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Innovation and Imitation in a Model of North-South Trade

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INNOVATION AND IMITATION IN A MODEL OF NORTH-SOUTH TRADE

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Innovation and Imitation in a Model of North-South Trade*

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Abstract

Recent evidence on world trade patterns reveals North-South specialization across products of the same industries and product groups but different quality, which is not matched by the predictions of traditional and new trade theory. This paper analyzes a model of North-South trade and endogenous growth through innovation and imitation that can predict the observed trade patterns. The model is used to re-examine the impact of trade and Intellectual Property Rights (IPR) protection on both the innovation in the North and the imitational lag of the South. Opening to trade increases the growth rate and welfare of both regions, but results in a larger lag in the quality level of the South. With free trade the quality lag of the South is positive even with no IPR protection as a result of a revealed comparative advantage in lower quality goods production and trade. This contradicts the common predictions of Southern take-over of the whole industries due to bad IPR enforcement. Stronger IPR protection has a negative effect on growth and deteriorates the lag of the South, but the welfare effects of the alternative IPR policy instruments may be different.

JEL: F12, F43, O31, O33, O34

Keywords: North-South trade, quality heterogeneity, endogenous growth, innovation and imitation, intellectual property rights

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1 Introduction

The issues of trade and economic growth have been popular debate topics in the literature for more than two decades. Given the rapid increase in trade activity between developed North and less developed South, the impact of South opening to trade on growth and welfare of the two regions has been of particular interest. At the same time, concerns have been raised over the common practice of the South to copy Northern innovations and win the market shares due to substantially lower production costs. Numerous papers have already dealt with this issue, but recent evidence on the dimensions and market segments in which the North-South competition occurs calls for a different approach. This paper applies the notion of vertical innovation, incorporating the idea of quality vintages. In that framework, a different modeling of the IPR regime and the target of imitative effort of the South is introduced in order to revisit the implications of the South opening to trade. Finally, the effect of different instruments and levels of the IPR protection is analyzed in order to assess whether this Northern fear of losing economic dominance is indeed reasonable even with the low levels of IPR protection in the South.

This paper considers a model of North-South trade and endogenous growth which attempts to be in accordance with the empirical evidence on current world trade patterns. Namely, the existing literature on North-South trade usually assumes that the trade pattern is determined either through endowment-driven specialization in different industries, or through technology-driven horizontal specialization in differentiated goods of the same value within the same industry. In the case of vertical intra-industry differentiation of goods, industries are modeled as monopolies so that imitation, targeting random industries, results in a product cycle with the whole industry being shifted between regions. Thus, the implied trade pattern is again of the inter-industry type. However, recent empirical evidence suggests that the North-South direct competition for dominance over whole industries might be exaggerated. Not neglecting the importance of the inter-industry specialization of countries and thus of one-way-trade flows in the world, Fontagne et al.(2008) presents strong evidence of North-South vertical specialization within industries. North includes USA, Japan and EU25 as developed countries, while South is a group of emerging countries, such as China, Russia, Brazil, India and others. When traded goods are distinguished according to the unit quality level¹, specialization in different quality ranges is revealed. It is argued that

¹Concerns have been raised over the use of unit values in the trade data as the proxies for product quality, e.g. in Hallak and Schott (2008). It is found that for several countries export prices and quality have different trends. However, on average, there is still high correlation between unit prices and quality. Accepting the

export bundles of these two regions are very similar at the industry level (low importance of inter-industry specialization), somewhat less similar at the product level (some evidence on horizontal intra-industry specialization), while the export structure is completely different at the quality level. South exports are of low quality, while North exports are of high quality. This supports intra-industry vertical specialization and the two-way trade in qualities within products.² In terms of market shares, there is strong evidence of down-market (low quality) share shifts in favor of the South, while in the up-market segment North has the advantage. At the same time, within the South, only China is making slight gains in up-market share. Thus, there might be some basis for the Northern fear of competition from growing South. However, this fear should not be exaggerated nor based on the common accusations that large South, led by China, will soon become the manufacturing factory of the world and overtake this and other industries from the North. The reasoning should be based on the degree of the technological development of the South and its incentive and ability to advance in overtaking the up-market shares, no matter which industry is in question. Undoubtedly, IPR violation helps the South in doing so, but it seems that North has been able to resist the competitive pressure through specialization in high qualities. Following the empirical findings, the aim of this paper is twofold. On one hand, this exercise attempts to develop a theoretical framework which replicates the new specialization pattern, and on the other, to use it for the analysis of endogenous technological progress, the impact of IPR protection policy and welfare implications.

This paper develops an endogenous R&D model of two regions and analyzes two scenarios based on the degree of trade openness. North conducts innovating R&D which results in the creation of new varieties, each of a higher quality than the preceding one. South is involved in the imitation of Northern products but at a certain lag. In the autarky scenario, there is no trade between the regions, but the South is still able to imitate Northern products at a lag. There are no patents, but the North can limit the leak of information concerning blueprints and thus affect the associated difficulty of imitation. In the second scenario, both regions are open to trade and the difficulty of imitation is still affected by the protection of information. This paper analyzes the determinants of the innovation effort in the North and the distance (on the quality-product scale) between the highest quality goods produced in the North and in the South in a steady-state equilibrium within the two stated set-ups. The

problems of such a proxy, the role of quality and its positive correlation with income per capita and prices have been documented in previous literature to an extent that might allow for trusting the price-quality proxy on average, and on aggregate.

²See also Schott (2004) for evidence on the unit value of US imports conditional on exporter's income per capita, which supports the specialization across quality in relation to income per capita.

question of the incentives and the mechanisms for closing the gap is implicitly addressed as well.

The foundation for this study comes from two related groups of literature - a large body of literature on trade and growth (particularly in the North-South framework), and literature on product cycles with the issues of innovation and imitation. Vernon (1966) was first to raise the question of the North-South shift of production location in different stages of a product life cycle. A contemporary version of product cycle is presented by Antras (2005). What is common to both papers is that technological transfer comes only as a result of optimizing behavior of Northern firms.

Following the initial steps of Krugman (1979), Grossman and Helpman (1991a,b) are the most influential articles according to which production shifts occur due to imitation in an endogenous growth set-up. In both articles, the North is endowed with a comparative advantage, high enough to ensure that innovation takes place in the North and production transfers to the South due to endogenous imitation whose intensity determines the time of the transfer. They combine the notions of a quality ladder (a) or variety expansion (b) with product cycles to develop a theoretical framework for analyzing the simultaneous behavior of innovation and imitation rates. The results show an increase in innovation and imitation rates with the two regions opening to trade. Although this paper uses the same framework in many aspects, one of the main differences is the imitational R&D mechanism and the resulting target of imitation. The South does not necessarily aim at imitating the state-of-the-art products, but reproduces the less advanced goods up to the quality level determined in the stationary equilibrium. In other words, the endogenous level of R&D effort in the South determines how far, in terms of quality level, the imitation can reach, and not only how quickly and not at what scale it can replicate the most advanced industries of the North. In this way, the focus is shifted from the differences in growth rates to the differences in quality attainment of the two regions. With opening to trade, the innovation effort in the North increases, which results in the higher growth rates of both regions, but does not imply faster imitation by the South. An increase in the innovation activity now results in an increase of the quality lag, as the rising value of imitation and R&D labor productivity no longer counteract the increase in the R&D labor cost. This is the result of a drop on the quality ladder of the highest quality good in the South relative to the highest and the most profitable in the market, which was not the case in the autarky. Therefore, the increase in the returns to imitation now do not match the required stronger copying effort (higher cost) for a given lag behind the North. This opens a new dimension along which the regions' comparative advantage over quality is determined and allows for the international IPR policy analysis in

a set-up that can predict the observed North-South trade patterns.

Helpman (1993) analyzes the welfare effects of the IPR protection in a framework that considers endogenous innovation but only exogenous imitation, and thus, does not capture the endogenous response of the imitation effort in the South to the changes in innovational R&D in the North. More recent work in this field that relies on Grossman and Helpman framework but considers also endogenous imitation is presented in Parello (2008), Sener (2006), Stryzowski (2006). However, these papers do not consider the endogenous quality level attained by the South, only the endogenous rate of imitation of the Northern industries as aggregate measures. Horowitz and Lai (1996) analyze the IPR policy in autarky, but similarly to the idea here, they consider a technological lag in the sense that imitators cannot copy the most advanced products but copy only up to a certain level of quality, depending on the productivity of imitation. However, this lag is a result of the legally binding patents of a certain length and not a consequence of the imitators' optimization given the imitation technology. The first IPR policy instrument introduced in this paper is the intensive protection (information secrecy vs. extensive protection in the form of patents) and it is given by a parameter that directly affects the imitational R&D productivity in the South. However, this instrument of IPR protection is not the only factor of influence on the R&D productivity in the South relative to that in the North. Increased IPR protection does make imitation more difficult, but the R&D technology in the South is also a function of the quality distance behind the North. The further behind the most advanced Southern variety is, the less difficult it is to imitate and the productivity of R&D is higher. In those terms, following the idea of Barro and Sala-i-Martin (1997)³, R&D technology in the South is modeled as a function of the relative quality index (South quality relative to that in the North), and thus as a function of the distance. In this way, this paper assumes also natural impediments of a technological transfer besides the imposed IPR protection.

The framework in which this paper deals with the issues of the North-South trade mostly resembles Segerstrom and Dinopoulos (2006), whose structure of presentation is followed closely. They study a quality ladder model with a fixed number of industries, each producing only state-of-the-art goods. Once the good has been imitated, production moves to the South, yet returns to the North when that specific industry innovates again. In this paper, the number of varieties increases, but the notion of vintages is used to enrich the variety-expanding set-up with the improvements in quality. In this way, different qualities are not perfect substitutes, which allows for the production and consumption of the whole range of qualities, not only state-of-the-art goods. Furthermore, Segerstrom and Dinopoulos (2004)

³See also Gancia and Zilibotti(2005), Acemoglu et al.(2006), Stryzowski(2006)

analyzes the effect of globalization through an increase in the size of the South, but does not study the effect of moving from autarky to trade, which is of interest here. Also, the growth rate of the two regions is semi-endogenous and is a function of the population growth rate, while here the equilibrium growth rate is a result of the interaction of the innovation and imitation mechanisms and is also affected by the IPR policy.

The second part of the paper introduces patents of finite length as an alternative instrument, most commonly used in the actual IPR policy measures. There are two questions to consider. The first question concerns the welfare and growth implications of the perfectly enforceable patents of finite length, implying no copying of protected varieties, neither for domestic consumption nor for the export to the North. The equilibrium results under the optimal patent scenario are compared to those in the free information flow scenario in which there are no other impediments to imitation by the South but its own productivity in the R&D sector. As for the second question, having in mind the practical difficulty in implementing and enforcing patent rights internationally, the main assumption is the lack of patent enforceability. Although the North cannot prevent the South from imitating, it can ensure that Southern copies of protected varieties are not placed in the Northern markets.⁴ In that scenario, trade occurs only in goods which are produced exclusively by one region; goods whose patents have expired are traded by the South, while the North produces and trades high quality goods that are too advanced to be imitated. The middle range varieties are not traded. In such a set-up, the paper analyzes the effects of alternative IPR policy measures on the welfare and growth prospects of the two regions. In particular, it should be determined whether an intensive form of protection (knowledge flow restriction or secrecy) or the extension of the patent length can serve as a substitute for the poor IPR enforcement in the South.

