FIW – Working Paper

FIW Working Paper N° 127
August 2013

Asymmetric trade liberalisation, sector heterogeneity and innovation

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Abstract

Innovation, mark-ups and the degree of trade openness vary substantially across sectors. This paper builds a multi-sector endogenous growth model to study the influence of asymmetric trade liberalisation and sectoral differences in the degree of product market competition on the effect that trade has on R&D investments at a firm level. I find that differences in the degree of competition generate large differences in firm 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. However, when the initial tariff level is common across sectors, a homogeneous tariff reduction promotes innovation in those sectors which are initially more competitive. The paper suggests that trade liberalisation could be a source of industry productivity divergence: firms that are located in industries with greater exposure to foreign trade, invest a greater amount in R&D contributing to industry productivity growth. Finally the paper outlines the importance of reallocation effects within industry and across industries that are the result of these asymmetries. An asymmetric trade liberalisation has a small but negative impact on aggregate productivity growth.

JEL: F12, O43
Keywords: Sectorial productivity, international trade, innovation

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Asymmetric trade liberalisation, sector heterogeneity and innovation.[1]

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June 2013

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[2]I would like to thank the participants of Royal Economic Society Annual Meeting, 2013, WIFO Meeting Vienna 2013, Annual Meeting of th European Economic Association, (EEA-ESEM) 2012, European Trade Study Group Meeting, 2011, Simposio de Analisis Economico, 2011, and seminar participants of Universidad de Valencia, Universidad de Alicante and University of Sheffield, for useful comments and suggestions. This work could have not been done without the financial support of the Spanish Ministry of Science (ECO2008-1300).

Abstract

Innovation, mark-ups and the degree of trade openness vary substantially across sectors. This paper builds a multi-sector endogenous growth model to study the influence of asymmetric trade liberalisation and sectoral differences in the degree of product market competition on the effect that trade has on R&D investments at a firm level. I find that differences in the degree of competition generate large differences in firm 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. However, when the initial tariff level is common across sectors, a homogeneous tariff reduction promotes innovation in those sectors which are initially more competitive. The paper suggests that trade liberalisation could be a source of industry productivity divergence: firms that are located in industries with greater exposure to foreign trade, invest a greater amount in R&D contributing to industry productivity growth. Finally the paper outlines the importance of reallocation effects within industry and across industries that are the result of these asymmetries. An asymmetric trade liberalisation has a small but negative impact on aggregate productivity growth.

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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 an industry'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 (Rivera-Batiz and Romer (1991a)), Rivera-Batiz and Romer (1991b)), Segerstrom, Anant and Dinopoulos (1990). Peretto (2005), Licandro and Navas (2011)), and more recently, firm heterogeneity and industry dynamics (Atkenson and Burstein (2010), Navas and Sala (2010), Long, Raff and Stahler (2011), Ederignton and Mc Calman (2007), Impulliti and Licandro (2011), Gustafsson and Segerstrom (2008), Baldwin and Nicoud (2008)).

These papers focus on the representative sector case, hence differences among sectors and the interactions that could emerge because of these differences are not explored. Empirical evidence suggests that industries are 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. The former is a key determinant of innovation both in early endogenous growth models (Romer (1990), Grossman and Helpman (1991)), and more recent contributions (Peretto (1998), Aghion et al. (2001), Aghion et al. (2002)). In addition, several papers argue that trade may increase innovation efforts precisely through an increase in competition.[1] 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 asymmetries for the effect that trade has on innovation.

INSERT FIGURE (1) HERE

The fact that industries differ largely in the degree of product market competition within a country is a stylized fact well documented in the data (Griffith, Harrison and Simpson (2010), Eslava, Haltiwanger and Kugler (2009)). For example, Epifani and Gancia (2011) report that in the US manufacturing sector at a four-digit level of disaggregation, mark-ups vary substantially across industries. These authors observe that mark-ups vary also across countries (mark-ups are larger in poor countries) and over time. The degree of trade openness varies substantially across industries and this is the case even for developed economies. Figure (1) plots an average of trade barriers faced by different US manufacturing industries (3-digit NAICS code) during the period 1989-2005 obtained from Bernard, Jensen and Schott (2006). The figure reveals substantial variation across industries going from 3% up to 18%. This difference is even larger when we move to more disaggregated data.

This paper builds a multi-sector endogenous growth model with oligopolistic competition and private R&D investments to study the effects of trade openness and trade liberalisation policies on innovation and productivity growth at the industry level. The aim of this paper is to introduce asymmetries across sectors in both, the degree of product market competition and the degree

[1] The main mechanism through which trade has an impact on innovation in the above cited papers, is the increase in competition. This could come through different channels: An effect through direct changes in the profitability of R&D: Peretto (2005), 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, 2008).

of trade openness, to see how trade affects innovation in the presence of these two sources of heterogeneity. More precisely, I first consider the implementation of a common trade policy in an environment in which industries 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 a movement from autarky to free trade as well as a more realistic partial trade liberalisation via a change in tariffs. Two alternative scenarios are considered: exogenous and endogenous differences in the degree of product market competition. In both scenarios, trade affects innovation through a joint effect of an increase in market size and an increase in competition. However, the latter will be different across industries due to differences in the initial degree of competition. Consequently, the level of competition that the industry faces initially becomes an important determinant of the final effect that trade liberalisation has on innovation.

In a second exercise, I investigate whether asymmetries in the process of trade liberalisation across sectors generate steady state differences in innovation and productivity growth in otherwise identical industries. In this case, I isolate the contribution of asymmetric exposure to foreign trade in the evolution of an industry's TFP. Through this analysis I find that asymmetric trade liberalisation has a heterogenous impact. This implies that exposure to foreign trade is a source of industry productivity divergence. I also show that asymmetric trade liberalisation generates a small but negative impact on aggregate productivity growth. The model suggests that a common trade policy across sectors may be beneficial since introducing asymmetries across sectors reduces growth.

The model is based on the framework developed in Licandro and Navas (2011), that explores the effect of trade liberalisation on innovation and growth through a pro-competitive effect in an oligopolistic general equilibrium model (OLGE). In this set-up I introduce differences in trade barriers and the degree of product market competition across industries, considering both a case in which the latter differences are exogenous and the one in which these differences are endogenous. Then I undertake counterfactual experiments in the two alternative scenarios, calibrating the model using data on R&D activities and trade costs from the US manufacturing industries. The first set of results considers the case when the number of firms is exogenous, and this allows us to understand the role played by the pro-competitive effect of trade on the results. The second set of exercises generalizes the previous results allowing for endogenous market structure. Interestingly, in both exercises the existence of these two sources of heterogeneity generates substantial reallocation effects. In the first case, the reallocation effect is larger between industries while in the second set of results reallocation is larger across firms and activities within the same industry.

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 these two sources of heterogeneity across industries in innovation and industry productivity growth. Two related papers in the area are Impulliti and Licandro (2010) and Ederignton and Mc Calman (2007). The first paper introduces firm heterogeneity into the oligopolistic competition model of Licandro and Navas (2011) to disentangle the effects of trade openness on industry productivity growth that are derived from selection from the effecs that are derived from a pure increase in competition. Though their results could be interpreted in terms of industry heterogeneity, the only source of industry heterogeneity in this model is the initial productivity and the consequences of the presence of asymmetries in other variables, like the degree of product market competition or the degree of trade openness, are not explored. Ederignton and Mc Calman (2007) explore the effect of trade liberalisation on the rate of technology adoption in a small open economy. This paper finds that unilateral trade liberalisation is likely to delay the adoption date for the median firm. This effect depends on several industrial characteristics and the effect is stronger in, for example, more competitive industries (low entry costs, large domestic markets). The current paper differs in an important dimension. Their model uses a monopolistic competition model in partial equilibrium. Thus, the rich interaction across sectors that emerges in a general equilibrium context and the strategic interaction among firms, which is a crucial element in our model is not explored.

In addition, few theoretical papers have explored differences in the degree of product market competition and trade asymmetries when analyzing the impact of trade on aggregate outcomes. One exception is Epifani and Gancia (2011) which outlines the importance of existing mark-up differences across sectors, across countries and over time, which causes a misallocation of production factors. Their paper studies the importance of resource misallocation induced by trade in a static framework and its implications for welfare. The current study complements this research, as it outlines the importance of these asymmetries in a dynamic context by studying its consequences for innovation and growth.

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 respectively the consumption baskets of goods X and Y. Good Y is an homogeneous good.[2] 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 ϕ_j controlling for the weights of each of these goods in a consumer's budget. Each of these varieties consists on a continuum of subvarieties of measure Z that are aggregated following the standard CES functional form:

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

where the parameter α_j controls for the elasticity of substitution across varieties. The structure of our economy distinguishes between industries (varieties) and subindustries (subvarieties) where

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

we have assumed a unitary elasticity of substitution across industries. This preference structure is needed to ensure the existence of a Balanced Growth Path in which labor 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 (2006)).[3] This is going to be the case in this paper.

Each subvariety is produced under Cournot competition[4] with a number of firms n_j which are exogenously given.[5] Each firm produces according to the following technology:

$$q_{lij} = z_{lij} l^{x}_{lij}, \tag{3}$$

where q_{lij} denotes the quantity produced by firm l producing subvariety i in industry j, and z_{lij} denotes the firm's stock of knowledge. Firms can also undertake cost-reducing innovations using the following technology:

$$\dot{z}_{lij} = T_j \left(l^{z}_{lij}\right)^{\gamma} z_{lij}, \ \gamma \in (0,1), \tag{4}$$

, which depends on the firm's stock of knowledge (z_{lijt}), and the resources that are devoted to innovation, l^{z}_{lij}. In this set-up the stock of knowledge is firm-specific and there are no technological spillovers among firms. This assumption is made, to perfectly isolate the contribution of the increase in competition that is derived from trade openness on innovation and productivity from other sources i.e.international R&D spillovers. T_j is a technological constant, that includes differences in technological opportunities across sectors.

