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Credit Market Quality, Innovation and Trade

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Non-technical Summary

This paper investigates how the quality of credit market can affect the impact of trade openness on innovation, trade pattern and, ultimately, the people's welfare. More broadly, this research pertains to the relation between the institutional framework and innovation, since the quality of credit market is very much related to the quality of the institutional framework.

This paper proposes a mechanism through which trade openness may have opposing impact on innovation rates, depending of the country's institutional environment. More specifically, we develop a growth model in which the amount of resources allocated to innovation depends on the quality of credit markets. Credit market quality, on its turn, is related to its ability to reduce the moral hazard problem created by the informational asymmetry between investors and entrepreneurs. It is the driving force of differences in innovation rate across countries, and, consequently, in trade patterns and in welfare. In this context, we investigate the impact of trade on innovation, trade and welfare for countries differing in the quality of their credit markets.

The paper concludes that opening to trade increases innovation in countries with better credit markets and decreases it in countries with worse credit markets. With respect to trade pattern, the country with worse credit market imports high tech goods and exports traditional goods. In terms of welfare, opening to trade may lower the welfare of individuals in the short run, but in the long run everyone is better off under free trade than if they were under autarky.

Sumário Não Técnico

Esse artigo investiga como a qualidade do mercado de crédito pode afetar o impacto da abertura comercial na inovação tecnológica, nas pautas de exportação e importação e, em última instância, no próprio bem-estar da população. Sob uma perspectiva mais ampla, o artigo aborda a relação entre inovação e arcabouço institucional uma vez que a forma como se organiza o mercado de crédito é muito sensível à qualidade das instituições presentes.

O artigo propõe um mecanismo por meio do qual a abertura comercial pode levar a efeitos opostos sobre a produção de inovação tecnológica, dependendo do ambiente institucional presente em cada sociedade. Mais especificamente, elaboramos um modelo de crescimento econômico no qual a quantidade de recursos alocados para a atividade de pesquisa e desenvolvimento depende da qualidade do mercado de crédito, isto é, a capacidade do mercado de crédito de atenuar a fricção informacional entre o investidor e o inovador. Nesse contexto, investigamos o impacto do comércio sobre a produção de inovação tecnológica, sobre o comércio e sobre o bem estar em países que diferem entre si apenas pela qualidade de seus mercados de crédito. Em suma, a qualidade do mercado de crédito é a força propulsora da produção de inovação tecnológica, que, por sua vez, determina a pauta de comércio e o bem-estar nos países.

Por fim, o artigo conclui que a abertura comercial aumenta a produção de inovação tecnológica naqueles países que possuem mercados de crédito mais eficientes e diminui naqueles com mercados de crédito menos eficientes. Os países que possuem mercados de crédito menos eficientes passam a importar bens *high-tech* e exportar bens *low-tech*. Em termos de bem-estar, a abertura comercial tende a diminuir o bem-estar dos indivíduos no curto prazo ainda que no longo prazo todos os países estejam melhor sob livre comércio do que estariam se a economia permanecesse fechada ao comércio internacional.

Credit Market Quality, Innovation and Trade*

Cristina Terra†

Enrico Vasconcelos‡

Abstract

Using a general equilibrium model with private R&D financing, we investigate the impact of trade openness on innovation, trade pattern and welfare for two countries equal in all aspects, except for the quality of credit markets. We show that trade openness increases innovation only in the country with better credit market, while it has a negative impact on innovation when credit markets are less developed. With respect to trade pattern, the country with worse credit market imports high tech goods and exports traditional goods. In terms of welfare, opening to trade may lower the welfare of individuals in the short run, but in the long run all of them are better off under free trade than if they were under autarky.

JEL Codes:F12,G11,O16

Keywords: institutions, innovation, trade pattern

1 Introduction

The large differences in economic development across countries have been an important concern of economists. The endogenous growth models developed in the 1980's identify technological progress as a major source of growth (Romer, 1988, 1990; and Lucas, 1988). They posit that differences in growth rates stem from disparities in the amount of resources allocated to innovation, as in Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992). More recently, Acemoglu, Johnson and Robinson (2001, 2002 and 2006), Engerman and Sokoloff (2007) and Hall and Jones (1999), among others, spot institutions as a fundamental cause of economic growth disparities, revitalizing an old idea in economics with compelling new empirical evidence and theoretical analysis. According to this view, institutions affect economic incentives and, ultimately, decisions related to growth enhancing activities such as investment in innovation.

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In parallel, empirical studies have investigated the role of trade openness as a possible engine for growth. Rodríguez and Rodrik (2000) have a skeptical view on the findings of the empirical literature regarding the positive impact of trade openness on growth. They criticize, among others, the measures of openness used and the difficulty to disentangle the impact of trade liberalization from other sound policies that could in general accompany trade liberalization. Wacziarg and Welch (2008), on their turn, tackle the criticisms from Rodríguez and Rodrik (2000) to find a positive and significant impact of trade liberalization on growth, on a within-country response over time. Interestingly, for the sub-sample of developing countries, they find large heterogeneity on the growth response to openness. Although the average effect is positive, for about half of them trade has either no impact or even a negative impact on growth. By the same token, Kim (2011) results indicate a positive impact of trade liberalization on growth for developed countries, and a negative one for developing countries.

Frankel and Romer (1999) find a positive relation between trade and growth, but only moderately significant. They use geography as instrument for trade, which has been also identified as a good instrument for institutions. Going one step further, Dollar and Kraay (2003), Rodrik et al (2004) and Rigobon and Rodrik (2005) try to disentangle the relative roles of trade and institutions in explaining growth disparities. The results are puzzling. In most cases, the impact of trade on growth disappears when institutions are controlled for, and in others it turns out to have a negative impact. These results suggest that there is an interrelation between trade and institutions on their impact on growth.

This paper proposes a mechanism through which trade openness may have opposing impact on innovation rates, depending of the country's institutional environment. More specifically, we develop an endogenous growth model in which the amount of resources allocated to innovation depend on the quality of credit markets. In this context, we investigate the impact of trade on innovation, trade and welfare for countries differing in the quality of their credit markets. We show that opening to trade increases innovation in countries with better credit markets and decreases it in countries with worse credit markets.

In this paper we focus on credit markets, which we believe is very much related to the quality of the institutional framework in each country, since it reacts to law, political and ethical systems. Several papers link institutional environment to financing, such as Towsend (1979), Stiglitz and Weiss (1981), Aghion and Bolton (1992) and Hart and Moore (1994,1998). Furthermore, La Porta et al (1997) and Djankov et al (2007) present empirical evidence that countries with weaker institutions have also less developed financial markets.

We propose a general equilibrium model to investigate the role of differences in the quality of credit markets as the driving force of differences in innovation rate across countries, and, consequently, in trade patterns and in welfare. We focus on moral hazard as the informational friction disturbing the investor-entrepreneur relationship in R&D. The quality of credit markets affects the intensity of this friction which, in turn, impacts the rate of return in innovation projects. More specifically, our model is inspired on Grossman and Helpman (1991) with respect to the way innovation creates dynamic comparative advantages for countries, and to the way that it becomes an endless and self-sustained process. We extend the original Grossman-Helpman model by incorporating moral hazard in R&D activity, using the moral hazard model from Tirole (2006). Thereby, we investigate the interaction between credit market quality and R&D intensity. R&D determines innovation rates, which, in turn, affects trade patterns and welfare.

We model credit market imperfections as affecting R&D decisions but not production, since R&D activity is more likely to be sensitive to the quality of credit markets than production. In R&D projects, in general, investors are less informed about entrepreneur actions and failed project have lower liquidation value.

There are two types of final goods in our model economy: a 'traditional' final good which uses only labor as input, and a 'high-tech' good which requires intermediate goods for its production. Intermediate goods are of different varieties, and they are produced only after being invented through R&D. Credit market quality affects the amount of resources devoted to R&D activity. We analyze the impact of trade in final goods between two countries differing in the quality of their credit markets. We consider alternative assumptions with respect to the possibility of trade of intermediate goods, knowledge spillover and technology transfers across countries.

We find that both innovation rates and wages are higher in countries with better credit markets. International trade increases the innovation rate in countries with better credit markets, while countries with worse credit markets are not able to compete in R&D and lose their innovation sector when opening to trade. Consequently, trade liberalization has a positive impact on innovation for countries with better credit markets, and a negative impact for the less financially developed countries.

Additionally, countries with better credit markets export high-tech goods and import traditional ones. This result is in line with recent empirical evidence on financial development and trade patterns, as in Beck (2002), Hur et al (2006), Levchenko (2007), Manova (2005 and 2013) and Svaleryd and Vlachos (2005). Antràs and Caballero (2009 and 2010) and Chesnokova (2007) also propose explanations for a link between financial development and trade pattern, in settings where one sector of the two sectors in the economy faces an exogenous credit constraint. They do not consider long-run growth, though.

With respect to welfare, we find that both countries are better off under free trade compared to autarky in the long run. World innovation rate is higher under free trade, which has a positive effect on the productivity of high-tech good production. In the short run, however, trade liberalization may lower welfare in the country with worse credit markets, since this country looses part of its wealth at opening. Opening to trade is more likely to be welfare enhancing in the short run when there is knowledge spillover across countries and when technology may be transferred internationally.

The paper is organized as follows. Section 2 describes the basic setup of the economy, section 3 describes the equilibrium in a closed economy, while section 4 derives the open economy equilibrium. Some extensions are analyzed in section 5. Welfare analysis is in section 6, and section 7 concludes.

2 Model Setup

In this model economy, there are two types of firms: those that produce final goods, and those that invent and then produce different varieties of the intermediate good. Final consumption goods are either of the traditional type, which uses only labor in production, or high-tech, using only intermediate goods as input. R&D activity, engaged to invent new varieties of intermediate goods, and the production of intermediate goods use only labor in production. Final goods market is competitive, while each intermediate good producer has monopoly power over his variety. We use a representative consumer setup, where all variables are in per capita values.

2.1 Consumers

We assume all consumers have identical preferences, represented by a Cobb-Douglas utility function as in:

$$U_t^i = \int_t^\infty e^{-\rho(\tau - t)} \log C^i(\tau) d\tau, \tag{1}$$

where $C^i(\tau) \equiv C_h^i(\tau)^\sigma C_{tr}^i(\tau)^{1-\sigma}$, $C_h^i(\tau)$ and $C_{tr}^i(\tau)$ represent individual i's consumption of high-tech (h) and of traditional goods (tr) at time τ, $\rho \in (0,1)$ is the subjective discount rate, which we assume to be the same across consumers, and, finally, σ is the share of expenditures on high-tech goods.

Consumers may be workers, entrepreneurs or investors, as will be described in subsection *2.4*. They maximize their utility subject to an intertemporal budget constraint, given that they can lend or borrow at the interest rate $r(t)$. Finally, P is the consumer price index, given by:

$$P(\tau) = \left(\frac{P_h(\tau)}{\sigma}\right)^\sigma \left(\frac{P_{tr}(\tau)}{1-\sigma}\right)^{1-\sigma}, \tag{2}$$

where P_h and P_{tr} are the prices of high-tech and traditional goods, respectively.

It is straightforward to show that the solution of the consumer intertemporal problem yields the optimal spending evolution:

$$\frac{\dot{E}^i(\tau)}{E^i(\tau)} = \frac{\dot{E}(\tau)}{E(\tau)} = r(\tau) - \rho, \text{ for } \tau \geq t, \tag{3}$$

where $E^i(\tau) \equiv P(\tau)C^i(\tau)$ represents individual i's expenditure, and $E(\tau) \equiv \sum_i E^i(\tau)$ is aggregate expenditure.

