

The role of intellectual property rights in a directed technical change model *

Oscar Afonso[†] and Manuela Magalhães[‡]

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Abstract

We propose a two country, *Innovator* and *Follower*, directed technical change model between tradable and nontradable sectors. The *Innovator* performs innovative R&D and the *Follower* adopts the available technological knowledge. Substitutability between sectors, scale effects, international IPRs protection and R&D productivity determine the economic growth and the technological-knowledge bias, which, in turn, affects relative prices and wages. Wages are higher in the *Innovator*, namely in the nontradable sector under strong substitutability. Technological-knowledge and intra-country wage inequality are biased towards the tradable sector, the effect being reinforced by positive IPRs protection and substitutability. Real exchange rates accommodate the Balassa-Samuelson proposal and increase with positive IPRs protection and substitutability. The effect of IPRs on the steady-state growth rate is ambiguous, depending on the substitutability. Theoretical results are also influenced by labor movements and are confirmed by a calibrated exercise for 11 developed/*Innovator* countries and 11 developing/*Follower* countries, and by the empirical evidence.

Keywords: Directed technical change, International trade, Intellectual property rights, Scale effects, Substitutability, Prices, Wages.

Classification: O30, O41, F10, F43, J31.

1 Introduction

Several important macroeconomic trends have been observed in the past decades: price level differences between countries – real exchange rates (or terms of trade) (e.g., De Gregorio and Wolf, 1994; McDonald and Ricci, 2007); inter-country wage inequality in favor of developed/*Innovator* countries, but not balanced between tradable and nontradable sectors (e.g., Freeman and Oostendorp, 2000; Atkinson and

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[†]Faculty of Economics, University of Porto; CEFAGE and OBEGEF. Corresponding author: please email to oafonso@fep.up.pt or address to Rua Dr Roberto Frias, 4200-464, Porto, Portugal.

[‡]Department of Economics, Public University of Navarre, Campus de Arrosadia, s/n, 31006 Pamplona, Spain; Department of Economics, University of Coimbra, Portugal; and CEFAGE-UBI Research Center, Portugal. Email: mane.magalhaes@gmail.com

Brandolini, 2010); intra-country wage inequality in favor of the tradable sector (e.g., Amiti and Davis, 2008; Krishina et al., 2011; Frias et al., 2012); strong technological-knowledge progress (e.g., Acemoglu, 2008); and enlarged trade flows between developed and developing/*Follower* countries as a result of the economic liberalization (e.g., Gancia and Bonfiglioli, 2008; Dicken, 2015; WTO, 2013a,b, 2014a,b, 2015a,b).

This paper fills the gap in what is known about the economic mechanisms that explain the above trends, by considering a two country, *Innovator* and *Follower*, directed technical change model between two sectors, the tradable and the nontradable, under possible different degrees of substitutability between them. The *Innovator* performs innovative R&D with different intensity of scale effects, whereas the *Follower* adopts technological knowledge in the presence of international Intellectual Property Rights (IPRs) protection. We are able to take into account economic effects on prices, wages, and technological knowledge generated by the Trade Related IPRs (TRIPS) agreement (in the statute of the WTO in 1994), that establishes minimum standards of protection for several categories of IPRs and a schedule for developing countries to adopt them.

The evidence shows that inter-country differentials in prices are generated exclusively by differences in final/consumer nontradable goods – e.g., Berka and Devereux (2010, 2013) in European Union countries – since traded goods in different countries are perfect substitutes. The Balassa (1964)-Samuelson (1964) model is the dominant proposal to explain these observed differences. Its popularity resides in the widespread observation that the relative price of nontradable goods is higher in developed countries (e.g., Summers and Heston, 1991) and the explainer mechanism is based on intra-sector productivity growth differences (e.g., MacDonald and Ricci, 2007). However, this mechanism is regarded by some as being quite weak (e.g., Rogoff, 1996; Lothian and Taylor, 2008; Chong et al., 2012). We consider that in each country the productivity mechanism depends on parameters and exogenous variables of the countries involved and is particularly induced by the bias of the technological-knowledge progress.

Regarding wages, multi-sector (open-economy) macro models propose long-run wage equalization across sectors owing to domestic labor mobility, union power, and/or fair-wage concerns (e.g., Ghironi and Melitz, 2005; Bergin et al., 2006; Kehoe and Ruhl, 2009; Carvalho and Nechio, 2011). By considering different labor types, the labor economics literature (e.g., Dickens and Katz, 1987; Krueger and Summers, 1987), the international trade literature (e.g., Bernard and Jensen, 2004; Bernard et al., 2007; Leamer, 1996; Wood, 1998), and the extended directed technical change literature (e.g., Gancia and Bonfiglioli, 2008; Afonso, 2012; Chu et al., 2015) contest the idea of long-run wage equalization across sectors.

However, these three branches of the economic literature usually consider skilled versus unskilled sectors and thus do not address all of the above observed trends. Moreover, even if they do, the sectoral division between tradable and nontradable *per se*, each of these three branches contradicts at least one trend.

The labor economics literature omits the enlarged trade flows between countries, the technological-knowledge progress, and thus the economic growth. The international trade literature emphasizes the Stolper-Samuelson theorem (e.g., Leamer, 1996; Wood, 1998), predicting a rise in the unskilled wage premium in developing countries and thus contradicts the evidence, and ignores the role of the technological-knowledge progress. The directed technical change literature (e.g., Juhn et al., 1993; Acemoglu, 2003) interprets the rise in the skill premium as a direct consequence of the increase in the relative supply of skilled labor, which, by affecting the technological-knowledge bias, increases still more the relative demand of skilled workers. However, some empirical evidence seems to contradict this explanation, and by highlighting the effect of the market size on the technological knowledge change, contradicts the dominant literature on scale effects since Jones (1995a, b). Our endogenous R&D growth model is then very flexible in relation to the scale effects, allowing for a distinct degree of scale effects.