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

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

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

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

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

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

$$V_l\,[A_l] \geq V_i\,[A'_l] \geq 0,$$

where $A'_l = [a'_l, a^*_{-l}]$, $\forall\ a'_l \neq a^*_{l,} \in \Omega_l$, $\forall_l$.

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

2.1 Solving for the autarkic equilibrium

Let E^x_j denote the expenditure dedicated to consumption of good j and let E^i denote the expenditure that is devoted to consumption of the final goods $i = x, y$. Consumers solve the standard optimal control problem whose first order conditions are as follows[6]:

$$E^x = \beta E, \tag{5}$$
$$E^y = (1-\beta)\,E, \tag{6}$$
$$E^x_j = \phi_j E^x, \tag{7}$$
$$\frac{\dot{E}}{E} = r_t - \rho, \tag{8}$$
$$p_j = \frac{LE^x_j}{x_j}, \tag{9}$$
$$p_{ij} = \left(\frac{LE^x_j}{p_j x_{ij}}\right)^{1-\alpha_j} p_j, \tag{10}$$

where E is total expenditure in consumption and $p_j = \left(\int\limits_0^Z p_{ij}^{\frac{\alpha_j}{\alpha_j - 1}}\, di\right)^{\frac{\alpha_j - 1}{\alpha_j}}$, is the standard aggregate price index.[7]

[6] The consumers solve the following optimal control problem:
$Max \quad U(C^x_t, C^y_t)$
s.t. conditions 1 and 2 and the budget constraint which is given by:
$\sum\limits_{j=1}^N \int\limits_0^1 p_{ijt} c_{ijt} di + C^y_t + \dot{S}_t = w_t L_t + S_t$

S_t 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 exogenous number of firms, are redistributed across consumers by means of these shares.

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

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

$$V_{lijs} = \max \int_s^\infty R_{s,t} \left((p_{ij} - z_{lij}^{-1}) q_{lij} - l_{lij}^z \right) dt, \qquad \text{s.t.} \tag{11}$$

$$\begin{aligned} p_{ij} &= \left(\frac{LE_j^x}{p_j x_{ij}} \right)^{1-\alpha_j} p_{jt} \\ x_{ij} &= \sum_{l=1}^{n_j} q_{lij} \\ \dot{z}_{lij} &= T_j (l_{lij}^z)^\gamma z_{lij}, \quad 0 < \gamma < 1 \\ z_{lij0} &> 0, \end{aligned} \tag{12}$$

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. $z_{lij0} = z_{ij0}, \forall\, l$. 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 l for the sake of simplicity. Deriving first order conditions, rearranging terms and applying symmetry, I get:

$$q_{ij} = \theta_j z_{ij} l_j E_j^x, \tag{13}$$

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

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

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

The left hand side of condition (15) is the marginal gain of accumulating one additional unit of knowledge, and it can be separated into two parts: the first consists of the reduction in the marginal production costs, which are proportional to the quantity supplied, and the second one represents learning by doing in research. The benefit of a cost-reduction innovation depends on the quantity produced, as it determines the amount of resources that are saved as a result of such a reduction in production costs.

Given that the quantity that is produced determines innovation effort, the way in which quantities are determined is fundamental for innovation. This is shown in equation (13). In this model, an increase in the number of firms generates two different, opposite effects. First, the market share of each firm declines, as shown in the last term of condition (13), as $l_j = \frac{L}{n_j Z}$. This is the *size effect* or the market share effect. Second, the markup $\frac{1}{\theta_j}$ depends positively on the perceived elasticity of demand which is positively associated with the number of firms and the elasticity of substitution

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

across varieties.[8] An increase in competition, given by an increase in the number of firms or an increase in the degree of substitutability across products, increases the perceived elasticity of demand. The increase in the perceived elasticity of demand provides an incentive for firms to increase the quantity supplied. This effect is represented by the first term on the right hand side of (13). This is the *competition effect*.

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

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

$$\sum_{j=1}^{N} \int_{0}^{Z} n_j \left(l_{ij}^{x} + l_{ij}^{z} \right) di + L^y = L. \tag{16}$$

Each final good market must satisfy that:

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

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

$$LS = \sum_{j=1}^{N} \int_{0}^{Z} n_j V_j di. \tag{17}$$

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

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

2.2 Balanced growth path

A Balanced Growth Path (BGP) is an equilibrium path in which variables $l_j^x, l_j^z, L^x, L^z, L^y, r, E, E_j^x,$ 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. Next I will show that a BGP exists and is unique.

Notice that l_j^x, l_j^z, L^y are constant in BGP since they are upper and lower bounded from condition (16).

Symmetric equilibria imply that $q_{lij} = q_j$, $\forall i, l$. From (12), this implies that $x_{ij} = x_j = n_j q_j$. It follows from (10) that $p_{ij} = p_j$. Plugging this in the demand function I obtain, $p_j = \frac{LE_j^x}{Zx_j}$. Using the latter, condition 9 and substituting these in (13), yields the following:

$$p_j = \frac{1}{\theta_j} (z_j)^{-1}. \tag{19}$$

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

Notice that

$$Zn_jp_jq_j = \frac{n_j}{\theta_j}Zl_j^x. \tag{20}$$

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

$$\frac{n_j}{\theta_j}Zl_j^x = \frac{\phi_j}{\phi_k}\frac{n_k}{\theta_k}Zl_k^x$$

and then

$$\frac{l_j^x}{l_k^x} = \frac{\phi_j}{\phi_k}\frac{\theta_j}{\theta_k}\frac{n_k}{n_j} \tag{21}$$

The per firm labor demand that is dedicated to production activities is larger in sectors characterised by less competition. However the industry labor demand that is dedicated to production activities (i.e. $L_j^x = n_jZl_j^x$) is larger for more competitive industries. As is standard under Cournot, firms in sectors that are associated with lower competition produce higher quantities, but the total production of the sector is lower.[9] This implies that the per firm labor demand in the production sector is larger in those sectors that are less competitive.

Combining (4), (13), (14) and (15), under $\dot{l}_j^z = 0$, I obtain the following equation

$$\gamma T_j(l_j^z)^{\gamma-1}l_j^x = \rho. \quad j = 1, 2, ...N \tag{22}$$

and therefore

$$\gamma T_j(l_j^z)^{\gamma-1}l_j^x = \gamma T_k(l_k^z)^{\gamma-1}l_k^x \quad \forall\ j, k.$$

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

$$\frac{l_j^z}{l_k^z} = \left(\frac{T_j}{T_k}\frac{l_j^x}{l_k^x}\right)^{\frac{1}{1-\gamma}} \tag{23}$$

Conditions (21) and (23) reveal the dual nature of our model as a result of a standard mechanism in oligopoly models. If I measure competition by measuring the elasticity of substitution across products, then I find that as markets become more competitive (products become more substitutable), each firm produces more, uses more labor in production, and therefore innovates relatively more. However, if I measure competition by measuring the number of competitors, as markets become more competitive, each firm produces less, uses less labor in production and therefore innovates relatively less. According to this measure, lower degrees of product market competition are associated with relatively greater per-firm resources devoted to R&D. The total industry R&D expenditure is given by the following:

[9] Notice that the total labor force that is dedicated to production activities in both sectors is given by: $\frac{n_jXl_j^x}{n_kXl_k^x} = \frac{\phi_j}{\phi_k}\frac{\theta_j}{\theta_k}$
An increase in the number of firms in sector j increases the allocation of labor to production activities in sector j. Notice that the aggregate allocation of labor to production activities depends on the degree of competition adjusted by size (that we will later call $\tilde{\theta}_j$).

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

In this context, and for lower values of n_j, a larger number of firms within an industry is associated with a relatively larger volume of resources devoted to R&D in that industry. [10]

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

$$l_j^x = \frac{\rho}{\gamma T_j}\left(l_j^z\right)^{1-\gamma}, \tag{24}$$

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

$$\left(\frac{(1-\beta)+\beta\tilde{\theta}}{\beta\tilde{\theta}_k}\right)\frac{\rho}{\gamma T_k}\left(l_k^z\right)^{1-\gamma} + \left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k}\frac{T_j}{T_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_k}{n_j}\right)^{\frac{\gamma}{1-\gamma}}\right) l_k^z = l_k \tag{25}$$

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. [11]

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

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

Proposition 2 *A BGP exists and is unique*

Proof. The BGP exists if a solution to equation (25) 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 (25) 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 $\beta = \frac{1}{2}, \phi_j = \phi_k$ 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). ■

[10] More precisely, taking the logs of the right hand side expression and differentiating with respect to n_j we obtain:
$\frac{d \ln \frac{n_j l_j^z}{n_k l_k^z}}{dn_j} = \frac{1}{1-\gamma}\frac{1}{n_j - 1 + \alpha_j} - \frac{\gamma+1}{1-\gamma}\frac{1}{n_j}$
This is larger than zero iff:
$\frac{1}{\theta_j} > 1 + \gamma$
This is going to be the case whenever:
$n_j < \frac{(1-\alpha)(1+\gamma)}{\gamma}$
This condition is satisfied for most of the exercises developed in the calibrated version of the model (section 3).