Besides the old debate on the importance of the IPR protection for promoting R&D in a closed economy, a large body of literature has dealt with the issue of international harmonization of the IPR protection, especially after this topic was included in the official WTO discussion agenda.⁵ Depending on a model set-up, the results related to the effects of the IPR protection have been mixed.⁶

⁴Under most patent laws, the imitators in the South are not allowed to export copies to the Northern market, which along with the poor protection of IPR implies the interpretation of the patent as a certain form of trade barrier.

⁵The WTOs Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), was negotiated in the 1986-94 Uruguay Round and it imposed the intellectual property rules into the multilateral trading system.

⁶See, e.g. Scotchmer (2003), Saint-Paul (2007), Lai and Qiu (2003), McCalman (2001).

In general, most studies on North-South trade, growth and IPR introduce only a certain policy parameter measuring the level of protection in terms of how hard (legally or technically) it is to copy a product successfully, but once that occurs, a copy competes freely with the original in the market, and normally wins the battle due to lower costs. This IPR instrument corresponds to the notion of information protection in the first part of the paper. However, in a framework that assumes differentiation of goods based on quality that is tied to the timing of the invention, protection in the form of patent (time) has a fundamentally different effect. Those two IPR instruments can not be regarded as the same: the first one affects the difficulty of copying directly, the other affects the timing of copying or the export ban lifting. Thus, patents and secrecy deserve separate consideration, as the individual producers' profits, the resulting aggregate labor allocation and the investment in R&D are affected in different ways, through different mechanisms.

Dinopoulos et al. (2008a) considers a North-South growth and trade model where the IPR protection is a finite-length, perfectly enforceable global patent which is awarded to Northern firms that discover new higher-quality products. That paper shows that an increase in the global patent length worsens the wage gap between the North and the South, increases the rate of imitation and has an ambiguous effect on growth. However, if the number of protected industries is high, then an increase in the patent length reduces the innovation and growth rates. Dinopoulos et al. (2008b) analyzes the IPR policy harmonization based on a stronger Southern protection and finds that a move towards better harmonization accelerates the global rates of innovation and growth, reduces the North-South wage gap, and has an ambiguous effect on the rate of technology transfer. When there is a common patent policy regime, then a stronger global IPR protection increases the rates of innovation, growth and international technology transfer, and has no impact on the North-South wage gap. The novelty in this paper is that it models the imitational R&D in the South in a way that the R&D productivity decreases as the South attempts to copy products from the higher position on the quality scale. It is found that the natural distance of the South in the equilibrium is positive even with no IPR protection. However, the welfare optimizing patent length, from the perspective of the North, is positive and larger than the natural distance of the South, but it necessarily reduces the welfare of the South and growth in both regions. The result stems from the fact that patents do not enforce incentives for R&D. On the contrary, they only protect the monopoly rents, increase the wage gap and the cost of R&D in both regions, and thus reduce the innovation in the North, and imitation and welfare in the South. Higher Northern welfare comes only as a result of a higher wage. Compared to the social optimum, welfare and growth in both regions are reduced, as the patent distorts

the optimal specialization pattern of the two regions over quality.

As far as the IPR enforcement is concerned, Lai and Qiu (2004) investigate the interaction of the IPR and trade protections and their impact on Northern and Southern welfare. They find a rationale for a higher Northern tariff when protection is weak in the South. While the IPR protection comes through finite patents and the trade protection through tariffs, in this paper the instruments are somewhat opposite. The IPR protection is based on secrecy and the trade barrier is an IPR policy instrument - finite length patent. Namely, when patents are not enforced to prevent copying, they might allow the North to prevent import of protected varieties and therefore serve as a trade barrier. Although the analogy might seem obvious, the results are significantly different. In this paper, higher protectionism in any form results in a lower welfare in the South, while increasing information protection up to a certain point might increase the welfare in the North. This positive effect does not occur when the trade barrier is increased. Furthermore, growth effects are always negative, and neither global nor individual region's welfare can attain the levels of the no-IPR protection world.

The rest of the paper is organized as follows: section 2 presents the benchmark scenario, autarky, under intensive form of IPR protection and solves for the steady-state equilibrium analytically, while section 3 analyzes the growth and welfare effect of opening to trade. Section 4 focuses on the impact of stronger IPR protection which is still represented only in the form of intensive protection. Section 4 presents the model of enforceable patents as an alternative IPR instrument and compares the results with the no-patent scenario and the social optimum, while section 5 assumes non-enforced patents and analyzes the effect of the two IPR instruments in a numerical exercise. Section 6 concludes.

2 Autarky

2.1 The Model

The model considers two regions, the North and the South, which differ in the abilities to conduct R&D and in the wages (w) their workers earn, with Northern wage higher than that in the South ($w_N(t) > w_S(t)$). As presented in Figure 1, there is a continuum of goods in the world market indexed by $z(t) \in [-\infty, n_N(t)]$. Each good is characterized by a higher quality than the preceding one. Innovation is conducted by the North and each successful innovation results in a new variety with increased quality compared to the previous one invented. The North produces the whole range of existing varieties, $[-\infty, n_N(t)]$, where $n_N(t)$ grows through

innovation. Workers in the South conduct imitative R&D and the highest quality variety copied by the South is $n_S(t)$, being inside the range of varieties produced in the North. The distance between the highest quality varieties produced in the North and the South is of measure d , i.e. $d(t) = n_N(t) - n_S(t)$.



Figure 1: Autarky

Thus, the production in the two regions overlaps up to the variety $n_N(t) - d$, while varieties $[n_N(t) - d, n_N(t)]$ have not been copied and are produced only by the North. As there is no trade, the consumption bundles of the two regions are different and consist only of the varieties produced domestically.

2.1.1 Consumers

The population in both regions is fixed and it is of measure L_N and L_S in the North and the South, respectively. Each individual supplies one unit of labor inelastically and earns the wage (w). The wage is the same in both sectors of the economy, the manufacturing and R&D, w_N in the North and w_S in the South. Labor is not mobile between the regions.

Consumers in both regions have the same preferences and they maximize lifetime utility of the following form

$$U = \int_0^{\infty} e^{-\rho t} \ln u(t) dt, \quad (1)$$

with $\rho > 0$ as the discount factor and $u(t)$ the instantaneous utility given by

$$u(t) = \left\{ \int_{-\infty}^{n(t)} q(z) x(z, t)^\alpha dz \right\}^{\frac{1}{\alpha}} \quad (2)$$

Utility at time t is a quality-augmented CES consumption index with $x(z, t)$ as the consumption of variety z of quality index $q(z)$, where

$$(3) \quad q(z) = \begin{cases} e^{(1-\alpha) \int_0^z \gamma_s ds} & \text{if } z \geq 0 \\ e^{-(1-\alpha) \int_z^0 \gamma_s ds} & \text{if } z < 0 \end{cases}$$

Variable γ measures the size of quality improvement of each successive variety and is equal for both North and South, i.e. when the South copies a particular variety, it has to produce the same quality jump that occurred in the North at the time of the variety's invention. The quality index of each variety z is thus given by $q(z) = q(z_{-1})e^{(1-\alpha)\gamma z}$. The parameter α measures the substitution between varieties, with $\frac{1}{1-\alpha}$ as the elasticity of substitution. With $0 < \alpha < 1$, consumers prefer goods of higher quality (higher z).

Given prices, consumers maximize the instantaneous utility subject to their individual expenditure on all goods ($C(t)$). This is a problem of static optimization across varieties

$$\max \left\{ \int_{-\infty}^{n(t)} q(z)x(z,t)^\alpha dz \right\}^{\frac{1}{\alpha}} \quad \text{subject to} \quad C(t) = \int_{-\infty}^{n(t)} p(z,t)x(z,t)dz$$

which gives the optimal demand for each variety

$$x(z,t) = \frac{(p(z,t)/q(z))^{\frac{1}{\alpha-1}}}{\int_{-\infty}^{n(t)} (p(z,t)^\alpha/q(z))^{\frac{1}{\alpha-1}} dz} C(t) = \frac{(p(z,t)/q(z))^{\frac{1}{\alpha-1}}}{P(t)^{\frac{\alpha}{\alpha-1}}} C(t). \quad (4)$$

The demand function takes the familiar form, where the share of each variety in the total consumption is given by the share of its quality-price ratio in the index of quality-price ratios of all varieties consumed (P).

Dynamic optimization of the lifetime utility given (2), (4) and the budget constraint

$$\dot{A}(t) = w(t) - C(t) + r(t)A(t), \quad (5)$$

where $A(t)$ represents individual assets and $r(t)$ the market interest rate at time t , results in the Euler condition

$$\frac{\dot{C}(t)}{C(t)} = r(t) - \rho. \quad (6)$$

Expenditure grows only when the market interest rate exceeds subjective discount factor. This paper will analyze a steady-state equilibrium in which wages (w_N and w_S) and expenditures (C_N and C_S) do not change over time, and thus, market interest rate is constant and equal to the subjective discount factor.

2.1.2 Production

The North conducts costly innovative R&D, where the cost depends on the amount of labor employed in the research and the productivity of the R&D technology. When a new variety is invented, the producer that buys the blue-print becomes a monopolist. This is due to the fact that under Bertrand competition, no other Northern firm will have an incentive to copy a variety at any time. Its entry into the market and the competition with the first successful innovator would drive profits down to zero and would not allow for covering the R&D costs of imitation. For that reason, there is no need for any instrument of the IPR protection domestically. Each good requires one unit of labor for production, so the firm faces a marginal cost equal to wage w_N . The monopolist determines the product price by maximizing profits subject to the consumers demand

$$\max p(z, t)x(z, t) - w(t)x(z, t) \quad \text{subject to (4)} \quad (7)$$

yielding the optimal monopoly price

$$p_N(z, t) = p_N(t) = \frac{1}{\alpha}w_N(t), \quad (8)$$

which is equal across varieties. This implies that the consumers' demand across varieties increases with the quality level, but the demand for each variety decreases over time due to invention of the higher quality varieties.

The South is involved in the imitative R&D and incurs costs depending on the R&D labor and the productivity of copying, which will also determine the highest quality level copied. When a variety is copied successfully, the imitator becomes a monopolistic producer using one unit of labor per good, so the marginal cost equals wage w_S . The firm charges the monopoly price which is needed to compensate for the cost of the blue-print

$$p_S(z, t) = p_S(t) = \frac{1}{\alpha} w_S(t). \quad (9)$$

As in the North, under Bertrand competition, no other Southern firm will have an incentive to copy an already copied product since its entry drives profits down to zero and does not allow for covering the R&D costs of copying a copy.

