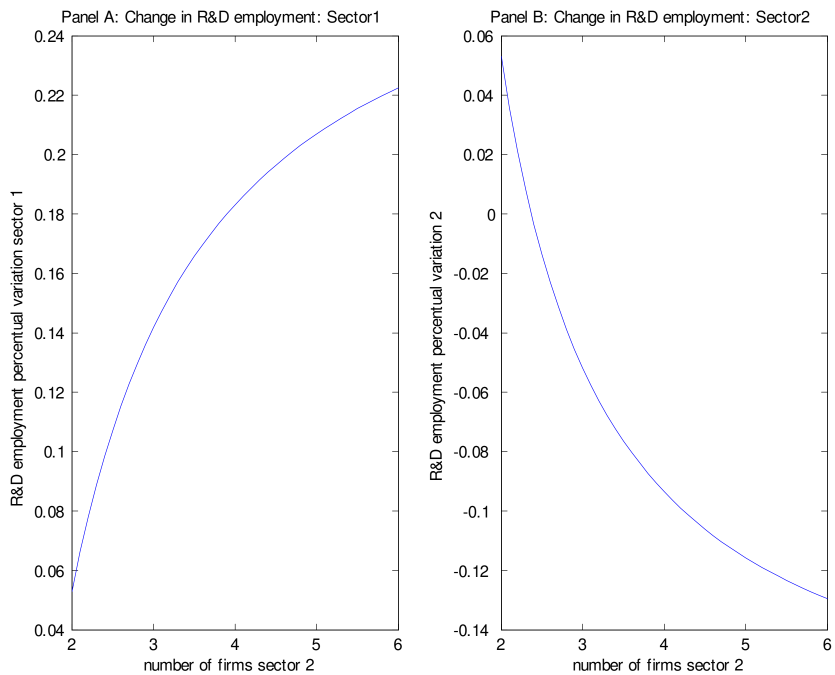


Figure 3: Symmetric Trade Liberalisation under differences in competition. Sectors start with the same degree of trade openness which corresponds to the degree of trade openness with an average trade cost of 8% (Degree of Trade Openness: 95% ) and the number of firms equal to two (n=2). We can observe that the results are analogous in qualitative terms to the exercise from autarky to free trade. Trade liberalisation pushes innovation more in less competitive sectors.

