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Abstract

This paper explores how trade openness affects both product and process innovation in a factor proportions model of trade that incorporates firm heterogeneity. Trade openness expands the profit opportunities of the most productive firms and expels the less efficient firms out of the market, making process innovation more attractive for the most productive firms in both industries. Incentives, however, are larger in the industry in which the country has the comparative advantage and so process innovation increases relatively more. Trade also increases the profits of prospective entrants leading to further increase in product innovation in the comparative advantage industry. The relationship between trade costs and a country's trade pattern is non-monotonic: When trade costs are high, a reduction in trade costs leads to an increase in process innovation in both industries, being stronger in the comparative advantage one; when trade costs are low the effect is stronger in the comparative disadvantage one. This final result could rationalize recent empirical findings suggesting that Ricardian comparative advantage has become weaker over time.

Keywords: Innovation, Firm Heterogeneity, Comparative Advantage.
JEL Codes: F12, F43

1 Introduction

The "new new" trade theory based on firm heterogeneity and increasing returns to scale developed by Melitz (2003) and Melitz and Ottaviano (2008), has outlined a new mechanism by which trade increases welfare in trading countries: the impact of trade on technology through selection. Trade induced competition expels the less efficient firms out of the market, reallocating market shares at the most productive incumbents. By concentrating the production in the most efficient industry units, this increases an industry's average productivity. Bernard, Redding and Schott (2007) incorporate firm heterogeneity into a factor proportions model of trade, finding that differences in factor endowments through selection generates a Ricardian comparative advantage. Tougher selection in the industry that uses more intensively the factor in which the country is relatively more abundant leads to a relatively larger increase in the average productivity of that industry after trade openness.

This paper explores further the link between technology and factor endowments, by expanding a 2x2x2 standard factor proportions model of trade with firm heterogeneity in which firms

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are allowed to upgrade their current state of technology. In this framework it distinguishes between process innovation (technology upgrading) and product innovation (the creation of new varieties).

The results suggest that the selection effect found in Melitz (2003) leads to a rise in technology upgrading in both industries, with technology upgrading being stronger in the industry in which the country has a comparative advantage. This results from trade expanding the business opportunities for the most productive firms in both sectors, but to a greater extent in the comparative advantage industry where the goods are offered relatively cheaper compared to the foreign counterpart. This increases the expected profits of prospective entrants and induces a disproportionate entry in the comparative advantage industry. As a consequence, the relative demand of the abundant factor rises and this has a positive impact on relative factor remuneration. Domestic firms see their profits reduced and the less efficient ones exit. The combination of a business stealing effect in the foreign country and a reallocation of market shares from the firms which exit, towards the most productive ones, induces a larger proportion of firms to upgrade their technology.

A further section in the paper explores the evolution of the comparative advantage by considering a reduction of trade costs when both industries are opened to trade. The paper establishes a non-monotonic relationship between the level of trade costs and the evolution of comparative advantage. When trade costs are high, a reduction in trade costs increases technology upgrading relatively more in the comparative advantage industry, inducing TFP divergence across sectors. However, if the trade costs are low enough a reduction in trade barriers increases technology upgrading relatively more in the comparative disadvantage industry leading, to TFP convergence across industries. Overall, TFP and the proportion of firms that upgrade their technology increases in both industries as trade costs fall and, provided that there is self-selection into exporting markets, these are always larger in the comparative advantage industry. This suggests that a gradual reduction in trade costs may strengthen the pattern of comparative advantage at the initial stages whilst weaken it when the trade costs become sufficiently low.

This paper relates to several existing literatures. Firstly, a recent literature based on models with firm heterogeneity outlines the importance of selection effects in promoting process innovation (Atkeson and Burstein (2010), Bustos (2011), Impulliti and Licandro (2011), Navas and Sala (2007,2013), Long et al. (2010) and Mrazova and Neary (2011) among others). Unlike these papers,this studies the role played by factor endowments in determining the effect that trade has on innovation at the industry level. Secondly, a recent literature that incorporates differences in factor endowments in models of trade with economies of scale (Krugman (1981), Helpman and Krugman (1987) (HK)) finds that many Heckscher-Ohlin results are also present in an environment in which there are increasing returns to scale at the firm level. This paper reinforces the idea that the H-O results are robust to richer environments. In addition, by including the possibility of firms upgrading technologies, this paper finds that differences in factor intensities across industries and factor endowments across countries generates a differential impact on trade-induced plant productivity improvements across firms with the same initial productivity. Our model therefore reinforces the Ricardian-led factor endowment comparative advantage results obtained by Bernard, Redding and Schott (2007) by adding an effect on average productivity via within plant productivity improvements which may persist along time.

Finally, this paper is related to a recent literature that investigates the evolution of comparative advantage. Levchenko and Zhang (2011) find that, in the last 50 years on average, productivity has increased by more in a country's revealed comparative disadvantage industries. This paper suggests a non-monotonic relationship between trade costs and the pattern of comparative advantage and for sufficiently low levels of trade costs, a reduction in trade barriers may benefit the comparative disadvantage industry, narrowing the differences in TFP across industries within a country. The empirical evidence of Levchenko and Zhang (2011) would be consistent within this framework with a gradual reduction in trade barriers across countries provided that the initial level of trade costs were sufficiently low in the 1960s.

2 The model

Consider an economy consisting of a continuum of consumers. There are two final goods. Denote with C_i the consumption of good $i = 1, 2$. Each C_i is a composite good defined over a continuum of varieties belonging to the set Ω_i. Preferences over these goods are given by the following utility function:

$$U(C_1, C_2) = (C_1)^{\alpha} (C_2)^{1-\alpha}$$

$$C_1 = \left(\int\limits_{\omega \epsilon \Omega_1} (q_1(\omega))^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}$$

$$C_2 = \left(\int\limits_{\omega \epsilon \Omega_2} (q_2(\omega))^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}$$

Solving the consumer's problem gives the standard CES aggregate demand function for each variety of the composite good:

$$q_i(\omega) = \frac{R_i}{P_i} \left(\frac{p_i(\omega)}{P_i} \right)^{-\sigma}$$

where R_i denotes consumer's expenditure dedicated to good i.[1]

Firms use an intermediate input (x_i) that is homogeneous to all products within the same industry but differ across industries. It is produced competitively combining both skilled and unskilled labour using the following Cobb-Douglas technology:

$$x_1 = A_1 (S_1)^{\beta_1} (L_1)^{1-\beta_1}$$

$$x_2 = A_2 (S_2)^{\beta_2} (L_2)^{1-\beta_2}$$

with $A_i = (\beta_i)^{-\beta_i} (1 - \beta_i)^{\beta_i - 1}$.