Both regions firms earn profits only at the local markets, and the profits are given by

$$\Pi_N(z, t) = (p_N(t) - w_N(t))x_N(z, t)L_N = (1 - \alpha) \frac{q(z)^{\frac{1}{1-\alpha}}}{\int_{-\infty}^{n_N(t)} q(z)^{\frac{1}{1-\alpha}} dz} C_N(t)L_N \quad (10)$$

$$\Pi_S(z, t) = (p_S(t) - w_S(t))x_S(z, t)L_S = (1 - \alpha) \frac{q(z)^{\frac{1}{1-\alpha}}}{\int_{-\infty}^{n_N(t)-d(t)} q(z)^{\frac{1}{1-\alpha}} dz} C_S(t)L_S. \quad (11)$$

At any time t , the innovator's and the imitator's profits increase in total expenditure ($C_N L_N$, $C_S L_S$) and quality jump (γ), but they decrease over time as the quality level of the particular variety decreases relative to the highest quality produced.

2.1.3 R&D Processes

The North employs labor of measure $R_N(t)$ in research which, if successful, results in the invention of a new good of higher quality. The innovation is characterized by a difficulty parameter $\beta > 0$, with $\frac{1}{\beta}$ as the productivity of the innovation. The R&D technology is modeled as

$$\hat{\gamma}_N(t) = \frac{R_N(t)}{\beta}. \quad (12)$$

$\hat{\gamma}_N(t)$, as the effective research labor, represents the growth rate of the quality index in the North

$$\frac{\dot{q}_{n_N}(t)}{q_{n_N}(t)} = \hat{\gamma}_N(t). \quad (13)$$

With $q_{n_N}(t)$ given by (3), the specification above implies that $q_{n_N}(t) = q_0 e^{\hat{\gamma}_N(t)t}$. Taking logs and derivative with respect to time using the Leibniz rule, one obtains

$$(1 - \alpha) \int_0^{n_N(t)} \dot{\gamma}_z dz + (1 - \alpha) \gamma_{n_N(t)} \dot{n}_N(t) = (1 - \alpha) \int_0^{n_0} \dot{\gamma}_z dz + \frac{d\hat{\gamma}_N(t)}{dt} t + \hat{\gamma}_N(t). \quad (14)$$

The technological progress comes in two forms, the invention of new goods and the increase in quality, which we might call extensive and intensive margins of change, respectively. Diverging from the common practice found in the growth literature, where the size of each quality jump is taken as constant and exogenous when analyzing the endogenous innovation rate, the assumption here is exactly the opposite. The invention frequency is exogenous and new products arrive along with time, i.e. $\dot{n}_N = 1$. However, the size of quality improvement with each new product is left free to be determined endogenously. In this way, the ranges of varieties can also be regarded as the measure of time, so that d in fact represents the lag of South in time. The analysis in this paper focuses on the balanced growth path (BGP) with a constant growth rate of the quality index ($\frac{d\hat{\gamma}_N(t)}{dt} = 0$) and the constant size of endogenous quality jumps across time and thus across varieties ($\dot{\gamma}_z = 0$ and thus $\gamma_z = \gamma$). Therefore, the last expression, with $\dot{n}_N = 1$, collapses to

$$\gamma(1 - \alpha) = \hat{\gamma}^N$$

and the quality index simplifies to $q(z) = e^{(1-\alpha)\gamma z}$.

Imitation is conducted by the Southern R&D labor of measure $R_S(t)$, with the difficulty parameter $\theta(d) > 0$. The effective Southern research labor, $\hat{\gamma}_S(t)$, gives the growth rate of the quality index in the South

$$\hat{\gamma}_S(t) = \frac{R_S(t)}{\theta(d)} \quad (15)$$

$$\frac{\dot{q}_{n_S}(t)}{q_{n_S}(t)} = \hat{\gamma}_S(t).$$

As for the North, $\dot{\gamma} = 0$ and $\frac{d\hat{\gamma}_S(t)}{dt} = 0$ at the BGP, so that $\gamma(1 - \alpha)\dot{n}_S = \hat{\gamma}^S$. The main trade-off in this paper is expressed in the relation between the intensive margin of innovation, given by γ , and the imitation distance coming from the South, given by d , in a steady-state equilibrium. To analyze this relation, this paper focuses on a steady-state equilibrium in which the quality distance $d = n_N - n_S$ between the North and the South is constant. This

implies that for each new variety invented, one more variety is copied. In other words, \hat{n} is the same in both regions, so it equals 1 in the South as well. Finally, this implies that $\hat{\gamma} = \gamma(1 - \alpha)$ and equal in both regions.

The R&D difficulty parameter in the South is proportional to β , but depends on the North-South distance. Namely, it can be argued that as the South attempts to imitate more intensively and decrease the quality gap relative to the North, the copying process increases in difficulty, and thus, $\theta = \theta(d)$ is assumed to be a decreasing function of d . This factor of proportionality to β is given by the ratio of the highest quality in the South and the one in the North.⁷ An additional parameter, η , with $\eta \geq 1$, represents the degree of the IPR protection by the North and directly affects the difficulty (productivity) of copying.⁸ Therefore, the productivity of copying ($\frac{1}{\theta}$) is decreasing in η and increasing in d . With the free flow of information ($\eta = 1$) and no distance in quality ($d = 0$), θ becomes equal to β .

$$\theta(d) = \eta\beta \frac{e^{\gamma(n_N-d)(1-\alpha)}}{e^{\gamma n_N(1-\alpha)}} = \eta\beta e^{-\gamma d(1-\alpha)}. \quad (16)$$

2.1.4 R&D Optimization

The expected benefit of a successful R&D effort, the value of a new variety, is represented by expected discounted profits from innovating or copying in the North and the South, respectively. Having assumed that $\frac{dz}{dt} = \dot{z} = 1$, it is convenient in computational sense to discount the profit flows over the index z , since, under given assumptions, it is equivalent to discounting over time.

With wages, prices and expenditures constant over time, profits change due to the growth in the price index. Therefore, the values of a new variety (V_N) and a copy (V_S) in a steady-state are given by

$$V_N = (1 - \alpha)\gamma e^{\gamma n_N} C_N L_N \int_{n_N}^{\infty} e^{-\gamma z} e^{-r(z-n_N)} dz = (1 - \alpha) \frac{\gamma}{\gamma + r} C_N L_N \quad (17)$$

$$V_S = (1 - \alpha)\gamma e^{\gamma(n_N-d)} C_S L_S \int_{n_N-d}^{\infty} e^{-\gamma z} e^{-r(z-n_N+d)} dz = (1 - \alpha) \frac{\gamma}{\gamma + r} C_S L_S \quad (18)$$

⁷See Gancia and Zilibotti (2005) for similar modeling of imitational R&D productivity.

⁸Mansfield et al. (1981) finds that patents rarely hinder imitation but make it more expensive. This closely corresponds to the idea of making imitation more difficult, and thus more labor demanding and more costly, which would be the interpretation of η . Moreover, η stands for any institutional impediment that may increase the cost of imitation.

The value of introducing a new variety is increasing in the total consumer expenditure and size of the quality jump, while it is decreasing in the elasticity of substitution between varieties.

The entry into the R&D races is free and all participants have access to the same R&D technology, so the benefits of winning a race will equal the costs of R&D in a steady-state equilibrium.

Given the specification of the R&D technology, research labor required for each innovation in the North is given by

$$R_N = \beta\gamma(1 - \alpha), \quad (19)$$

and with w_N as the cost of each unit of the research labor, the optimal R&D condition (arbitrage condition) in the North is given by

$$V_N = w_N\beta\gamma(1 - \alpha) \quad (20)$$

Combining this condition with the expression for the value of a new variety, V_N , it yields

$$\frac{1}{\gamma + r}C_N L_N = w_N\beta. \quad (21)$$

Similar derivation applies also to the South. Research labor needed for one new copy is given by

$$R_S = \theta(d)\gamma(1 - \alpha), \quad (22)$$

which, with the wage w_S , yields the arbitrage condition in the South

$$\frac{1}{\gamma + r}C_S L_S = w_S\theta(d). \quad (23)$$

2.1.5 Labor Markets

Full employment of labor requires that in both regions at any time t all workers are employed in either R&D sector or manufacturing. Under the assumption of $dz = dt$, at each point in time, the total R&D labor in either region is actually equal to the labor requirement for the development of one new product or a copy given by (19) for the North and (22) for the South. Therefore, the full employment labor market conditions for the two regions are given by

$$L_N = R_N + \int_{-\infty}^{n_N} D_N L_N dz = \beta\gamma(1 - \alpha) + \frac{C_N L_N}{p_N} \quad (24)$$

$$L_S = R_S + \int_{-\infty}^{n_N-d} D_S L_S dz = \theta(d)\gamma(1 - \alpha) + \frac{C_S L_S}{p_S} \quad (25)$$

2.2 Steady-State Equilibrium Analysis

Combining the full labor employment conditions, (24) and (25), with the R&D optimization conditions given by (21) and (23) for the North and the South, respectively, two steady-state equilibrium conditions are obtained,

$$L_N = \beta\gamma(1 - \alpha) + \frac{w_N \beta}{p_N} (\gamma + r) = \beta(\gamma + r\alpha) \quad (26)$$

$$L_S = \theta(d)\gamma(1 - \alpha) + \frac{w_S \theta(d)}{p_S} (\gamma + r) = \theta(d)(\gamma + r\alpha). \quad (27)$$

The Northern condition determines the endogenous size of the quality jump (γ) as

$$\gamma = \frac{L_N}{\beta} - r\alpha. \quad (28)$$

The quality jump depends positively on the productivity of the R&D labor, $\frac{1}{\beta}$, while a higher interest rate and a larger α (higher elasticity of substitution) decrease γ due to their

negative impact on the value of the innovation.⁹ In the autarky scenario, the quality lag of the South has no impact on the quality jump which is solely determined by the conditions of the North. This results in the vertical Northern condition in the (γ, d) space in the autarky steady state equilibrium diagram (Figure 2).

The Southern equilibrium condition determines the quality lag (d) as a function of γ ,

$$d = \frac{1}{1 - \alpha} \ln\left(\frac{L_N}{L_S} \eta\right) \frac{1}{\gamma} \quad (29)$$

Higher γ implies smaller quality distance between the North and the South, as it increases the value of imitation and R&D labor productivity in the South, which together counteracts the increase in the R&D labor cost. In autarky, γ comes as "manna from North" whose increase results in a higher productivity in the South, reallocation of labor towards the R&D sector and a faster catch-up. Therefore, the Southern equilibrium condition is downward sloping in Figure 2. The elasticity of substitution and the degree of information protection both increase the distance as they decrease the value of copying and the productivity of imitative R&D labor.