[11] Details about the derivation of 25 are provided in the appendix.

To explore the properties of the model, we observe Panel A in figure (2), which depicts the left and right hand sides of condition (25) for calibrated parameter values (discussed below) and for the simple case of two industries that we denote with subscripts 1 and 2. While the LHS part of (25) is monotonically increasing and concave in the argument $l_2^{\tilde{z}}$, the value of γ suggested by the data is close to zero which makes the function nearly linear.

Notice that an increase in the degree of product market competition induced by an increase in α_2 increases the per firm resources dedicated to innovation in industry 2. This is clearly shown in Panel B of figure (2). The increase in α_2 causes an increase in θ_2 and moves the LHS to the right (the LHS is monotonically decreasing in θ_2). When firms face a more elastic-demand they increase the quantity supplied in the market. The increase in firm-size translates into greater innovation efforts and stimulates plant and industry productivity growth.

However, an increase in the degree of product market competition (measured as an increase in n_2) decreases the per firm resources dedicated to innovation in industy 2. The main difference with respect to the experiment above is that when we increase n_2 the direct effect appears, and moves the RHS down (Panel C in the same figure). As is standard in the Cournot model, the direct effect is dominant; therefore an increase in the number of firms translates into a decrease in output per firm. As firm size decreases, firm level innovation efforts decrease.

An increase in the degree of product market competition in industry 1 (measured as an increase in α_1) decreases the firm resources that are dedicated to innovation in industry 2 (Panel D in the same figure). The increase in α_1 causes an increase in θ_1 moving the LHS into the left. This reduces innovation efforts in industry 2. As industries compete for labor, the increase in efficiency in industry 1 is associated with a reallocation of resources from the remainder of the industries to industry 1. Interestingly, this general equilibrium effect is shaped by the importance of industry 1 in the consumer's budget (ϕ_1). As ϕ_1 approaches to zero, this effect will be negligible.

Technological opportunities also play an interesting role in determining firms' innovation efforts in sector 2. The increase in R&D productivity in sector 2 increases innovation efforts but is detrimental to other sectors.

Therefore, in autarky, the increase in product market competition produces an ambiguous effect on innovation efforts and industry productivity growth. This ambiguity results from the fact that when the number of firms increases the size effect appears. In the next section I explore what happens when the economy opens to trade and we will see how this size effect is compensated by an increase in the market size of the firm. The introduction of asymmetries across industries generates an interesting reallocation of resources towards production and innovation in some industries that ultimately affect the industry both statically, through a change in the quantity produced and dynamically favoring industry productivity growth in some industries to the detriment of other industries.

INSERT FIGURE (2) HERE

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

Firms solve the following optimisation problem:

$$V_{lijs} = \max \int_s^\infty R_{s,t} \left[(p_{ij} - z_{lij}^{-1}) q_{lij} + \sum_{m=1}^{M} (p^{*m}_{ij} - z_{lij}^{-1}(1+\tau_j)) q^{*m}_{lij} - L^z_{lij} \right] dt, \tag{26}$$

$$\begin{aligned} s.t. p_{ij} &= \left(\frac{LE^x_j}{p_j x_{ij}} \right)^{1-\alpha_j} p_j \\ p^{*m}_{ij} &= \left(\frac{LE^x_j}{p^{*m}_j x^*_{ij}} \right)^{1-\alpha_j} p^{*m}_j \\ x_{ij} &= x^{*m}_{ij} = \sum_{l=1}^{n_j} q_{lij} + \sum_{m=1}^{M} \sum_{l=1}^{n_j} q^{*m}_{lij} \\ \dot{z}_{lij} &= T_j (l^z_{lij})^\gamma z_{lij}, \quad 0 < \gamma < 1 \\ z_{lij0} &> 0, \end{aligned} \tag{27}$$

I focus on a symmetric Nash equilibrium where q_{lij} and q^{*m}_{lij} are equal for all firms within the same sector in all countries but differ across sectors and across destinations (i.e, $.q_{lij} = q_j$,$.q^{*m}_{lij} = q^*_j$ $\forall\ l\ \epsilon\ n$,$\forall i$,$\forall\ m\ \epsilon\ M$, and $q_j \neq q^*_j$). I obtain the following first order conditions:

$$\left(\frac{LE^x_j}{n_j(q_j + Mq^*_j)p_j} \right)^{1-\alpha} p_j \left(1 - \frac{(1-\alpha_j)q_j}{n_j(q_j + Mq^*_j)} \right) = z_j^{-1} \tag{28}$$

$$\left(\frac{LE^x_j}{n_j(q_j + Mq^*_j)p_j} \right)^{1-\alpha} p_j \left(1 - \frac{(1-\alpha_j)q^*_j}{n_j(q_j + Mq^*_j)} \right) = z_j^{-1}(1+\tau_j) \tag{29}$$

$$1 = \gamma v_{ij} T_j (l^z_j)^{\gamma-1} z_j, \quad j = 1,2 \tag{30}$$

$$\frac{z_j^{-2}\left(q_j + M(1+\tau_j)q^*_j\right)}{v_{ij}} + \left(l^z_j\right)^\gamma T_j = \frac{-\dot{v}_{ij}}{v_{ij}} + r, \quad j = 1,2 \tag{31}$$

Firms consider the total volume of production when selecting the amount of resources to devote to R&D. Dividing (28) and (29) I obtain the following equation:

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

I simplify the equation as follows:

$$q_j^* = \frac{(1 + \tau_j)(1 - \alpha_j) - \tau_j n_j}{1 - \alpha_j + M n_j \tau_j} q_j \tag{32}$$

(32) implies an interesting result. Manipulating (32) I deduce that if $\tau_j \geq \frac{1-\alpha_j}{n_j - 1 + \alpha_j}$, then $q_j^* = 0$. Unlike the monopolistic competition model where the CES preference structure ensures that all firms have positive trade flows independently of the trade cost, trade exists in this economy if and only if trade costs are not excessively high. This is the consequence of the fact that foreign goods and home goods are perfect substitutes. Therefore, a sufficient and necessary condition for foreign firms to survive in a local market is that the cost disadvantage that is introduced by transportation costs is not too large. [12] Substituting in 28, yields:

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

I simplify the equation as follows:

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

and substituting in 32

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

and then, I express total output per firm $Q_j = q_j + M(1 + \tau_j) q_j^*$ as

$$Q_j = \theta'_j z_j l_j E_j^x$$

where

$$\theta'_j = \frac{((1 + M) n_j - 1 + \alpha_j) \left[(1 - M + 2M(1 + \tau_j))(1 - \alpha_j) + \tau_j^2 (1 - \alpha_j - n_j) \right]}{n_j (1 - \alpha_j)(1 + M(1 + \tau_j))^2} \tag{33}$$

It can be shown (see the appendix) that the steady state solution of the model can be summed up by the following equation:

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

$$\left(\frac{(1-\beta)+\beta\tilde{\theta}'}{\beta\tilde{\theta}'_k}\right)\frac{\rho}{\gamma T_k}\left(l_k^z\right)^{1-\gamma}+\left(\sum_{j=1}^{N}\left(\frac{\tilde{\theta}'_j}{\tilde{\theta}'_k}\frac{T_j}{T_k}\right)^{\frac{1}{1-\gamma}}\left(\frac{n_j}{n_k}\right)^{\frac{\gamma}{1-\gamma}}\right)l_k^z=l_k \tag{34}$$

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

In the appendix, I show that $\theta'_j>\theta_j$. Licandro and Navas (2011) also reveal that a movement from autarky to free trade, or a trade liberalisation (understood as a decrease in transportation costs) increases employment in the R&D sector, and this increased employment has positive effects on innovation and productivity growth in a situation with perfect symmetry across sectors. The focus of this paper is to demonstrate how the situation changes when we allow for sectoral differences (in this context, differences in competition 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.

3 Results I: Exogenous Number of firms.

In this section I assess the importance of differences in exposure to foreign trade or in the degree of product market competition on the effect that trade openness has on innovation for the simple case where the number of firms is exogenous. To do so, I first calibrate the main parameters of the model using data for the US economy. Secondly, I carry out several counterfactual exercises to explore the impact of these asymmetries in the effect that trade openness has on innovation.

The structural parameters that I calibrate in this section are ρ,γ,L,β, Z and T_j. In steady state ρ, the traditional discount factor, is equal to the real interest rate (logarithmic intertemporal preferences). I use an average of the long-term interest rate for the US economy provided by the World Bank Development Indicators which is 0.0375. The parameter β measures the weight of the differentiated sector in total expenditures. I exclude the production of services in the analysis because of the special characteristics of this sector.[13] I consider the manufacturing sector to be the differentiated sector of the economy. The World Development Indicators database from the World Bank computes the value added of the manufacturing sector as a percentage of GDP. Manufacturing represents 25% of the total GDP for the US economy which implies a share of 91% of the total GDP net services. This justifies a value for the parameter β of 0.91.