More recently, some studies have extended the directed technical change literature to the international trade literature (e.g., Krugman, 2008; Verhoogen, 2008; Broda and Romalis, 2009; Egger and Kreickemeier, 2009; Burstein and Vogel, 2010; Helpman et al., 2010; Afonso, 2012). However, the discussion remains in terms of the explanation of the intra-country skill premium, which becomes dependent on either the market-size channel or the price of goods (price channel). Moreover, excluding the papers by Gancia and Bonfiglioli (2008) and Chu et al. (2015), the role of the IPRs on wages and growth remains basically omitted, not to mention the effect on the real exchange rate.¹

The related literature also includes Bernard and Jensen (1995, 1999, 2004), Bernard et al. (2007), Adams (2008), and Cozzi and Galli (2014). The cited Bernard papers explore the role of exporting plants within industries in the US manufacturing sector, showing that exporters have better performance than non-exporters. Exporter plants are larger, more productive, and pay higher wages. However, these empirical analyses do not discuss the theoretical mechanism nor do they consider the economy as a whole. Adams

¹Basically, the literature on IPRs discusses (i) the potential downsides of IPRs protection by affecting the efficient allocation of resources across countries (e.g., Helpman, 1993; Glass and Saggi, 2002; Dinopoulos and Segerstrom, 2004), (ii) the possibility of the IPRs promoting the technological-knowledge diffusion and growth (e.g., Lai, 1998; Yang and Maskus, 2001), by stressing the effects of IPRs on innovation (e.g., Akiyama and Furukawa, 2009), and (iii) the incentives that governments have to protect IPRs in a trading economy (e.g., Chin and Grossman, 1989; Goh and Oliver, 2002; Grossman and Lai, 2004).

(2008) analyzes the impact of globalization on income inequality, not on wage inequality, showing that strengthening IPRs and trade openness are positively correlated with income inequality in *Follower* countries. In a context without directed technical change, Cozzi and Galli (2014) reveal that tightening patent protection in basic research may increase or decrease (skill) wage inequality.

We then develop a general equilibrium endogenous growth model, which connects the (sector-specific) directed technical change and the international trade approaches. As stated above, the connection is achieved by considering a world economy composed of two sets of countries (*Innovator* and *Follower*), two sectors (tradable and nontradable), which can be substitutes or complements to produce the unique final good, by allowing the dominance of one channel – the price channel (Afonso, 2012) or the market-size channel (Gancia and Bonfiglioli, 2008) – affecting the technological-knowledge bias, by considering the role of IPRs and by accounting for technological-knowledge adoption under trade (Gancia and Bonfiglioli, 2008). Our stylized *Innovator* and *Follower* countries differ in productivity levels, labor levels, and R&D capacity. These differences are assumed to have historical roots that are reflected in current institutional characteristics. Our main concern is not to explain these differences, but rather to take them as given and analyze the behavior of both economies. The *Innovator* is more productive than the *Follower* due to domestic institutions and its R&D activities result in horizontal innovations that increase the quantity of intermediate goods. The *Follower* performs costless adoptions of innovations. However, producers of intermediate goods in the *Follower* (i.e., adopters) have to pay a fixed royalty fee to the original innovator for the use of the design.

Thus, concerning the degree of IPRs protection, it is assumed, in line with, e.g., Gancia and Bonfiglioli (2008) and international-finance models, that producers of intermediate goods in the *Follower* country have simply to pay a fixed royalty fee in terms of the aggregate output to the original innovator for the use of the design. Through our approach to model IPRs the monopoly distortion in the *Follower* does not rely on the degree of IPRs, a hypothesis that could have been followed. Nevertheless, it is important to stress that there is no agreement regarding the best way to introduce IPRs into this type of model (see, e.g., Mondal and Gupta, 2009; Sa et al., 2009; Wu, 2010).

We demonstrate that the effects on technological-knowledge bias and thus on the exchange rate, relative wages and economic growth depend crucially on the degree of substitutability between sectors, on the degree of scale effects, and on the degree of international protection of IPRs. In particular, the technological-knowledge bias measure towards the nontradable sector depends: (i) positively on the relative productivity of developing nontradable complementary intermediate goods and on the relative

importance of the nontradable sectors in production; (ii) negatively on the relative worldwide and country specific nontradable labor level; (iii) ambiguously on the degree of IPRs protection. Hence, through the bias, relative prices and intra-country wages depend ambiguously on the degree of IPRs protection, considering the range between 0 and 1, which, in turn, can affect positively or negatively the worldwide steady-state growth rate. The theoretical results, which are confirmed by a calibrated exercise for 11 developed countries (*Innovator*) and 11 developing countries (*Follower*), reveal that indeed the main macroeconomic variables – relative prices, relative wages, and economic growth rate – depend on parameters and exogenous variables of both countries:

- The inter-country relative price of the nontradable sector depends on the tradable labor levels and tends to be higher in the *Innovator* – as is also shown by the data in Figure 10 (Appendix B). In turn, the real exchange rates rely: (i) positively on the relative importance of the nontradable sector in production; (ii) negatively on the relative nontradable labor level, on the technological-knowledge bias and, in line with the Balassa (1964)-Samuelson (1964) proposal, on the relative nontradable advantage to entry through horizontal innovation. These results confirm the observed price level differences across sectors and countries (e.g., De Gregorio and Wolf, 1994; McDonald and Ricci, 2007).
- The inter-country wage inequality also tends to be higher in the *Innovator* due to the relative exogenous productivity, reflecting the country's institutions – as is also shown by the data in Figure 11a (Appendix B); moreover, under substitutability tends to be higher in the nontradable sector. In turn, the intra-country wage inequality in each country is basically positively related with the relative importance of the nontradable sector in production, negatively related with the relative supply of nontradable labor, and is also driven by technological-knowledge bias – as is also shown by the data in Figure 11b (Appendix B). These results also confirm the observed inter-country wage inequality in favor of developed/*Innovator* country(ies), which is, however, not balanced between tradable and nontradable sectors (e.g., Freeman and Oostendorp, 2000; Atkinson and Brandolini, 2010), and that, namely under strong substitutability and IPRs protection, intra-country wage inequality is biased towards the tradable sector (e.g., Amiti and Davis, 2008; Krishina et al., 2011; Frias et al., 2009).
- The strong worldwide technological-knowledge progress, reflected in the economic growth rate, is in line with, e.g., Acemoglu, (2008) and occurs in our theoretical context of trade between both countries, *Innovator* and *Follower*, thus accommodating the already emphasized trend of

enlarged trade flows between developed/*Innovator* and developing/*Follower* countries as a result of the economic liberalization (e.g., Gancia and Bonfiglioli, 2008; Dicken, 2015; WTO, 2013a,b, 2014a,b, 2015a,b). The progress is biased, however, towards the tradable sector, which as stated, due to complementarity between inputs in production, drives relative prices and intra-country wages – as is also shown by the data in Figures 12a,b (Appendix B).