As by the construction of the model, the quality lag of the South cannot be negative, the assumption $L_N \geq L_S$ is imposed. This restriction might seem too strong if the labor sizes are expressed in absolute terms of the population sizes. However, as the model does not include measures of the human capital and assumes equal productivity in manufacturing in the North and the South, the labor sizes might be regarded in terms of the effective labor size. In that sense, the assumption implies that the total effective labor in the North is at least as large as the total effective labor in the South. This paper focuses on the analysis of the effects of opening to trade, and not the analysis of the autarky itself, and therefore the human capital measure has been left out in order to keep the analysis simple and focus on the differences in the R&D productivities.

Consumers in both regions maximize their lifetime utility subject to their budget constraint given by the expression for the change in assets they possess, A , i.e. $\dot{A} = w - C + rA$. Under the assumption of financial autarky, the growth rate of assets, given by $\frac{\dot{A}}{A} = \frac{w-C}{A} + r$,

⁹The model exhibits scale effect, which might not be of concern in a model with no population growth. Moreover, in the free trade scenario, the scale effect appears only in a relative form, where the quality lag depends on the ratio of the regions' sizes. In this model, scale effect could be corrected for by assuming that the number of industries is proportional to the population size.

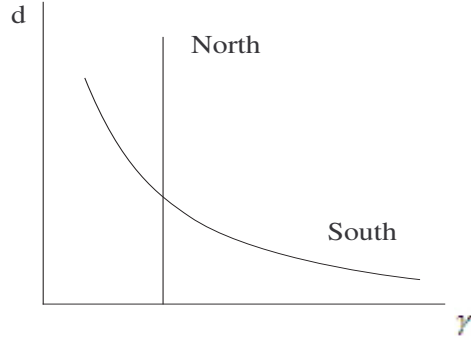


Figure 2: Steady state equilibrium in autarky

is constant in a steady-state equilibrium with constant w , C and r . It follows that A is constant which implies $C - w = rA$, and in aggregate form

$$C_N L_N = w_N L_N + r \bar{A}_N \quad \text{in the North, and}$$

$$C_S L_S = w_S L_S + r \bar{A}_S \quad \text{in the South.}$$

\bar{A}_N represents total Northern assets which are equal to the sum of the values of all existing firms in the North at time t , while \bar{A}_S stands for the total assets in the South, equal to the sum of the values of all copies at a given time t . Therefore, $\bar{A} = \int_0^\infty V(a) da$, where $V(a)$ stands for the value of a periods old firm at time t . This yields the expenditure conditions

$$C_N L_N = (1 - \alpha) r w_N \beta + w_N L_N \quad (30)$$

$$C_S L_S = (1 - \alpha) r w_S \theta(d) + w_S L_S \quad (31)$$

Utility in both regions is equal to $\frac{C}{P}$, and with constant consumer expenditure, the utility growth is given by the negative of the growth of the quality-price index

$$\frac{\dot{u}}{u} = \frac{1 - \alpha}{\alpha} \frac{d e^{\gamma n}}{dt} \frac{1}{e^{\gamma n}} = \frac{1 - \alpha}{\alpha} \gamma = (1 - \alpha) \left(\frac{L_N}{\alpha \beta} - r \right). \quad (32)$$

2.2.1 The IPR protection

Higher protection of information by the North and the resulting increase in the difficulty of copying in the South, has no effect on the quality jump and thus, no effect on the growth rate in the autarky. However, the quality lag is higher with a higher degree of protection. On the other hand, in a special case with equal sizes of the regions ($L_N = L_S$), a perfectly free flow of information ($\eta = 1$) implies that the North-South quality gap is closed in the long-run as the South completely converges to the Northern frontier through copying.

The steady-state welfare in the autarky scenario in the North and the South, respectively, is given by

$$U_N^A = [L_N - (1 - \alpha)\beta\gamma] \left[\frac{e^{\gamma n}}{\gamma} \right]^{\frac{1-\alpha}{\alpha}}$$

$$U_S^A = \alpha\theta(d)(\gamma + r) \left[\frac{e^{\gamma(n-d)}}{\gamma} \right]^{\frac{1-\alpha}{\alpha}}$$

The effect of a higher IPR protection on the steady-state welfare in the North and the South in the autarky equilibrium is different. While there is no change in the Northern welfare with an increase in η , the welfare in the South decreases due to the increase in the quality lag and the drop in the average quality index of the goods consumed in the South,

$$\frac{dU_S^A}{d\eta} = -\frac{1}{\alpha} e^{-\ln \eta \frac{1+\alpha}{\alpha}} \alpha\beta(\gamma + r) \left[\frac{e^{\gamma n}}{\gamma} \right]^{\frac{1-\alpha}{\alpha}} < 0$$

3 Trade

3.1 The Model

The paper now considers two regions, the North and the South, which are open to trade. The South still produces varieties up to the one at d distance from the highest quality variety in the North. Since $w_N > w_S$, the South can produce these varieties at a lower cost and due to free trade, it is no longer optimal for the North to continue their production. However, the range of varieties that have not been copied by the South, $[n_N(t) - d, n_N(t)]$, are produced and traded exclusively by the North. As presented in the figure below, there is a continuum of goods in the world market indexed by $z(t) \in [-\infty, n_N(t)]$, but there is no overlapping in

the production as in the autarky case; the South specializes in the production and trade of low quality varieties, while the North specializes in the high quality ones. The IPR protection policy is still represented by the degree of information protection which affects the difficulty of copying.

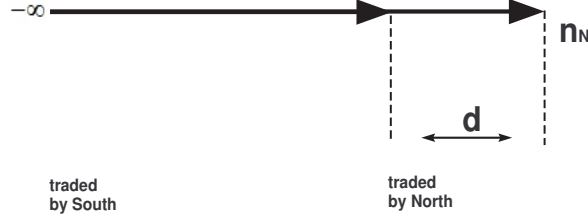


Figure 3: Trade

The composition of the consumption bundles is the same in both regions, as Southern consumers have access to the whole range of varieties due to trade. Since all world consumers are buying a particular variety at the same price (markup over the marginal cost in the region of production), the quality-price index is the same in both regions.

$$P_N = P_S = \left\{ \frac{1}{\gamma} e^{\gamma n_N} \left[p_N^{\frac{\alpha}{\alpha-1}} (1 - e^{-\gamma d}) + p_S^{\frac{\alpha}{\alpha-1}} e^{-\gamma d} \right] \right\}^{\frac{\alpha-1}{\alpha}} \quad (33)$$

As in the autarky, the North (the South) conducts innovative (imitative) R&D and after a new variety is invented, each unit of good requires one unit of labor for production. The monopolist, innovator or imitator, determines the product price by maximizing profits subject to the consumers demand which again, yields the optimal monopoly price $p_i(z, t) = p_i = \frac{1}{\alpha} w_i$ with $i = N, S$.

However, the revenue now comes from both domestic and foreign market, and for the North it comes from sales of the $[n_N(t) - d, n_N(t)]$ range of varieties, while the South sells varieties in the range $[-\infty, n_N(t) - d]$. The value of a new variety or a new copy is determined as the discounted stream of profits from the domestic and the foreign market over the period of firm's operation. However, the life of a variety in the North is now not infinite but terminates at the time it is successfully copied by the South, i.e. d periods after the invention. Therefore, the time span over which the profits are discounted is different in the North and the South, and the values of innovation and imitation are given by

$$V_N = \frac{1-\alpha}{\alpha} w_N p_N^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \frac{CL}{\tilde{P}} (1 - e^{-(\gamma+r)d}) \quad (34)$$

$$V_S = \frac{1-\alpha}{\alpha} w_S p_S^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \frac{CL}{\tilde{P}} e^{-\gamma d}, \quad (35)$$

where $\tilde{P} = P^{\frac{\alpha}{\alpha-1}} e^{-\gamma n_N}$ and $CL = C_N L_N + C_S L_S$. Both values are functions of the total world demand, however, they are also functions of different life length of a new variety, compared to the autarky. In the North, this comes as the explicit cut of the variety life from below, represented by the $(1 - e^{-(\gamma+r)d})$ term, as the North loses the production of low quality varieties. In the South, this life span change does not come in the form of the finite life of a variety, but rather as an implicit cut of its life from above, as the highest quality in the South is no longer the highest one consumers allocate their expenditure to. In that sense, $e^{-\gamma d}$ term represents the loss in quality position relative to the highest in the market, and thus the loss in the variety's demand share relative to the total consumers demand. The R&D technology is defined in the same way as in the autarky scenario, and the arbitrage conditions for the North and the South, obtained by equalizing the benefits and costs of R&D, are given by

$$\frac{1}{\alpha} p_N^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \frac{CL}{\tilde{P}} (1 - e^{-(\gamma+r)d}) = \beta\gamma \quad (36)$$

$$\frac{1}{\alpha} p_S^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \frac{CL}{\tilde{P}} e^{-\gamma d} = \theta(d)\gamma \quad (37)$$

3.2 Steady-State Equilibrium Analysis

The full employment labor market conditions for the two regions are given by

$$L_N = \beta\gamma(1-\alpha) + p_N^{\frac{1}{\alpha-1}} \frac{1}{\gamma} \frac{CL}{\tilde{P}} (1 - e^{-\gamma d}) \quad (38)$$

$$L_S = \theta(d)\gamma(1-\alpha) + p_S^{\frac{1}{\alpha-1}} \frac{1}{\gamma} \frac{CL}{\tilde{P}} e^{-\gamma d}, \quad (39)$$

which, when combined with the arbitrage conditions in the North and the South, (36) and (37), yield the first two steady-state equilibrium conditions, endogenous in γ and d

$$L_N = \beta\gamma(1 - \alpha) + \alpha\beta(\gamma + r) \frac{1 - e^{-\gamma d}}{1 - e^{-(\gamma+r)d}} \quad (40)$$

$$L_S = \theta(d)(\gamma + \alpha r) \quad (41)$$

In the free trade scenario, the size of the quality jump is not determined exclusively by the North, but also depends on the conditions of the South, so that γ and d are jointly determined by the two equations above.

The third endogenous variable in the model is the relative wage ω , defined as $\frac{w_N}{w_S}$. Dividing the Northern arbitrage condition by that of the South yields the following condition

$$\omega^{\frac{1}{1-\alpha}} = \frac{\frac{1}{\beta}(1 - e^{-(\gamma+r)d})}{\frac{1}{\theta(d)}e^{-\gamma d}}. \quad (42)$$

The relative wage is proportional to the ratio of R&D productivities, corrected by the terms referring to the varieties lifetime. Thus, the relative wage in fact comes from the ratio of factual productivities in creating the value of new businesses in the two regions. When simplified, the relative wage condition determines ω as

$$\omega = [(1 - e^{-(\gamma+r)d})e^{\gamma d\alpha}\eta]^{1-\alpha}. \quad (43)$$

Both γ and d have a positive impact on the relative wage, and so does the degree of information protection which decreases the productivity of copying. For the model to be one of the North-South trade, it is necessary for monopolistic price in the South to be lower than the competitive price in the North. Therefore, the equilibrium ω has to be at least $\frac{1}{\alpha}$.¹⁰ From the condition above, it follows that the equilibrium distance in the trading world has to be positive. Moreover, the size of the quality jump is strictly positive in order to satisfy the wage condition for any value of η and the equilibrium condition (40).