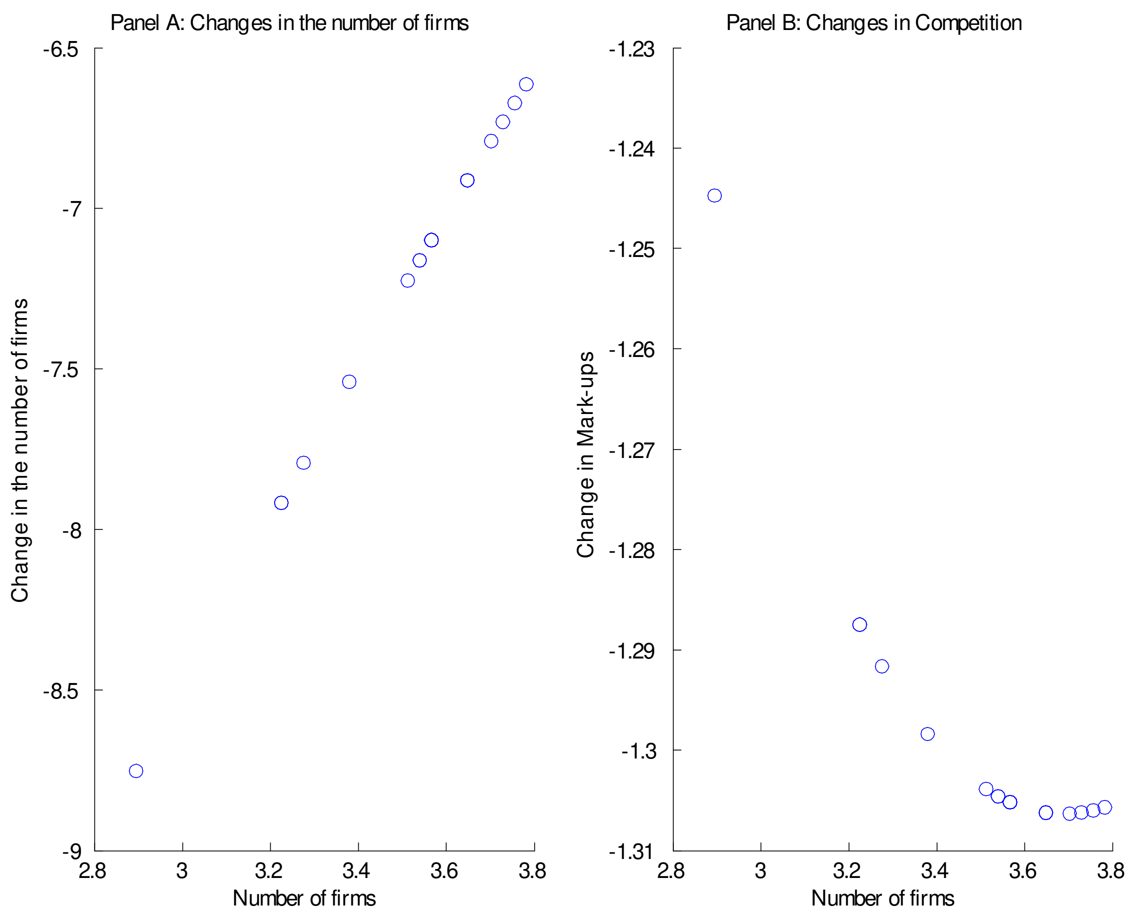


Figure 4: The effects of a movement from a common trade cost to free trade on competition. Changes are in percentage points.