Given the homothetic preferences, it follows that final goods aggregate consumption is:

$$C_{tr}(\tau) = \frac{(1-\sigma)\,E}{P_{tr}(\tau)}, \text{ and} \tag{4a}$$

$$C_h(\tau) = \frac{\sigma E}{P_h(\tau)}. \tag{4b}$$

2.2 Final Goods Production

The traditional good, tr, is produced using only labor, whereas only intermediate goods are used in the high-tech goods production, h. Productions functions are thus given by:[1]

$$Y_{tr} = L_{tr}, \qquad \text{and} \tag{5a}$$

$$Y_h = \left[\int_0^{n(t)} x(j)^{\alpha} dj\right]^{\frac{1}{\alpha}}, \; 0 < \alpha < 1, \tag{5b}$$

where L_{tr} is labor in traditional good production, $x\,(j)$ represents intermediate good of variety j, and $n(t)$ is the number of such varieties invented until period t. Note that the productivity in the high-tech goods sector increases with the number of varieties of intermediate goods. This is an interesting feature for our purposes, since the innovation activity will be the driver for growth and the source of comparative advantages between countries when they are open to trade.

The final goods market is perfectly competitive, hence prices equal average cost:

$$P_{tr} = w, \text{ and} \tag{6a}$$

$$P_h = \left[\int_0^{n(t)} p(j)^{-\frac{\alpha}{1-\alpha}} dj\right]^{-\left(\frac{1-\alpha}{\alpha}\right)}, \tag{6b}$$

where w is the wage rate and $p(j)$ is the price of intermediate good j.

Finally, the demand for each variety of intermediate goods is given by:

$$x(j) = \frac{p(j)^{-\frac{1}{1-\alpha}}}{\int_0^{n(t)} p_h(j)^{-\frac{\alpha}{1-\alpha}} dj}\sigma E, \; j \in [0, \; n(t)]\,. \tag{7}$$

[1] The indication that the variable is a function of time is suppressed whenever it is not confusing to do so.

Note that σE stands for the aggregate sales revenue of the high-tech good, or, equivalently, the aggregate expenditure on this type of good, from equation (4b).

2.3 Intermediate Goods

2.3.1 Production

We assume that each intermediate good is manufactured by a single producer, who has monopoly power over it. This assumption may be justified by a positive cost of imitation which, combined with the assumption that firms engage in ex-post price competition in a Bertrand fashion, yields no incentive to imitate. Once invented, an intermediate good is produced using one unit of labor per unit of production. Each producer of an intermediate good faces the demand function given by equation (7).

Due to the symmetry across firms, in the Bertrand-Nash equilibrium the prices of all intermediate goods are equal and given by:

$$p(j) = p \equiv \frac{w}{\alpha}, \ j \in [0, \ n(t)]\,. \tag{8}$$

The demand for each intermediate good and profits thereby generated are, respectively:

$$x(j) = x \equiv \frac{\sigma E}{pn} = \frac{\alpha \sigma E}{wn}, \ \text{ and} \tag{9a}$$

$$\pi(j) = \pi \equiv \frac{(1-\alpha)\,\sigma E}{n}\,, \, j \in [0, n(t)]\,. \tag{9b}$$

2.3.2 R&D

To be produced, an intermediate good has first to be invented, and invention is achieved through R&D. Following Romer (1990), we assume that past R&D generates public knowledge that renders the next generation of innovation more productive. We model this phenomenon as Grossman and Helpman (1991) do and assume there is a public pool of information which contains the stock of accumulated knowledge. The measure of this pool K is taken to be the same as that of the existing intermediate goods diversity, that is:

$$K(t) = n(t). \tag{10}$$

We are aware that the assumption in equation (10) has some important drawbacks. First, it does not consider the obsolescence of past contributions or any complementarities between different kinds of knowledge. Second, spillovers are likely not to happen instantaneously, as suggested by the equation, but, rather, gradually. Third, it does not consider heterogeneity between industries with respect to degree of informational content. Nevertheless, we follow previous literature and use this representation for simplicity.

R&D activity uses only labor as input, and its outcome is uncertain: research is successful with a probability q. If successful, L_γ units of labor generate $aK(t)L_\gamma(t)$ new varieties, where a is a parameter of labor productivity in R&D and $K(t)$ is given by equation (10). With probability $1-q$, no new brands are invented, and we assume that the liquidation value of R&D investment is zero. Therefore, the expected outcome of R&D is thus $qv(t)an(t)L_\gamma(t)$, where $v(t)$ is the value of a blueprint specific to sector k. More precisely, $v(t)$ is the present value of the stream of future profits π generated by the intermediate good production, that is:

$$v(t) = \int_t^\infty e^{-[R(\tau)-R(t)]}\pi(\tau)d\tau. \tag{11}$$

Entrepreneurs borrow from investors in the credit market to engage in R&D to try and invent new brands. According to the debt contract, if a project is successful, the inventing firm pays an agreed upon amount for its debt. If unsuccessful, there is no payment to the creditor. Following Tirole (2006), we assume that the probability of success of an investment project depends on unobservable actions taken by the entrepreneurs. In particular, 'good behavior' yields a higher probability of success, q_H, and no private benefits to entrepreneurs. 'Bad behavior' means that entrepreneurs are able to retain a share B of the investment made in the project, which lowers its probability of success, q_L.[2] A higher B means that investors' rights are less protected by the legal or regulatory institutions.

To have an interesting case, we assume that the expected outcome of the project is greater than its costs only if entrepreneurs have good behavior. Clearly, investors will only lend to the inventing firm if the financing contract promotes good behavior from entrepreneurs. Since entrepreneurs' behavior cannot be observed, it cannot be written in a contract. The only way to induce good behavior is to have debt repayments that will make entrepreneurs themselves prefer good behavior. If R_b is the amount the entrepreneur retain after paying its debt in case of success in sector h, good behavior will be induced when the following incentive compatibility constraint is satisfied:[3]

$$q_H R_b \geq q_L R_b + BwL_\gamma. \tag{12}$$

[2]Notice that the outcome of R&D is that either a new blueprint in invented or not, and a new blueprint has its market value independent of the entrepreneurs behavior. Hence, cheating by the part of the entrepreneur should not affect the value of R&D outcome when it is successful. Furthermore, R&D has no liquidation value, so private benefits through bad behavior are not related to that either.

[3]Note that the condition (12) implies risk neutrality from entrepreneurs. Although all individuals have concave utility functions, implying risk aversion, they behave as if risk neutral with respect to this investment outcome for two reasons. First, there is no aggregate uncertainty. By the law of large numbers, an exact share of q_H or q_L (depending on the entrepreneur's behavior) of the projects undertaken will be successful. Second, we assume all investors are represented by one sole financial institution that invests in all R&D projects, so that they can take advantage of the law of large numbers.

Thus, the minimum entrepreneurs must retain to keep incentives aligned is given by:

$$R_b^* \equiv \frac{BwL_\gamma}{q_H - q_L}. \tag{13}$$

In addition, investors will only be willing to invest in R&D if the expected rate of return in innovation projects is not smaller than the rate of return of the riskless asset, that is, his participation constraint in sector k is:

$$q_H vanL_\gamma - wL_\gamma - q_H R_b \geq rwL_\gamma.$$

Note that the participation constraint above incorporates the assumption that R&D investment has no liquidation value. Using R_b^* from equation (13) and rearranging terms, we write the participation constraint of investors as:

$$aq_H \frac{vn}{w} \geq \Psi, \text{ where } \Psi \equiv (1+r) + \frac{q_H}{q_H - q_L}B. \tag{14}$$

Equation (14) states that the project is undertaken only if its returns is strictly higher than $1+r$, since $\Psi > 1+r$ due to the credit market imperfection.

We will adopt, without loss of generality, the simplifying assumption that the effective measure of productivity of labor in the R&D activity, aq_H, is equal to 1. Thus, the investors participation constraint becomes:

$$\frac{vn}{w} \geq \Psi. \tag{15}$$

Note that the left-hand side of equation (15) is the return of the project. When this ratio is greater than $1+r$, the project has positive expected net return. Ψ may be interpreted as a measure of the credit market imperfection. When $\Psi = 1+r$, all projects with positive expected net return are financed, whereas, when $\Psi > 1+r$, the projects with expected return in the range $[1+r, \Psi)$ are not financed, although they have positive expected net return. The higher the value of Ψ, the larger is the range of projects with positive expected net return that are not financed due to informational asymmetry problems. The credit market imperfection is increasing in the private benefit accrued to managers with bad behavior, $\frac{\partial \Psi}{\partial B} > 0$, and decreasing in the degree of observability and/or accountability, $\frac{\partial \Psi}{\partial (q_H - q_L)} < 0$.

2.4 Individuals

There are three types of individuals in this economy: workers, who also own final goods firms, entrepreneurs, and investors.

Entrepreneurs Entrepreneurs borrow to invest in the discovery of new blueprint. Those who do not succeed receive nothing, while successful ones receive R_b^* given by equation (13). For simplicity, we assume that there is a sufficiently large number of firms, so that the law of large numbers applies and there is no aggregate uncertainty. At each point in time, exactly a fraction q_H of all investment projects are successful. Thus, the aggregate income of all entrepreneurs at any point in time equals $q_H R_b^*$.

Workers There are L workers in the economy, each one endowed with one unit of labor which they supply inelastically. Their labor income is the wage rate w.

Investors Investors are represented by a financial institution in the economy that receive all savings available in the economy, paying the current interest rate $r(\tau)$ at any point in time. The financial institution lends wL_γ to entrepreneurs, and it pays a total of $q_H R_b^*$ to the ones with successful R&D projects. Moreover, at each point in time the financial institution receives the monopoly profits $\pi = \frac{(1-\alpha)\sigma E}{n}$ from production of each of the n successfully invented varieties.

Aggregate Income Summing up the individual's revenue for each of his activities, aggregate income in a closed economy equals:

$$Inc = wL + \theta E, \tag{16}$$

where $\theta \equiv (1-\alpha)\,\sigma$

Note that total expenditures is equal to the total income, from which we subtract investment. In a closed economy, we would have:

$$E = w\,(L - L_\gamma) + \theta E, \tag{17}$$

from which we get:

$$E = \frac{w\,(L - L_\gamma)}{1-\theta}. \tag{18}$$

Substituting expenditures back into the income equation, we have that income in a closed economy is:

$$Inc = \frac{w\,(L - \theta L_\gamma)}{1-\theta}. \tag{19}$$

On aggregate, the individual's payments as investors to entrepreneurs cancel out with what they receive as entrepreneurs. All individuals have the same behavior and they participate as workers and entrepreneurs in the same number of firms. Hence, their net income per capita is equal.

In the case of an open economy, we assume that the domestic financial institution receives all savings from domestic residents, and it may lend both to domestic and to foreign entrepreneurs. Total lending for domestic entrepreneurs equals $wL_\gamma = \mu\,(Inc - E) + \mu^{row}\,(Inc^{row} - E^{row})$, where μ and μ^{row} are the share of domestic and rest-of-the-world savings, respectively, in domestic projects, and superscripts row indicates the 'rest of the world'. Analogously, total lending for foreigners is equal to $w^{row}L_\gamma^{row} = (1-\mu)\,(Inc - E) + (1-\mu^{row})\,(Inc^{row} - E^{row})$. Payments to entrepreneurs are computed in the same fashion. As for monopoly profits received, the domestic financial institution collects profits from the blueprints invented so far under the institution's financing. In the steady state, the domestic financial institution will own a share $\frac{\mu(Inc-E)}{wL_\gamma}$ of domestic blueprints and $\frac{(1-\mu)(Inc-E)}{w^{row}L_\gamma^{row}}$ of foreign ones. In transition periods these shares change over time.

3 The Closed Economy

3.1 Equilibrium in a Closed Economy

Following Grossman and Helpman (1991), we will normalize nominal expenditures so that $E(\tau) = 1$, $\forall\tau$. Consequently, optimal spending evolution in equation (3) implies that $r\,(\tau) = \rho$.

Final goods prices from equations (6) can be written as:

$$P_{tr} = w, \quad P_h = \frac{w}{\alpha n^{\frac{1-\alpha}{\alpha}}}, \tag{20}$$

using the equilibrium price of intermediate goods in equation (8).