Assume, without loss of generalization that, $\beta_1 > \beta_2$, which implies that the industry 1 uses intermediate inputs that are more skilled labour intensive. Perfect competition in the intermediate input sector implies that:

$$p_{mi} = (w_s)^{\beta_i} (w_l)^{1-\beta_i}$$

The production side in the final good sector is identical to that of Melitz (2003). To enter a market, a firm needs to invest f_e units of the intermediate input to create a new variety.

[1]Under Cobb-Douglas preferences $R_i = \alpha_i R$ where R denotes total revenue.

Once the firm has created this variety it has the monopoly rights to produce it. Firms have a technology which is linear in the intermediate input:

$$q_i(\varphi_i) = \varphi_i x_i$$

It is assumed that firms' productivity φ_i is unknown before the creation of this new variety although the firm knows that the productivity parameter φ follows a random process with support $[0, \infty)$ and a cumulative continuous distribution function $G(\varphi)$. It is only after entry that the productivity is revealed to the firm. The creation of new varieties of the same composite good is considered as product innovation. To operate the technology the firm needs to pay a per period fixed investment of f_D units of the intermediate input. After entry the firm needs to decide whether to stay and produce.

Once the firm decides to stay and produce, the firm has the possibility of adopting a new technology which improves their productivity by a factor of θ_i ($\theta_i \geq 1$). To do so they must invest a fixed amount f_I units of the intermediate input. This process of technology upgrading will be called process innovation. In the model, all activities within an industry (product, process innovation, production and exporting when applies) use the same intermediate input. Consequently, all activities within an industry have the same skill intensity. However, activities differ in skill intensity across industries.

The firms' problem is solved by backward induction. Since the variety produced by each firm is unique, a firm charges the standard monopoly price:

$$p_i(\varphi) = \frac{\sigma}{\sigma - 1} \frac{p_{mi}}{\varphi} = \frac{\sigma}{\sigma - 1} \frac{\omega_i}{(\theta_i)^d \varphi}$$

where d is the indicator function taking the value of 1 if the firm adopts the new technology and 0 otherwise, and $\omega_i = (w_s)^{\beta_i} (w_l)^{1-\beta_i}$. The firm's operating profits are given by the following expression:

$$\pi_{vi}(\varphi) = \frac{R_i}{\sigma (P_i)^{1-\sigma}} \left(\rho (\theta_i)^d \varphi\right)^{\sigma-1} (\omega_i)^{1-\sigma} = \frac{r_{iD}(\varphi)}{\sigma}.$$

A firm decides to adopt the new technology iff:

$$\left((\theta_i)^{\sigma-1} - 1\right) \left(\frac{r_{iD}(\varphi)}{\sigma}\right) \geq \delta f_{iI} \omega_i \tag{1}$$

When equality holds, the firm is the marginal innovator and its productivity is denoted with φ_{iI}.

The firm is indifferent between staying or leaving the market when:

$$\frac{r_{iD}(\varphi_{iD})}{\sigma} = f_{iD} \omega_i \tag{2}$$

Denote with φ_{iD} the value of the productivity of this "marginal survivor". This condition is known in the Melitz (2003) model as the Zero Profit (ZP) condition. Dividing (1) and (2) gives:

$$\left(\frac{\varphi_{iI}}{\varphi_{iD}}\right)^{\sigma-1} = \left(\frac{\delta f_{iI}}{f_{iD}}\right) \frac{1}{\left((\theta_i)^{\sigma-1} - 1\right)}$$

Notice that the proportion of surviving firms undertaking process innovation is independent of factor prices and therefore on factor endowments in autarky. This is the consequence of the fact that both activities use the same intermediate input and therefore they use production factors with the same intensity.

A firm decides to enter the industry iff

$$E(V) \geq f_{ei}\omega_i. \tag{3}$$

In steady state a firms' value function is given by the following expression:

$$V_i = \max\left\{0, \frac{\pi_{vi}(\varphi)}{\delta}, \frac{\pi_{vi}(\theta\varphi)}{\delta} - f_{iI}\omega_i\right\} \tag{4}$$

Finally, to facilitate the interpretation of the results, and without loss of generalisation, it is assumed that the Home country is the skilled-labour abundant country $\left(\frac{S^H}{L^H} > \frac{S^F}{L^F}\right)$.

2.1 Equilibrium in a Closed-Economy Model

A property of Melitz-type models is that the equilibrium of the economy, in our case perfectly characterized by the two productivity thresholds $\varphi_{iI}, \varphi_{iD}$, can be summarised by two conditions: The ZP condition (Condition (2)) and the Free Entry condition (FE) (Condition(3)). In this framework however, the Zero Innovation Profits condition (Condition (1)) is also needed. Combining the three conditions, the Free Entry condition becomes:

$$\left(\left(\frac{\tilde{\varphi}_{iD}}{\varphi_{iD}}\right)^{\sigma-1} - 1\right) f_{iD} + \frac{(1 - G(\varphi_{iI}))}{(1 - G(\varphi_{iD}))}\left(\left(\frac{\tilde{\varphi}_{iI}}{\varphi_{iI}}\right)^{\sigma-1} - 1\right)\delta f_{iI} = \frac{\delta f_{ei}}{(1 - G(\varphi_{iD}))}.$$

The left hand side of the above condition is similar to the FE condition found in a standard heterogenous-firm trade model. There is, however, an extra term, which represents innovation profits. The possibility of technology upgrading increases the expected value of profits from entry by increasing the profits of the most productive firms.[2] Compared to Melitz (2003), the possibility of technology upgrading reallocates market shares from the less productive firms to the most productive ones, making survival more difficult in this economy. Consequently, φ_{iD} is larger in this case.