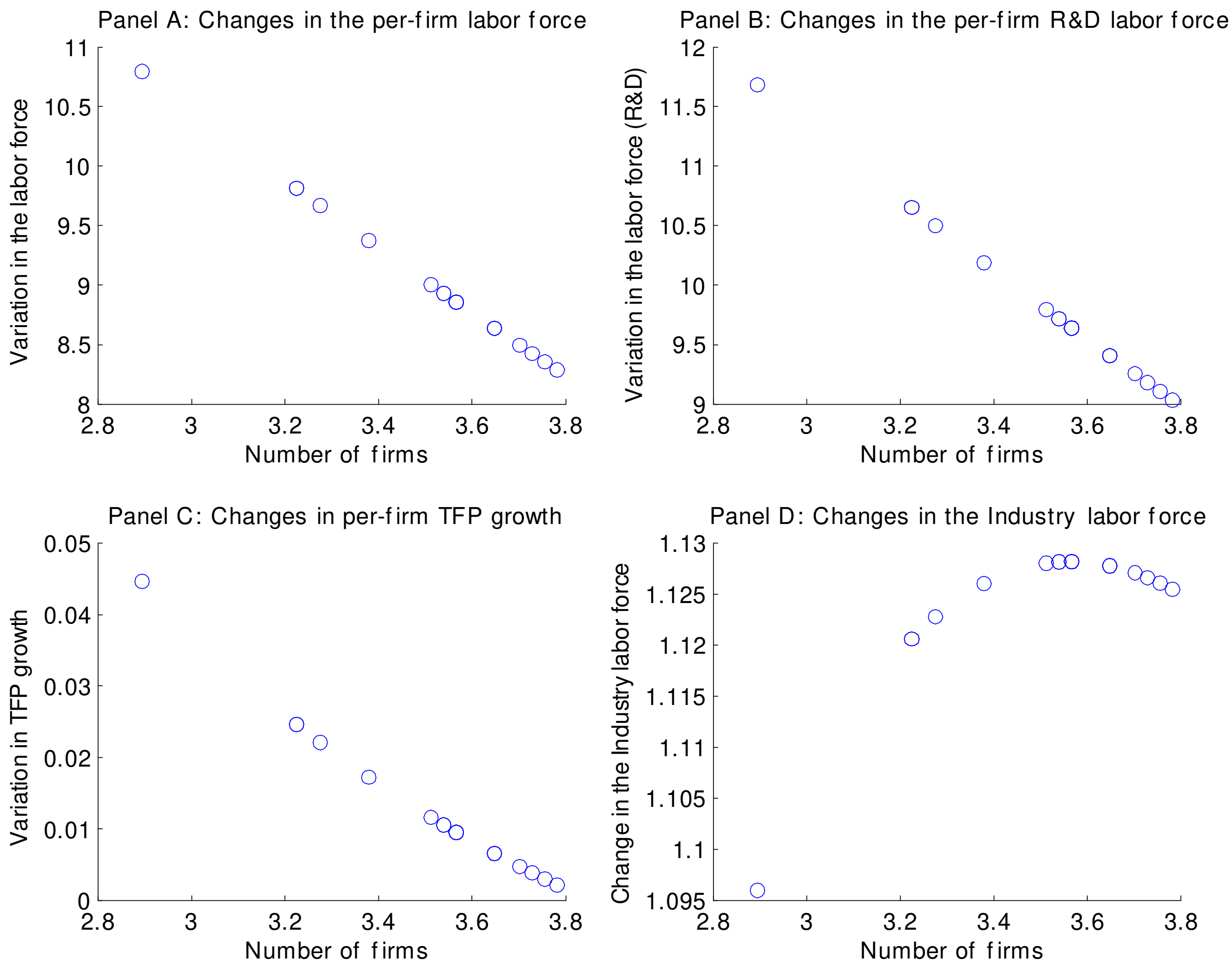


Figure 5: The effects of a movement from a common degree of trade openness to free trade. Changes in TFP growth and the sector labour force are in percentage points. Changes in the labour force are percentage changes.

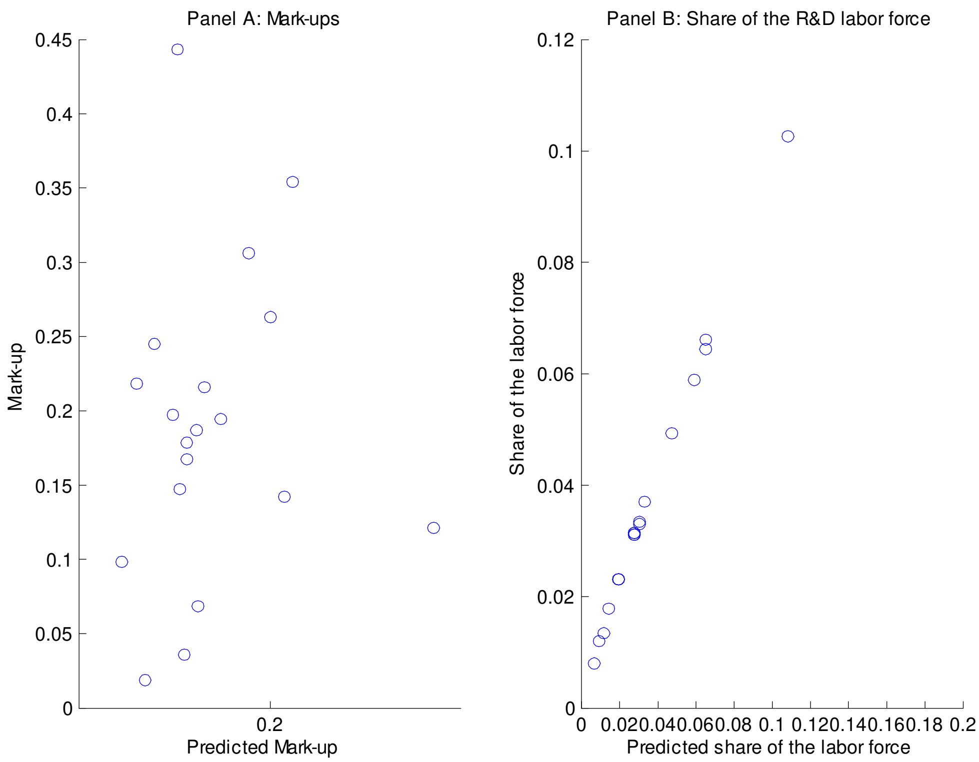


Figure 6: Data Fit. Panel A refers to Mark-ups (Average: 18.96% ) vs. Predicted Average (18.75%). Correlation Coefficient: 0.1209. Panel B refers for each sector to the share of the labor force engaged in R&D activities (Data Average. 4.84% vs Predicted Average 3.63%). Correlation Coefficient 0.9985