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

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

(2010) that explores the main determinants of differences in long run industry productivity growth rates. Their work suggests a value of $\gamma = 0.08$. [14] Given that it is not a calibrated parameter, I will perform robustness checks for this parameter.[15]

In this section, I consider that the technological constant, T_j, is common across sectors. This will provide a better picture of how differences in the two dimensions I explore affect innovation.[16] From equation (24), It is the case that:

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

With γ 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 follows: $T = \frac{\rho}{\gamma} \frac{L_z}{L_x}$. To calibrate this parameter, I rely on the share of the labor force devoted to R&D activities provided by the National Science Foundation. While in the next section I will exploit the variability across industries, in this section I use the average share that it is 4.43%.[17] This implies that the technological constant should take the value: $T = 0.020$.[18]

Because in this model the population is identical to the labor force, L, I proxy for this parameter by using the size of the US labour force. I adjust the size of the labor force by the average number of products per industry and therefore I consider a value for (L/Z) equal to 77750.

In this section I assume the simplest case in which there are only two differentiated industries ($N = 2$). In our first counterfactual exercise, I assume that both industries are equal in all dimensions except in the degree of Product Market Competition. More precisely, Industry 1 has initially 2 firms per product.[19] Industry 2, however, has a varying number of firms per product which goes from 2 to 6.[20] When both industries have the same number of firms there are no differences in Product Market Competition. If the number of firms in Industry 2 is larger than 2, then there would be differences in competition,with Industry 2 being the most competitive one. In these different scenarios, in our first experiment I consider a common trade policy which consists of either a movement from autarky to free trade or a tariff reduction. This allows us to isolate the effect of differences in the degree of Product Market Competition, on the impact that trade liberalisation has on innovation. I consider for simplicity that $\phi_j = 0.5, \alpha_j = 0$ and $M = 1$.[21]

INSERT FIGURE (3)HERE

[14] These authors use a richer but similar innovation function. In their paper, new knowledge is entirely produced using an intermediate research input. The elasticity of new knowledge to this intermediate research input is equal to 0.13. This research intemediate good is produced with physical capital and labor using a Cobb-Douglas technology. The Intermediate input's labor share is 0.6. The elasticity of R&D to research labor is therefore $\gamma = 0.6*0.13 = 0.078$.

[15] A Robustness check for this parameter is available by request.

[16] This assumption, however will be relaxed in a later section of the paper.

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

[18] More precisely $\left(\frac{1}{50}\right)$.

[19] I choose a number of firms $n = 2$ in industry 1 for simplicity.

[20] Given the parameter configuration, six is the maximum number of firms per industry, compatible with positive profits in equilibrium when the number of trade partners is equal to one.

[21] Robustness checks are provided by request.

Figure (3) shows how a movement from autarky to free trade alters the per-firm innovation efforts in industries 1 and 2, respectively. When there are no differences in competition, R&D employment increases by 6% as a consequence of trade openness. However, if Industry 2 is more competitive, trade openness increases R&D employment to a greater extent in the less competitive industry. Moreover, if the differences in competition are large enough, the per-firm investment in R&D in industry 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. The latter 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 labor demand increases to a greater extent in the less competitive sector, general equilibrium effects induce a labor reallocation from the most competitive industry to the less competitive one.

INSERT FIGURE (4)HERE

Figure (4), shows the impact of a reduction in variable trade barriers. For this section, I set the initial variable trade cost $\tau = 0.08$ which is very close to the average variable trade cost for the US manufacturing sector computed in Bernard, Jensen and Schott (2006). [22] 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, when there are differences in competition, the larger increase in R&D employment following trade liberalisation appears to be in the most competitive industry. Moreover, R&D could fall in the initially less competitive industry. To explain this result, it is useful to plot the change in θ after the tariff reduction across different initial degrees of competition as shown below. Figure 5 displays the value of θ under two different tariff levels, $\tau = 0.08$, and $\tau = 0$ and for different degrees of competition. Notice that the variation in θ following trade liberalisation is stronger when the industry is more competitive. The main reason for this result lies in the upper bound tariff level τ^*. When $\tau = \tau^*$ the open economy collapses to the autarkic one. τ^* is decreasing with the number of firms. Thus for a given τ, a larger number of firms indicates that the industry is closer to an autarkic situation and therefore relatively less open to foreign trade. The same trade policy will increase competition and consequently innovation in the most competitive industry or the industry relatively less open to trade.

In our second counterfactual exercise I assess the impact of asymmetric trade liberalisation. To do so, I consider an initial situation in which both industries are exactly identical. However, a trade policy will be implemented in Industry 1 but will not be implemented in Industry 2.[23]

INSERT FIGURE (6) HERE

Figure (6) shows the variation in percentage points in per firm R&D-employment in both the liberalized industry (industry 1) and the non-liberalized industry. Each line represents the results for a different initial degree of competition (number of firms) which becomes larger as the line moves to the right. The OY axis shows the variation in percentage points in R&D employment

[22] The average across sectors is 7.57%. The next section uses an upgraded version of the database built in Bernard, Jensen and Schott (2006), to obtain values for the variable trade cost at a sectoral level.

[23] While earlier versions of this paper consider both a movement from autarky to free trade and an undercut tariffs, I am going to consider only the second one due to similarity and space constraints. The other figure is available by request.

compared with the initial situation with 8% trade costs. The OX axis shows the different values that trade barriers in Industry 1 can take. R&D employment increases in the liberalized industry and decreases in the non-liberalized industry. The largest increase in R&D employment is obtained when there are no trade barriers in Industry 1, and this increase varies from 0.3 (with two firms in each industry) to almost 1% (with six firms). Larger tariff reductions are associated with larger increases in R&D employment, although the function is concave. Trade liberalisation enhances productivity growth in those industries which liberalize, but it has a non-linear effect. The effect is stronger when those industries are relatively more closed to foreign trade.

To summarise, this analysis shows how initial differences in the degree of Product Market Competition affect the effect that a common trade policy has on innovation across industries. In the case of a partial trade liberalisation policy, a reduction in tariffs intensifies competition to a greater extent in those industries that are initially more competitive. Consequently, firms' size and R&D efforts increase in these industries. The fact that all sectors are competing for the same rival inputs implies that the reduction in tariffs in this context may reallocate productive resources towards the more competitive industries.

This analysis also shows that asymmetric trade liberalisation contributes to industry productivity divergence. The reduction in tariffs increases competition in these industries leading to an increase in firms' size and R&D efforts. The competition for labor across industries implies a reallocation effect from those industries that liberalize more to those industries that stay more protected.

In the next section I show the extent to which these results are reinforced in a more general case in which initial differences in the degree of Product Market Competition are endogenous.

4 Endogenous Number of firms

In this section I endogenise the number of firms in the analysis. While the previous assumption simplifies substantially the computations, it leaves aside one interesting mechanism through which trade contributes to innovation: the "selection effect". The increase in competition from foreign markets reduces mark-ups. At the current number of firms, this implies that profits will be negative. 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 incumbents and this may provide additional incentives to these firms to engage in more innovation. The way in which I take into account the selection effect in this paper differs substantially from current models of trade with firm heterogeneity: Since all firms are identical , the model does not provide a criteria ny which firms will remain inoperative. It may be also the case that the size of this selection effect differ substantially across both frameworks.[24]

[24] 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 one is Impulliti and Licandro (2012). 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

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

$$\sum_{j=1}^{N} \int_{0}^{Z} n_j \left(l_{ij}^{x} + l_{ij}^{z} + f_j\right) di + L^y = L. \tag{35}$$

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

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

I set it equal to zero. Substituting the expression for a firms ´revenue, and rearranging terms yields:

$$\left(\frac{1-\theta_j}{\theta_j}\right) l_j^x = l_j^z + f_j \tag{36}$$

Notice that profits do not depend on the variety subscript and therefore, they are common across varieties. Substituting 36 into 16 and rearranging terms yields:

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

and

$$l_j^x = \beta \phi_j \theta_j l_j.$$

Substituting in the profit function, using (24) and rearranging terms:

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

That is a non-linear equation in n_j. The case of free trade is analogous and therefore:

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

5 Results II Endogenous Number of Firms

In this section I first calibrate the model according to the US manufacturing industries at a 3-digit code level of disaggregation. Secondly, I undertake analogous counterfactual exercises to section 3 that give us an idea of how the two sources of heterogeneity, product market competition and exposure to foreign trade, would affect innovation in the US manufacturing industries.[25]

paper Long, Raff and Stahler (2010) incorporates a selection effect along the lines discussed above. Their model however is static, and this simplifies the analysis at some expenses. In addition, they do not explore differences across industries.

[25] I use a 3-digit code level of disaggregation because this is the finest level for which the share of the labor force engaged in R&D activities across industries is available.

In these exercises I have relaxed the assumption that there were no differences in technological opportunities across sectors and I have calibrated T_j using data on the share of the labor force that was engaged in R&D activities in 2004 at an industry level obtained from the National Science Foundation (NSF). The remaining parameters are τ_j, f_j, M, ϕ_j and α_j.

For the volume of trade costs τ_j, I have used an upgraded version of the database constructed by Bernard, Jensen and Schott (2006). In that paper, the authors compute the value of duties and transportation costs for each of the 6-digit code 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 code industries, I take for each year a weighted average of the trade costs for each of the 6 digit-code products using the import shares as weights. I compute for each industry an average of trade costs for the period 1989-2005.

In this model, the existence of fixed operational costs determines the number of firms active in each industry. To the best of my knowledge there is no reliable data on fixed operational costs at an industry 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, Laporta and Lopez de Silanes (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 GDP p.c. This gives us a total cost of 1146$. Since in our model there is no exit, I assume that the entry cost 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 industries in the degree of product market competition comes from differences in technological opportunities (T_j) and trade costs across sectors (τ_j).