In a closed economy goods production must equal consumption. Using demand equations (4), price equations (20) above, and the normalization $E(\tau) = 1$, we have that:

$$Y_{tr} = \frac{(1-\sigma)}{w}, \quad Y_h = \frac{\alpha\sigma n^{\frac{1-\alpha}{\alpha}}}{w}. \tag{21}$$

Finally, production of intermediate goods and their profits from equations (9a) and (9b) can be written as:

$$x = \frac{\alpha\sigma}{wn}, \quad \pi = \frac{\theta}{n}, \tag{22}$$

remembering that $\theta \equiv \sigma\,(1-\alpha)$.

There are two equilibrium conditions stemming from R&D activity. First, if inequality $\frac{vn}{w} > \Psi$ were true, entrepreneurs' profits would be higher the larger were investments, leading to unbounded R&D (see equation (15)). Since labor supply is fixed, this would not be an equilibrium. Moreover, the investors participation constraint (15) is not satisfied when $\frac{vn}{w} < \Psi$. In that case there is no investment in innovation and $\dot{n} = 0$. When $\frac{vn}{w} = \Psi$ investors participation constraint is satisfied, and there is a positive innovation rate. In sum, the financing equilibrium condition (FEC) in the

R&D activity is given by:

$$\frac{vn}{w} \leq \Psi, \text{ with equality when } \dot{n} > 0. \text{ (FEC)} \tag{23}$$

The second equilibrium condition stems from a non-arbitrage condition. Assuming that agents have access to a riskless bond that pays $r(t)$ per period, the non-arbitrage condition implies that the rate of return of a blueprint must be equal to the riskless rate,[4] that is:

$$\frac{\pi(t) + \dot{v}(t)}{v(t)} = r(t). \tag{24}$$

Log-differentiating the FEC (expression 23) when $\dot{n} > 0$,that is, in equilibrium with positive innovation, we get:

$$\frac{\dot{w}}{w} = \frac{\dot{v}}{v} + \gamma, \tag{25}$$

where $\gamma \equiv \frac{\dot{n}}{n}$. Substituting it in the non-arbitrage condition (24), using the profit equation (22) and our normalization that $r(t) = \rho$, we can write the non-arbitrage condition as:

$$\frac{\dot{w}}{w} = \gamma + \rho - \frac{\theta}{w\Psi}, \text{ when } \dot{n} > 0. \tag{26}$$

The economy is in steady state equilibrium when the aggregate equity $V \equiv vn$ (or the aggregate market value of firms) is constant. It means that in equilibrium we must have that:

$$\frac{\dot{v}}{v} + \gamma = 0,$$

that is, the value of a blueprint v must decrease over time at the same rate of increase in the number of blueprints. From equation (25), it implies constant wages, $\frac{\dot{w}}{w} = 0$.

For an economy with strictly positive innovation rates, the no-arbitrage conditions from equation (26) can be combined to compute the economy's overall innovation rate:

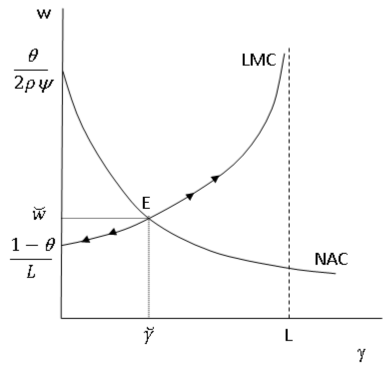
$$\gamma = \frac{\theta}{w\Psi} - \rho, \quad \text{(NAC)} \tag{27}$$

We denote this equation the economy's combined no-arbitrage condition (NAC).

Finally, labor market must clear. Labor supply, L, must equal total labor demand, which is the sum of demand for labor for R&D activities, L_γ, intermediate goods production, L_x, and traditional good production, L_{tr}. According to our production functions, one unit of labor produces either one unit of intermediate good or one unit of traditional good. Hence, using production values in equations (21) and (22), we get that $L_{tr} = \frac{(1-\sigma)}{w}$ and $L_x = \frac{\alpha\sigma}{w}$. As for the demand for labor

[4] We refer to the argument in footnote 3 for the risk neutral behavior of the individual here.

Figure 1: Equilibrium in the Closed Economy



in R&D, note that, from our assumptions in section 2.3.2, the innovation rate is $\frac{dn}{dt} = aq_H n L_\gamma$. Therefore, $L_\gamma = \gamma$, using the simplifying assumption that $aq_H = 1$. Thus, the labor market clearing condition (LMC) is:

$$\gamma + \frac{1-\theta}{w} = L. \text{ (LMC)} \tag{28}$$

The dynamics of the economy is represented in Figure 1. The LMC curve represent equation (28), while the NAC curve represents equation (27). Wages increase at points above and decrease at points below the NAC curve. The economy is in equilibrium at the intersection point of the two curves, and it is represented by point E in the figure. The arrows indicate the equilibrium paths of the economy. As in Grossman and Helpman's (1991) model, the steady-state is unstable, hence the economy must then be always at the equilibrium point E, where wage and innovation rates are constant. The equilibrium values for w and γ are:

$$\breve{w} = \frac{\theta + (1-\theta)\,\Psi}{(L+\rho)\,\Psi}, \tag{29}$$

and:

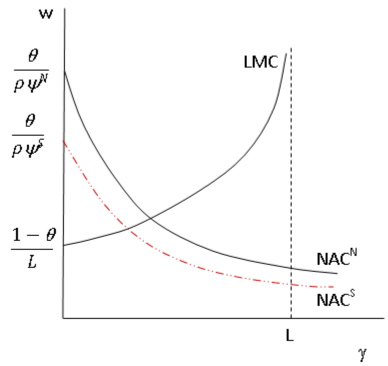
$$\breve{\gamma} = \frac{\theta L - (1-\theta)\,\rho\Psi}{\theta + (1-\theta)\,\Psi}. \tag{30}$$

This equilibrium is feasible if $\breve{\gamma} > 0$, which requires that:

$$L \quad > \quad \frac{(1-\theta)\,\rho\Psi}{\theta}. \tag{31}$$

In terms of Figure 1, this condition ensures that the combined NAC curve crosses the vertical axis at a higher point than the point the LMC curve does, so that they cross at a positive value of the

Figure 2: Comparing Economies with Different Credit Market Quality



innovation rate γ.

Given that $\breve{\gamma}$ and $\breve{w}$ are constant, labor allocation remains constant across all activities (R&D, traditional and intermediate goods production). Nevertheless, the ratio $\frac{Y_h}{Y_{tr}}$ increases at rate $\left(\frac{1-\alpha}{\alpha}\right)\breve{\gamma}$, since goods Y_h's productivity increases continuously due to the increase in the number of varieties of intermediate goods.

3.2 Institutions and Innovation

Figure 2 depicts the equilibria for two closed economies differing only with respect to the quality of their credit markets, that is, the value of Ψ. The LMC is the same for the two economies, but the difference in the credit market quality affects the NAC. In terms of Figure 2, the NAC curve for the country with better credit market (NAC^N) is upper and to the right compared the one for the other country (NAC^S). The impact of credit market imperfection on equilibrium is summarized in Proposition 1.

Proposition 1 *In economies where credit market frictions are less severe (lower Ψ), wages are higher, there is more investment in R&D activity and real GDP grows faster.*
Proof. *It is straightforward to check that and $\frac{\partial \breve{w}}{\partial \Psi} = -\frac{\theta}{(L+\rho)\Psi^2} < 0$ and $\frac{\partial \breve{\gamma}}{\partial \Psi} = -\frac{(1-\theta)\theta}{[\theta+(1-\theta)\Psi]^2} < 0$. Investment in R&D is equal to wL_γ, by definition. Given the two previous inequalities, it is clear that investment in R&D is also a decreasing function of Ψ in both sectors. From equation (30), real GDP growth in positively related to innovation rates, hence negatively related to Ψ.* ■

In sum, investment in R&D is higher in countries with better institutions, which yields a higher innovation rate in those countries. Innovation, on its turn, increases productivity. Consequently, real GDP increases faster when institutions are better.

4 The Open Economy

We extend the previous model to a world economy with two countries engaging in international trade, with free flow of financial capital. Since we want to focus on the effects of the quality of credit market, we abstract from other possible differences across countries. Hence, countries are assumed to differ only with respect to the quality of their credit markets, which will be responsible for trade pattern and growth rates, through the differences in innovation rates and wages. Hereafter we denote the country with better credit market as 'North' and the other one as 'South'. The superscript i , $i = N, S$, is used to denote the two countries, hence $\Psi^N < \Psi^S$.

We also assume that both countries have been in autarky for the same length of time before they start to trade. From Proposition 1, we have then that the country with the best credit market will have a larger number of intermediate goods when they open to trade.[5] We start by analyzing a benchmark case where we allow for financial flows across countries and for trade in final goods. We assume away trade in intermediate goods, so that producers of high-tech final goods must use domestically produced intermediate goods. Moreover, in our benchmark case there is no spillover of knowledge across countries, that is, the stock of knowledge, which affects R&D productivity, is proportional to the number of varieties that were invented domestically, that is, from equation (10), $K^i(t) = n^i(t)$. Section 5.1 extends the analysis to incorporate trade in intermediate goods, knowledge spillover, and also the possibility for a blueprint to be invented in one country and produced in the other, which would stand for a multinational firm.

4.1 Equilibrium in the Open Economy

Similarly to the closed economy case, we take global expenditures as our numeraire, so that $E^N + E^S = 1$ at all times. With international trade of final goods, consumer will buy final goods from the country with lower prices, which are given by equation (20). The country with lower production cost will serve the entire market, hence equilibrium conditions in the goods markets for country i, $i = N, S$, are given by:

$$P_{tr} Y_{tr}^i = s_{tr}^i (1 - \sigma) \;\text{, where }\; s_{tr}^i = \begin{cases} 0, \text{ if } w^i > w^k; \\ s_{tr}^i \in [0, 1]\,, \text{ if } w^i = w^k; \text{ and} \\ 1, \text{ if } w^i < w^k, \end{cases} \tag{32}$$

[5] We argue this is a reasonable assumption, since countries with better institutions tend to have relatively more developed industries intensive in technology. Notice that our results still hold when both countries start trading with the same level of technological development.

$$P_h Y_h^i = s_h^i \sigma \text{ , where } s_h^i = \begin{cases} 0, \text{ if } \frac{w^i}{\alpha (n^i)^{\frac{1-\alpha}{\alpha}}} > \frac{w^k}{\alpha (n^k)^{\frac{1-\alpha}{\alpha}}} \\ s_h^i \in [0,1], \text{ if } \frac{w^i}{\alpha (n^i)^{\frac{1-\alpha}{\alpha}}} = \frac{w^k}{\alpha (n^k)^{\frac{1-\alpha}{\alpha}}} \\ 1, \text{ if } \frac{w^i}{\alpha (n^i)^{\frac{1-\alpha}{\alpha}}} < \frac{w^k}{\alpha (n^k)^{\frac{1-\alpha}{\alpha}}} \end{cases} , \tag{33}$$

where $k = N, S$, $i \neq k$, and s_j^i is country i's global market share of good j, $j = t, h$, with $s_j^N + s_j^S = 1$.

Intermediate goods in country i is in equilibrium when:

$$x^i(j) = \frac{\alpha Y_h^i}{w^i n^i} = \frac{s_h^i \alpha \sigma}{w^i n^i}, \tag{34}$$

and profits for each intermediate good producer in that sector are:

$$\pi^i = \frac{s_h^i \theta}{n}. \tag{35}$$

It is worth emphasizing that the high-tech good is produced only in the country in which its price is lower, as can be seen by the definition of the market share of high-tech goods s_h^i in equation (33). The country that, when opening to trade, loses the high-tech good market will also lose all its market for intermediate goods, as established in equation (34). In that case all blueprints invented in that country become useless, and no further innovation takes place.

Given demand for intermediate goods in equation (34), and production of tradition good in equation (32), the labor market equilibrium condition (equation (28)) becomes:

$$\gamma^i + s_h^i \frac{\alpha \sigma}{w^i} + s_{tr}^i \frac{(1-\sigma)}{w^i} = L \tag{36}$$

In current setup, the equilibrium conditions yield the same characterization of the steady state as in the closed economy case, that is,

$$\frac{\dot{w}^i}{w^i} = 0, \; i = N, S.$$

Given the FEC (23), we have that $v^i n^i = w^i \Psi^i$ when the country is innovating. The corresponding steady-state NAC (27) for the open economy becomes:

$$\gamma^i = \frac{s_h^i \theta}{w^i \Psi^i} - \rho. \tag{37}$$

4.2 Institutions and Innovation

The relation between credit market quality and innovation in a global economy is summarized in Proposition 2.