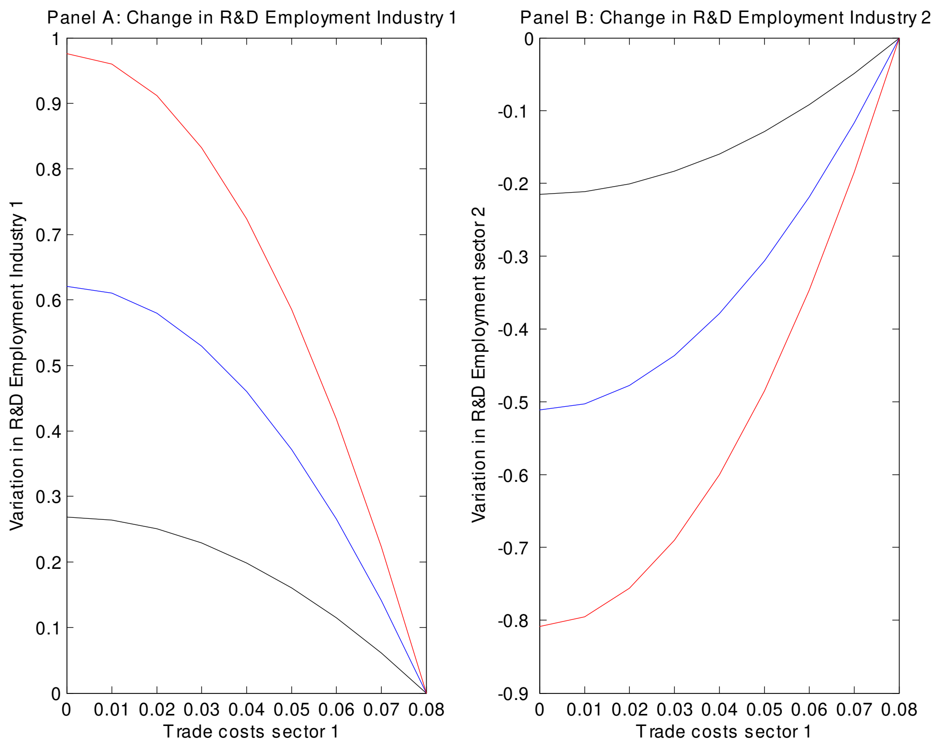


Figure 7: Asymmetric trade liberalisation (Restricted Entry). OY axis represents the variation in R&D employment for the respective sector (sectors 1 and 2) (increments in percentage points) for different values of trade costs in sector 1. (OX axis) keeping constant the trade cost in sector 2 (0.08). Sectors are otherwise identical, however the different lines represent different initial degrees of competition. The more outwards the line is the more competitive the sectors are.