I set the parameter $M = 1$, considering that the economy is open with a symmetric economy.[26] For the case of α_j, I consider a simple case in which $\alpha_j = 0$, and I set the share of expenditure devoted to each manufacturing sector to be equal across sectors.[27]

The calibration exercise provides a number of firms per product and consequently a measure of the product market competition in the industry. To assess the model fit, I have obtained measures of the average mark-ups for each 3-digit-code NAICS manufacturing industry using the NBER productivity Database by Bartelsman, Becker and Gray (2000). This database contains information about the value of shipments, production costs and TFP measures for the US manufacturing industries at a 6-digit-code level of disaggregation. To compute the mark-ups I have used the standard measure in the literature: $\mu = \frac{vship - prodc.}{prodc.}$.[28] To aggregate across industries I have taken a weighted

[26] The majority of US firms do not export. From those which export a substantial number of them export only to one destination (Bernard, Jensen, Eaton and Kortum (2003)). A robustness check related to this parameter is provided under request.

[27] Robustness checks on these parameters are available from the author upon request.

[28] In the production costs I have used labor 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 δ is the depreciation cost. For the latter I have distinguished between equipments (with a depreciation rate of 10%) and plants (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).

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 (7) HERE

Figure (**??**) 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 12.67% while the average mark-up obtained in our sample was 19.59%). The standard deviation however reveals that in our model there is substantially less variation as compared to the real value (0.0460 vs 0.1061). The correlation coefficient between both series is positive but not so strong. 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. It is very likely that the latter is the result of the fact that the fixed operational costs do not vary in our sample. Panel B in the same figure shows how the model fits the share of the labor force engaged in R&D activities. In this case the model performs extraordinarily well both in average and in the variability.

To make our results comparable to the previous section I carry out two analogous counterfactual exercises. In the first exercise I compare the calibrated US economy 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 industry obtained from the data. With this counterfactual exercise I am measuring indirectly the consequences of asymmetric trade liberalisation by comparing the US economy with what the US economy would look like if trade barriers were common across all manufacturing industries.

INSERT FIGURE (8) HERE

Figure (8) shows how the degree of competition across industries differs in both economies. In panel A we observe the change in the domestic number of firms between both scenarios. In those industries where trade barriers are above the average, the number of firms is larger while the reverse happens in those industries where tariffs are below the average. This implies that in a hypothetical movement to a common tariff, the number of firms would decline (increase) in those industries whose tariffs are above (below) the average. However, markups would fall (increase) in those industries whose tariffs are above (below) the average, as panel B shows. This suggests that trade would intensify competition in those industries that suffer from a reduction in tariffs. The effect is more intense the larger the tariff change.

INSERT FIGURE (9) HERE

Figure (9) reveals that labor in production and R&D activities would change substantially across industries. Panel A reveals that the labor force engaged in these activities would increase in those industries that suffers from a decline in trade barriers and the opposite would happen in those industries for which trade barriers increase. The industry that would enjoy the largest increase is the leather and allied products industry (code 316) whose labor in R&D activities could increase by 33.18%. In contrast, the transportation equipment manufacturing industry (code 336) would suffer from the largest fall (5.80%). The effect is also stronger the larger the change in tariffs, and the larger the initial number of firms.[29]

Panel D in figure (9) suggests a very interesting result and this differs from the case with an exogenous number of firms. Almost all of the reallocation of labor that we have observed in the previous figure is not coming from a reallocation of labor across industries but from a reallocation across activities within an industry. That is, in industries where the trade costs decrease, the number of firms falls, and labor would be reallocated towards the incumbent firms. The opposite would happen in industries where the trade costs would increase. The model also suggests that the change in tariffs generates a reallocation effect from production to innovation activities. Although reallocation across manufacturing industries is negligible, the total labor force would still increase (decrease) in industries where trade barriers would decrease (increase).

The large changes in the labor force across industries would generate however limited changes in industry productivity growth. This is the consequence of the large decreasing returns in labor associated with R&D activities suggested by the data.[30] Though small, a movement towards a unique tariff would increase aggregate productivity growth. [31]

In the second counterfactual exercise, I compared our previous economy (with an average trade cost of 7.57%) with an identical one in which there are no trade barriers. Since initial tariffs are identical across industries but industries differ in the degree of Product Market Competition, this exercise is the equivalent of our first experiment in the previous section.

INSERT FIGURE (10) HERE

In panel A of figure (10) I show how the number of firms would change in a hypothetical situation in which there are no trade barriers. Industries would be less populated. The reduction in the number of firms would be stronger in the initially more competitive industries, or those relatively less open to foreign trade. Panel B shows that the decline in markups would be also stronger in those industries which are initially more competitive, consistent with the conclusions in the previous section.

INSERT FIGURE (??) HERE

[29] For example, the Computer and Electronic Industry (code 334) suffers from one of the largest tariff cuts, however, the industry is one of the less competitive (at a local level) and consequently the change in the labor force in R&D activities is relatively small 1.30%). These results goes in line with the ones derived in the analogous case with exogenous number of firms.

[30] For example, in the leather industry (316) the increase in the labor force is translated into an increase in the industry productivity growth of 0.022 percentage points. In the transportation industry (336) industry productivity growth would fall by 0.015 points

[31] Since the expenditure shares on the different goods are constant we can approximate aggregate productivity growth by $\frac{\dot{z}}{z} = \beta \sum_{j=1}^{N} \phi_j \frac{z_j}{z_j}$. A movement to a common tariff increases aggregate productivity growth by 0.0004 percentual points. This tiny effect is due to the fact that the data suggests very low levels for γ. On average labor in R&D activities increases as a consequence of a common tariff policy by 3.79%.

The movement towards free trade would bring a substantial reallocation of the labor force towards production and innovation, but this increase would not be equally shared across all manufacturing industries. More precisely the most competitive industries would experience a larger increase in the labor force (panels A in figure (**??**)).[32] Again, this reallocation would be stronger in innovation activities (Panel B in the same figure). Interestingly, the effect on per firm TFP growth, though small is asymmetric across industries favoring, however, those industries which are initially less competitive (Panel C in the same figure). The reason behind this result underlies on the fact that the initially less competitive industries are also the ones in which firms are more productive in R&D activities.

The previous reallocation effects across industries also have an impact on industry productivity growth. Although the trade policy has brought productivity growth to all industries, the increases are small but vary substantially across industries (ranging from 0.0053 percentage points to 0.0187 percentage points). Aggregate productivity growth would increase by 0.0116 points.

6 Conclusions

Empirical evidence suggests that there is substantial variation in mark-ups, across industries. In addition, industries are not equally exposed to foreign trade. In this paper, I explore how these two sources of heterogeneity across industries affect the impact that trade liberalisation has on innovation. To do so, I consider a multi-sector endogenous growth model with oligopolistic competition in which firms undertake innovation. Then, I calibrate the model using data from the US manufacturing industries and I undertake two counterfactual exercises in which I isolate each of the dimensions: The degree of product market competition and the degree of trade openness.

I find that an industry's degree of product market competition is a key determinant of the impact of trade on innovation. A movement from autarky to free trade will increase innovation efforts in those industries which are initially less competitive. This is the consequence of the fact that the increase in competition coming from foreign markets is tougher in industries which are initially less competitive. However, when considering a common reduction in tariffs in industries which start with the same tariff level, innovation and industry productivity growth increase in those industries that are initially more competitive. This is the consequence of the fact that, for the same tariff level, an industry which is initially more competitive is relatively more closed to foreign trade and therefore competition intensifies more in those industries. In both cases, tougher competition increases firms' size and promotes innovation in those industries and it generates a reallocation of productive resources towards these industries. When I allow for endogenous number of firms, the same competition effect reduces the mass of active firms by more in those industries. 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 industry, but there is almost no reallocation across industries.

[32] That is the case of The Wood Product Manufacturing Industry whose labor force increases by 11.50%.

I find also that an asymmetric trade liberalisation policy generates substantially different effects on innovation across industries. Innovation increases in those industries that cut tariffs and the latter is larger in those industries that benefit from a larger tariff cut. This comes from the fact that a tariff reduction increases competition and this increases firms' size and innovation efforts. The larger the tariff reduction, the larger the increase in competition and consequently the larger the effect on innovation. This result is reinforced under the presence of endogenous differences in the degree of product market competition because the reduction in tariffs reduces the mass of active firms in the industry. Market shares and productive resources are reallocated towards the surviving firms which serves to increase firms' size and innovation efforts. Finally, I find that asymmetric trade liberalisation has a negative but limited impact on aggregate productivity growth. Moving to a common tariff consequently increases aggregate productivity growth.

The counterfactual exercises suggest that the reallocation effects across activities within an industry following a movement towards a unique tariff may be important. However, these exercises also suggest that these reallocation effects have a limited but varied effect on industry productivity growth. The change may vary from a modest increase in 0.02 percentual points in the industry which enjoys a larger increase in R&D employment to a modest decrease in 0.015 points in the industry that suffers from the largest fall. A movement towards free trade would promote limited industry productivity growth across all industries but the effect will be larger in the initially more competitive industries. In these industries the increase could be of a size of approximately 0.02 percentual points.