The remainder of the paper is organized as follows. Section 2 deals with the set-up of the model. Section 3 extends the model to analyze the relationship between two countries under technological-knowledge diffusion through adoption with international trade, and to study the implications with respect to the technological-knowledge bias, real exchange rates, wages, and economic growth. Section 4 presents supportive quantitative results, presenting the calibration and the sensitivity analysis performed. Section 5 concludes.

2 Theoretical model

2.1 Overview

This section describes the economic set-up, emphasizing the interactions among economic agents, and the dynamic general equilibrium in which (i) households and firms are rational and solve their problems, (ii) free-entry R&D conditions are met, and (iii) markets clear.

Infinitely-lived households inelastically supply labor, maximize utility of consumption, and invest in the firm's equity. The inputs of the aggregate final good (or numeraire) are two final goods (tradable and nontradable), each composed by a large number of competitive firms: the tradable sector, T -sector, and the nontradable sector, D -sector, and each one, $j = T, D$, uses specific labor and a continuum of specific non-durable intermediate goods, $N_j(t)$. Each intermediate-goods sector consists of a continuum of industries, $n \in (0, N_j(t)]$, and there is monopolistic competition: the monopolist in industry n uses a design, sold by the R&D sector (domestically protected by a perpetual patent), and also aggregate final good in order to produce and sell at a price that maximizes profits. In the R&D sector each potential entrant devotes aggregate final good to invent successful horizontal designs to be supplied a new monopolist intermediate-goods firm/industry; i.e., the R&D sector allows increasing the number of intermediate-goods industries $N_j(t)$ and thus the technological knowledge.

2.2 Technology and preferences

Infinitely-lived households consume and collect income from investments in financial assets (equity) and from labor. They inelastically supply labor to the T -sector, L_T , or to the D -sector, L_D . Thus, total labor supply, $L_T + L_D$, is exogenous and constant. We assume that consumers have perfect foresight concerning the technological-knowledge change over time, $\frac{\dot{N}_j(t)}{N_j(t)}$, $j = T, D$, and choose the path of final-good aggregate consumption $[C(t)]_{t \geq 0}$ to maximize discounted lifetime utility $U = \int_0^\infty \left(\frac{C(t)^{1-\theta} - 1}{1-\theta} \right) e^{-\rho t} dt$, where $\rho > 0$ is the subjective discount rate, ensuring that U is bounded away from infinity if C were constant over time, and $\theta > 0$ is the inverse of the inter-temporal elasticity of substitution, subject to the flow budget constraint $\dot{a}(t) = r(t) \cdot a(t) + w_T(t) \cdot L_T + w_D(t) \cdot L_D - C(t)$, where a denotes household's real financial assets holdings and w_j is the wage for labor employed in the j -sector. The initial level of wealth $a(0)$ is given and the non-Ponzi games condition $\lim_{t \rightarrow \infty} e^{-\int_0^t r(s) ds} a(t) \geq 0$ is imposed. The resulting optimal consumption path is given by the Euler equation,

$$\frac{\dot{C}(t)}{C(t)} = g = \frac{1}{\theta} \cdot (r(t) - \rho), \quad (1)$$

and the transversality condition, $\lim_{t \rightarrow \infty} e^{-\rho t} \cdot C(t)^{-\theta} \cdot a(t) = 0$, are standard. The aggregate financial wealth held by households is composed of equity of intermediate goods producers $a(t) = a_T(t) + a_D(t)$, where $a_j(t) = N_j(t)V_j(t)$, $j = T, D$, where N_j is the number of available intermediate goods and the technological-knowledge frontier in the j -sector, and V_j is the present value of monopoly profits seized by each intermediate good producer – see the analysis below. The aggregate flow budget constraint is equivalent to the final product market equilibrium condition $Y(t) = C(t) + X(t) + Z(t)$, where $Y(t)$ is the aggregate final good (or numeraire), $X(t)$ is the total investment in intermediate goods production and $Z(t)$ is the aggregate R&D expenditures. Final-good producers are competitive and Y is produced with a CES aggregate production function of tradable and nontradable final goods:

$$Y(t) = \left[\chi_T Y_T(t)^{\frac{\varepsilon-1}{\varepsilon}} + \chi_D Y_D(t)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \quad \varepsilon \in (0, +\infty), \quad (2)$$

where: Y_T and Y_D are the total outputs of the T -sector and the D -sector, respectively – i.e., the tradable and nontradable final goods; χ_T and χ_D , with $\chi_T + \chi_D = 1$, are the distribution parameters, measuring the relative importance of the inputs; $\varepsilon \geq 0$ is the elasticity of substitution between the two inputs, wherein $\varepsilon > 1$ ($\varepsilon < 1$) means that sectors are gross substitutes (complements) in

the production of Y .² We normalize the price of the aggregate final good at unit, $P_Y \equiv 1$;³ thus, $P_Y \equiv 1 = [\chi_T^\varepsilon P_T^{1-\varepsilon} + \chi_D^\varepsilon P_D^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$, where P_T and P_D are the prices of the outputs of, respectively, the T -sector and the D -sector, and the right-hand side of the expression is the unit cost of production. This normalization, together with the assumption of competitive final-good firms, implies the following maximization problem: $\text{Max } \Pi = Y - P_T Y_T - P_D Y_D$. From the first order conditions, the relative price of the D -sector (in terms of the T -sector); i.e., “the real exchange rate”, is:⁴

$$\frac{P_D}{P_T} = \frac{\chi_D}{\chi_T} \left(\frac{Y_D}{Y_T} \right)^{-\frac{1}{\varepsilon}}, \quad (3)$$

Hence, the relative price of the D -sector is an increasing function of the relative importance of the sector's output, $\frac{\chi_D}{\chi_T}$, and a decreasing function of the relative output of the sector, $\frac{Y_D}{Y_T}$.