Proposition 2 *There is no equilibrium where both countries innovate under free trade of final goods. Only the country with the better credit market innovates, and it captures all the market of high-tech goods. Moreover, for that country, innovation rate is higher under free trade compared to autarky.*

Proof. Appendix 8.1 proofs that there is no equilibrium with both countries innovating. We argue below that the only innovating country is North, and then we compute the equilibrium to show that innovation rate increases with openness for North. ■

North is the only innovating country

In the case of factor price equalization (FPE), North, which is the country that has the larger stock of blueprints when international trade starts, takes the whole high-tech good market (see equation (33)). Intermediate goods have no value in South, since there is no longer high-tech good production in that country and intermediate goods trade is not allowed. Therefore, only North innovates and the situation is self-perpetuating.

In the case of non-FPE, wages would have to be lower in South to render its production of high-tech goods competitive, since, with a smaller stock of blueprints, South is relatively less productive in that sector. With lower wages, South would capture all the market for the traditional good. South would have a higher demand for labor both in the high-tech and in the traditional good production. The demand for labor for innovation would be same in both countries, as they must innovate at the same rate in order for both to remain equally competitive in the high-tech sector with constant wages. Hence, South would have a higher demand for labor than North, which is not possible in equilibrium because, by assumption, their labor supplies are the same. With no FPE, only North innovates in equilibrium.

Innovation rate in the open economy

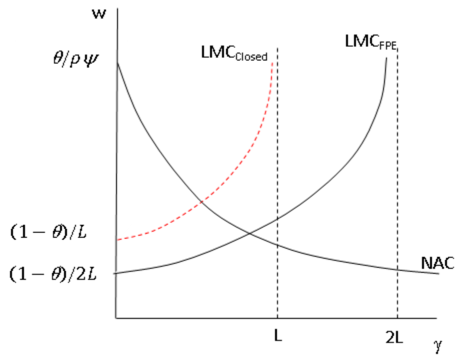
The equilibrium is computed by the solution of the system composed by the NAC in equation (37) for North and the LMC in equation (36) for both countries. There is no innovation in South, $\gamma^S = 0$, the market share of traditional goods, s^i_{tr}, is defined in equation (32), and North captures all the market for high-tech good, that is $s^N_h = 1$.

FPE equilibrium[6] Under FPE, by definition, we have that $\bar{w}^N = \bar{w}^S \equiv \bar{w}$. Summing up the LMCs for the two countries (equation (36)) we get that:

$$w = \frac{1-\theta}{2L-\gamma^N} \tag{38}$$

[6] Appendix 8.2 derives the range of parameter values for the FPE or the non-FPE equilibria to be feasible.

Figure 3: FPE Equilibrium



Using the NAC condition (37) for North, we get that the equilibrium wage is:

$$\bar{w} = \frac{\theta + (1-\theta)\,\Psi^N}{(2L+\rho)\,\Psi^N}. \tag{39}$$

From equations (37), we have that the innovation rates in North is:

$$\bar{\gamma}^N = \frac{2\theta L - (1-\theta)\,\rho\Psi^N}{\theta + (1-\theta)\,\Psi^N}. \tag{40}$$

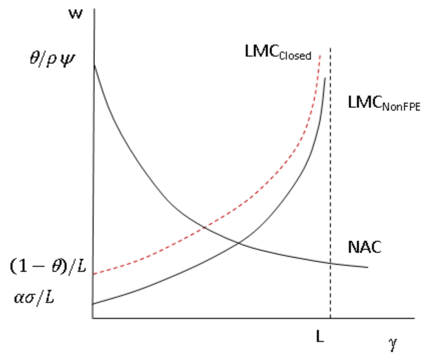
Finally, using South's LMC from equation (36), we have that South share in traditional goods supply is:

$$\bar{s}^S_{tr} = \frac{\bar{w}L}{1-\sigma} = \frac{\left[\theta+(1-\theta)\Psi^N\right]L}{(1-\sigma)(2L+\rho)\Psi^N}. \tag{41}$$

Comparing equations (30) and (40), it is clear that North innovates faster under free trade of final goods compared to autarky. Figure 3 compares the closed economy equilibrium to the FPE equilibrium in the open economy for North. The NAC curve for North, in equation (37), does not change when North opens to trade, since it captures all market for high-tech goods. The LMC curve for the open economy, in equation (38), shifts downwards. The graph shows that, for North, wages are lower and innovation rate higher under free trade. Notice, though, that real wages do not change at the moment of trade opening and they will be higher than what their level would be in autarky as time passes, as we will see in section 5.[7] Moreover, the rate of innovation under free trade (equation (40)) is more than two times higher than that of North under autarky (30): $\bar{\gamma}^N > 2\breve{\gamma}$.

[7]This will also be true for the non-FPE equilibrium represented in Figure 4.

Figure 4: Non-FPE Equilibrium: North



Non-FPE equilibrium In the non-FPE equilibrium, the only possible configuration for wages in equilibrium is $\hat{w}^N > \hat{w}^S$. It implies that $\hat{s}_t^N = 0$, and, the LMC in equation (36) for South determines its wage:

$$\hat{w}^S = \frac{1-\sigma}{L}. \tag{42}$$

For North, wages are given by the combination of LMC (36):

$$w^N = \frac{\alpha\sigma}{L-\gamma^N} \tag{43}$$

and NAC (37), so that:

$$\hat{w}^N = \frac{\theta + \alpha\sigma\Psi^N}{(L+\rho)\,\Psi^N}, \tag{44}$$

which yield the following innovation rate:

$$\hat{\gamma}^N = \frac{\theta L - \rho\alpha\sigma\Psi^N}{\theta + \alpha\sigma\Psi^N} \tag{45}$$

Here again, innovation rate in North is higher under free trade compared to autarky. Figure 4 compare equilibrium in autarky to the equilibrium in the open economy for North for the non-FPE equilibrium. Similarly to the FPE case, the LMC for the open economy, now in equation (43), shifts downwards compared to the closed economy LMC. It is interesting to note that the increase in innovation rate is larger in the FPE equilibrium, shown in Figure (3) compared to the non-FPE one.

5 Innovation, Trade Pattern, Capital Flow and Welfare

Innovation

Proposition 2 establishes that North is the only country that innovates when countries are open to trade, and that its innovation rate is higher under openness: innovation growth becomes zero in South while it increases in North. Hence, **opening to trade increases innovation in the country with better institutions and decreases it in the other country**.

With this result, we offer a rationale for the empirical finding that the impact of trade liberalization on growth either disappears or become negative when institutions are controlled for (Dollar and Kraay, 2003; Rodrik et al., 2004; and Rigobon and Rodrik, 2005). Our result can also explain the negative impact of openness on growth found among developing countries (Wacziarg and Welch, 2008; and Kim, 2011).

Trade Pattern

The model also predicts the trade pattern between countries. North is the only country that innovates when countries are open to trade. The high-tech good is produced only in North, while South specializes in traditional goods. North, then, exports high-tech goods to South and imports traditional goods. That is, the country with better institutions exports high-tech goods and imports traditional goods.

This result is in line with empirical results that show that more financially developed countries tend to export more in industries that use more intangible assets or that are more dependent on external finance, as in Beck (2002), Hur et al (2006), Manova (2005) and Svaleryd and Vlachos (2005). Our result also relates to Levchenko (2007), who shows that the quality of institutions affects trade pattern. In particular, he finds that countries with better institutions tend to have a lower import share of goods that are more institutionally dependent, defined as goods with higher complexity in production. Indeed, high-tech goods in our setting can be interpreted as institutional dependent goods, in the sense of Levchenko (2007).

Capital Flow

With free flow of financial capital, individuals can invest in any innovation project, no matter whether he is resident of the country where the investment project takes place or not. Since only North engages in R&D under free trade, capital will flow from South to North. Antràs and Caballero (2009) find the same patter of financial capital flows in a setting where one sector in the economy is subject to an exogenous credit constraint.

Welfare

We compare the welfare in autarky and in free trade for North and South, which differ only with respect to the quality of their credit markets. The possibility of knowledge accumulation as new blueprints are invented allows for different impacts of trade opening in the short and in the long run. As usual in the literature, we measure welfare by the utility function. Substituting optimal consumption from equations (4a) (4b) into the utility function (1), we have that:

$$U_t^i = \int_t^{\infty} e^{-\rho(\tau - t)} \log\left[\frac{E^i(\tau)}{P(\tau)}\right] d\tau, \tag{46}$$

where $E^i(\tau)$ is the expenditure in country i and the price index $P(\tau)$ is in equation (2). Note that each period the utility is given by $\frac{E^i(\tau)}{P(\tau)}$, which can be interpreted as the purchasing power of the country. Let us denote it by $G^i(\tau) \equiv \frac{E^i(\tau)}{P(\tau)}$.

Closed economy

The purchasing power of country i's residents in autarky, G^i_{aut}, is given by their expenditures, given by equation (17), divided by the price index in autarky P_{aut}:

$$G_a^i = \frac{w^i_{aut}\left(L - \gamma^i_{aut}\right) + \theta}{P^i_{aut}}, \tag{47}$$

where we used $L_\gamma^i = \gamma^i_{aut}$ and $E = 1$. Using the equilibrium values of w^i_{aut} and γ^i_{aut} in equations (29) and (30), it is easy to check that $E = w^i_{aut}\left(L - \gamma^i_{aut}\right) + \theta = 1$, as it should be.

Using the definition of the price index from equation (2) and the equilibrium prices of final and intermediate goods from equations (6a), (6b) and (8), we have that the price index in autarky is:

$$P^i_{aut} = \frac{w^i_{aut}}{z\left(n^i\right)^{\frac{\theta}{\alpha}}}, \tag{48}$$

where $z \equiv (\alpha\sigma)^{\sigma}(1-\sigma)^{1-\sigma}$. It depends positively on wages and negatively on the number of varieties of the intermediate goods.

Substituting equation (48) into (47), we have that the welfare in autarky is equal to:

$$G^i_{aut} = z\left(n^i\right)^{\frac{\theta}{\alpha}}\left[\left(L - \gamma^i_{aut}\right) + \frac{\theta}{w^i_{aut}}\right] \tag{49}$$

$$= z\left(n^i\right)^{\frac{\theta}{\alpha}}\left[\frac{(1-\theta)(L-\rho)\Psi^i}{\theta + (1-\theta)\Psi^i}\right] \tag{50}$$

Notice that the purchasing power is a decreasing function of investment in R&D. Since, from

Proposition 1, investment is higher in North, its residents' welfare is lower than that of South residents when the stock of knowledge is the same across countries. The reason for this result is that residents of North invest a higher share of their income in R&D projects, so that, given the same stock of knowledge, they consume less than residents in South. Nevertheless, the number of blueprints increases faster in North, leading to a faster decrease of its price index. If initially both countries have zero blueprints, there will be a moment t^* where the lower price index compensates the higher level of investment in North. Thereafter, the residents of North are better off, and the difference in welfare across countries increases continuously.