Despite the fact that this model exhibits a larger industry average productivity compared to a model without innovation both sectors share the same productivity thresholds, $\varphi_{iD}, \varphi_{iI}$ and consequently the same average productivity, provided that the rest of the parameters are identical across industries. In autarky, differences in factor endowments across countries do not generate differences in average productivity across industries.[3] In the skilled-labour abundant country, firms initially have larger expected profits in the comparative advantage industry (Industry 1) as there marginal costs of production in that industry are smaller. Consequently, firms can charge lower prices and have relatively larger sales. However, the costs of entry are also smaller in this industry which, together with the rise in the expected profits of the

[2] Navas and Sala (2013) studies the decision of technology upgrading in a representative sector model of trade with firm heterogeneity when firms undertake cost-reducing innovations. In that article, I show uniqueness for the survival cost cutoff (and consequently the innovation cost cut-off). An identical proof to show uniqueness of each φ_D applies in this context.

[3] The same result has been found in a similar framework without technology upgrading (Bernard, Redding and Schott (2007)).

representative firm, increases entry. The increase in entry offsets the positive effect that the comparative advantage mechanism has on firms' profits.

Since there is more entry in the comparative advantage industry, the model generates differences across industries in the mass of surviving firms in equilibrium. To see this, notice that:

$$\frac{M_1}{M_2} = \frac{R_1}{R_2}\frac{\bar{r}_2}{\bar{r}_1} = \frac{\alpha}{1-\alpha}\frac{\left(\frac{\tilde{\varphi}_{2D}}{\varphi_{2D}}\right)^{\sigma-1}\sigma f_{2D}\left(\omega_2\right)}{\left(\frac{\tilde{\varphi}_{1D}}{\varphi_{1D}}\right)^{\sigma-1}\sigma f_{1D}\left(\omega_1\right)} = \frac{\alpha}{1-\alpha}\left(\frac{w_s}{w_L}\right)^{\beta_2-\beta_1} \tag{5}$$

Since the home country is skilled-labour abundant:[4]

$$\left(\frac{w_s^H}{w_L^H}\right) < \left(\frac{w_s^F}{w_L^F}\right)$$

where the superscript H, F denotes respectively Home and Foreign country. Since $\beta_1 > \beta_2$, it can be seen that: $\frac{M_1^H}{M_2^H} > \frac{M_1^F}{M_2^F}$.

This result is already present in standard models of trade with imperfect competition and increasing returns to scale (Helpman and Krugman, 1985). Unlike existing work however,the innovation resources in this economy are not constant across industries. The comparative advantage industry invests more resources in both product and process innovation. *R&D* expenditures in each sector are given by:

$$R\&D\exp_i = \underbrace{\left(f_{ei}M_{ei} + \delta f_{iI}M_{iI}\right)}_{\text{amount of resources}}\underbrace{\left(\omega_i\right)}_{\text{Resource cost}}$$

Considering the stationarity condition for each sector and rearranging terms:

$$R\&D\exp_i = \left(\frac{\delta f_{ei}}{(1-G(\varphi_{iD}))} + \delta f_{iI}\frac{(1-G(\varphi_{iI}))}{(1-G\left(\varphi_{iD}\right))}\right)M_i\left(\omega_i\right)$$

Since φ_{iD}, φ_{iI} the ratio of $R\&D\exp_i$ across industries is given by:

$$\frac{R\&D\exp_1}{R\&D\exp_2} = \frac{M_1}{M_2}\left(\frac{w_s}{w_L}\right)^{\beta_1-\beta_2} = \frac{\alpha}{1-\alpha}.$$

Whilst the relative R&D expenditures just depend on the size of the sector, α, the amount of resources invested is larger in the industry in which the economy has a comparative advantage. To see this, consider the simpler case in which $\alpha = \frac{1}{2}$. In this situation the same amount of income is invested in innovation in both industries. However, in the industry in which the economy has the comparative advantage, the resource cost is cheaper, and consequently more resources is invested.

A common indicator used in the industrial organization literature to measure the intensity of innovative activity within an industry is *R&D* intensity ($\frac{R\&D \text{ expenditures}}{sales}$). This measure corrects for the fact that R&D expenditures are positively affected by the size of the industry. The model suggests that R&D intensities are identical across industries since:

$$\frac{R\&Dint_1}{R\&Dint_2} = \frac{R\&D\exp_1}{R\&D\exp_2}\frac{R_2}{R_1} = 1.$$

[4]See appendix for a formal proof.

3 Costless Trade

In this section, the implications for innovation of a movement from autarky to free trade is considered. Firms can serve the foreign market at no cost. The operating profits of a domestic firm in the domestic market are given by:

$$\pi_{viD}^{H}(\varphi) = \left(\frac{R^H}{\sigma \left(P_i^H\right)^{1-\sigma}} \right) \left(\rho \left(\theta_i\right)^d \varphi \right)^{\sigma-1} \left(\omega_i^H\right)^{1-\sigma}$$

and the operating profits of a domestic firm in the foreign market are given by:

$$\pi_{viD}^{F}(\varphi) = \left(\frac{R^F}{\sigma \left(P_i^F\right)^{1-\sigma}} \right) \left(\rho \left(\theta_i\right)^d \varphi \right)^{\sigma-1} \left(\omega_i^H\right)^{1-\sigma}.$$

The marginal innovator in the Home country must satisfy the following condition:

$$\left(1 + \frac{R^F}{R^H} \left(\frac{P_i^F}{P_i^H} \right)^{\sigma-1} \right) \left((\theta_i)^{\sigma-1} - 1 \right) \frac{r_{iD}(\varphi_{iI})}{\sigma} = \delta f_{iI} \left(\omega_i^H\right)$$

where $r_{iD}(\varphi_{iI}) = \left(\frac{R^H}{\left(P_i^H\right)^{1-\sigma}} \right) (\rho\varphi_{iI})^{\sigma-1} \left(\omega_i^H\right)^{1-\sigma}$. The marginal survivor is defined by the following condition:

$$\left(1 + \frac{R^H}{R^F} \left(\frac{P_i^H}{P_i^F} \right)^{\sigma-1} \right) \frac{r_{iD}(\varphi_{iD})}{\sigma} = f_{iD} \left(\omega_i^H\right)$$