Proposition .1. *The size of the quality jump, γ increases with opening to trade.*

¹⁰With a wide range of parameters used in the numerical exercise, ω proves to be larger than $\frac{1}{\alpha}$. Even when this is not the case, relative wage never becomes lower than one. That calls for the limit pricing with the maximum price in the South being equal to the marginal cost in the North, without any loss in generality of the results.

Proof. With $\gamma, \eta > 0$, the term $\frac{1-e^{-\gamma d}}{1-e^{-(\gamma+r)d}}$ is necessarily smaller than 1. For the equilibrium condition (40) to be satisfied, γ in the free trade scenario has to be larger than γ in the autarky that satisfies the condition (26), which completes the proof. \square

The mechanism behind this effect comes from the fact that varieties now live only d periods in the North. This translates in the loss of the value of innovation represented by $(1 - e^{-(\gamma+r)d})$, which implies that the innovators need larger quality jump to ensure higher demand and their survival in the market. At the same time, the cut in the life of varieties corresponds to the loss in the production of the whole range of low quality varieties in the aggregate, those that are now produced exclusively by the South. Thus, the total demand for Northern production and therefore manufacturing labor depends only on $(1 - e^{-\gamma d})$ share of expenditures. The excess manufacturing labor is being reallocated to the R&D sector, which in turn raises γ , the demand for new varieties and for production labor. The process continues until the full employment is restored, but as a result of more resources devoted to R&D, γ is necessarily higher, compared to autarky.

The life of any variety introduced and produced in the South is still infinite, so the Southern equilibrium condition is of the unchanged form, however, γ and d in equilibrium will be different. The quality distance d in the free trade equilibrium is given by

$$d = \frac{1}{1-\alpha} \ln\left(\frac{\eta\beta(\gamma+\alpha r)}{L_S}\right) \frac{1}{\gamma} \quad (44)$$

Proposition .2. *Quality lag of the South, d , increases with opening to trade.*

Proof. In the special case with no IPR protection ($\eta = 1$) and equal size of population ($L_N = L_S$), the proof is straightforward. The distance of the South in the autarky given by equation (29) is equal to zero. In the trade scenario, with an increase in γ , the term $\beta(\gamma+\alpha r)$ is larger than L_N and thus, $\ln\left(\frac{\eta\beta(\gamma+\alpha r)}{L_S}\right) > 0$. Therefore, $d > 0$ in the trade equilibrium. For $\eta > 1$ or $L_N > L_S$, see Appendix B. for proof. \square

Intuitively, opening to trade reveals the specialization pattern which comes about as a result of the comparative advantage in the innovation/imitation and production of different ranges of varieties in the North and in the South, high and low quality ranges respectively. The loss of the low quality varieties allows the North to reallocate labor to comparatively more productive R&D sector as it gets freed from the manufacturing of the low quality

varieties. The South concentrates on the production of the low quality range for the world market.

Free trade steady state equilibrium is presented in Figure 4, in (γ, d) space. Compared to the autarky scenario, both the North and the South conditions are changed. The Northern condition is now downward sloping, implying a negative relation between γ and d . Namely, with the larger lag of the South, on one hand the North faces lower competitive pressure from the South due to increased life of varieties, and thus a lower incentive for R&D, and on the other hand it has to produce a larger range of varieties. Both effects work in favor of reallocating labor to manufacturing which results in the lower quality jump. Compared to the autarky scenario, the Southern steady state condition is perhaps more striking. In the free trade case, the condition is upward sloping. An increase in the quality jump now results in an increase of the quality lag, as the rising value of imitation and R&D labor productivity no longer counteract the increase in the R&D labor cost. This is the result of a drop on the quality ladder of the highest quality good in the South relative to the highest in the market, which was not the case in the autarky.

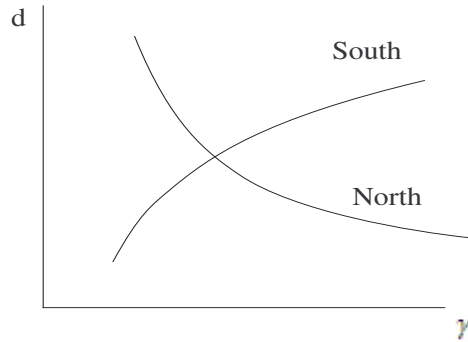


Figure 4: Steady state equilibrium with trade

The role of η as the measure of the IPR protection will be analyzed in the following subsection, but it should be noted that by affecting productivity of copying and thus the quality distance of the South, η has an effect on γ in the free trade, and therefore on the common growth rate in both regions, still given by

$$\frac{\dot{u}}{u} = \frac{1 - \alpha}{\alpha} \gamma. \quad (45)$$

Trade is balanced and the increase in the size of the market caused by the opening to trade has no direct effect on the endogenous variables of the model. What plays the central role is the competition effect which brings along the specialization in different ranges of varieties, and thus the static and dynamic benefits of trade.

Proposition .3. *With the number of varieties sufficiently large ($n_N > \frac{1}{\gamma}$), the steady-state welfare in both regions increases with their opening to trade.*

Proof. With the initial number of varieties large enough, the numerical solution that with opening to trade and the resulting increase in γ and d , the positive effect on the quality index (quality consumed) is larger than the negative effect on the manufacturing labor (quantity produced and consumed), and thus the welfare is raised in both regions. See Appendix A for calibration and Appendix C for the proof details. \square

3.2.1 The IPR protection

This section investigates the impact of increasing information protection (η) on the size of the quality jump (γ) and thus the growth rate of the economy, on the North-South distance in quality (d), relative wage (ω) and the steady-state utility (welfare). The model is solved numerically, and the effect of an increase in η on the variables of interest are presented below, as well as the graphical illustration for the $\gamma - d$ effect and the intuition on the mechanisms driving the results. For the details of the parametrization and the calibration of the model see Appendix A. In all exercises, the degree of information protection (IPR protection) varies from 1 which stands for a perfectly free flow of information regarding the blue-prints, to 1.4, a 40% tighter information flow.

For a given quality jump (γ), an increase in the degree of IPR protection causes an increase in the equilibrium quality distance of the South (d) as the difficulty of imitation rises. This shifts the Southern equilibrium condition up to the left (Figure 5), which results in the move from the equilibrium point A to the equilibrium point B with a lower quality jump and a higher distance.

Figure 6 shows these results numerically. In the free trade scenario, the positive effect of η on the distance translates into the change in the size of the quality jump. With a higher

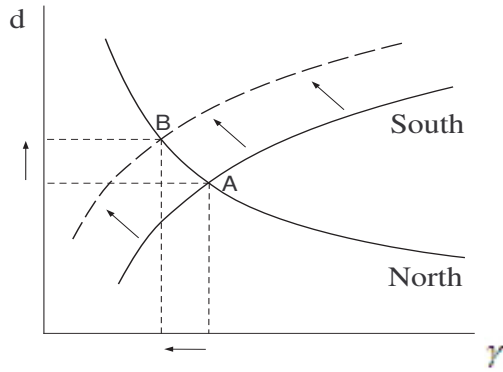


Figure 5: Trade: Increase in IPR protection diagram

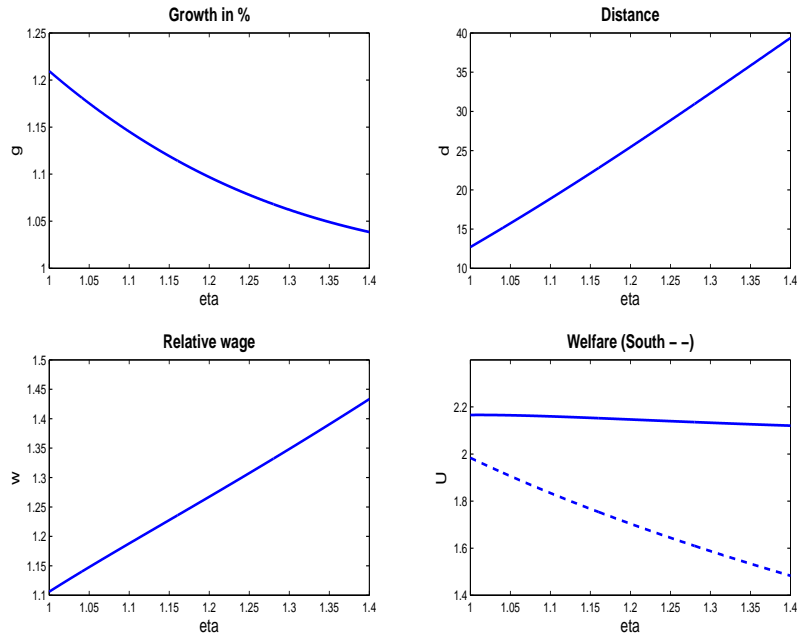


Figure 6: Trade: The effect of increase in IPR protection

information protection, γ and the welfare in both regions decrease, while the relative wage increases.

The effect of η on the quality lag is positive as in the autarky case, though the distance is not zero even in the special case of free information sharing and equal sizes of the regions. It might be concluded that trade necessarily brings incentives for the specialization of both regions, no matter how weak the IPR protection policy is. This result contradicts the com-

mon fear of the developed North that the South might overtake all manufacturing industry from the North due to violation of the IPR.

In most R&D driven growth models, higher protection of monopoly rights would bring about an incentive to increase R&D effort, which is not the case here (Figure 7). Raising η raises the value of innovation in the North. However, due to the increase in the wage it also raises the cost of R&D more than proportionally and puts a downward pressure on the R&D labor demand. Together with the growing lag of the South and thus higher demand for the manufacturing labor in the North, there is a lower R&D effort and a decrease in γ , until the arbitrage condition is satisfied.

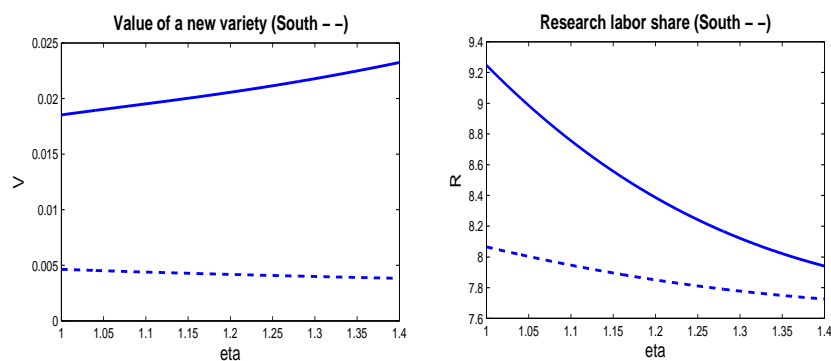


Figure 7: Trade: The effect of increase in IPR protection on R&D variables

Intuitively, stronger IPR protection is not enhancing growth but relieving the monopolists from the competitive pressure. In the South, an increase in η lowers the productivity of copying, and the lower quality jump also results in a lower value of imitation, which cannot be compensated for by the decrease in the R&D cost. This brings about a decrease in the Southern research labor and a higher d . Besides the dynamic loss in growth, the static loss in both Northern and Southern welfare comes as a result of the lower quality index and the increase in the price index (higher relative wage and higher d).