Period t^* is implicitly defined as the moment when $G_{aut}^N = G_{aut}^S$, that is, when:

$$\frac{n\left(t^*\right)^N}{n\left(t^*\right)^S} = \left[\frac{\theta/\Psi^N + 1 - \theta}{\theta/\Psi^S + 1 - \theta}\right]^{\frac{\alpha}{\theta}}. \tag{51}$$

Open Economy

With free flow of financial capital, all individuals can invest in any innovation project, no matter whether he is resident of the country where the investment project takes place or not. Let us denote $k^i(t)$ the share of the world capital (total number of blueprints) that belongs to residents of country i, and let T be the moment the countries open to trade. We have that:

$$k^i(t) = \frac{n^i\left(T\right) + \beta^i\left(t\right)\left[n\left(t\right) - n\left(T\right)\right]}{n\left(t\right)}, \text{ for } t \geq T \tag{52}$$

where $n = n^N + n^S$ and β^i is the share of the blueprints discovered after trade opening that belongs to country i, which is the share of country i investment in total global investment. Since all individuals have the same logarithmic preferences, all of them devote the same share of income to investment in R&D. Hence, β^i is the share of country i's income in total world income. Using equation (16), the income of country i in the open economy is equal to $Inc^i\left(t\right) = w^iL + k^i(t)\theta$. Hence,

$$\beta^i\left(t\right) = \frac{w^iL + k^i(t)\theta}{w^NL + w^SL + \theta}. \tag{53}$$

In the benchmark case, when there is no trade in intermediate goods, all blueprints of South become useless with trade liberalization, therefore $k^N\left(T\right) = 1$ and $k^S\left(T\right) = 0$. With trade in intermediate goods, as developed in section 6.1, we have that $0 < k^S\left(T\right) < k^N\left(T\right) < 1$, and those shares converge to:

$$\lim_{t\to\infty} k^i(t) = \frac{w^i}{w^N + w^S}. \tag{54}$$

It means that, under FPE, residents of both countries share equally the profits of intermediate goods firms in the long run, whereas, when a non-FPE equilibrium arises, North residents have a higher share of profits in the long-run.

In the open economy, total expenditures are the numeraire, so that expenditures in North and in South lie in the interval $[0,1]$. Expenditures in country i will be equal to $E^i = w^i L - \beta^i w^N \gamma + \theta k^i(t)$, that is, total wages $w^i L$, minus spending in investment $\beta^i w^N \gamma$, plus the profits from the varieties that belong to the country $\theta k^i(t)$. The purchasing power of country i' residents under free trade equals:

$$G^i_{free}(t) = \frac{w^i L - \beta^i w^N \gamma^N + \theta k^i(t)}{P_{free}}. \tag{55}$$

In all cases studied, South always supplies the traditional good and North the high tech good. Hence, the price index is:

$$P_{free} = \frac{\left(w^S\right)^{1-\sigma} \left(P_h\right)^{\sigma}}{\sigma^{\sigma} \left(1-\sigma\right)^{1-\sigma}} = \frac{\left(w^S\right)^{1-\sigma} \left(w^N\right)^{\sigma}}{z \left(n^N\right)^{\frac{\theta}{\alpha}}}. \tag{56}$$

Combining equations (55) and (56), we get the following expression for the purchasing power for country i:

$$G^i_{free}(t) = \left[\frac{w^i L - \beta^i w^N \gamma^N + \theta k^i\left(t\right)}{\left(w^S\right)^{1-\sigma} \left(w^N\right)^{\sigma}}\right] z \left(n^N\left(t\right)\right)^{\frac{\theta}{\alpha}}. \tag{57}$$

Comparing the purchasing power under free trade in equation (57) to the one under autarky in equation (49), we see that, in both of them, the term between brackets is stationary, while $\left(n^i\left(t\right)\right)^{\frac{\theta}{\alpha}}$ increases over time as new varieties of the intermediate good are develped. Since the innovation rate is greater under free trade compared to autarky, eventually the purchasing power under free trade will be greater than the one under autarky.

It is interesting to compare their purchasing power at the moment T they open to trade. Given that South's existing varieties become useless, we have that $k^S\left(T\right) = 0$ and $k^N\left(T\right) = 1$. Let us see then compare $G^i_{free}\left(T\right)$ to $G^i_{aut}\left(T\right)$ for the cases when there is factor price equalization and there is no factor price equalization.

FPE equilibrium Under FPE, the only difference in the purchasing power between the two countries stems from their difference in wealth. North residents have an accumulated capital, which are the existing varieties they continue to produce, which gives them a higher income. From equation (55), the purchasing power for North and South can be written as:

$$G^N_{free}\left(T\right) = \frac{\overline{w}\left(L - \beta^N\left(T\right)\bar{\gamma}^N\right) + \theta}{P_{free}}, \; and \tag{58}$$

$$G^S_{free}\left(T\right) = \frac{\overline{w}\left(L - \beta^S\left(T\right)\bar{\gamma}^N\right)}{P_{free}}. \tag{59}$$

where the FPE wage $\overline{w}$ is given by equation (39), the innovation rate $\bar{\gamma}^N$ by equation (40) and the shares β are $\beta^N(T) = \frac{\overline{w}L+\theta}{2\overline{w}L+\theta}$ and $\beta^S(T) = \frac{\overline{w}L}{2\overline{w}L+\theta}$.

North For North, the difference in purchasing power at the moment of trade opening stems from the change in real wage and in the amount of investment, which affect the net revenue from labor (first term in equation (58)), and in the price level, which affect the real value of profits (last term in equation (58)). Let us see what happens to each of these elements.

Using equation (48), real wage in autarky is $\frac{w^i_{aut}}{P^i_{aut}} = z\left(n^i\right)^{\frac{\theta}{\alpha}}$, while under FPE in the open economy it is equal to $\frac{\overline{w}}{P_{free}} = z\left(n^N\right)^{\frac{\theta}{\alpha}}$. Hence, there is no change in real wage for North, at the moment the country opens to trade. As for the innovation rate, comparing the innovation under autarky in equation (30) to the one under FPE in equation (40), it is clear that $\breve{\gamma} < \frac{\bar{\gamma}^N}{2}$, that is, the amount invested in innovation is greater under free trade than in autarky. These two results indicate that the first term of equation (58) decreases at the moment North opens to trade: the real wage does not change and the country invests more.

There is a positive effect of opening to trade through the last term of equation (58): a lower price level increases the real value of the profits from the high-tech sector production, since, from equations (39) and (29), we have that $P_{free} = \frac{\overline{w}}{z(n^N)^{\frac{\theta}{\alpha}}} < \frac{\breve{w}}{z(n^N)^{\frac{\theta}{\alpha}}} = P^N_{aut}$. It turns out that the gain in purchasing power from a lower price level more than compensates the higher investment made by North, so that the country experiences a net welfatre gain at the moment it open to trade, as shown in Appendix 8.3. This gain increases over time, since the innovation rate in greater under free trade compared to autarky, which further increases the purchasing power.

South When it opens its economy, South's stock of blueprints become useless, which represents a loss of income. This is captured by the fact that the term $\frac{\theta}{P}$ disappears from equation (47) to equation (59). However, differently from North, real wages in South increase after opening, since the high-tech good is now imported from North, who produces it at a lower cost since it has more blueprints than South had before opening its economy. If the gain from higher real wages is large enough, it is possible the South still gains at the moment of opening, despite the loss of its blueprints. Intuitively, it will happen when there is such a large difference in the number of blueprints from North and South, so that decrease in price of high-tech goods (and the increase in real wages that it produces) compensates for the loss of the blueprints. After some algebra, we get that the condition for South to gain at the moment of opening is the following:

$$\frac{n^N(T)}{n^S(T)} > \frac{1}{\breve{w}^S L}, \tag{60}$$

where $\breve{w}^S$ is given by equation (29).

Non-FPE equilibrium In the non-FPE equilibrium, the purchasing power for the two countries can be written as:

$$G^N_{free}(T) = \frac{\hat{w}^N\left(L - \beta^N\hat{\gamma}^N\right) + \theta}{P_{free}}, \; and \tag{61}$$

$$G^S_{free}(T) = \frac{\hat{w}^S\left(L - \beta^S\hat{\gamma}^N\right)}{P_{free}}, \tag{62}$$

where $\hat{w}^S$ and $\hat{w}^N$ are given by equations (42) and (44), respectively, P_{free} by equation (56) andβ^i by equation (53).

It is easy to check that $\hat{w}^S < \hat{w}^N < w^S_{aut} < w^N_{aut}$. The first inequality is the condition for the non-FPE equilibrium to exists, while the last one is derived from Proposition 1. The middle inequality is shown through:

$$\hat{w}^N = \frac{\theta + \alpha\sigma\Psi^N}{(L+\rho)\,\Psi^N} < \frac{\theta + \alpha\sigma\Psi^S}{(L+\rho)\,\Psi^S} < \frac{\theta + (1-\theta)\,\Psi^S}{(L+\rho)\,\Psi^S} = w^S_{aut}.$$

North Clearly, North residents are better off than those who live in South. The latter not only lose their accumulated capital (stock of blueprints), but also face lower wages that those in North.

To simplify the analysis, we use the lower bound for $G^N_{free}(T)$, which is calculated for $\beta^N = 1$. At the moment the countries open to trade, the lower bound for the ratio of North residents welfare under free trade and under autarky equals:

$$\frac{G^N_{free}(T)}{G^N_{aut}(T)} = \sigma\left(\frac{w^N_{aut}}{\hat{w}^N}\right)\left(\frac{\hat{w}^N}{\hat{w}^S}\right)^{\sigma}. \tag{63}$$

Then last two terms are larger than one and they represent the country's gain in purchasing power from opening to trade. The first term, σ, indicates a loss steming from the fact that investment in R&D is higher under free trade (see Figures 3 and 4), which decreases disposable income at the moment trade starts. For a share of high-tech good in consumption σ sufficiently large, the country has a net gain when trade starts. More specifically, it is possible to show that $\sigma \geq \frac{1}{2(1-\alpha)}$ is a sufficient condition for $\frac{G^N_{free}(T)}{G^N_{aut}(T)} > 1$.

South As for the residents in South, they have more to loose when trade starts. Similarly to what we have done for North, we compute the lower bound for $G^S_{free}(T)$, in which $\beta^S = 1$. The lower bound for ratio of North welfare under free trade and under autarky is:

$$\frac{G^S_{free}\left(T\right)}{G^S_{aut}\left(T\right)} = \alpha\sigma\left(\frac{w^S_{aut}}{\hat{w}^N}\right)\left(\frac{\hat{w}^S}{\hat{w}^N}\right)^{\sigma}\left(\frac{n^N}{n^S}\right)^{\frac{\theta}{\alpha}} \tag{64}$$

First, they lose part of their wealth when their stock of blueprints loses its value. Second, investment in R&D is higher under free trade compared to autarky, which decreases its disposable income for consumption in the short run. These two effects are captured in the first term between brackets, which is lower than one. Finally, the effect of opening to trade on purchasing power in terms of the high tech good is uncertain. On the one hand, those goods are now produced by North, which has higher wages (second to last term in the equation). On the other hand, that country has a larger number of varieties of the intermediate goods, which renders production more efficient and less costly (last term). The net effect depends on the difference in the number of varieties both countries had just before starting to trade.

In summary, we have seen that, although both countries gain from globalization in the long run, there may be losses in the short run when the economies, prior in autarky, open their goods and financial markets. The gain in the long run stems basically from faster productivity growth, given that the innovation rate in the open economy is higher that in autarky. The possible short-run loss is due to the higher investment rate in the open economy, which reduces the disposable income in the short run. Moreover, South, the country with worse credit markets, suffers a capital loss when opening, since its stock of varieties of the intermediate good become useless. South may still gain in the short run, despite its capital loss, if the productivity in the high-tech sector in North is sufficiently higher than in South.

6 Extensions

Our benchmark model of the open economy does not allow for trade in intermediate goods nor knowledge spillovers. We show that our results hold when we relax those two assumptions.

6.1 Equilibrium With Intermediate Goods Trade

When trade of intermediate goods is allowed, countries may produce intermediate goods even if they do not produce the high-tech good. In this case there is no waste of past invention when countries engage in international trade. The demand for a variety of intermediate good from country i, from equation (7), can be written as:

$$x^i(j) = \frac{\sigma p^i(j)^{-\frac{1}{1-\alpha}}}{\int\limits_0^{n^i(t)} p^i(j)^{-\frac{\alpha}{1-\alpha}}\, dj + \int\limits_0^{n^k(t)} p^k(j)^{-\frac{\alpha}{1-\alpha}}\, dj},$$

which, given intermediate goods price in equation (8), becomes:

$$x^i(j) = s_x^i \frac{\alpha\sigma}{n^i w^i},$$

where s_x^i is market share of intermediate goods produced by country i firms defined by:

$$s_x^i \equiv \frac{n^i \left(w^i\right)^{-\frac{\alpha}{1-\alpha}}}{n^N \left(w^N\right)^{-\frac{\alpha}{1-\alpha}} + n^S \left(w^S\right)^{-\frac{\alpha}{1-\alpha}}}. \tag{65}$$

All equations that determine equilibrium in the model of section 4, where there is trade only in final goods, are still valid for the case of trade in intermediate goods. More specifically, equilibrium is determined by LMC in equation (36) for both countries, and NAC for North in equation (37). The only difference is that the market share of intermediate goods s_x^i, defined in equation (65), replaces the market share of high-tech goods s_h^i.