The output of each final-goods sector, tradable and nontradable, is produced with specific labor, L_j , and with a quantity x_j of a continuum set of available complementary non-durable differentiated intermediate goods $n \in (0, N_j]$. To solve the model analytically, we use the Dixit-Stiglitz constant elasticity structure for production:

$$Y_j = A \cdot L_j^\alpha \cdot \int_0^{N_j} x_j(n)^{1-\alpha} dn, \quad j = T, D, \quad (4)$$

where: A is a positive exogenous variable representing the level of productivity, dependent on the country's institutions; $1 - \alpha$ and $\alpha \in [0, 1]$ are the intermediate-goods and the labor shares, respectively; N_j represents the number of already available intermediate goods. The maximization problem facing the firms in the j -sector is $\text{Max } P_j Y_j - w_j L_j - \int_0^{N_j} P_{x_j(n)} x_j(n) dn$, $j = T, D$, where $P_{x_j(n)}$ is the prices of the intermediate good n used in the j -sector and w_j is the wage paid for L_j .⁵ From the first order conditions, we have $w_j = \alpha \cdot P_j \cdot A \cdot L_j^{\alpha-1} \cdot \int_0^{N_j} x_j(n)^{1-\alpha} dn = \alpha \frac{P_j Y_j}{L_j}$ and $x_j(n) = \left(\frac{A \cdot (1-\alpha)}{P_{x_j(n)}} \right)^{\frac{1}{\alpha}} L_j$, $j = T, D$; that is:

²In particular, cases where $\varepsilon = 0$, $\varepsilon = 1$ and $\varepsilon = +\infty$ we have, respectively, a Leontieff, a Cobb-Douglas and a Linear production function. There is a spirited discussion in the literature on the estimated value, by looking at the elasticity of substitution between domestic and foreign goods. Some examples, using the US data, include Blonigen and Wilson (1999) – average value of 0.81 –, Feenstra et al. (2014) – with elasticities ranging from approximately 0.88 to 4 –, Acemoglu and Ventura (2002) – average value of 2.60 –, Gallaway et al. (2003) – average value for macro elasticities of 1.55 –, Broda and Weinstein (2006) and Epifani and Gancia (2009) – have estimated ε , respectively, in the intervals 2.7-3.6 and 2.2-2.6. Moreover, for the European Monetary Union, Rabanal and Tuesta (2013) present values that range between 0.13 and 1.

³To simplify notations, we suppress the time argument t and will do so throughout, wherever this causes no confusion.

⁴It is a measure of the real exchange rate between tradable and nontradable final goods sectors since it evaluates how one unit of the T -sector exchanges for a unit of the D -sector. Moreover, since the international trade is assumed to be balanced and, under international trade, P_T should be common in all countries, whereas P_D generally differs across countries, the ratio $\frac{P_D}{P_T}$ is indeed “the real exchange rate”.

⁵Since the (labor complementary) intermediate goods depreciate fully after use, the optimizations for the j -sector, $j = T, D$, are static.

(i) the wage paid for the labor employed in each sector $j = T, D$, w_j , is equal to the respective marginal contribution; (ii) the demand for the n -type intermediate good used in each sector, $x_j(n)$, depends on the price of the respective output, P_j , since the higher the price of the output, the greater the demand for n , on the price of the intermediate good, $P_{x_j(n)}$, since the demand for n is a decreasing function of its own price, and on the respective employed labor level, L_j , since greater supply of labor raises the productivity of n , thereby increasing its demand.

Once the intermediate-good firm has a new design, sold by the R&D sector, it can retain a perpetual monopoly over its use. The production of one intermediate good requires η units of Y . Thus, the flow of the monopolist's operational profit, which sells its good to the j -sector, at a point of time, is $\pi_j(n) = [P_{x_j(n)} - \eta] \cdot x_j(n)$, $j = T, D$, and the present value of the returns from the operation is $V_j = \int_t^\infty \pi_j(v) \cdot e^{-\int_t^v r(\omega) d\omega} dv$, $j = T, D$, where r is the interest rate. Hence, the monopolist faces a demand curve, solves the problem $\max \int_t^\infty [P_{x_j(v)} - \eta] \cdot x_j(v) \cdot e^{-\int_t^v r(\omega) d\omega} dv$, $j = T, D$, and reaches $P_{x_j(n)} = P_x = \frac{\eta}{1-\alpha} = 1$, considering by simplification that $\eta = 1 - \alpha$, as in Acemoglu (2002).⁶ Hence, the profit maximizing price of intermediate goods is equal to one unit of Y , implying that one unit of each intermediate good employed by either sector is exchanged one for one with Y . Indeed, the isoelastic nature of the demand for n implies that each monopolist sets a constant markup over the marginal cost: $1 > \eta$ since $\alpha \in [0, 1]$. Thus, each monopolist charges the same price, produces the same amount, and has the same profit at every period, and the present value of the monopoly operational profit is therefore the same for each firm.