This paper could be extended in two directions. The first one could include firm heterogeneity and investigate how between industry heterogeneity in these two dimensions and within industry heterogeneity interplays on the effect that trade has on average productivity and innovation. The second one 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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8 Appendix

8.1 Derivation of equations 25 and 34

8.1.1 Autarky (Equation 25)

Condition (34) comes from the labor market condition:

$$\sum_{j=1}^{N}\int_{0}^{Z} n_j l_{ij}^{x} di + \sum_{j=1}^{N}\int_{0}^{Z} n_j l_{ij}^{z} di + L_t^{y} = L. \tag{37}$$

From the production function I have that

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

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

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

that under the symmetric equilibrium only depends on industry and not firm characteristics. This implies that $\int_{0}^{Z} l_{ij}^{x} di = l_j^{x} = \frac{\theta_j}{n_j}\phi_j LE^{x}$. The latter leads to,

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

Since in steady state l_{jt}^{x}, l_{jt}^{z} L_t^{y} are constant I omit subscript t for notational clarity. From (5), (6) and (18):

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

Notice that from (20) (the corresponding one to sector k):

$$LE^x = \frac{Zn_k}{\phi_k \theta_k} l_k^x = \frac{Zn_k}{\tilde{\theta}_k} \frac{\rho}{\gamma T_k} \left(l_k^z\right)^{1-\gamma}$$

and then:

$$L^x + L^y = \left(\frac{\tilde{\theta} + \frac{1-\beta}{\beta}}{\tilde{\theta}_k} \right) Zn_k \frac{\rho}{\gamma T_k} \left(l_k^z\right)^{1-\gamma} = \left(\frac{\beta\tilde{\theta} + 1 - \beta}{\beta\tilde{\theta}_k} \right) Zn_k \frac{\rho}{\gamma T_k} \left(l_k^z\right)^{1-\gamma}$$

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

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

$L^z = \sum_{j=1}^{N} \int_0^Z n_j l_{ij}^z di = Z \left(\sum_{j=1}^{N} n_j l_j^z \right) = \sum_{j \neq k}^{N} n_j \left(\frac{l_j^x}{l_k^x} \frac{T_j}{T_k} \right)^{\frac{1}{1-\gamma}} + n_k l_k^z = \left(\sum_{j \neq k}^{N} n_j \left(\frac{\tilde{\theta}_j}{\tilde{\theta}_k} \frac{n_k}{n_j} \frac{T_j}{T_k} \right)^{\frac{1}{1-\gamma}} + n_k \right) l_k^z$

and working through this expression I get:

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

Substituting the previous expressions in (16) and dividing both sides by Zn_k I get:

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

8.1.2 Free trade (Equation 34)

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

$$l_j^x = z_j^{-1} \theta_j' z_j l_j E_j^x = \frac{\theta_j'}{n_j} \phi_j LE^x \qquad (39)$$

so following the previous steps, replacing θ_j by θ_j' leads to the same expression.

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

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

From (33) and the definition of θ in the autarkic economy, the following expression is obtained.

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

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

and manipulating the previous expression 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 is reduced to $\theta_j' - \theta_j = \frac{M(1-\alpha_j)}{n_j(1+M)}$. Notice that this expression is increasing in M which implies that 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 α_j reflecting that the larger the competition levels in autarky, the lower the increase in competition coming from trade openness, and therefore the lower is the industry productivity growth rate.

9 Figures

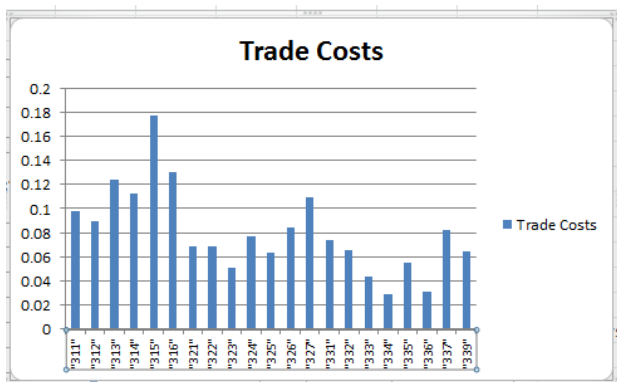

Figure 1: Average Trade Costs for the US manufacturing industries for the period (1989-2005). Source: Author's calculations based on Bernard, Jensen and Schott (2006)

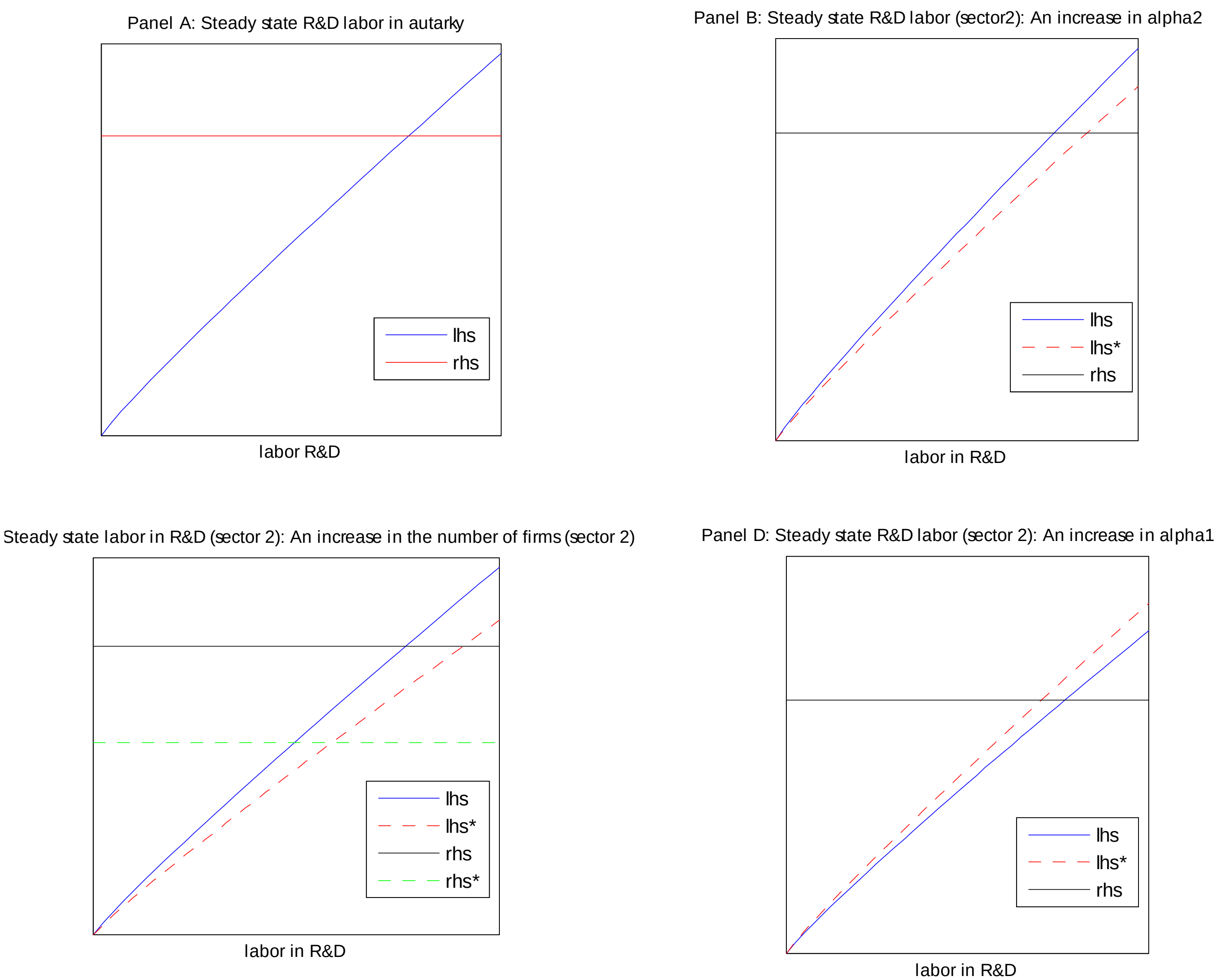

Figure 2: The model in autarky

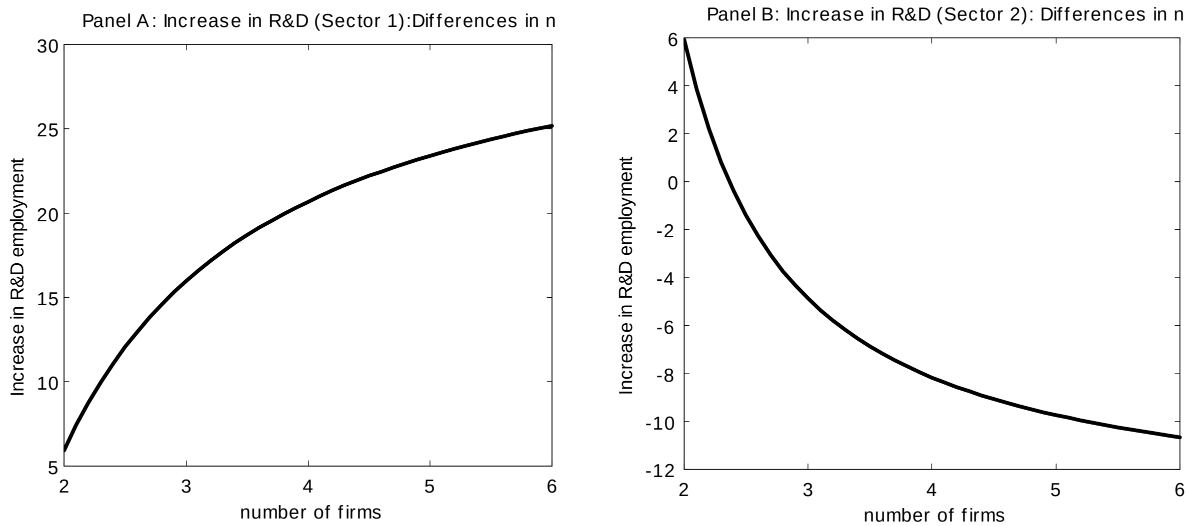

Figure 3: Exogenous number of firms: Differences in he degree of Product Market Competition (PMC).