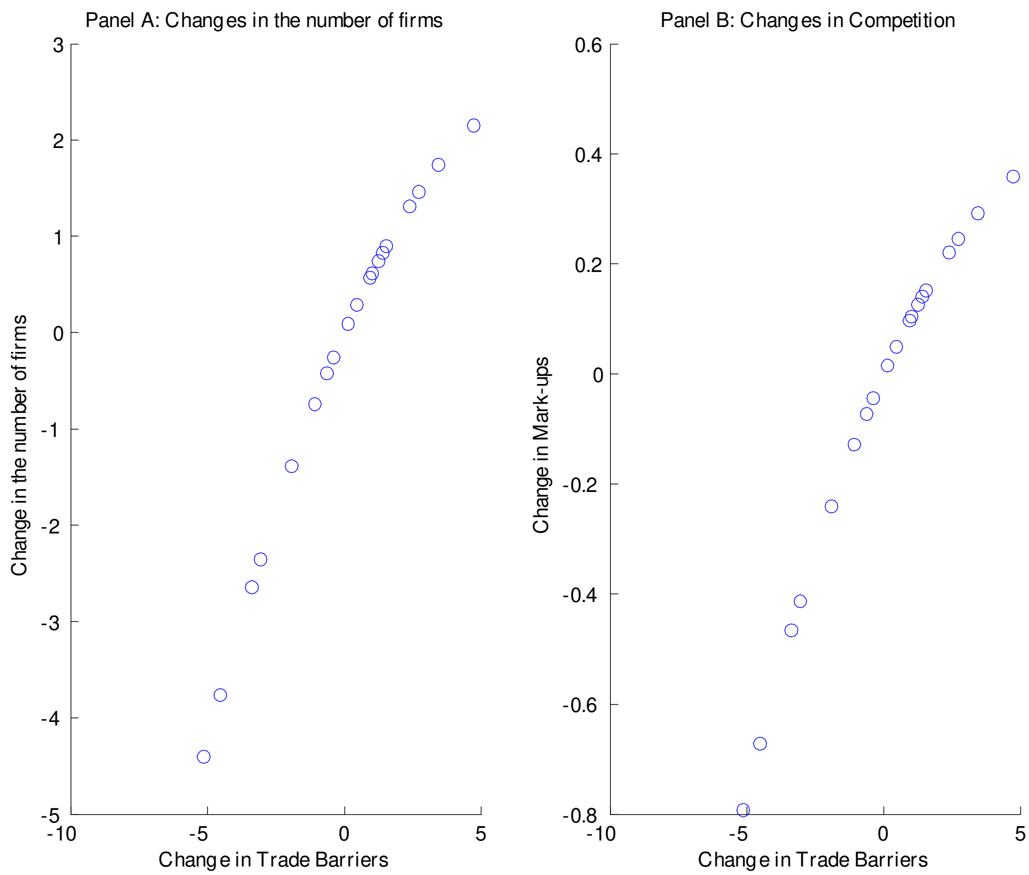


Figure 8: The impact of a movement towards a common trade cost on competition. Changes in trade barriers are measured in percentage points. Changes in the number of firms or in the mark-ups are expressed in percentage changes.