In the trade scenario, numerical solution shows a decrease in both the Northern and the Southern welfares with stronger IPR protection.

4 No IPR Protection vs. Perfectly Enforced Patents

4.1 The Model

The model for the analysis of the enforceable patent impact on welfare and growth is presented in the trade scenario section (Section 3.1). As a benchmark, η is set equal to 1, so that, under no restrictions in the form of patents, there is no international IPR protection. After solving for the equilibrium of this scenario, a patent of finite length T is introduced. The patents do not serve the domestic IPR protection as copying of the products in the same region is not optimal, but rather represent a form of international protection. It is assumed that patents impose perfect protection: there is no imitation by the South up to the variety of index $n_N(t) - T$. In that sense, T acts as exogenously imposed d for the South, so that the highest quality attainment of the South is not an endogenous outcome in the equilibrium, but a constraint imposed by the North which optimizes its welfare. Finally, this section considers a social planner who maximizes the global welfare and determines the optimal distance of the South, i.e. the optimal patent length. The equilibrium welfare and growth in both regions in the three scenarios are compared.

4.2 Numerical exercise

The dotted lines in Figure 8. represent the no-patent equilibrium values of growth rate and welfares in the North and the South, respectively, with the resulting equilibrium quality distance of the South at 14.5 years. The full lines present the equilibrium values under patents of length T , which is found to be optimal for the North at the value of 19.5 years. The assumption of a perfectly free information flow ($\eta = 1$) is kept in order not to interfere the effects of the patents with the effects of the alternative IPR protection instrument.

As shown in Figure 8, there are both growth and welfare effects of introducing fully enforced patents, compared to the no IPR protection scenario. As the optimal patent length for the North is higher than the endogenous distance of the South, the life of any variety in the North is now longer, which results in an increase in the demand for manufacturing labor in that region. On the other hand, as the relative wage rises, the products from the North become relatively more expensive for the consumers, putting a downward pressure on the demand for Northern products. However, the first effect is larger, and thus the decrease in research labor results in a fall in γ and the growth rate (1.14% decrease) until the equilibrium in the labor market is restored. Figure 8 shows substantial welfare changes as opposed to the

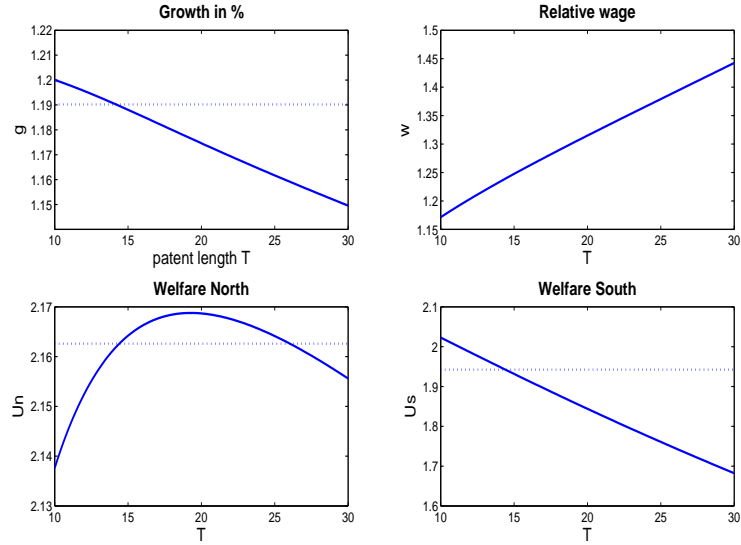


Figure 8: No IPR protection vs. perfectly enforced patents

no protection scenario, but they go in different directions in the North and the South. Since the rise in the relative wage is more than proportional to the rise in the price index, Northern welfare increases (0.27% increase), while the welfare in the South is reduced (4.54% decrease) due to the negative effect of the increase in the price index (lower quality and higher prices, common to both regions). More importantly, the total world welfare is reduced by 2%.

The positive effect of increasing the patent length on Northern welfare is not present when the IPR protection is tightened through an increase in the information protection. In that case, stronger protection raises the overall difficulty of copying directly and the increase in the lag of the South is faster than when patent length is changed. The increase in the relative wage is not high enough to compensate for the faster increase in the price index, which comes due to a slower transfer of production to the low-cost South.

It might be reasonable to assume that when strong IPR protection in the form of patents is imposed, not only that copying is prohibited for T range of varieties, but the productivity of copying is reduced for any particular distance from the quality frontier point. In other words, besides direct impediments for imitational R&D, patents might also impose an indirect impediment for the transfer of general knowledge and degrade the process of the imitator's knowledge accumulation. This corresponds to an increase in η that comes along with the introduction of patents. In this case, the effect on growth is negative and so is the effect on both Northern and Southern welfares, as opposed to the world with unrestricted knowledge diffusion. With a 10% higher η , optimal patent length increases to 25 years. The relative

wage increase is not big enough to counteract the rise in the price index for the North and the welfare is reduced. In the South, welfare losses come as a result of a higher price index. Global welfare now drops by 5.34%.

4.3 Social optimum

This section introduces a social planner who maximizes global welfare and decides on the optimal patent length, T^{sp} , and labor allocation between the manufacturing and the R&D sector. The social planner associates a certain weight to each regions utility, with $(1 - \delta)$ and δ , $\delta \in [0, 1]$, as the weights on consumers' utility in the North and the South, respectively. The constraints social planner faces are given by (i) total labor resources, (ii) production technology, (iii) the law of motion for the quality index in the North and the South, i.e. the R&D sector technology, and (iv) the trade balance which is now expressed in terms of quantities, and the shadow values of input factors and traded output between the two regions.¹¹ The social planner's problem is given as

$$\begin{aligned}
\max U^{sp} &= \int_0^{\infty} e^{-\rho t} \ln u(t) dt \quad \text{subject to} & (46) \\
u(t) &= (1 - \delta)u^N(t) + \delta u^S(t) \\
R_N + L_N^p &\leq L_N \\
R_S + L_S^p &\leq L_S \\
x(z) &= l(z) \\
\dot{q}^N &= \frac{R^N}{\beta} q^N \\
\dot{q}^S &= \frac{R^S}{\theta(d)} q^S \\
X^{Sexp} &= \bar{\omega} X^{Nexp},
\end{aligned}$$

where L^p represents manufacturing labor, q the quality index, $\bar{\omega}$ the rate at which goods are exchanged in the international market, and X^{exp} the quantity exported. The social planner takes into account that the efficient allocation would imply symmetry of $\frac{x(z)}{e^{\gamma z}}$ ratios across the goods produced in the same region, and thus the instantaneous utility, $u(t)$, can be expressed as a function of total labor employed in manufacturing (for domestic consumption and export) and the quality index, q .

¹¹See Grossman and Helpman (1992), Chapter 6.

Figure 9 presents the optimal labor allocation between the manufacturing and the R&D sector in the North, and the optimal patent length, T^{sp} . The first panel gives the solutions of a planner who is concerned only with the welfare of the North, the middle panel assumes equal weights on the welfare in the North and the South, while in the third panel the planner associates full weight to the consumers in the South. The circled areas present the combination of R&D labor share and patent length that result in the highest global welfare, given the weights on each region's utility.

Compared to the results of a decentralized equilibrium, the panels show an increase in the research labor share in the North, resulting in a higher growth rate (11.1% with $\delta = 0$), and a shorter optimal patent length for all values of δ . Global welfare exhibits a substantial increase compared to the decentralized outcome. With δ increasing from 0 to 1 (from full weight on u^N to full weight on u^S), the optimal patent length increases from 2.5 to 4.2 years, while the welfare is the highest when the weights on the two region's utilities are the same (49% increase compared to decentralized equilibrium results).

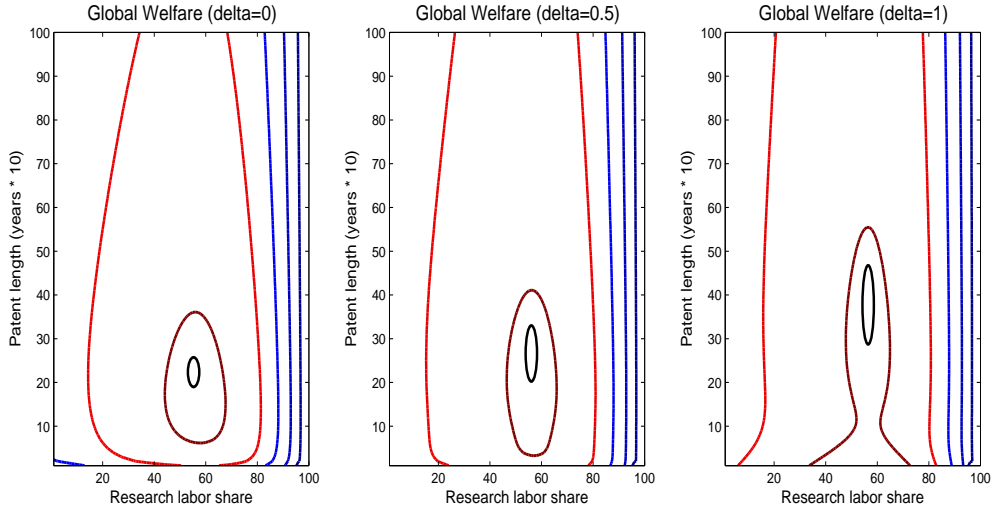


Figure 9: Social planner's solution

From a social point of view, there is no rationale for promoting longer patents as a way of promoting innovation in the North and welfare in both regions. As the social planner's optimal patent length is even smaller than the natural distance of the imitating South with no IPR protection, it comes as straightforward to call for optimal government policy which would restore static and dynamic efficiency using instruments other than the IPR protection.

5 Non-Perfect Enforcement (Restricted Trade)

5.1 The Model

In the restricted trade scenario patents of a finite length are introduced, but are no longer assumed to be enforced. Patents cannot prevent the South from imitating, but allow the North to ban the copies of the protected originals from its market. Since the South produces these varieties at a lower cost, it has no incentive to import them from the North, so that there is an interval of non-traded varieties, those that are protected in the North and already copied by the South. Thus, the trade occurs only in the ranges in which the regions are sole producers; the North imports low quality varieties, $[-\infty, n_N(t) - T]$, while the South imports the high quality range, $[n_N(t) - d, n_N(t)]$.