Dividing these two last conditions:

$$\left(\frac{\varphi_{iI}}{\varphi_{iD}} \right)^{\sigma-1} = \left(\frac{\delta f_{iI}}{f_{iD}} \right) \left(\frac{1}{(\theta_i)^{\sigma-1} - 1} \right) \tag{6}$$

which is the same as in autarky. In fact since the operating profits for each firm is a constant times the operating profits in autarky the FE condition is given by:

$$\left(\left(\frac{\tilde{\varphi}_{iD}}{\varphi_{iD}} \right)^{\sigma-1} - 1 \right) f_{iD} + \frac{(1 - G(\varphi_{iI}))}{(1 - G(\varphi_{iD}))} \left(\left(\frac{\tilde{\varphi}_{iI}}{\varphi_{iI}} \right)^{\sigma-1} - 1 \right) \delta f_{iI} = \frac{\delta f_{ei}}{(1 - G(\varphi_{iD}))} \tag{7}$$

Since this is identical to the one in autarky, productivity thresholds are unchanged after trade openness if trade is costless. This implies that the productivity distributions remain unchanged.

The standard results in the Heckscher-Ohlin model hold in this environment. Factor Price Equalisation prevails provided that economies do not experience factor intensity reversals (i.e. factor endowments are not to be very different across countries). However, unlike previous studies, trade has an impact on innovation. Trade promotes investment in product innovation in the industry in which the country has a comparative advantage.

In contrast, the relative R&D intensities are unchanged after trade openness. To see this notice that the R&D intensity ratio is given by:

$$\frac{R\&Dint_1}{R\&Dint_2} = \frac{M_1}{M_2} \frac{R_2}{R_1} \left(\frac{w_s}{w_L} \right)^{\beta_1 - \beta_2}$$

Using the expression $R_i = M_i \bar{r}_i$, and rearranging terms gives:

$$\frac{R\&Dint_1}{R\&Dint_2}=\frac{\left(\left(\left(\frac{\tilde{\varphi}_{2D}}{\varphi_{2D}}\right)^{\sigma-1}\right)\sigma f_{2D}+\frac{(1-G(\varphi_{2I}))}{(1-G(\varphi_{2D}))}\left(\frac{\tilde{\varphi}_{2I}}{\varphi_{2I}}\right)^{\sigma-1}\sigma\delta f_{2I}\right)(\omega_2)}{\left(\left(\left(\frac{\tilde{\varphi}_{iD}}{\varphi_{iD}}\right)^{\sigma-1}\right)\sigma f_{1D}+\frac{(1-G(\varphi_{1I}))}{(1-G(\varphi_{1D}))}\left(\frac{\tilde{\varphi}_{1I}}{\varphi_{1I}}\right)^{\sigma-1}\sigma\delta f_{1I}\right)(\omega_1)}\left(\frac{\omega_1}{\omega_2}\right)=1$$

The reason why costless trade does not have an impact on process innovation (and an industry average productivity), is that it does not alter the distribution of profits within the industry. When trade is costless, trade openness widens the profit opportunities of all firms although this increase is more pronounced in the industry in which the country has the comparative advantage because the relative cost of factors is cheaper. This induces entry and an increase in the relative demand for skilled labour. The increase in entry perfectly offsets the increase in profit opportunities and leaves the market share of each firm in each market unaltered. Since the global size of the firm is unchanged under this setting, a firm's incentives to undertake process innovation activities are not altered.

4 Costly Trade

The recent literature on trade and firm heterogeneity has suggested that both fixed and variable trade costs are important in international trade activities (Roberts and Tyebout, 1998). In this section both types of trade costs are introduced and the consequences for innovation examined.

To introduce variable trade costs, as it is standard in the literature, the existence of iceberg transportation costs are assumed (i.e. to get one unit of the product sold in the foreign market,a firm must ship $\tau_i \geq 1$ since $\tau_i - 1$ units of the good melt in the process of transportation). To serve the foreign market the firm also needs to incur a fixed cost f_{iX} units measured in units of the specific intermediate input. As commented before, it is assumed that exporting activities uses the same intermediate input as innovation and production activities within the same industry.[5] To outline the role played by factor endowments on innovation outcomes, I assume that sectoral structural parameters other than factor endowments are identical across countries.

Similarly to Navas and Sala (2013), this model exhibit different type of equilibria depending on the parameter configuration.[6] These are associated with different partitions of firms according to innovation and export status. The variety of equilibria becomes greater in this context since different industries could, in principle, sustain different type of equilibria depending on the value of fixed costs of exporting, innovation and trade barriers. Rather than describing every case, let focus on a symmetric equilibrium (assuming all industries share the same structural parameters) and an equilibrium in which innovators are a subset of the most productive exporters for both industries and countries, in line with recent evidence found by Aw, Roberts and Xu (2011). Consequently, both industries are characterized by a partition of firms across

[5]A great part of this fixed cost of exporting consists on advertisement and complying with regulation standards. It seems to be sensible to assume that these costs differ across industries and reflect, somehow, the skill composition of the industry

[6]Navas and Sala (2013) explore the effects of trade openness on innovation in a representative sector model in which firms invest in cost-reducing innovations. Depending, among other things, on the costs of exporting and technology adoption, that paper distinguishes three interesting cases: The one explored here, in which innovators are a subset of the most productive exporters and the authors denote this ones as equilibrium BW, another one in which all exporters and some domestic firms undertake innovation (equilibrium B), and they denote as equilibrium C an intermediate case in which all exporters are innovators but no domestic firms undertake innovation.

status given by the following hierarchy: Innovators and exporters, exporters and non-exporting domestic firms. The appendix describes the conditions under which this equilibrium holds, and through simulations it is shown that this equilibrium holds provided that the level of variable trade costs are low enough. To avoid confusion, denote with superscript $j = H, F$ the variables associated with the home country and with superscript $k = H, F$ the variables associated with the destination country (both of them can be either Home (H) or Foreign (F)).