To analyze the productive equilibrium under constant technological knowledge we begin by substituting the equilibrium price of intermediate goods into the demand functions, resulting in $x_j(n) = x_j = P_j^{\frac{1}{\alpha}} \cdot L_j$, $j = T, D$. Thus, the equilibrium intermediate-goods demand functions do not depend on the intermediate good and, as a result, profits are also independent of intermediate-goods variety. Substituting the demand functions into the flow of the monopolist's operational profit gives $\pi_j(n) = \pi_j = \alpha \cdot P_j^{\frac{1}{\alpha}} \cdot L_j$, $j = T, D$. Bearing also in mind the intermediate-goods demand functions, equation (4) can be written as $Y_j = P_j^{\frac{1-\alpha}{\alpha}} \cdot A \cdot L_j \cdot N_j$, $j = T, D$, which indicates that the equilibrium quantity produced in each final-goods sector, tradable and nontradable, depends positively on the sector's output price, P_j , labor level, L_j , technological-knowledge level, N_j , as well as on the exogenous productivity, A . Now, from the expression for Y_j and (3), the relative price of the D -sector intermediate

⁶Without loss of any generality, we normalize the marginal cost to $\eta = 1 - \alpha$ in order to simplify the algebra, since, even in the calibration exercise, we are not interested in comparative statics with respect to α .

input (“real exchange rate”) can be rewritten as:

$$\frac{P_D}{P_T} = \left[\left(\frac{\chi_D}{\chi_T} \right)^{\varepsilon\alpha} \left(\frac{L_D \cdot N_D}{L_T \cdot N_T} \right)^{-\alpha} \right]^{\frac{1}{1+\Omega}}, \quad (5)$$

where $1 + \Omega$, with $\Omega \equiv (\varepsilon - 1)\alpha$, is the elasticity of substitution between the two (tradable and nontradable) final goods in the aggregate final good production; in fact, $1 + \Omega > 1$ occurs only when $\varepsilon > 1$. Thus, the “real exchange rate” depends positively on $\frac{\chi_D}{\chi_T}$ and negatively on $\frac{N_D}{N_T}$ and on $\frac{L_D}{L_T}$. To reach the relative wage, $\frac{w_D}{w_T}$, with constant technological knowledge, the expression for Y_j and (5) should be substituted into the expression for w_j above:

$$\frac{w_D}{w_T} = \left[\left(\frac{\chi_D}{\chi_T} \right)^{\varepsilon} \left(\frac{L_D}{L_T} \right)^{-1} \left(\frac{N_D}{N_T} \right)^{\Omega} \right]^{\frac{1}{1+\Omega}}, \quad (6)$$

and thus the intra-country wage inequality depends positively on $\frac{\chi_D}{\chi_T}$ and on $\frac{N_D}{N_T}$ if $\varepsilon > 1$, and negatively on $\frac{L_D}{L_T}$ and on $\frac{N_D}{N_T}$ if $\varepsilon < 1$.

3 Technological-knowledge diffusion under trade

We now extend the model to analyze the relationship between two countries/areas. We consider, as in trade-theory tradition (e.g., Barro and Sala-i-Martin, 1997; Afonso, 2012), that there are neither *Innovator-Follower* movements of labor nor *Innovator-Follower* movements of firms; as a result, wages and interest rates are domestically found,⁷ and that international trade between the *Innovator* and the *Follower* in tradable final goods, Y_T , is always balanced. Moreover, we assume that R&D adoption activity, allowed by international trade, is costless. Concerning the degree of IPRs protection, in line with, e.g., Gancia and Bonfiglioli (2008) and international-finance models, it is also assumed that producers of intermediate goods in the *Follower* country; i.e., adopters have to pay a fixed royalty fee in terms of Y to the original innovator for the use of the design.⁸ Each adopter is granted by the government (in F)

⁷In order to emphasize the technological-knowledge diffusion under trade, we assume, as in the tradition of international trade theory, that there are inter-internationally immobility of assets (institutions, labor, and shares of firms that have the exclusive use of the designs). As a result, interest rates and wages are domestically determined. Therefore, although intra-*Follower* and inter-country productivity differences are affected when diffusion under trade starts, this level effect does not fully equalize inter-country productivity, due to the international immobility of assets and international differences in the exogenous productivity.

⁸Through this procedure to model IPRs, the monopoly distortion in the *Follower* does not rely on the degree of IPRs, a hypothesis that could have been followed. This alternative option would be innocuous for our main qualitative results except for welfare analysis, which, however, is not in the main scope of the paper. It could still be considered that adopted intermediate goods are sold at marginal cost and model IPRs protection as an additional per-unit cost that must be paid to the original innovator in the form of royalties; however, we would complicate the algebra of the model without affecting the quality of the main results. Moreover, in contexts in

monopoly power in producing domestically the adopted intermediate good. Since the post-trade adoption royalty fee is positive, it is profitable for just one firm in F to adopt a new design. Furthermore, we assume that intermediate goods are nontraded, implying that, consistent with most patent laws, firms in F are never allowed to re-export adopted intermediate goods to I and rule out international competition between intermediate-goods firms.⁹ Thus, by the costless technological-knowledge adoption, F has access to the top technological knowledge, but its productivity is smaller due to the exogenous productivity dependent on the country's institutions, $A^I > A^F$, and also may be due to the labor levels.

Therefore, in order to analyze how international trade in tradable final goods can account for intra and inter-country productivity differences, we use, for the sake of the derivations, the subscript/index W to define the world level of the variables. Hence, we assume that: (i) there is international trade in tradable final goods, having an integrated single market (the world market) for Y_T ; (ii) F adopts intermediate goods if unavailable domestically, and thus has access to the same technological knowledge as I since ideas can flow rapidly across borders, and therefore both countries use the technological knowledge in I , N_D^I and N_T^I , in production. As a result, the improvement in the technological-knowledge level available and used in F is a static benefit of international trade since F enjoys an immediate absolute and relative to I benefit in terms of aggregate product and factor prices. The dynamics (growth effects) involve F as well as I , due to interaction (feedback) between the countries. As in the pre-trade context, the country's demand for intermediate goods in $j = T, D$ depends on the price of the sector's output, P_j , and on the respective labor level, L_j .