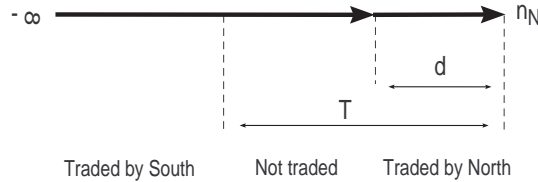


Figure 10: Restricted trade

The bundles consumed by the North and the South are of the same composition. However, the prices of varieties in the non-traded range are now different in the two markets. Therefore, the price-quality indices in the North and the South are different, and given by

$$\begin{aligned}
 P_N &= \left\{ \frac{1}{\gamma} e^{\gamma n_N} \left[p_N^{\frac{\alpha}{\alpha-1}} (1 - e^{-\gamma T}) + p_S^{\frac{\alpha}{\alpha-1}} e^{-\gamma T} \right] \right\}^{\frac{\alpha-1}{\alpha}} \\
 P_S &= \left\{ \frac{1}{\gamma} e^{\gamma n_N} \left[p_N^{\frac{\alpha}{\alpha-1}} (1 - e^{-\gamma d}) + p_S^{\frac{\alpha}{\alpha-1}} e^{-\gamma d} \right] \right\}^{\frac{\alpha-1}{\alpha}}.
 \end{aligned} \tag{47}$$

The value of a new variety or copy is determined as a discounted stream of profits over the periods of firms' operation. The production of a variety in the North does not cease with its successful imitation but only after the patent expires. Once it has been copied, the variety is no longer shipped to the South which produces by its own, but it is still placed in the Northern market. Therefore, both Northern and Southern producers do not earn export profits over the whole period of operation, which is taken into account when

discounting. Assumed financial autarky implies that in every period export revenues of the two regions are the same, thus the trade balance condition has to be satisfied. Combining the arbitrage conditions with the labor market conditions (see Appendix D for derivation), and using the trade balance, two out of three steady-state equilibrium equations are derived. The third equation comes from the arbitrage conditions combined with the trade balance, which completes the equilibrium system of three equations endogenous in γ , d and ω .

$$L_N = \beta\gamma(1 - \alpha) + \beta\alpha(r + \gamma) \frac{(1 - e^{-\gamma T}) + \omega^{\frac{\alpha}{1-\alpha}} e^{-\gamma T}}{(1 - e^{-(r+\gamma)T}) + \omega^{\frac{\alpha}{1-\alpha}} e^{-\gamma T} \frac{(1 - e^{-(r+\gamma)d})}{(1 - e^{-\gamma d})}} \quad (48)$$

$$L_S = \theta(d)\gamma(1 - \alpha) + \theta(d)\alpha(r + \gamma) \frac{e^{-\gamma T} + \omega^{\frac{\alpha}{1-\alpha}} \frac{e^{-\gamma(T+d)}}{(1 - e^{-\gamma d})}}{e^{-(r+\gamma)T} e^{rd} + \omega^{\frac{\alpha}{1-\alpha}} \frac{e^{-\gamma(T+d)}}{(1 - e^{-\gamma d})}} \quad (49)$$

$$\omega^{\frac{1}{1-\alpha}} = \frac{(1 - e^{-(r+\gamma)T}) + \omega^{\frac{\alpha}{1-\alpha}} e^{-\gamma T} \frac{(1 - e^{-(r+\gamma)d})}{(1 - e^{-\gamma d})}}{e^{-(r+\gamma)(T-d)} + \omega^{\frac{\alpha}{1-\alpha}} \frac{e^{-\gamma T}}{(1 - e^{-\gamma d})}} \eta e^{\gamma d \alpha} \quad (50)$$

As in the free trade scenario, equilibrium conditions in the restricted trade case can be compared to those in the autarky. The manufacturing labor is necessarily lower than in the autarky, which implies reallocation of workers towards R&D and an increase in the size of quality jumps. However, the magnitude of this change is now affected also by the patent length T and the equilibrium relative wage, which makes the analytical analysis complicated enough to call for a numerical solution.

5.2 Numerical exercise

Figures 11 and 12 present the results of a numerical solution in the restricted trade scenario, and the effects of different IPR policy measures introduced by the North (an increase of η and an increase of patent length T , respectively).¹² Compared to the optimal enforced patent case, the size of quality jumps is smaller for any level of protection, while the distance and the relative wage are reduced. That contributes to a higher welfare in the South, but a lower one in the North. The social planner's welfare levels are still the highest. However, in a decentralized economy, if the South is copying, the North will find it optimal to impose patents. In turn, if there is a possibility of not enforcing the patent and keeping the trade

¹²The calibration procedure is the same as that used in the previous section. See Appendix A for details.

partners, the South will find the imitation strategy to be the optimal one. In other words, the two regions end up in an equilibrium with imitation and imperfectly enforced patents.

More interestingly, the two channels of the IPR policy measures (information protection or patent length) have different welfare effects. The important issue is whether a change in any of the two IPR instruments decided by the North could compensate for the poor enforceability of the patents and restore the equilibrium welfare and growth rate under the enforced patent (dotted lines in Figures 11 and 12). For a given $T = 19.5$, which corresponds to the optimal enforceable patent length for the North, an increase in η results in a rise of the quality lag of the South (Figure 11).¹³

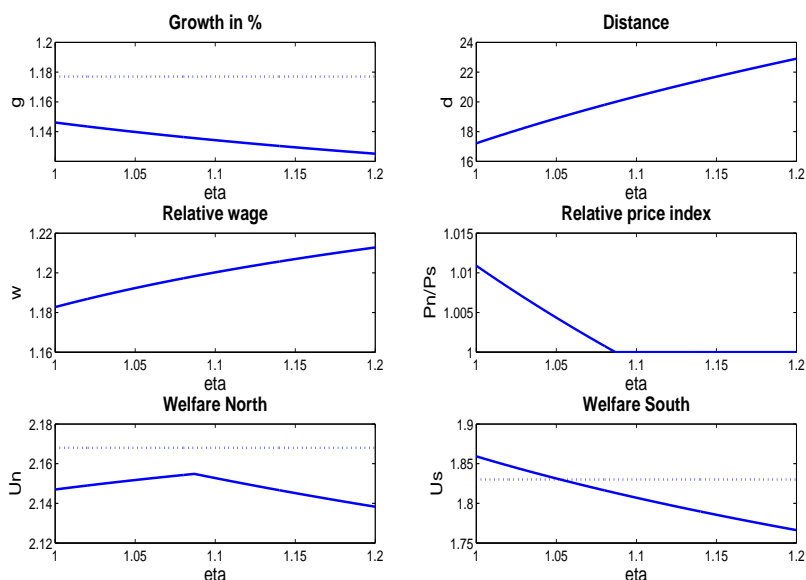


Figure 11: Non-enforced patents: effects of the information protection

For a change in η up to a certain level, the increase in the distance of the South does not affect the composition of the domestic and imported bundles of the North, i.e. the goods are still obtained from the same producer. With a rise in the relative wage, Northern goods are more expensive, resulting in an increase in the price index. However, the rise in the relative wage more than compensates for this increase in the price index and the Northern welfare rises. On the other hand, the South not only pays higher prices for Northern goods as the relative wage rises, but pays high price on more goods that are now too difficult to copy.

¹³ $T = 19.5$ is also very close to the general US patent length of 20 years.

Therefore, the Southern welfare necessarily decreases. At the same time, the relative price index falls. For an increase in η larger than 8%, the distance of the South becomes larger than the patent length, and the North has to continue with the production of some of the goods that are no longer protected but are also not copied by the South. This hurts the price index in the North as it can no longer import some of the cheap varieties from the South. At that point, the rise in the relative wage does not cover for the rise in the price index and the Northern welfare starts decreasing. It is important to note that even though the initial increase in the intensive IPR protection has a positive effect on the welfare in the North, it is not possible to reach the welfare levels of the optimal (fully enforced) patent scenario by substituting the information flow restriction for the lack of patent enforceability. Moreover, the effect on the welfare in the South is negative for any change in η .

The same conclusion holds for the change in the other policy instrument, patent length. In fact, increasing the patent length in order to compensate for bad enforcement is welfare reducing for both regions, for any change in T (Figure 12).

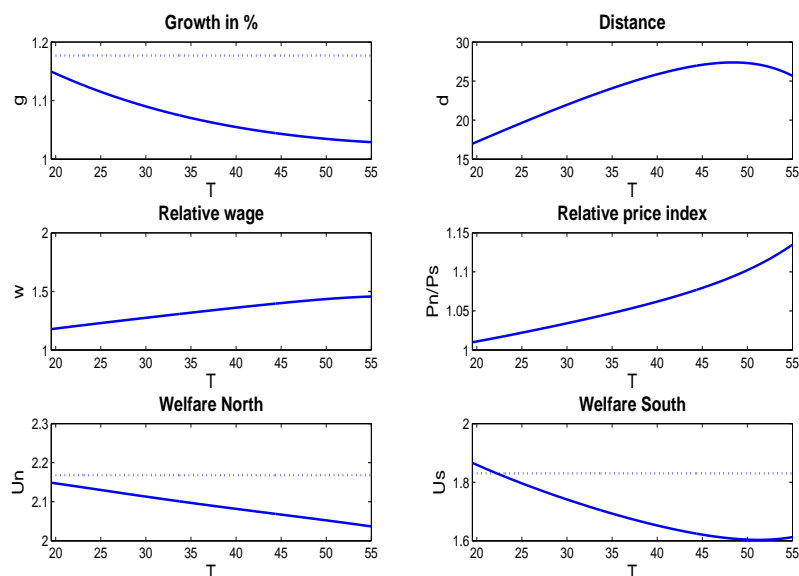


Figure 12: Non-enforced patents: effect of the patent length increase

For a given η , an increase in the patent length brings about an increase in the relative price index, which is an effect opposite to the one of the previously analyzed IPR policy tool. Rise in the quality distance is pushing up the price index in the South due to an

increase in the relative wage. Southern welfare decreases, but longer T , on the other hand, implies that now the North imports fewer varieties as more copies are banned, and thus pays higher prices for more low quality varieties (the composition effect). It turns out that the latter effect always dominates the wage effect and the welfare in the North decreases, as well. Moreover, it is not only that the price index composition effect is much stronger, but the rise in the relative wage is not as strong as in the previous scenario. Namely, longer patent increases d , but does not hurt the productivity of the R&D labor in the South directly, and therefore does not affect the relative wage to a large extent. On the other hand, an increase in η has a direct negative effect on the R&D productivity in the South which results in a stronger relative wage rise.

At lower patent lengths, the increase in the relative wage is still strong enough to secure a rising relative utility, but compared to the effect of η , the rise in the relative utility is now slower. For an even larger patent length, d starts falling and the relative wage (expenditure) increase is not sufficient to reverse the strong effect the rising relative prices have on the utility. As a result, relative welfare falls. In other word, by increasing the patent length, the North does not only hurt the welfare of both regions, but may do so to a larger extent in the case of its own consumers.