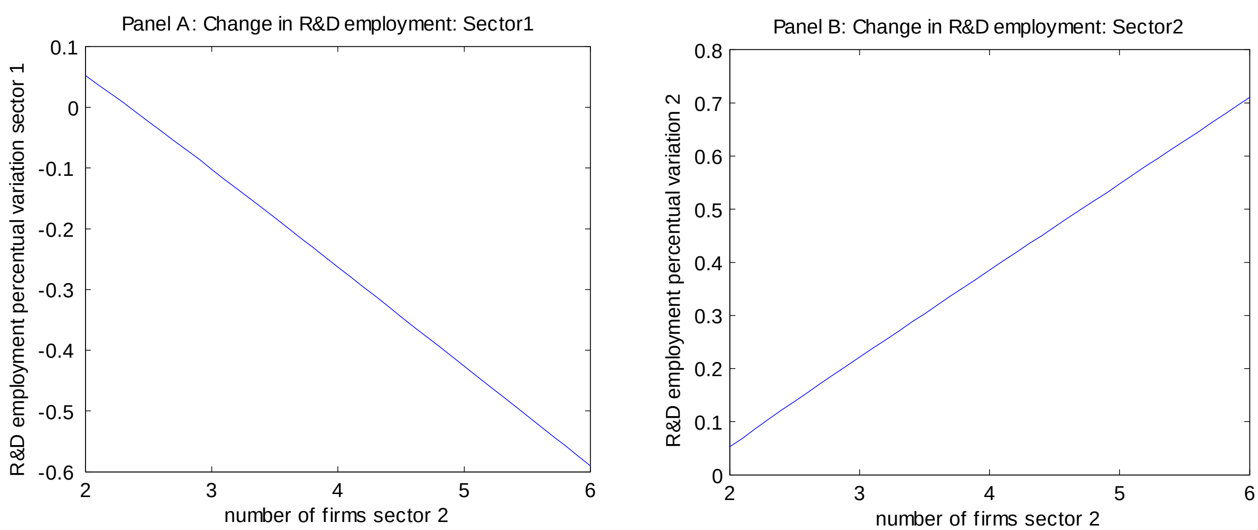

Figure 4: Exogenous number of firms. Differences in the degree of PMC. Tariff Cuts

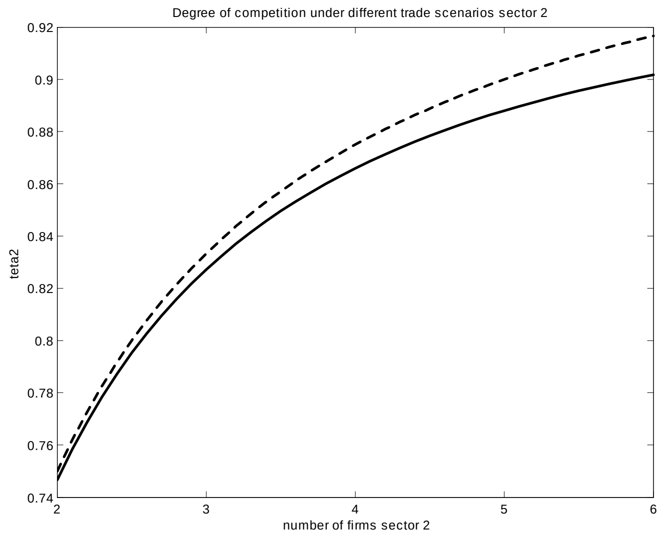

Figure 5: PMC across different tariff levels. Varying number of firms.

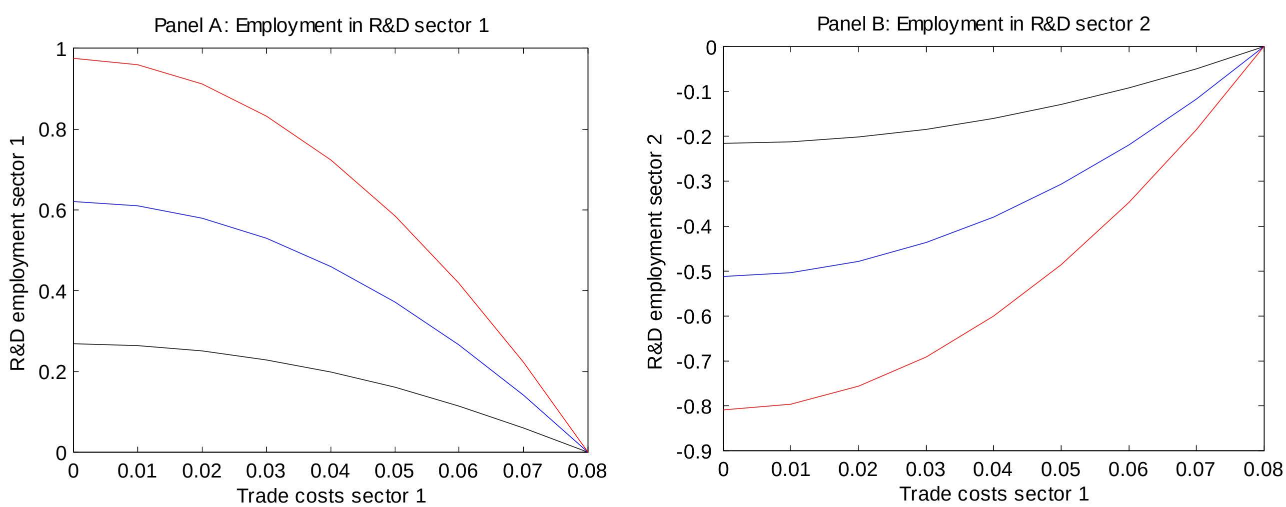

Figure 6: Asymmetric trade liberalisation. Exogenous number of firms

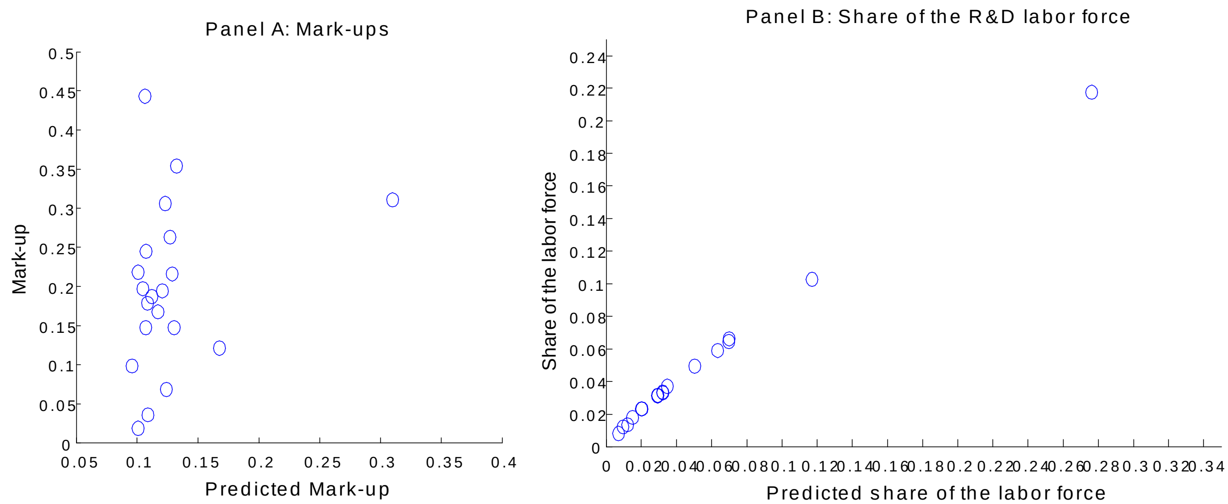

Figure 7: Data Fit. Panel A refers to Mark-ups (Average: 12.67%) vs. Predicted Mark-ups (19.59%). Correlation Coefficient: 0.2621. Panel B refers for each industry to the share of the labor force engaged in R&D activities (Actual (Av. 4.84% vs Predicted 4.54%). Correlation Coefficient 0.9985

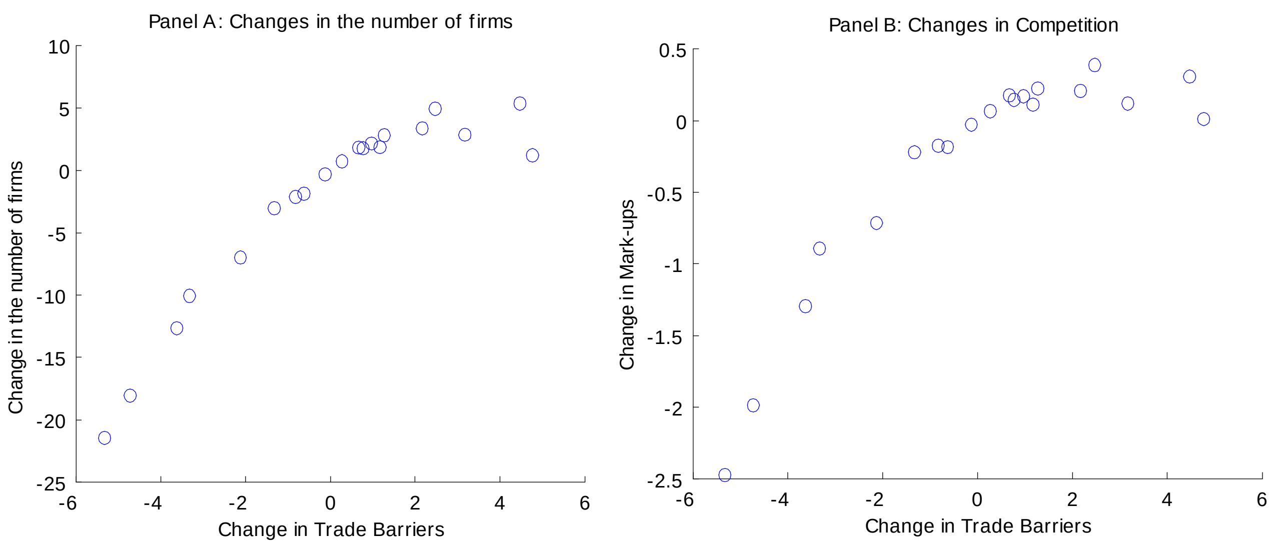

Figure 8: The impact of a common tariff on competition. Changes in trade barriers are measured in percentual points. Changes in the number of firms or in the mark-ups are expressed in percentual changes.