Only North innovates

Proposition 3 *There is no equilibrium where both countries innovate under free trade of final and intermediate goods. Only North innovates, and both economies tend to the equilibrium of the case without international trade of intermediate goods as time goes to infinity, which is defined either by equations* (39), (40) *and* (41), *in the case of FPE, or by equations* (42), (44) *and* (45), *in case of non-FPE.*

Proof. *Appendix 8.4 proves that only North innovates in all possible equilibria. In the long run wages are stationary and, as time goes to infinity,* $s_x^N \to 1$. *The NAC in equation (37) approaches the one in the case of no trade in intermediate goods, where* $s_h^N = 1$. *Therefore, the long run equilibrium will be the same as in the case with no intermediate good trade.* ■

6.2 With International Knowledge Spillover

In section 4 we have assumed that the stock of accumulated knowledge that affects productivity in R&D was a function of the number of existing varieties of blueprints within the country, that is, previous invention renders R&D more productive, but only within the country's frontiers. It is reasonable to think that there may be knowledge spillovers across countries, particularly when they engage in trade in goods. We investigate here the alternative assumption that the stock of knowledge available in both countries is equal to the total number of blueprints in the world, that is:

$$K^N(t) = K^S(t) = n(t) \equiv n^N(t) + n^S(t).$$

The FEC in equation (23) becomes:

$$\frac{v^i n^i}{w^i} \leq s_n^i \Psi^i, \text{ with equality when } \dot{n}^i > 0, \tag{66}$$

where $s_n^i \equiv \frac{n^i}{n}$ is the share of country i in the global stock of blueprints. Differentiating this equation in the case of equality, we get:

$$\frac{\dot{v}^i}{v^i} + \gamma^i = \frac{\dot{s}_n^i}{s_n^i} + \frac{\dot{w}^i}{w^i}. \tag{67}$$

We also have, from the differentiation of the definition of s_n^i, that:

$$\frac{\dot{s}_n^i}{s_n^i} = s_n^j(\gamma^i - \gamma^j). \tag{68}$$

Substituting (68) into (67) yields:

$$\frac{\dot{w}^i}{w^i} = \frac{\dot{v}^i}{v^i} + \sum_{k=N,S} s_n^k \gamma^k. \tag{69}$$

Finally, we substitute the non-arbitrage condition (24) into the previous expression to rewrite it as:

$$\frac{\dot{w}^i}{w^i} = \sum_{k=N,S} s_n^k \gamma^k + \rho - \frac{s_x^i \theta}{s_n^i w^i \Psi^i}, \tag{70}$$

where s_x^i, the market share of intermediate goods produced by country i in equation (65). Notice that here we are assuming that there is trade in both final and intermediate goods, as we did in the previous section 6.1.

The LMC in each country is given by:[8]

$$s_n^i \gamma^i + s_x^i \frac{\alpha\sigma}{w^i} + s_{tr}^i \frac{(1-\sigma)}{w^i} = L. \tag{71}$$

As usual, equilibrium is characterized by a constant value of the aggregate equity value. Using

[8]The labor resources used in R&D activity by country i, L_γ^i, is calculated as follows. We have that the innovation rate is given by $\frac{dn^i}{dt} = aq_H n L_\gamma^i$. Using the simplifying assumption that $aq_H = 1$, we have that $L_\gamma^i = \frac{1}{n}\frac{dn^i}{dt} = s_n^i \gamma^i$.

the result in equation (67), we have that:

$$\frac{\dot{V}^i}{V^i} = \frac{\dot{v}^i}{v^i} + \gamma^i = \frac{\dot{w}^i}{w^i} + \frac{\dot{s}_n^i}{s_n^i} = 0, \; i = N, S. \tag{72}$$

Note that equation (72) does not ensure that wages are constant. According to the equation, they may decrease while the country's blueprints share increases, in such a way as to keep the value of the aggregate equity constant. However, this cannot be considered an equilibrium since labor allocation would be changing across productive activities over time. Thus, we also require that, in equilibrium:

$$\frac{\dot{w}^i}{w^i} = \frac{\dot{s}_n^i}{s_n^i} = 0. \tag{73}$$

Substituting this equilibrium condition into the non-arbitrage condition (70) we get the NAC:

$$\sum_{k=N,S} s_n^k \gamma^k = \frac{s_x^i \theta}{s_n^i w^i \Psi^i} - \rho. \tag{74}$$

Only North innovates

Proposition 4 *When there are international knowledge spillovers, only North innovates in equilibrium, under free trade of final and intermediate goods. Both economies tend to the equilibrium of the case without international knowledge spillover when there is no trade of intermediate goods.*

Proof. Appendix 8.5 shows that there is no equilibrium with both countries innovating and that North is the only innovating country. Below, we show that the economies will tend to the case with no knowledge spillover. ■

FPE equilibrium[9] Under FPE we have that $s_x^N = s_n^N$. The NAC for North in equation (74) becomes:

$$s_n^N \gamma^N = \frac{\theta}{w \Psi^N} - \rho, \tag{75}$$

while the combination of the LMC for both countries, from equation (71), yields:

$$w = \frac{1-\theta}{2L - s_n^N \gamma^N}. \tag{76}$$

Since only North innovates, $s_x^N = s_n^N \to 1$, and equations (75) and (76) tend to equations (37) and (38), respectively. It is interesting to note that wages are constant throughout the path to the long-run steady state. The reason is that wage that ensures the simultaneous validity of equations

[9] Appendix 8.6 presents the parameter conditions for the FPE and the non-FPE equilibria to exit.

(75) and (76) is the same both for $s_n^N < 1$ and for $s_n^N = 1$. Hence, wages are constant and given by equation (39) at all times, while the rate of innovation equals:

$$\tilde{\gamma}_{FPE}^N = \frac{2\theta L - \rho(1-\theta)\Psi^N}{s_n^N\left[\theta + (1-\theta)\Psi^N\right]}, \tag{77}$$

tending to $\bar{\gamma}$ from equation (40) as $s_n^N \to 1$.

Comparing equations (77) and (40), we see that the rate of innovation is larger in the transition period to the steady state under knowledge spillover, compared to the benchmark case with no knowledge spillovers nor trade in intermediate goods. Nevertheless, the amount of labor in R&D, $L_\gamma = s_n^N \tilde{\gamma}_{FPE}^N$, is the same as in the two cases. This result is due to the fact that the inventions from the non-innovating country are still produced in the current case, which increases the stock of knowledge and renders R&D more productive.

North's share of traditional goods equals:

$$\tilde{s}_{tr}^N = \frac{\left[1-\sigma+\left(1-s_n^N\right)\alpha\sigma\right](2L+\rho)\Psi^N - L\left[\theta+(1-\theta)\Psi^N\right]}{(1-\sigma)(2L+\rho)\Psi^N}.$$

Non-FPE equilibrium In the non-FPE equilibrium, we know that wages are higher in North, so that South captures all market for the traditional good. From (71), the LMC for South becomes:

$$w^S = \frac{s_x^S\alpha\sigma + (1-\sigma)}{L}, \tag{78}$$

while for North it can be written as:

$$w^N = \frac{s_x^N\alpha\sigma}{L - s_n^N\gamma^N}. \tag{79}$$

The NAC for North in equation (74), on its turn, become:

$$w^N = \frac{s_x^N\theta}{\left(s_n^N\gamma^N + \rho\right)s_n^N\Psi^N}, \tag{80}$$

Clearly, equations (78), (79) and (80) that establish the equilibrium approach equations (42), (43) and (44) as $s_x^N \to 1$ and $s_n^N \to 1$. Similarly to the FPE equilibrium, innovation rate is higher over the path to the long run steady-state. It is given by:

$$\tilde{\gamma}_{NFPE}^N = \frac{\theta L - s_n^N\rho\alpha\sigma\Psi^N}{s_n^N\left(\theta + s_n^N\alpha\sigma\Psi^N\right)}.$$

6.3 Multinational Corporations

Here, we relax the assumption that invention and manufacturing of an intermediate variety must be located in the same country. Firms may now explore the comparative advantages across countries by producing the intermediate goods in a country different from the one where it was invented. We denote these firms multinational corporations (MNC).

The variables p^i, x^i, π^i denote no longer price, demand and profits of intermediate good varieties *produced* in country i, but, rather, *invented* in that country. In previous sections one could use both interpretations interchangeably, since production and invention of a variety were located in the same place. Now the whole production of intermediate goods is located wherever wage is lower, no matter where the goods were invented. These variables are given by:

$$p^i = \frac{1}{\alpha} \min\left\{w^N, w^S\right\}, \tag{81}$$

$$x^i = \frac{s_n^i \alpha\sigma}{\min\left\{w^N, w^S\right\}}, \text{ and} \tag{82}$$

$$\pi^i = s_n^i \theta. \tag{83}$$

The FEC is the same as in the case without multinational corporations, given by expression (66). With the same procedure used to derive the NAC in equation (70), we get the NAC for the case with multinationals:

$$\frac{\dot{w}^i}{w^i} = \sum_{k=N,S} s_n^k \gamma^k + \rho - \frac{\theta}{w^i \Psi^i}. \tag{84}$$

As now the production of intermediate and traditional goods is located wherever the wage is lower, we have that $s_x^i = s_{tr}^i$, and s_{tr}^i is still defined by equation ((32)). The LMC can, thus, be written as:

$$s_n^i \gamma^i + \frac{(1-\theta)\, s_{tr}^i}{\min\left\{w^N, w^S\right\}} = L. \tag{85}$$

Finally, the steady-state equilibrium characterization remains the same as in equations (72) and (73) in the previous section.

Only North Innovates

Proposition 5 *When there are international knowledge spillovers and multinational corporations, only North innovates in equilibrium, under free trade of final and intermediate goods. Both economies tend to the equilibrium of the benchmark case, with no international knowledge spillover no trade of intermediate goods.*

Proof. Appendix 8.7 shows that only North innovates, and below we show that the economies will tend to the case with no knowledge spillover. ■

The NAC (84) is satisfied for North, which is the innovating country, while LMC (85) is satisfied for both countries.

It is easy to check that with FPE the NAC and LMC turn out to be the same as in the previous case, with knowledge spillover and trade in intermediate goods. On its turn, the non-FPE equilibrium is given by:

$$\check{\gamma}^N = \frac{L}{s_n^N}, \tag{86a}$$

$$\check{w}^N = \frac{\theta}{(L+\rho)\,\Psi^N} \tag{86b}$$

$$\check{w}^S = \frac{1-\theta}{L} \tag{86c}$$

$$\check{s}_{tr}^N = 0 \tag{86d}$$

and is feasible if $\check{w}^N > \check{w}^S$, i.e., $L > \frac{\rho(1-\theta)\Psi^N}{\theta-(1-\theta)\Psi^N}$.

Note that under the non-FPE equilibrium North specializes in R&D, while South produces all final and intermediate goods.

7 Concluding Remarks

New ideas may pop up at every moment and every place, but it is hard to know ex-ante their chances of success. The risks involved in a project increase considerably when their assets are intangible, since in case of failure the liquidation value is negligible. R&D projects are then a good example of investments that ask for diversification as a form of risk sharing among economic agents, which is achievable through a well functioning financial system. Thus, when countries engage in technological competition, R&D financing becomes the main instrument for creating comparative advantage over time. A better functioning financial system generates more R&D, which increases the innovation rate and renders the country's high-tech sector more productive than abroad. This is the basic idea of the model developed in this paper.