Now, under trade, we need to specify/detail the aggregate tradable output, Y_T , in each country $i = I, F$. In line with Gancia and Bonfiglioli (2008) and Gancia et al. (2013), we interpret this aggregate output as a continuum mass of tradable varieties indexed by $u \in [0, 1]$, which, as we will see, is equivalent but makes the analysis clearer. Since countries have different tradable factor en-

which international trade can be dispensed, two other alternative modeling strategies are usually considered: (i) one abstracts from international trade and focuses on international technology linkages, as has been frequently adopted in the growth literature that looks into cross-country data (e.g., Borensztein et al., 1998; Dinopoulos and Thompson, 2000; Caselli and Coleman, 2006; Vandenbussche et al., 2006; Fadinger and Mayr 2014); (ii) the other takes into account a scenario of North-South technological-knowledge diffusion even without trade – in line with, e.g., Barro and Sala-i-Martin (1997) – where one country innovates, the *Innovator*, and the other imitates, the *Follower*, in which the costly imitation activity is inversely related to the inter-country technological-knowledge gap. In this latter case, IPRs protection would affect imitation activity (e.g., Park and Lippoldt, 2005; Nair-Reichert and Duncan, 2008; Trommetter, 2010; Ivus, 2011). However, it is important to highlight that there is no agreement in the literature regarding the best way to model IPR in this type of model (see, e.g., Mondal and Gupta, 2009; Sjöe et al., 2009; Wu 2010).

⁹As emphasized by Gancia and Bonfiglioli (2008), by considering that the royalty fee from selling intermediate goods in F is a form of trade in technology and equipment, we are in line with, for example, Eaton and Kortum (2001) and Caselli and Wilson (2004), who claim that advanced countries export technology and equipment to the rest of the world.

dowments and the productivity in each tradable variety depends on factor endowments, under free trade each country will then produce different varieties. In particular, we consider that each competitive variety u is produced by F or I , such that the respective output at any period of time is $Y_{Tu} = \left[\int_0^{N_T^I} x_{Tu}(n)^{1-\alpha} dn \right] \left[\left((1-u) A^{F(\frac{1}{\alpha})} L_{Tu}^F \right)^\alpha + \left(u A^{I(\frac{1}{\alpha})} L_{Tu}^I \right)^\alpha \right]$, where: (i) $x_{Tu}(n)$ is the quantity of the intermediate good n used by variety u ; (ii) the labor terms include the quantities employed in the production of the u^{th} variety, L_{Tu}^i ($i = F, I$), and two types of corrective, but important, factors accounting for productivity differentials. Firstly, as I 's institutions are, by hypothesis, more advanced, we consider $A^I > A^F$, which means that an absolute productivity advantage of L_T^I over L_T^F is accounted for. Secondly, the relative productivity advantage of each L_T^I or L_T^F is captured by the adjustment terms $1-u$ and u , meaning that L_T^F (L_T^I) is relatively more productive in tradable varieties indexed by u close to 0 (1); i.e., the use of the adjustment terms transforms the index u into a relevant ordering index, implying that I is relatively more productive in producing varieties indexed by larger u s and vice-versa. Since $u \in [0, 1]$, there is a threshold variety $\bar{u}$, where the switch from one technology to another becomes advantageous. Hence, the optimal choice of the producer country of the variety u is reflected in the equilibrium threshold variety $\bar{u}$ (e.g., Acemoglu and Zilibotti, 2001; Afonso, 2012), which defines the structure of varieties production; i.e., there are $\bar{u}$ varieties produced in F and $(1 - \bar{u})$ varieties produced in I .

The production function of each variety combines complementarity between inputs with substitutability between countries. Proceeding similarly as in Subsection 2.1 for the aggregate tradable sector, the price of each intermediate is $P_{x(n)}^i = P_x^i = 1$, and then bearing in mind the intermediate-goods demand functions, $x_{Tu}(n)$, the set of u tradable varieties produced by each country is, similarly to the one obtained in Subsection 2.1, $\int_0^{\bar{u}} P_{Tu}^F Y_{Tu}^F du \equiv Y_T^F = (P_T^F)^{\frac{1-\alpha}{\alpha}} A^F L_T^F N_T^I$ and $\int_{\bar{u}}^1 P_{Tu}^I Y_{Tu}^I du \equiv Y_T^I = (P_T^I)^{\frac{1-\alpha}{\alpha}} A^I L_T^I N_T^I$, where P_T^F and P_T^I are the index prices of tradable varieties produced by F and I , respectively, and $L_T^F = \int_0^{\bar{u}} L_{Tu}^F du$ and $L_T^I = \int_{\bar{u}}^1 L_{Tu}^I du$. Therefore, the consideration of the production function in the previous paragraph for tradable varieties is equivalent to the consideration of the aggregate production function (4) for the tradable sector in Subsection 2.1.

Moreover, balanced international trade implies that:

$$\underbrace{\mathcal{B}^F \cdot \left(P_T^W \right)^{\frac{1-\alpha}{\alpha}} \cdot A^F \cdot L_T^F \cdot N_T^F}_{F\text{-}exports=I\text{-}imports} = \underbrace{\mathcal{B}^I \cdot \left(P_T^W \right)^{\frac{1-\alpha}{\alpha}} \cdot A^I \cdot L_T^I \cdot N_T^I}_{I\text{-}exports=F\text{-}imports} \Leftrightarrow \frac{\mathcal{B}^F}{\mathcal{B}^I} = \frac{A^I \cdot L_T^I}{A^F \cdot L_T^F}, \quad (7)$$

where: (i) $\mathcal{B}^F$ and $\mathcal{B}^I$ are the fixed fraction of the output of the T -sector traded, respectively, by F and I ;