In this equilibrium, the marginal innovator is an exporter. Consequently, the marginal innovator in country j and industry i is defined by the following condition:

$$\left(1 + \tau_i^{1-\sigma} \frac{R^k}{R^j} \left(\frac{P_i^k}{P_i^j}\right)^{\sigma-1}\right) \left((\theta_i)^{\sigma-1} - 1\right) \left(\frac{r_{iD}(\varphi_{iI}^j)}{\sigma}\right) = \delta f_{iI} \left(\omega_i^j\right) \quad i = 1, 2 \tag{8}$$

where $R_1^j = \alpha R^j$ and $R_1^k = \alpha R^k$ The marginal exporter in country j is described by the following expression:

$$\left(\tau_i^{1-\sigma} \frac{R^k}{R^j} \left(\frac{P_i^k}{P_i^j}\right)^{\sigma-1}\right) \left(\frac{r_{iD}(\varphi_{iX}^j)}{\sigma}\right) = f_{iX} \left(\omega_i^j\right) \tag{9}$$

and the marginal survivor is given by the following condition:

$$\frac{r_{iD}(\varphi_{iI}^j)}{\sigma} = f_{iD} \left(\omega_i^j\right). \tag{10}$$

Dividing (9) and (10) gives:

$$\frac{\varphi_{iX}^j}{\varphi_{iD}^j} = \underbrace{\tau_i \left(\frac{P_i^j}{P_i^k}\right) \left(\frac{R^j}{R^k} \frac{f_{iX}}{f_{iD}}\right)^{\frac{1}{\sigma-1}}}_{\Lambda_i^j} \tag{11}$$

Dividing (8) and (10) gives:

$$\left(\frac{\varphi_{iI}^j}{\varphi_{iD}^j}\right)^{\sigma-1} = \frac{\delta f_{iI}}{f_{iD} \left((\theta_i)^{\sigma-1} - 1\right) \left(1 + \left(\Lambda_i^j\right)^{1-\sigma} \frac{f_{iX}}{fiD}\right)} \tag{12}$$

Notice that, as a consequence of trade openness, there is a larger proportion of firms undertaking process innovation in both industries, and this result is independent of factor endowments. This is the consequence of the fact that innovators have access to a larger market where they can take advantage of the increasing returns to scale nature of innovation. Taking the ratio across industries yields:

$$\frac{\left(\frac{\varphi_{1I}^j}{\varphi_{1D}^j}\right)^{\sigma-1}}{\left(\frac{\varphi_{2I}^j}{\varphi_{2D}^j}\right)^{\sigma-1}} = \frac{\left(1 + \left(\Lambda_2^j\right)^{1-\sigma} \frac{f_{iX}}{fiD}\right)}{\left(1 + \left(\Lambda_1^j\right)^{1-\sigma} \frac{f_{iX}}{fiD}\right)} \tag{13}$$

and I can conclude the following

Proposition 1 *Ceteris paribus, Iff* $\Lambda_k^j < \Lambda_l^j \quad k = l = 1, 2 \quad k \neq l$ *then the proportion of incumbent firms exporting and the proportion of incumbent firms innovating are larger in industry* k *compared to industry* l.

Proof. Assume without loss of generalisation, $k = 1$ and $l = 2$. Considering 11 for both industries and taking the ratio I have that: $\frac{\left(\frac{\varphi_{1X}^j}{\varphi_{1D}^j}\right)^{\sigma-1}}{\left(\frac{\varphi_{2X}^j}{\varphi_{2D}^j}\right)^{\sigma-1}} = \left(\frac{\Lambda_1^j}{\Lambda_2^j}\right)^{\sigma-1}$. Then iff $\Lambda_1^j < \Lambda_2^j$

$$\left(\frac{\varphi_{1X}^j}{\varphi_{1D}^j}\right)^{\sigma-1} < \left(\frac{\varphi_{2X}^j}{\varphi_{2D}^j}\right)^{\sigma-1}. \tag{14}$$

and by 13

$$\left(\frac{\varphi_{1I}^j}{\varphi_{1D}^j}\right)^{\sigma-1} < \left(\frac{\varphi_{2I}^j}{\varphi_{2D}^j}\right)^{\sigma-1}. \tag{15}$$

■

In the appendix the aggregation properties of the model under costly trade are discussed. Compared to the benchmark case of firm heterogeneity without technology upgrading, the difference in profits between autarky and trade is larger in this setup due to the effect that trade has on process innovation. Trade openness increases the size of the market for the most productive firms and consequently their sales. For a given innovation productivity threshold, the innovators are able to exploit their knowledge advantage across more production units since they are able to sell more. This increases profits. Substituting the expression for profits in the Free Entry condition and rearranging terms it can be seen that:

$$\left[\pi_{iD}^j + p_{iX}^j \pi_{iX}^j + p_{iI}^j \pi_{iI}^j\right] = \frac{\delta f_{ei}}{1 - G(\varphi_{iD}^j)} \tag{16}$$

Examining this condition, several results emerge: First, trade openness improves the average productivity in both industries by increasing the productivity threshold to survive in the market; Second, the inclusion of process innovation increases the effect that trade has on average productivity. This is due to the fact that trade increases technology upgrading across the most productive firms helping them to increase their market share to the detriment of the local competitors.

Specific to this paper is the asymmetric impact on innovation across industries. More precisely, in the appendix is shown that:

Proposition 2 *Under costly trade:*

1. *The increase in the survival productivity threshold is larger in the industry in which the economy has a comparative advantage.*

2. *In the industry in which the economy has a comparative advantage there is a relative larger share of incumbent firms undertaking process innovation.*

3. *Assuming a Pareto-Distribution for productivity, the R&D intensities are larger in the sector in which the economy has comparative advantage and this is due to a joint effect of more product and process innovation.*

Proof. See Appendix. ■

The intuition behind these results relies on the fact that when the economy opens to trade, firms are asymmetrically exposed to different industry opportunities. In the home skilled-abundant country, the marginal cost of production in industry 1 is lower than in the foreign country. When the economy opens up to trade, firms see their opportunities expanded because the access to a larger market allows them to exploit the increasing returns to scale associated with both production and innovation. However, these profit opportunities are larger in the industry in which the economy has the comparative advantage since this industry is able to offer the good cheaper than its analogous counterpart in the foreign country (Industry 1). This promotes a disproportionate entry in that industry, and consequently more *product innovation.* As a consequence, the relative demand for skilled labour rises and this has a positive impact on the relative factor remuneration. The massive entry of firms makes profits fall and it becomes more difficult for firms to survive. The less productive firms can no longer make positive profits and consequently the productivity threshold needed to survive in the market increases. The expulsion of the less efficient firms generates a reallocation of market shares to the most productive firms. Process innovation increases due to a combination of larger opportunities and market share reallocation.