Recent empirical studies fail to find a positive relation between trade and growth. Furthermore, when controlling for institutions the relation between trade and growth may even turn out to be negative in certain cases. We offer a possible explanation for these results. We suggest that the impact of trade on innovation may depend on institutions. More specifically, we show that opening to trade increases the innovation rate in the country with better credit market, and decreases growth in the country with worse credit market.

In terms of welfare, we show that the innovating North is better off than the South. In the short run, South's welfare may be lower under free trade than in autarky. In the long run, however, all residents are better off under free trade than if they were under autarky due to the higher rate innovation under free trade.

Wealth inequality across countries is strictly increasing in the wage gap. Hence, there is no inequality when FPE equilibria arise under free trade. Among all non-FPE equilibria, the largest inequality happens when there are no knowledge spillovers between countries and when there are no multinational corporations, whereas the least inequality arises when both of these features exist. In sum, these results point out that if South opens to trade, it should try to promote knowledge spillover and multinational corporations.

References

[1] Acemoglu D., S. Johnson, and J.A. Robinson (2001), "The Colonial Origins of Comparative Development: An Empirical Investigation," *American Economic Review* 91(5): 1369-1401.

[2] Acemoglu D., S. Johnson, and J.A. Robinson (2002), "Reversal of Fortune: Geography and Development in the Making of the Modern Income Distribution," *Quarterly Journal of Economics* 117(4): 1231-1294.

[3] Acemoglu D., S. Johnson, and J.A. Robinson (2006), "Institutions as a Fundamental Cause of Long-Run Growth" in Philippe Aghion and Steven Durlauf (eds.) *Handbook of Economic Growth*, Amsterdam, North-Holland.

[4] Aghion, Philippe and Peter Howitt (1992). "A Model of Growth through Creative Destruction," *Econometrica* 60(2): 323-351.

[5] Antràs, P. and R. Caballero (2009). "Trade and Capital Flows: A Financial Frictions Perspective," *Journal of Political Economy* 117(4): 701744.

[6] Antràs, P. and R. Caballero (2010). "On the Role of Financial Frictions and the Saving Rate during Trade Liberalizations," *Journal of the European Economic Association Papers and Proceedings* 8(23): 442-455.

[7] Beck, Thorsten (2002). "Financial Development and International Trade. Is there a Link?", *Journal of International Economics* 57:107-131.

[8] Bolton, Patrick, and Philippe Aghion (1992). "An Incomplete Contracts Approach to Financial Contracting," *The Review of Economic Studies* 59(3): 473-494.

[9] Chesnokova, Tatyana (2007). "Immiserizing deindustrialization: A dynamic trade model with credit constraints," *Journal of International Economics* 73(2): 407-420.

[10] Djankov, Simeon, Caralee McLiesh and Andrei Shleifer (2007). "Private credit in 129 countries," *Journal of Financial Economics* 84(2): 299-329.

[11] Dollar D. and A. Kraay (2003), "Institutions, Trade and Growth," *Journal of Monetary Economics* 50(1): 133-162.

[12] Engerman S.L. and K.L. Sokoloff (2002). "Factor Endowments, Inequality and Paths of Development among New World Economies," Economia 3(Fall): 41-109.

[13] Frankel J.A. and D. Romer (1999), "Does Trade Cause Growth?," *American Economic Review* 89(3): 379-399.

[14] Grossman, Gene M., and Helpman, E. (1991). *Innovation and Growth in the Global Economy*, The MIT Press.

[15] Hall, Robert E. and Charles I. Jones (1999). "Why Do Some Countries Produce So Much More Output Per Worker Than Others?," *The Quarterly Journal of Economics* 114(1): 83-116.

[16] Hart, Oliver and John Moore (1994). "A Theory of Debt Based on the Inalienability of Human Capital," *The Quarterly Journal of Economics* 109(4): 841-79.

[17] Hart, Oliver and John Moore (1998). "Default And Renegotiation: A Dynamic Model Of Debt," *The Quarterly Journal of Economics* 113(1): 1-41.

[18] Hur, Jung, Manoj Raj and Yohanes E.Riyanto (2006). "Finance and trade: A cross-country empirical analysis on the impact of financial development and asset tangibility on international trade," *World Development* 34(10): 1728-1741.

[19] Kim, Dong-Hyeon (2011). "Trade growth and income," *The Journal of International Trade & Economic Development: An International and Comparative Review* 20(5): 677-709.

[20] La Porta, Rafael, Florencio Lopez-de-Silanes, Andrei Shleifer and Robert W. Vishny (1997). "Legal Determinants of External Finance," *Journal of Finance* 52(3): 1131-50.

[21] Levchenko, Andrei (2007). "Institutional Quality and International Trade," *Review of Economic Studies* 74(3): 791-819.

[22] Levine, R.; Loayza, N.; and Beck, T. (2000). "Financial Intermediation and Growth: Causality and Causes." *Journal of Monetary Economics* 46.

[23] Lucas, Robert (1988). "On the Mechanisms of Economic Development," *Journal of Monetary Economics* 22: 3–42.

[24] Manova, K., (2005). "Credit Constraints in Trade: Financial Development and Export Composition",mimeo Harvard University.

[25] Manova, K., (2013). "Credit Constraints, Heterogeneous Firms, and International Trade," *Review of Economic Studies* 80: 711-744.

[26] Rigobon R. and D. Rodrik (2005), "Rule of Law, Democracy; Openness, and Income: Estimating the Interrelationships," *The Economics of Transition* 113(3): 533-564.

[27] Rodrik D., A. Subramanian, and F. Trebbi (2004), "Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development," *Journal of Economic Growth* 9(2): 131-165.

[28] Romer, Paul M. (1988). "Increasing Returns and Long-Run Growth," *Journal of Political Economy* 94(5): 1002-1037.

[29] Romer, Paul M. (1990). "Endogenous Technological Change." *Journal of Political Economy* 98(5): S71-S102.

[30] Stiglitz, Joseph and Andrew Weiss (1981). "Credit Rationing in Markets with Imperfect Information," *American Economic Review* 71(3): 393-410.

[31] Svaleryd, Helena and Jonas Vlachos (2005). "Financial Markets, the Pattern of Industrial Specialization and Comparative Advantage: Evidence from OECD countries," *European Economic Review* 49.

[32] Tirole, J. (2006). *The Theory of Corporate Finance*. Princeton University Press.

[33] Townsend, Robert M. (1979). "Optimal contracts and competitive markets with costly state verification," *Journal of Economic Theory* 21(2): 265-293.

[34] Wacziarg, Romain and Karen Horn Welch (2008). "Trade Liberalization and Growth: New Evidence," *World Bank Economic Review* 22 (2): 187-231.

8 Appendix

8.1 Proof of Proposition 2

If both countries innovated, the FEC (23) would imply:

$$\Psi^S = \frac{v^S n^S}{\bar{w}^S} > \frac{v^N n^N}{\bar{w}^N} = \Psi^N. \tag{87}$$

Under FPE, $v^N = v^S$. When countries start to trade $n^N \geq n^S$, hence $\frac{vn^N}{w} \geq \frac{vn^S}{w}$, and equation (87) is not satisfied. The FEC (23) can only be satisfied simultaneously for both countries if North is the only country that innovates.

Let us now investigate the possibility of an equilibrium with both countries innovating in intermediate goods when $w^N \neq w^S$. Since there is no trade in intermediate goods, both countries would have to produce high-tech goods to use up their production of intermediate goods. Therefore, the price of high-tech good would have to be equal in both countries, which, given equation (20), implies:

$$P_h^N = \frac{w^N}{\alpha(n^N)^{\frac{1-\alpha}{\alpha}}} = \frac{w^S}{\alpha(n^S)^{\frac{1-\alpha}{\alpha}}} = P_h^S. \tag{88}$$

For the price of the high-tech goods to be equal across countries, it would be necessary that $w^N > w^S$, given that $n^N \geq n^S$ when the countries start to trade and given equation (88). From equation (32), we have that South captures all market of traditional goods: $s_{tr}^S = 1$. Furthermore, since $\dot{w}^N = \dot{w}^S = 0$ in equilibrium, it must also be the case that $\frac{n^N}{n^S}$ remains constant so that equation (88) is always satisfied. Hence, $\gamma^N = \gamma^S > 0$. Using this result, we calculate the high-tech good market shares equalizing innovation rates from the no-arbitrage condition (37), and we get that:

$$s_h^N = \frac{w^N \Psi^N}{w^N \Psi^N + w^S \Psi^S}. \tag{89}$$

We substitute it in the labor market clearing conditions of both countries (equation (36)) and equalize them. We get:

$$\frac{\Psi^N}{\bar{w}^N \Psi^N + \bar{w}^S \Psi^S} \alpha\sigma = \frac{\Psi^S}{\bar{w}^N \Psi^N + \bar{w}^S \Psi^S} \alpha\sigma + \frac{(1-\sigma)}{w^S}.$$

The above expression holds only if $\Psi^N > \Psi^S$, which is a contradiction. Thus, there is no non-FPE equilibrium with both countries innovating.

8.2 Parameter conditions for factor-price equalization (FPE) and non-FPE equilibria

FPE equilibrium

A FPE equilibrium is possible when $\bar{\gamma}^N > 0$, which implies:

$$L \quad > \quad \frac{\rho\,(1-\theta)\,\Psi^N}{2\theta} \tag{90}$$

In addition, it must be the case that $\bar{s}_{tr}^{S} \in [0,1]$. Given its definition in equation (41), it is clear it be positive for any parameter values, and it will not larger than one when:

$$L \leqq \frac{\rho(1-\sigma)\Psi^N}{\theta+(1-\theta)\Psi^N-2(1-\sigma)\Psi^N}, \tag{91}$$

that is, the wage bill is not larger than the share of income spent on traditional goods.

Non-FPE equilibrium

For a non-FPE equilibrium, the condition for a positive innovation rate is given by:

$$L > \frac{\rho\alpha\sigma\Psi^N}{\theta} \tag{92}$$

In addition, this equilibrium is feasible only if $\hat{w}^N > \hat{w}^S$, i.e.,

$$L > \frac{\rho(1-\sigma)\Psi^N}{\theta+(1-\theta)\Psi^N+2\alpha\sigma\Psi^N}. \tag{93}$$

The feasibility condition (93) is exactly the opposite of the condition for an FPE equilibrium to exist, given by inequality (91).

8.3 North gains at trade opening

From equations (47) and (58), and given that

$$\frac{w_{aut}^N}{P_{aut}^N(T)} = \frac{\overline{w}}{P_{free}(T)} = z\left(n^N(T)\right)^{\frac{\theta}{\alpha}}, \tag{94}$$

it is straightforward to see that:

$$\begin{aligned} G_{free}^N(T) &> G_a^N(T) \\ &\Updownarrow \\ \frac{\theta}{P_{free}(T)} - \frac{\theta}{P_{aut}^N(T)} &> \frac{w_{aut}^N}{P_{aut}^N(T)}\beta^N\bar{\gamma}^N - \frac{\overline{w}}{P_{free}(T)}\gamma_{aut}^N. \end{aligned} \tag{95}$$

The left hand side of inequality (95) corresponds to the gain in purchasing power after opening to trade, while the right hand side reflects the loss due to the higher investment rate. Using equation (94), inequality (95) can be written as:

$$\frac{\theta}{\overline{w}} - \frac{\theta}{w_{aut}^N} > \beta^N\bar{\gamma}^N - \gamma_{aut}^N. \tag{96}$$

Given the definition of β in equation (53) and the fact the $\theta \in (0,1)$, we have that, in the case of FPE, $\beta^N \in \left(\frac{1}{2}, \frac{2}{3}\right)$. Let us then investigate the feasibility of inequality (96) for the two extremes of that interval, that is, for $\beta^N \to \frac{1}{2}$ and for $\beta^N \to \frac{2}{3}$.