6 Conclusion

The topic of this paper has been the impact of trade and the IPR protection on the intensive margin of innovation (size of quality jumps) and the extensive margin of imitation (distance in quality, i.e. quality lag of the South) in a steady-state equilibrium. The motivation behind the proposed theoretical framework stems from the recent empirical evidence on the North-South trade patterns which reveals the regions' specialization in different qualities of the same product within industries, and much less in different products or different industries. By considering a model of North-South trade with the endogenous R&D processes in both regions, innovation in the North and imitation in the South, the paper attempts to derive the resulting growth and welfare effects of opening to trade and changes in the IPR in order to provide possible answers to some questions brought by globalization. Two alternative scenarios are considered: the autarky case as a benchmark and the trade case employing different levels and instruments of the IPR protection.

Based on the analytical and numerical analysis, it is found that opening to trade increases the growth rate of both regions while it also results in a larger lag in the quality level in the

South, implying the appearance of specialization in the South. Also, the quality lag of the South is always positive in the trading world, contradicting the predictions of the Southern catch-up due to intellectual theft.

Stronger IPR protection is not enhancing growth but relieving the monopolists from the competitive pressure. Besides the dynamic loss in growth, the static loss in both Northern and Southern welfare comes as a result of the lower quality jump and the increase in the price index (higher relative wage and higher d).

Several further questions are addressed, employing the notion of patents as opposed to the alternative IPR protection instrument, information secrecy. The paper discusses the welfare and growth implications of perfectly enforceable patents of finite length compared to the no-IPR protection scenario, and the effects of alternative IPR policy measures when patents are poorly enforced.

The imitational R&D productivity in the South decreases as the South attempts to copy products from the higher position on the quality scale, and thus, it is found that the natural distance of the South in the equilibrium will be positive even with no IPR protection. The welfare optimizing patent length, from the perspective of the North, is positive and larger than the natural distance of the South, but it necessarily reduces the welfare of the South and growth in both regions. This is due to the fact that patents do not enforce incentives for R&D, but only protect the monopoly rents, increase the wage gap and the cost of R&D in both regions. They, thus, reduce both the innovation and the imitation, and the welfare of the South. An increase in the welfare of the North comes only as a result of a higher wage. Compared to the social optimum, welfare and growth in both regions are reduced, as the optimal specialization pattern of the two regions over quality becomes distorted.

The goal of the analysis was also to determine whether an intensive form of protection (information secrecy) or the extension of the patent length can serve as a substitute in the case when patents are not enforced in the South. The results show that increased protectionism in any form results in a lower welfare in the South, while increasing information protection might increase welfare in the North up to a certain point. However, growth effects are always negative, and neither global nor individual region's welfare can attain the welfare levels of the no-IPR protection world.

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Appendix

A. Calibration

Two parameters in this model can be determined empirically (r, α), while the rest of the parameters, (β, L_N, L_S, η) , remain to be calibrated.

The interest rate is set equal to subjective discount factor and taken to be 0.04 (4 percent).

Most empirical studies show evidence on monopolistic mark-ups in the range of 10-40%, with the lowest ones being in the manufacturing industry. Since the model of interest in this paper mostly refers to such industries (with stronger monopolistic competition, less regulation and a larger number of producers), α is set closer to the lower bound at 0.89 which implies 12% mark-up and the elasticity of substitution between varieties of 8.

As there is no human capital in the model and due to presence of scale effects in the relative terms, equal size of the North and the South in the benchmark case is assumed, in order to abstract from the relative size effects. Nevertheless, the most important findings of the model prove to be robust to the changes in the relative size of the two region. There are three calibration targets:

1) 1.5-2% growth of the economy

2) Northern relative wage of 2.2 (World Bank, International Comparison Program database, online edition, 2009) which in turn gives benchmark IPR protection, η of 2.25. However, since this paper examines the impact of IPR protection (η) ranging from free information flow ($\eta = 1$) to stronger levels of protection ($\eta > 1$), the resulting relative wage with low protection will be lower. Had the model included the measure of human capital, that parameter could have been calibrated to match the size of the relative wage independent of η . In that sense, η now includes more information than IPR protection, it measures the overall productivity of the labor in the two regions, stemming from the level of the human capital and the institutional quality in the two regions.

3) 2% share of resources devoted to R&D relative to GDP in the North (average for OECD countries; National Science Foundation, US, <http://www.nsf.gov/statistics>)

The resulting parameter values are 1.0335 difficulty of innovation, β (0.97 productivity of innovation) and 0.1203 size of the population, L .

B. Proof of Proposition 2. with $\eta > 1$ or $L_N > L_S$

The quality distance in the autarky and the trade scenario are given by the condition

$$d = \frac{1}{1-\alpha} \ln\left(\frac{\eta\beta(\gamma + \alpha r)}{L_S}\right) \frac{1}{\gamma}$$

In autarky, $\eta\beta(\gamma + \alpha r) = L_N$ while in the trade equilibrium this term will increase due to increase in γ . However, γ enters the condition in the $\frac{1}{\gamma}$ term, and the direction of the change in d with opening to trade depends on the derivative $\frac{dd}{d\gamma}$.

$$\begin{aligned} \frac{dd}{d\gamma} &= \frac{1}{1-\alpha} \frac{1}{\gamma} \left(-\frac{1}{\gamma} \ln \frac{L_S}{\eta\beta(\gamma + r)} + \frac{1}{\gamma + \alpha r} \right) \\ &= (\alpha - 1)d + \frac{1}{\gamma + \alpha r}. \end{aligned}$$

For the autarky d not too large, such that it satisfies $d < \frac{1}{(1-\alpha)(\gamma + \alpha r)}$, the quality distance of the South increases with opening to trade. This also provides proof for the upward sloping Southern equilibrium condition in (γ, d) space.

C. Proof of Proposition 3.

Welfare in the North in the autarky and the trade scenario, respectively, is given by

$$U_N^A = [L_N - (1-\alpha)\beta\gamma] \left[\frac{e^{\gamma n}}{\gamma} \right]^{\frac{1-\alpha}{\alpha}}$$

in the autarky, and

$$U_N^T = [L_N - (1-\alpha)\beta\gamma] \left[\frac{e^{\gamma n}}{\gamma} \right]^{\frac{1-\alpha}{\alpha}} [\omega^{\frac{\alpha}{1-\alpha}} e^{-\gamma d} + 1 - e^{-\gamma d}]^{\frac{1-\alpha}{\alpha}}$$

in the trade scenario. The last term in the trade expression is larger than one, while the second term represents the average quality index in the North which increases with opening to trade due to an increase in γ , provided that the number of varieties (n) is large enough to satisfy $n\gamma > 1$. The first term in the welfare expression is the manufacturing labor which decreases with opening to trade. Therefore, the direction of change in the welfare is determined by the prevailing effect, an increase in average quality or decrease in manufacturing labor and thus lower production. If $n\gamma > 1$, the numerical solution shows that the positive effect dominates and the welfare increases with opening to trade.

Welfare in the South in the autarky and the trade scenario, respectively, is given by

$$U_S^A = \alpha\theta(d)(\gamma + r) \left[\frac{e^{\gamma(n-d)}}{\gamma} \right]^{\frac{1-\alpha}{\alpha}}$$

in the autarky, and

$$U_S^T = \alpha\theta(d)(\gamma + r) \left[\frac{e^{\gamma(n-d)}}{\gamma} \right]^{\frac{1-\alpha}{\alpha}} \left[1 + \omega^{\frac{\alpha}{\alpha-1}} (e^{\gamma d} - 1) \right]^{\frac{1-\alpha}{\alpha}}$$

in the trade scenario. The analysis is similar to that of the effect of opening to trade on the welfare in the North. The last term in the trade expression is larger than one, while the second term, the average quality index, increases if $n\gamma > 1$. The first term is the manufacturing labor which decreases with opening to trade. Assuming $n\gamma > 1$, the numerical solution shows that the welfare in the South increases with opening to trade.

D. Equilibrium conditions derivation, restricted trade.

The values of innovation and imitation are given by

$$\begin{aligned} V_N &= \frac{1-\alpha}{\alpha} w_N p_N^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \left[\frac{C_N L_N}{\tilde{P}_N} (1 - e^{-(r+\gamma)T}) + \frac{C_S L_S}{\tilde{P}_S} (1 - e^{-(r+\gamma)d}) \right] \\ V_S &= \frac{1-\alpha}{\alpha} w_S p_S^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \left[\frac{C_N L_N}{\tilde{P}_N} e^{-r(T-d)} e^{-\gamma T} + \frac{C_S L_S}{\tilde{P}_S} e^{-\gamma d} \right], \end{aligned} \quad (51)$$

with $\tilde{P}_i = P_i^{\frac{\alpha}{\alpha-1}} e^{-\gamma n_i}$, for $i = N, S$. Equating the value of a new variety (copy) with the cost of innovation (imitation) yields the arbitrage conditions in the North and the South, respectively

$$\begin{aligned} \frac{1}{\alpha} p_N^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \left[\frac{C_N L_N}{\tilde{P}_N} (1 - e^{-(r+\gamma)T}) + \frac{C_S L_S}{\tilde{P}_S} (1 - e^{-(r+\gamma)d}) \right] &= \beta\gamma \\ \frac{1}{\alpha} p_S^{\frac{1}{\alpha-1}} \frac{1}{r+\gamma} \left[\frac{C_N L_N}{\tilde{P}_N} e^{-r(T-d)} e^{-\gamma T} + \frac{C_S L_S}{\tilde{P}_S} e^{-\gamma d} \right] &= \theta(d)\gamma \end{aligned} \quad (52)$$

Full labor employment requires that all workers are allocated either to manufacturing or R&D sectors which translates into the following conditions

$$\begin{aligned} L_N &= \beta\gamma(1-\alpha) + p_N^{\frac{1}{\alpha-1}} \frac{1}{\gamma} \left[\frac{C_N L_N}{\tilde{P}_N} (1 - e^{-\gamma T}) + \frac{C_S L_S}{\tilde{P}_S} (1 - e^{-\gamma d}) \right] \\ L_S &= \theta(d)\gamma(1-\alpha) + p_S^{\frac{1}{\alpha-1}} \frac{1}{\gamma} \left[\frac{C_N L_N}{\tilde{P}_N} e^{-\gamma T} + \frac{C_S L_S}{\tilde{P}_S} e^{-\gamma d} \right] \end{aligned} \quad (53)$$

Assumed financial autarky implies that in every period export revenues of the two regions are the same, thus the trade balance condition has to be satisfied. This condition holds also in the free trade scenario, but due to no non-traded varieties, price-quality index is the same in both regions and the demand for any product is a share of the total world expenditure divided by the common index. Here, price indices differ and the trade balance condition is used to facilitate solving the model. The condition is given as

$$\frac{C_N L_N}{P_N^{\frac{\alpha}{\alpha-1}}} = \frac{C_S L_S}{P_S^{\frac{\alpha}{\alpha-1}}} \omega^{\frac{\alpha}{\alpha-1}} e^{\gamma T} (1 - e^{-\gamma d}) \quad (55)$$

Combining the arbitrage conditions, (52), with the labor market conditions, (53), and using the trade balance, two out of three steady-state equilibrium equations are derived. The third equation comes from the arbitrage conditions combined with the trade balance, which completes the equilibrium system of three equations endogenous in γ , d and ω .

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