In the appendix it is shown that for this equilibrium to hold, the following condition must be satisfied:[7]

$$\frac{f_{iD}}{f_{iX}} < \tau_i^{\sigma-1}\left(\frac{R^j}{R^k}\right)\left(\frac{P_i^j}{P_i^k}\right)^{\sigma-1} < \frac{\delta f_{iI}}{f_{iX}\left(\left(\theta_i\right)^{\sigma-1}-1\right)} - 1 \tag{17}$$

Condition (17) depends on four endogenous variables and the model does not exhibit a closed form solution for these variables. In the next section a simulation exercise suggests that this equilibrium holds in the case in which transportation costs are not large enough and there are no substantial differences in factor endowments across countries.

4.1 Simulation Exercises

In this section several simulation exercises are undertaken to explore the main implications of trade liberalisation on innovation. Firstly, a comparison between the results in autarky with the results in Free Trade is made and second, the effects of a partial trade liberalisation experiment (a reduction in trade costs)are examined. In this subsection, for common parameters, the values used by Bernard, Redding and Schott (2007) are adopted to ensure a better comparison between the two models and to isolate the role played by innovation in the productivity cut-offs and the average productivity across industries.

INSERT TABLE 1 HERE.

Table 1 shows the results in autarky and free trade for the home country. Notice that a movement towards free trade increases the survivor productivity cutoff and reduces the innovation productivity cutoff promoting technology upgrading. However, these effects are not the same across industries. In the comparative advantage industry there is more selection due to an increase in the mass of entrants (attracted by larger expected profits) and a lower innovation productivity cutoff (since trade expands the business opportunities of local firms more in the

[7]If the following condition holds:

$$\tau_i^{\sigma-1}\left(\frac{R^j}{R^k}\right)\left(\frac{P_i^j}{P_i^k}\right)^{\sigma-1} < \frac{f_{iD}}{f_{iX}}$$

then all firms will be able to export. In that case the economy will be in an equilibrium with costly trade but no selection into exporting markets.

comparative advantage industry). The effects on average productivity for the benchmark case are large (taking into account that under the current parametrization only a small proportion of the incumbent firms (3.75% and 3.5% respectively) undertake process innovation respectively in free trade). In the comparative advantage industry there is an increase in the mass of varieties created while in the comparative disadvantage industry is clearly reduced. This reflects the differences in profitability between both industries which reallocates potential entrants from the comparative disadvantage industry to the comparative advantage one. However, although the proportion of surviving firms is clearly large in the comparative advantage industry, there is a clear drop in survival in both industries.[8]

INSERT FIGURE 1 HERE.

Figure 1 is useful to examine the effects of a partial trade liberalisation on the export and domestic productivity cutoffs. Trade liberalisation reduces the export productivity cutoff in both industries and it increases the survival productivity cutoff in both industries. It is clear that the survival productivity cutoff is larger and the export productivity cutoff is smaller in the industry in which the economy has the comparative advantage. The former reflects tougher competition in that industry due to larger expanded opportunities for firms in that industry. Compared to a model without innovation, the survival productivity cutoffs in both industries have increased considerably. In the comparative advantage industry for the case of the trade costs equal to 20% the productivity cutoff is 3.8% larger while in the comparative disadvantage industry it is 3.67% larger. Although small, observe that when the possibility of technology upgrading is introduced in a model with firm heterogeneity and factor driven comparative advantage the difference between productivity cutoffs due to comparative advantage mechanisms across industries exacerbates.

Considering a more general case in which the fixed costs of exporting are not equal to the fixed costs of production, confirms the qualitative results obtained. (See figure 2).

INSERT FIGURES 2 AND 3 HERE.

Figure 3 displays the relative survival productivity cutoffs of industry 1 versus industry 2 for both the home and the foreign country revealing an interesting outcome. It becomes apparent that for high levels of transportation cost a reduction in costs increases the survival productivity cutoff by more in the comparative advantage industry. However, for sufficiently low levels of transportation costs, the opposite happens. This suggests that when the trade costs are high, selection becomes tougher in the industries in which the economy has the comparative advantage, but as the trade costs fall survival is more difficult in the comparative disadvantage industry. Consequently trade liberalisation has stronger effects in the comparative advantage export and survival productivity cutoffs when the trade costs are high but it has weaker effects when the trade costs are low.

INSERT FIGURE 4 HERE.

Figure 4 displays the innovation productivity cutoff across both industries for the home country as a function of the variable trade costs. It becomes apparent that a reduction in trade costs, decreases the innovation productivity cutoffs in both industries, and so increases the

[8]For the value of the innovation jump it is assumed 20% ($\theta = 1.2$) and the innovation cost is assumed to be 25 times the cost of entry. Changes in the parameter values do not generate qualitative substantial changes in the results, provided that the economy is in the analysed equilibrium. Robustness checks are available on request.

mass of firms that upgrade their technology. Yet, it can be also observed that the innovation productivity cutoff is smaller in the industry in which the home country has the comparative advantage and consequently the mass of firms engaging in process innovation is larger in the comparative advantage industry.

INSERT FIGURE 5 HERE.

Figure 5 represents the relative innovation productivity cutoffs for both the home country and the foreign country. Whilst the innovation cutoff is systematically larger in each country's comparative disadvantage industry, there is a non-monotonic relationship between the trade costs and the relative evolution of both cutoffs, which is a measure of the process innovation activity. When the trade costs are high, a reduction in trade costs decreases by more the innovation cutoff in the comparative advantage industry, (decreasing the relative cutoff for industry 1 in the home country and increasing the relative cutoff in the foreign country). However, when the trade costs are low enough the opposite result holds: A reduction in trade costs decreases the innovation cutoff more in the comparative disadvantage industry (and consequently the relative cutoff increases in the home country and decreases in the foreign country).