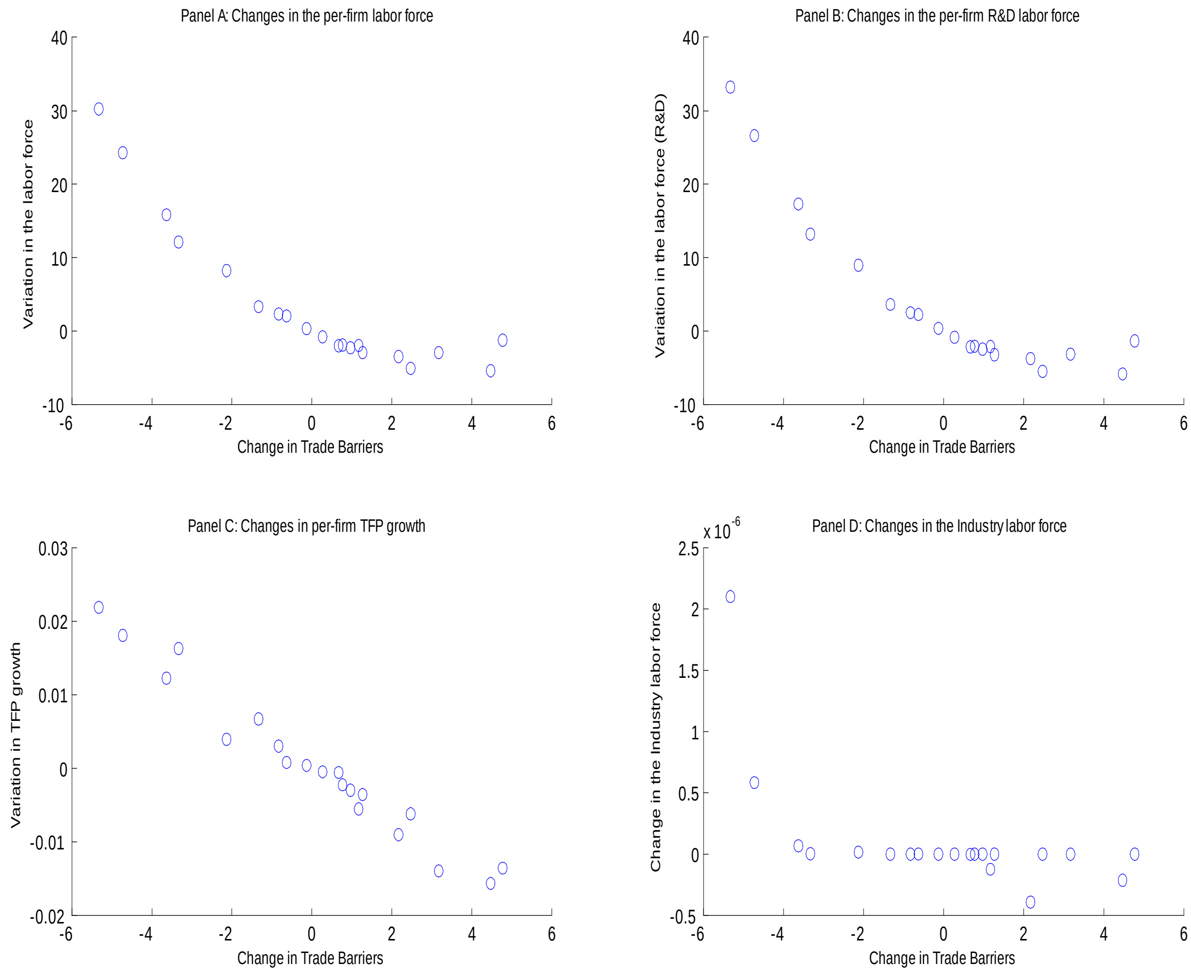

Figure 9: The impact of a common tariff policy on firm and industry characteristics. Changes in trade barriers and in TFP growth are in percentual points. Changes in the labor force are percentual changes.

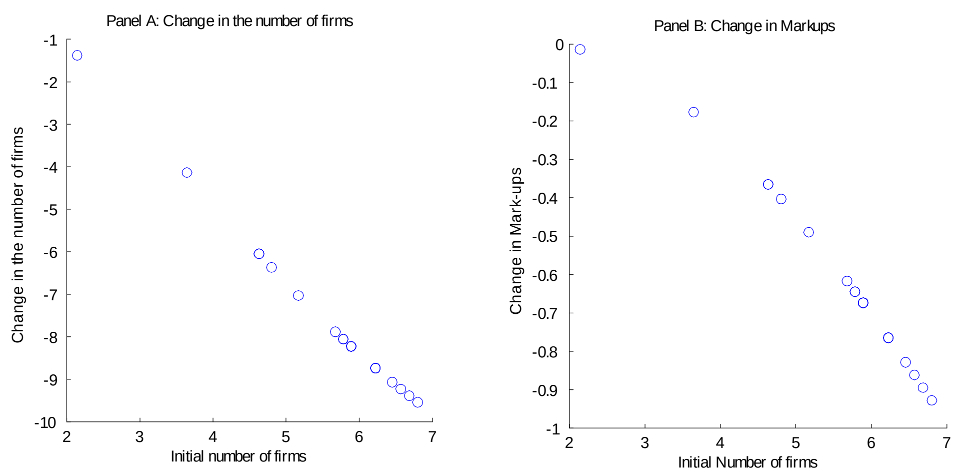

Figure 10: The effects of a movement from a common tariff to free trade on competition. Changes are in percentual points.

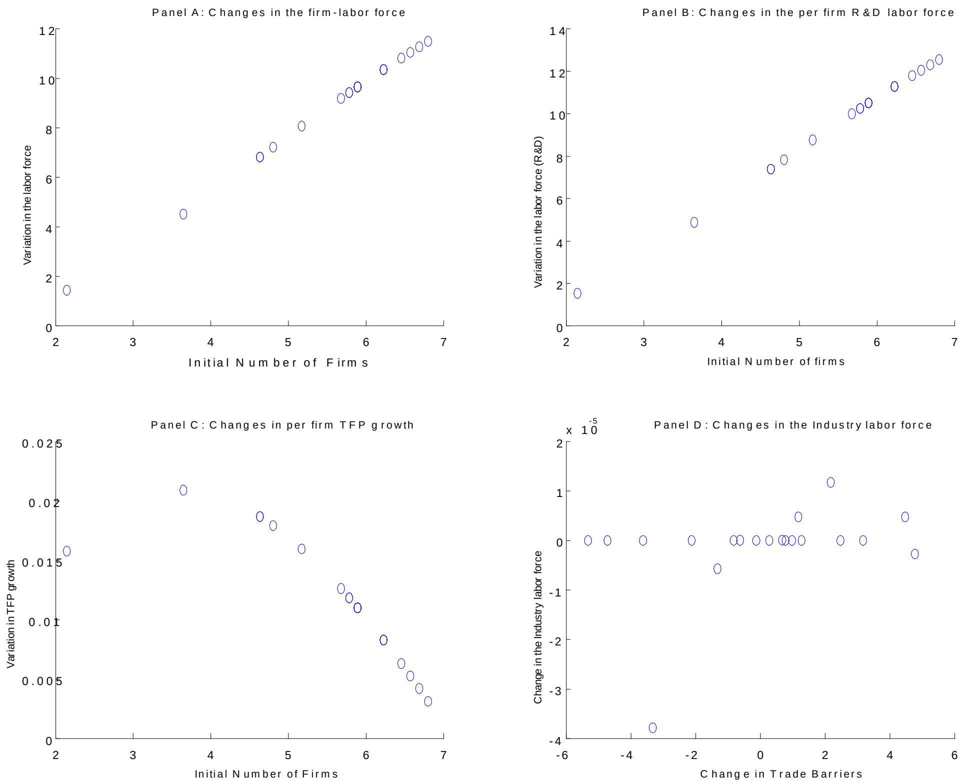

Figure 11: The effects of a movement from a common tariff to free trade. Changes in TFP growth and the industry labor force are in percentual points. Changes in the labor force are percentual changes.