Case 1: $\beta^N \to \frac{1}{2}$ Substituting the innovation rate from the LMC conditions from equations (28) and (38) and using $\beta^N = \frac{1}{2}$, inequality (96) becomes:

$$\begin{aligned} \theta\left(\frac{1}{\overline{w}} - \frac{1}{w_{aut}^N}\right) &> (1-\theta)\left(\frac{1}{w_{aut}^N} - \frac{1}{2\overline{w}}\right). \\ &\Updownarrow \\ \frac{w_{aut}^N}{\overline{w}} &> 2-\theta \end{aligned} \tag{97}$$

From the wage equations (29) and (39), inequality (97) is equivalent to:

$$\begin{aligned} \frac{\left(\frac{\theta+(1-\theta)\Psi^N}{(L+\rho)\Psi^N}\right)}{\left(\frac{\theta+(1-\theta)\Psi^N}{(2L+\rho)\Psi^N}\right)} &> 2-\theta \\ &\Updownarrow \\ L &> \frac{(1-\theta)\,\rho}{\theta} \end{aligned} \tag{98}$$

Inequality (98), on its turn, is satisfied whenever there exists an equilibrium under autarky, that is, when condition (31) is satisfied.

Case 2: $\beta^N \to \frac{2}{3}$ Substituting the innovation rate from the LMC conditions from equations (28) and (38) and using $\beta^N = \frac{2}{3}$, inequality (96) now becomes:

$$\theta\left(\frac{1}{\overline{w}} - \frac{1}{w_{aut}^N}\right) > \frac{L}{3} + (1-\theta)\left(\frac{1}{w_{aut}^N} - \frac{2/3}{\overline{w}}\right).$$

Since $\theta \to 1$ when $\beta^N \to \frac{2}{3}$, this inequality becomes:

$$\frac{1}{\overline{w}} - \frac{1}{w_{aut}^N} > \frac{L}{3}.$$

Using wages in equations (29) and (39), we get that $\frac{L}{3} < \frac{L\Psi^N}{\theta+(1-\theta)\Psi^N}$, which, with $\theta = 1$, yields:

$$\Psi^N > \frac{1}{3},$$

which is always true, since $\Psi^N > 1$.

8.4 Proof of proposition 3

If both countries innovate simultaneously, equation (87) must be satisfied. With an argument analogous to the one used in section 8.1, under FPE we have that $v^N = v^S$. When countries start to trade $n^N \geq n^S$, hence $\frac{v^N n^N}{\bar{w}^N} \geq \frac{v^S n^S}{\bar{w}^S}$, and equation (87) is not satisfied.

We turn to non-FPE equilibria. With trade in intermediate goods, given the definition of v^i in equation (11), the profit function (35) and the definition of the market share s_x^i in (65), we have that $\frac{\partial v^i}{\partial w^i} < 0$. Therefore, in the non-FPE equilibrium, it is true that $\frac{v^N n^N}{\bar{w}^N} > \frac{v^S n^S}{\bar{w}^S}$ when $w^N < w^S$, which means that equation (87) is not satisfied.

There is also no equilibrium with $w^N > w^S$ and positive innovation in both countries. Log-differentiating the equation 65, we get:

$$\dot{s}_x^N = s_x^N \left(1 - s_x^N\right) \left[\left(\gamma^N - \gamma^S\right) - \frac{\alpha}{1-\alpha}\left(\frac{\dot{w}^N}{w^N} - \frac{\dot{w}^S}{w^S}\right)\right]. \tag{99}$$

Since $\frac{\dot{w}^N}{w^N} = \frac{\dot{w}^S}{w^S} = 0$ in the steady-state, the sign of $\dot{s}_x^N$ equals the sign of$\gamma^N - \gamma^S$. If $\gamma^N - \gamma^S > 0$, then $\dot{s}_x^N > 0$. As $s_x^N \to 1$ we have that $\gamma^S \to -\rho$ (using the NAC in equation (37) for the South), which is not possible. On the other hand, with $\gamma^N - \gamma^S < 0$ we would have $\dot{s}_x^N < 0$. In that case we would have that $\gamma^N \to -\rho$ as $s_x^N \to 0$, which is not possible either. Hence, there is no non-FPE equilibrium with both countries innovating.

Finally, North is the country that innovates in the non-FPE equilibrium for the following reason. The non-innovating country must have the lower wage to capture the market for the traditional good. Otherwise, its demand for labor would tend to zero as its share of the intermediate good market tends to zero. Let us assume that South is the innovating one. We would have that $w^S > w^N$, hence $\pi^S < \pi^N$, yielding $v^S < v^N$. Since $n^S < n^N$ when the economies open to trade, we would then have that $\frac{v^N n^N}{w^N} > \frac{v^S n^S}{w^S}$. The FEC (23) for the innovating (South in this case) country implies $\frac{v^S n^S}{w^S} = \Psi^S$, which, combined with the previous inequality, yields:

$$\frac{v^N n^N}{w^N} > \Psi^S > \Psi^N, \tag{100}$$

where the last inequality is an assumption of the model. According to inequality (100), the FEC would not be satisfied for North. Hence, there is no equilibrium where South is the one that innovates.

8.5 Proof of proposition 4

There is no equilibrium with both countries innovating

The NAC in equation (74) must be satisfied for both countries, when both are innovating. Substituting the definition of s_x^i in equation (65) and $s_n^i \equiv \frac{n^i}{n}$ into equation (74) for both countries and combining them, we get that:

$$\frac{w^S}{w^N} = \left(\frac{\Psi^N}{\Psi^S}\right)^{1-\alpha} < 1. \tag{101}$$

Hence, innovation in both countries is only possible in the non-FPE equilibrium, where relative wages between countries is established by equation (101). It implies that:

$$s_x^N = \frac{s_n^N \left(\Psi^N\right)^\alpha}{s_n^N \left(\Psi^N\right)^\alpha + \left(1 - s_n^N\right)\left(\Psi^S\right)^\alpha}. \tag{102}$$

Furthermore, the FEC condition (66) must be satisfied with equality for both countries, since both innovate. We then have that:

$$\frac{v^N}{w^N \Psi^N} = \frac{v^S}{w^S \Psi^S}.$$

Substituting relative wages (101) into the equality above, we have that:

$$\frac{v^N}{v^S} = \left(\frac{\Psi^N}{\Psi^S}\right)^\alpha. \tag{103}$$

On the other hand, equation (24) establishes that, in steady state, the value of blueprints is:

$$v^i = \frac{\pi^i}{\rho} = \frac{s_x^i \theta}{n\rho}, \tag{104}$$

where we have used equation (35) for the last equality. Equation (104) implies:

$$\frac{v^N}{v^S} = \frac{s_x^N}{s_x^S} = \frac{n^N}{s^S}\left(\frac{\Psi^N}{\Psi^S}\right)^\alpha, \tag{105}$$

using the value of s_x^i in equation (102). Clearly, equations (105) and (103) can only be satisfied simultaneously if, and only if, $n^N = n^S$, that is, both countries must have exactly the same stock of blueprints if both are to innovate in steady state.

Since wage is lower in South, it captures all market of traditional goods, $s_{tr}^S = 1$. Given that

$n^N = n^S$ and using equation (102), the LMCs in equation (71) for North and South become:

$$\frac{\gamma^N}{2} + \frac{\left(\Psi^N\right)^\alpha}{\left(\Psi^N\right)^\alpha + \left(\Psi^S\right)^\alpha}\frac{\alpha\sigma}{w^N} = L,$$
$$\frac{\gamma^S}{2} + \frac{\left(\Psi^S\right)^\alpha}{\left(\Psi^N\right)^\alpha + \left(\Psi^S\right)^\alpha}\frac{\alpha\sigma}{w^S} + \frac{(1-\sigma)}{w^S} = L.$$

Combining the two LMCs we get that:

$$\frac{\gamma^N}{2} - \frac{\gamma^S}{2} = \frac{\alpha\sigma\left(\frac{\left(\Psi^S\right)^\alpha}{w^S} - \frac{\left(\Psi^N\right)^\alpha}{w^N}\right)}{\left(\Psi^N\right)^\alpha + \left(\Psi^S\right)^\alpha} + \frac{(1-\sigma)}{w^S}.$$

The first term in the left hand side is clearly positive, given relative wages in (101). Hence, innovation in North is higher that in South: $\frac{\gamma^N}{2} - \frac{\gamma^S}{2} > 0$. We have reached a contradiction, since it is not possible to keep the same number of blueprints in both countries with a higher innovation rate in North. Hence, there is no equilibrium with both countries innovating.

Only North innovates

The FEC (23) should be satisfied with equality for the innovating countries, and with strict inequality for the non-innovating one. If South were the innovating countries, that would imply:

$$\frac{v^S n^S}{w^S \Psi^S} = 1 > \frac{v^N n^N}{w^N \Psi^N}. \tag{106}$$

Under FPE, we have that $w^S = w^N$ and $v^S = v^N$. Given that $n^S < n^N$ when countries open to trade, the inequality (106) would hold only, and only if, $\Psi^S < \Psi^N$, which is not true, by assumption.

By the same token, under non-FPE condition (106) could hold if $w^S < w^N$. In that case South would capture all the market for the traditional good. Moreover, since it is the innovating country, its share of the high-tech good would also tend to one. Clearly, the labor market constraint in equation (71) cannot be true for both countries simultaneously.

8.6 Parameter conditions for FPE and non-FPE equilibria with knowledge spillovers

FPE equilibrium

North's share of traditional goods equals:

$$\tilde{s}_{tr}^N = \left(\frac{\theta + (1-\theta)\,\Psi^N}{(1-\sigma)\,(2L+\rho)\,\Psi^N}\right) L - \frac{s_n^S \alpha\sigma}{(1-\sigma)}$$

This is an equilibrium if $0 \leq s_{tr}^{N} \leq 1$. The first inequality is ensured when:

$$L \geq \frac{s_n^S \rho\alpha\sigma\Psi^N}{\theta + (1-\theta)\,\Psi^N - 2 s_n^S \alpha\sigma\Psi^N},$$

while the second requires that:

$$L \leqq \frac{\rho\left(1-\sigma-s_n^S\right)\Psi^N}{\theta+(1-\theta)\Psi^N-2\left(1-\sigma-s_n^S\right)\Psi^N}, \tag{107}$$

Note that the first inequality is always satisfied for a s_n^N sufficiently close to one, while the second approaches the corresponding condition (inequality (91)) of the case without knowledge spillover nor trade in intermediate goods when $s_n^N \to 1$. Finally, the condition for a positive innovation rate is the same as in the case without knowledge spillover, given by inequality (90).

Non-FPE equilibrium

In this equilibrium it is necessary that $w^N > w^S$. While it is not possible to write an explicit expression for this inequality, we know that:

$$\frac{L}{\rho} > \frac{s_n^N\left[(1-\sigma) + \left(1-s_n^N\right)\alpha\sigma\right]\Psi^N}{s_x^N\theta + s_n^N\left[\left(2s_x^N - 1\right)\alpha\sigma - (1-\sigma)\right]\Psi^N}, \tag{108}$$

which would be exactly the opposite of condition (107) for the FPE equilibrium if $s_n^N = s_x^N$. Although s_x^N is itself a function of $\frac{w^N}{w^S}$, we know that $s_x^N \to 1$ as $s_n^N \to 1$. Hence, for s_n^N sufficiently close to one, condition (108) approaches condition (93). Finally, the condition for a positive innovation rate is:

$$\frac{L}{\rho} > \frac{s_n^N \alpha\sigma\Psi^N}{\theta},$$

which is equal to condition (90) when $s_n^N = 1$.

8.7 Proof of proposition 5

The NAC equations when there are multinationals are the same as in the case with knowledge spillovers, from section 6.2. Therefore, if both countries innovate relative wages are given by equation (101), which means that South produces all intermediate and traditional goods. The LMC for North and South become, respectively:

$$s_n^N \gamma^N = L$$

$$s_n^S \gamma^S + \frac{(1-\theta)}{w^S} = L$$

Moreover, with the same reasoning as in section 8.5, it must be true that $n^N = n^S$. The two LMC above imply that $\gamma^N > \gamma^S$, which is not compatible with $n^N = n^S$ at all times. Hence, there is no equilibrium with both countries innovating.