These results suggest that a reduction in trade costs increases process innovation in both industries. When the trade costs are high however, the reduction in trade costs favours the comparative advantage industry and when the trade costs are low the trade cost reduction favours the comparative disadvantage one. Taking into account both, the effects on technology upgrading and the effects on the productivity survival cutoff, it can be concluded that trade liberalisation has relevant implications for the evolution of the average productivity across industries: A process of globalisation induces an increase in TFP in both industries provided that the trade costs are not too high (the economy is in the parameter configuration consistent with this equilibrium). Yet, globalisation induces TFP divergence across sectors when trade costs are high, but it induces TFP convergence across sectors when countries are low. This prediction is consistent with the findings of Levchenko and Zhang (2011), provided that trade costs have been declining over time, and they were relatively low at the start of the sample. More precisely, the threshold level below which a reduction in trade costs induce TFP convergence is around 15%, although this threshold is much higher for innovation cutoffs and R&D intensities (30%).[9] Figures 6 and 7 illustrate this point.

INSERT FIGURES 6 AND 7 HERE.

Figure 8 shows the effects of trade liberalisation on product innovation in both industries. As it becomes apparent, product innovation is already larger in the comparative advantage relative to the comparative disadvantage industry in each of the countries. As trade costs are reduced further the differences between product innovation across industries are enlarged: Product innovation becomes larger in the comparative advantage industry. This is the consequence of the fact that trade liberalisation expands the opportunities of the most productive firms in the comparative advantage sector and the increase in the expected profits in this sector promotes entry. In the comparative disadvantage sector domestic firms face disproportionate tougher competition, the average expected profit falls and this deters entry.

INSERT FIGURE 8 HERE.

[9] That is, the relative innovation cutoffs and R&D intensities increase by more in the comparative disadvantage industry when trade costs are below 30%

A common measure of innovative activity across industries is to look at R&D intensities. Figure 9 displays the evolution of the R&D intensities for both industries in the home country. Notice that R&D intensities increase in both industries as trade costs fall. Although the differences across industries are not substantial there are still differences in R&D intensities when the economy is open to trade favouring the comparative advantage industry in the home country. This is the consequence of the fact that in the comparative advantage industry there is more product and process innovation. Figure 10 displays the evolution of the relative R&D intensities in the home country. A similar pattern to the one observed in figure 3 is observed: When the trade costs are large, a reduction in the trade costs increases the R&D intensity by more in the comparative advantage industry in each country and this result is reversed if the trade costs are low enough.

INSERT FIGURE 9 AND 10 HERE.

5 Conclusions

This paper introduces technology upgrading into a factor proportions model with firm heterogeneity to explore how factor endowments shape the impact that trade has on innovation at an industry level.

Our results suggest that differences in factor intensities across industries and factor endowments across countries affect the impact on innovative activity across industries in a country that opens to trade. More precisely, firms in the industry where the economy has a comparative advantage undertake more product and process innovation. This reinforces previous results that outline the importance of the relative factor endowments in generating Ricardian comparative advantage.

The paper then explores how the evolution of technology is affected by a reduction in trade costs under the presence of differences in factor endowments across countries and factor intensities across industries. The results suggest that the reduction in variable trade costs promotes technology upgrading and increases R&D intensities in both industries. However, the results establish a non-monotonic relationship between the pattern of comparative advantage and trade costs: When the trade costs are high, a reduction in trade costs pushes technology upgrading more in the comparative advantage industry leading to TFP divergence across industries. However, when the trade costs are low enough, a reduction in trade costs pushes technology upgrading in the comparative disadvantage industry leading to a process of TFP convergence across both industries.

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6 Tables and figures

Paremeter	Autarky	Free Trade	Percentage Variation
φ_{1D}	0.42886	0.5171	20.57
φ_{2D}	0.42886	0.50675	18.16
φ_{1I}	1.20211	1.13761	-5.36
φ_{2I}	1.20211	1.13963	-5.19
$\tilde{\varphi}_1$	0.79419	1.0876	36.95
$\tilde{\varphi}_2$	0.79419	1.06432	34.01
M_1	499.376	271.409	-45.65
M_2	481.494	113.380	-77.29
M_1^e	152.93	171.511	12.63
M_2^e	152.27	66.87	-56.09

Table 1: A movement from autarky towards FreeTrade

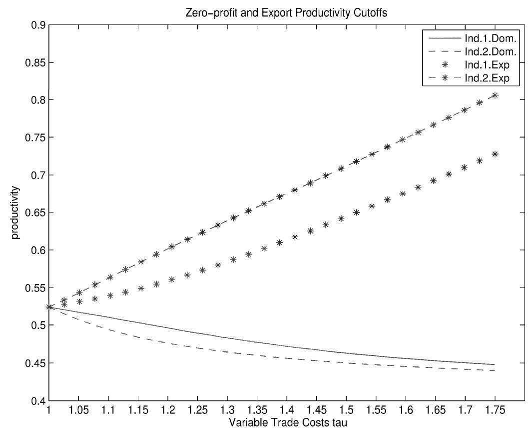

Figure 1: Export and domestic productivity cutoffs in the Home market

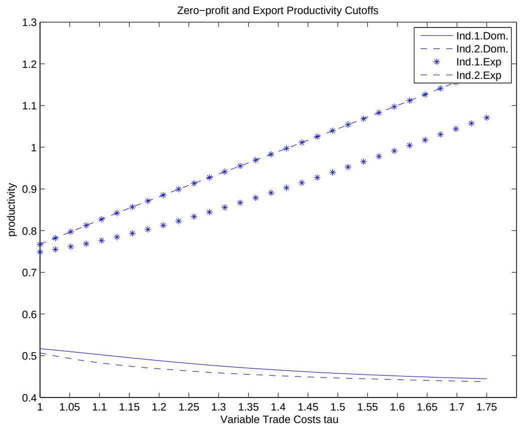

Figure 2: Export and domestic productivity cutoffs in the Home market(Selection into exporting with $\tau = 1$)

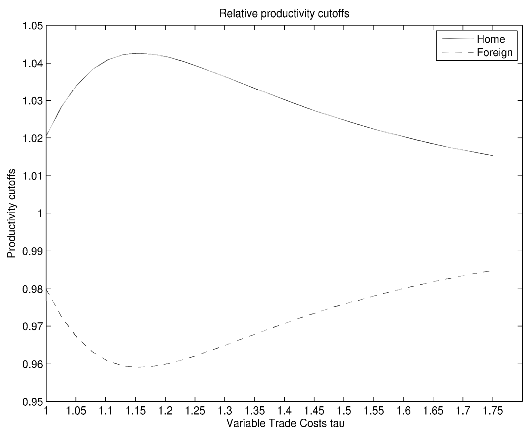

Figure 3: Relative productivity cutoffs. The figure displays the relative productivity cutoffs of Industry 1 vs Industry 2 for both countries.