(ii) $\frac{\mathcal{B}^F}{\mathcal{B}^I}$ measures the relative importance of the exports of F ; (iii) due to free trade, the index price is equal for both countries, $P_T^F = P_T^I = P_T^W$. Now, following Acemoglu and Zilibotti (2001) and Afonso (2012), for example, the threshold variety comes from profit maximization (by perfectly competitive producers of the varieties and by monopolist producers of intermediate goods) and full employment equilibrium in labor markets, given the labor supply, L_T^i ($i = F, I$), and the current technological knowledge, N_T^I : the resulting threshold is $\bar{u} = \left[1 + \left(\frac{\mathcal{B}^I A^I L_T^I}{\mathcal{B}^F A^F L_T^F} \right)^{1/2} \right]^{-1}$, which thus depends on country-specific aggregate tradable labor, L_T^i ($i = F, I$), on the exogenous (aggregate) country-specific productivity, A^i ($i = F, I$), and on the fixed fraction of the output of the T -sector traded, $\mathcal{B}^i$ ($i = F, I$). The threshold variety $\bar{u}$ can be expressed in terms of price indexes, which is achieved by considering that in the production of the threshold $\bar{u}$ both countries should break even. This turns out to yield the following ratio of price indexes $\frac{P_T^I}{P_T^F} = \left(\frac{\bar{u}}{1-\bar{u}} \right)^\alpha$. By considering balanced trade and $P_T^F = P_T^I = P_T^W$, the expression for $\bar{u}$ and $\frac{P_T^I}{P_T^F}$ are consistent: the ratio $\frac{\mathcal{B}^I A^I L_T^I}{\mathcal{B}^F A^F L_T^F}$ within the expression for the final threshold variety is 1 and, consequently, $\bar{u} = 0.5$, which, in turn, implies that $\frac{P_T^I}{P_T^F} = 1$. Thus, varieties indexed by u between 0 and 0.5 are produced in F , whereas varieties indexed by u between 0.5 and 1 are produced by I .

From (7) the following fact results.

Fact 1. *Since international trade between countries is balanced and due to the technological-knowledge diffusion the Follower country has access to the worldwide technological knowledge, $N_T^F \equiv N_T^I$, the relative importance of the Follower exports becomes given by exogenous variables – A^I , A^F , L_T^I and L_T^F . Moreover, if together the international differences in the exogenous productivity and the international differences in labor levels imply that $A^I \cdot L_T^I > A^F \cdot L_T^F$ the relative importance of the Follower exports is greater than 1, as is observed in data – see Table 6 in the Appendix.¹⁰*

To sum up, as in Subsection 2.1, in terms of aggregate tradable and nontradable final goods we have:

$$Y_D^i = \left(P_D^i \right)^{\frac{1-\alpha}{\alpha}} \cdot A^i \cdot L_D^i \cdot N_D^I, \quad Y_T^i = \left(P_T^W \right)^{\frac{1-\alpha}{\alpha}} \cdot A^i \cdot L_T^i \cdot N_T^I, \quad i = I, F, \quad (8)$$

indicating that the equilibrium quantity of the output of the j -sector depends positively on: (i) the price at which the input produced in the sector is sold, P_D^i or P_T^W ; (ii) the exogenous productivity, A^i ;¹¹ (iii)

¹⁰The average value for the relative exports of F in the set of 22 countries analysed between 2010 and 2014 is $\frac{\mathcal{B}^F}{\mathcal{B}^I} = \frac{1.4}{0.89} = 1.57$ – see Section 4.

¹¹As already stated in (4), A^i is a positive exogenous variable representing the level of productivity, dependent on the country's domestic institutions (i.e., non-international trade related), namely property rights, tax laws and government services.

the labor employed in the sector, L_D^i or L_T^i ; (iv) the (worldwide available) technological knowledge in I , N_D^I or N_T^I .

Bearing in mind (8) and (3), we can analyze how, intra-country, one unit of the intermediate input of the T -sector exchanges for intermediate input of the D -sector in each country:

$$\frac{P_D^i}{P_T^W} = \left[\left(\frac{\chi_D^i}{\chi_T^i} \right)^\varepsilon \left(\frac{L_D^i \cdot N_D^I}{L_T^i \cdot N_T^I} \right)^{-1} \right]^{\frac{\alpha}{1+\alpha}}, \quad i = I, F, \quad (9)$$

where $\chi_T^I \neq \chi_T^F$ and $\chi_D^I \neq \chi_D^F$ since, for example, countries have different factor endowments. $\frac{P_D^i}{P_T^W}$ in (9) is also the “real exchange rate” since only P_D^i (generally) differs across countries. In each country, $\frac{\chi_D^i}{\chi_T^i}$ raises the relative price of the D -sector and, on the other hand, $\frac{L_D^i}{L_T^i}$ and $\frac{N_D^I}{N_T^I}$ make the relative price lower. This means that, *ceteris paribus*, the endogenous technological-knowledge bias towards the tradable sector, $\frac{N_T^I}{N_D^I}$, positively affects $\frac{P_D^i}{P_T^W}$, which is nonetheless consistent with the Balassa (1964)-Samuelson (1964) proposal. In this proposal, the path of the relative price of nontradable goods is also driven by intra-sector productivity growth differences; however, in our case, intra-sector productivity growth differences rely on parameters and exogenous variables of the countries involved, it being clear that the international trade affects the price channel in F and in I , and are particularly induced by the technological-knowledge bias, $\frac{N_D^I}{N_T^I}$ – see equation (9). That is, in our case, the price level differences between countries can be ascribed to different productivity differentials between tradable and nontradable sectors induced by the technological-knowledge bias, resulting in the real exchange rate tending to be higher in countries whose tradable sector has greater productivity than the domestic sector.

In turn, from (9), the inter-country relative price of the D -sector is:

$$\frac{P_D^I}{P_D^F} = \left[\left(\frac{\chi_D^I}{\chi_D^F} \right)^\varepsilon \cdot \frac{L_T^I \cdot L_D^F}{L_D^I \cdot L_T^F} \right]^{\frac{\alpha}{1+\alpha}}, \quad (10)$$

and taking into account that the D -sector is relatively more important in I , we assume, concerning the distribution parameters in (2) and the labor level in (4), that $\frac{\chi_D^I}{\chi_T^I} > 1 > \frac{\chi_D^F}{\chi_T^F} \Leftrightarrow \frac{\chi_T^I}{\chi_T^F} > 1 > \frac{\chi_D^F}{\chi_D^I}$ and $\frac{L_D^I}{L_T^I} > \frac{L_D^F}{L_T^F} \Leftrightarrow \frac{L_T^I \cdot L_D^I}{L_D^F \cdot L_T^F} > 1$.