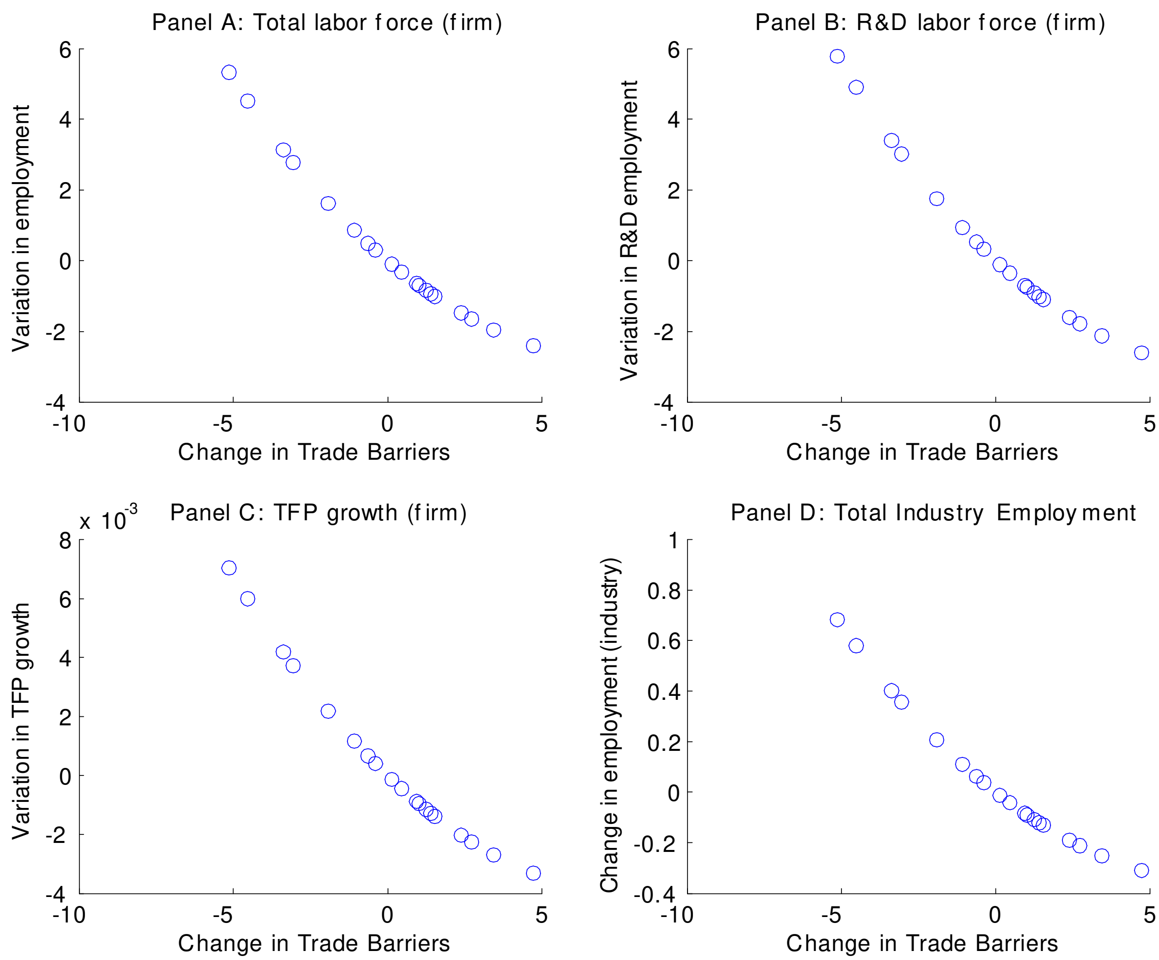


Figure 9: The impact of a movement to a common trade cost on firm and industry characteristics. Changes in trade barriers and in TFP growth are in percentage points. Changes in the employment are per firm and they are expressed as percentage changes.

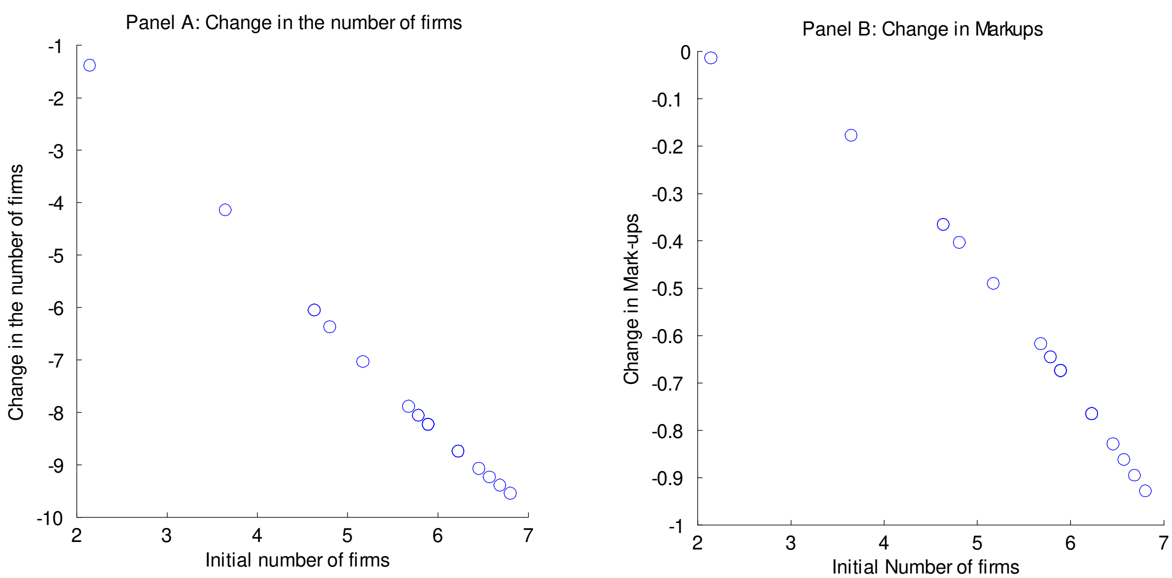


Figure 10: The effects of a movement from a common trade cost to free trade on competition. Changes are in percentage points.