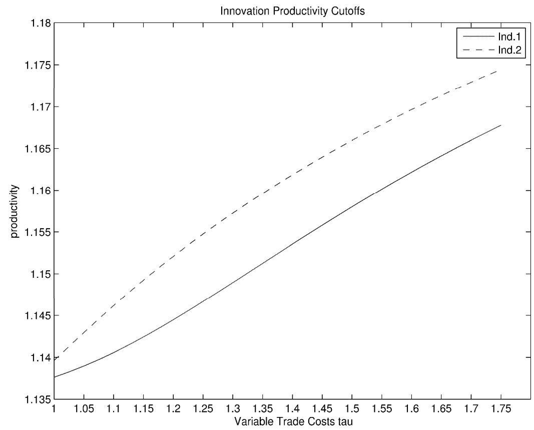

Figure 4: Innovation Productivity cut-offs in the Home country.

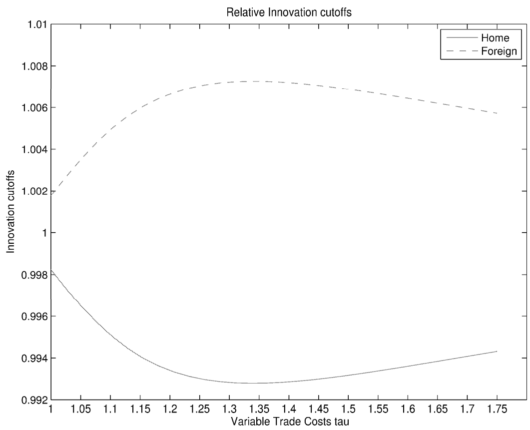

Figure 5: Relative Innovation Cutoffs. This figure displays the relative innovation cutoffs (Industry 1 vs Industry 2) for both countries.

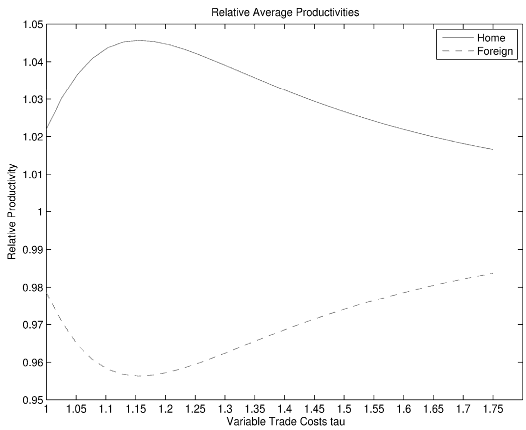

Figure 6: Evolution of the relative average Productivity (Industry 1/Industry 2) for both countries.

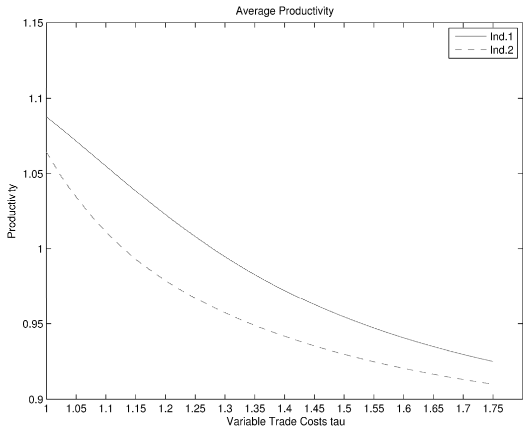

Figure 7: Evolution of the Average Industry Productivity in the Home Country.

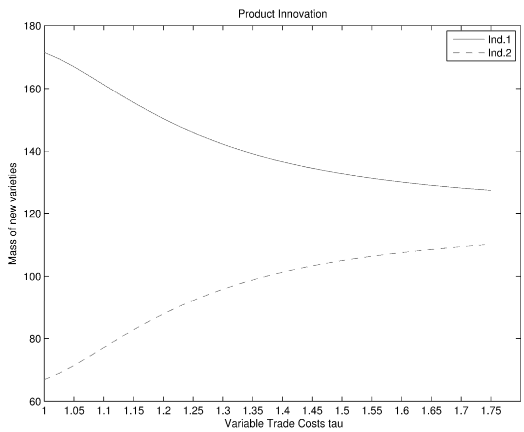

Figure 8: Product Innovation in the Home Country.

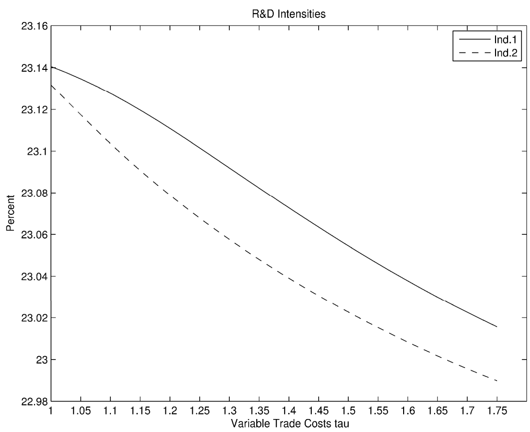

Figure 9: R&D intensities in the home country.

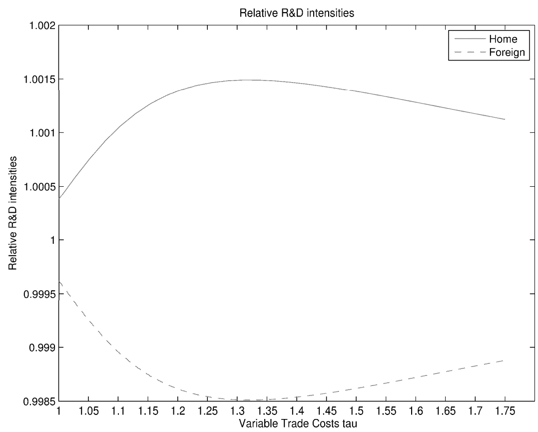

Figure 10: Relative R&D intensities (Industry 1/Industry 2) for both countries.