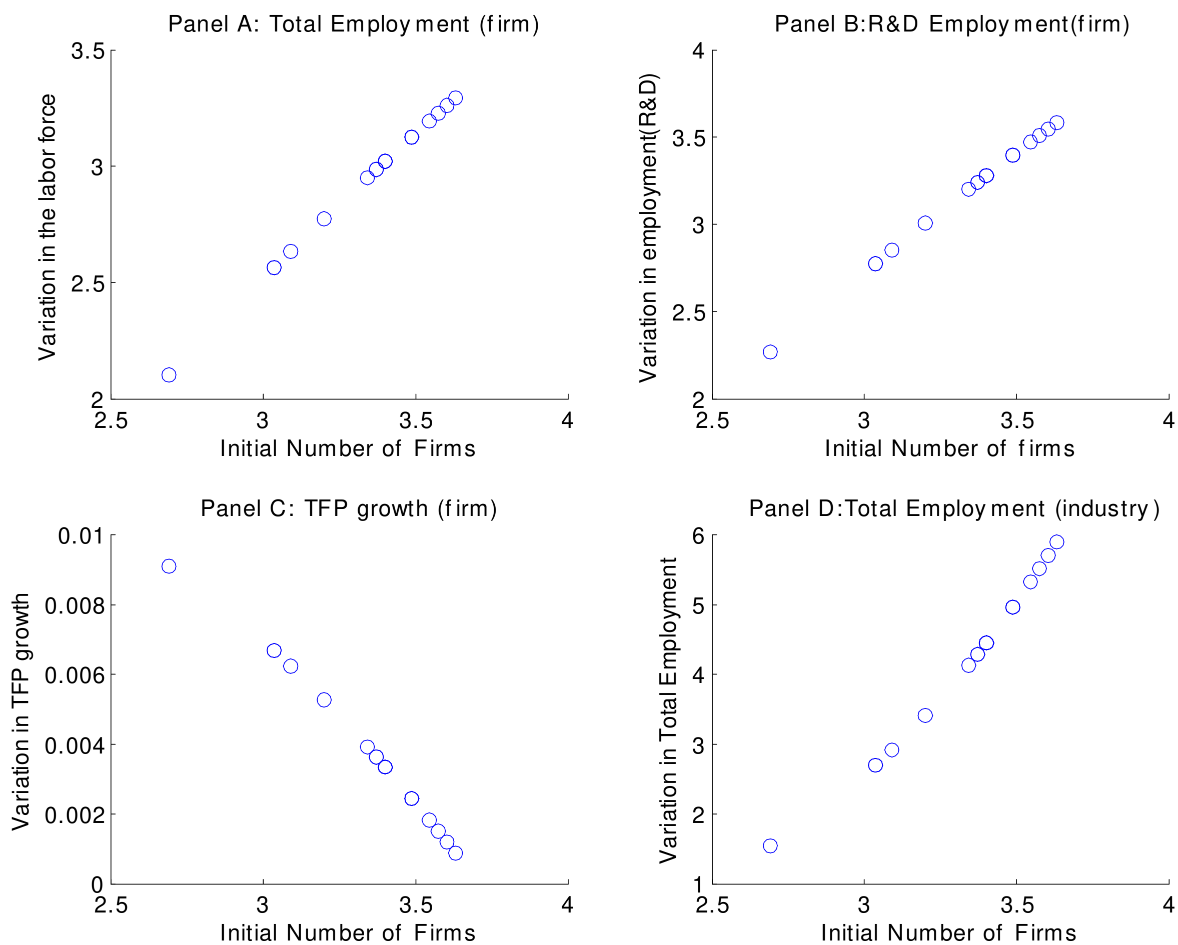


Figure 11: The effects of a movement from a common trade cost to free trade. Changes in TFP growth and the sector labour force are in percentage points. Changes in the labour force are percentage changes.