Proposition 1. *The inter-country relative price of the D -sector depends positively on the inter-country relative labor levels in the T -sector and, if $\left(\frac{\chi_D^I}{\chi_D^F} \right)^\varepsilon \cdot \frac{L_T^I \cdot L_D^F}{L_D^I \cdot L_T^F} > 1$, is greater than 1.*

Proof. It results directly from (10).

□

Without international movements of both labor and firms, wages and interest rates are domestically found. Therefore, concerning the intra-country, $\frac{w_D^i}{w_T^i}$, and inter-country relative wages, $\frac{w_D^F}{w_D^I}$, which are the wage inequality measures, it should be emphasized that, from w_j in Section 2, $w_D^i = \alpha \frac{P_D^i Y_D^i}{L_D^i}$ and $w_T^i = \alpha \frac{P_T^W Y_T^i}{L_D^i}$, and then bearing in mind (8), (9), and that $\frac{P_T^F}{P_T^I} = \frac{P_T^W}{P_T^I} = 1$ results in:

$$\frac{w_D^i}{w_T^i} = \left[\left(\frac{\chi_D^i}{\chi_T^i} \right)^\varepsilon \left(\frac{L_D^i}{L_T^i} \right)^{-1} \left(\frac{N_D^I}{N_T^I} \right)^\Omega \right]^{\frac{1}{1+\Omega}}, \quad i = I, F, \quad (11)$$

$$\frac{w_D^I}{w_D^F} = \left[\left(\frac{\chi_D^I}{\chi_D^F} \right)^\varepsilon \frac{L_T^I \cdot L_D^F}{L_D^I \cdot L_T^F} \right]^{\frac{1}{1+\Omega}} \cdot \left(\frac{A^I}{A^F} \right), \quad (12)$$

$$\frac{w_T^I}{w_T^F} = \frac{A^I}{A^F}. \quad (13)$$

From (11), the intra-country wage inequality depends: (i) positively on $\frac{\chi_D^i}{\chi_T^i}$; (ii) negatively on $\frac{L_D^i}{L_T^i}$; (iii) positively (negatively) on $\frac{N_D^I}{N_T^I}$ when the elasticity of substitution is greater (smaller) than one. Since intra-country wage inequality depends on $\frac{N_D^I}{N_T^I}$ a more detailed analysis will be made below after finding the expression for the equilibrium endogenous worldwide technological-knowledge bias.

Moreover, from (12) and (13) we conclude that:¹²

Proposition 2. *Inter-country wage inequality is greater than 1: in the T sector because the positive exogenous productivity dependent on the country's institutions is greater than 1, $A^I > A^F$, and in the D sector under the condition $\left(\frac{\chi_D^I}{\chi_D^F} \right)^\varepsilon \frac{L_T^I \cdot L_D^F}{L_D^I \cdot L_T^F} \left(\frac{A^I}{A^F} \right)^{1+\Omega} > 1$. However, it is not balanced between sectors, being higher in the D-sector if $\left(\frac{\chi_D^I}{\chi_D^F} \right)^\varepsilon \frac{L_T^I \cdot L_D^F}{L_D^I \cdot L_T^F} > 1$ and there is strong substitutability between sectors.*

Proof. It results directly from (12) and (13).

□

¹²Concerning the inter-country wage differentials, we are, in a certain way, in line with the North-South trade models of Helpman (1993) and Dinopoulos and Segerstrom (2004), as well as in Mondal and Gupta (2009) in which IPRs in “the South” increase the inter-country wage differential. In our case, however, inter-country wage differentials are not directly related with IPRs, but with the process of technological-knowledge diffusion that involve IPRs.

We can also compute the profitability facing new innovators in I , bearing in mind that each new intermediate good is produced in I and demanded in both I and F , $x_j^I(n) = \Re \cdot (P_j^F)^{\frac{1}{\alpha}} L_j^F + (P_j^I)^{\frac{1}{\alpha}} L_j^I$, $j = T, D$, where $\Re \in [0, 1]$ is thus the fixed fraction royalty fee in terms of Y paid to the innovator of the value of the design in F . As a result, substituting the expression for $x_j^I(n)$ into the maximization problem of innovators gives, under constant technological knowledge, the following equilibrium profits for innovator firms: $\pi_j^I = \alpha \cdot \left[\Re \cdot (P_j^F)^{\frac{1}{\alpha}} L_j^F + (P_j^I)^{\frac{1}{\alpha}} L_j^I \right]$, $j = T, D$, $P_T^F = P_T^I = P_T^W$. Hence, when IPRs are fully protected, $\Re = 1$, the royalty fee is exactly equal to the present discounted value of the stream of monopoly profits earned from selling the intermediate good in F . In turn, when IPRs protection is null, $\Re = 0$, innovators do not receive any payment from the adopter. In any case, the endogenous component of the technological-knowledge, N_j^I , is identical in both countries and all intermediate goods are sold by local monopolists (Bertrand competition ensures that only one firm adopts a new intermediate good). Thus, the role of $\Re$ is just to determine how much of the revenue from selling intermediate goods in F accrues to the original innovator, which can be interpreted as an index of the strength of IPRs protection.

Let us now consider the R&D sector to endogenize the rate and the direction of the technological knowledge, considering once again that a successful innovator has the exclusive rights over the use of his/her new intermediate good. The technological-knowledge progress $\frac{\dot{N}}{N}$ arises from the production of new designs in the R&D sector, since each new design is publicly observable.¹³ Below, we start by presenting the seminal technological-knowledge production functions to justify our lab-equipment set-up, also discussing the relationship between scale effects and market-size effects, and then we also justify the crucial terms of our lab-equipment R&D production function.

Based on the R&D technology, Rivera-Batiz and Romer (1991) considered that when the inputs to R&D are labor and the level of technological knowledge, the model is called knowledge-driven – e.g., Romer (1990). When R&D technology uses the same inputs and in the same proportion as aggregate output or, equivalently, if aggregate output itself is the input to R&D, the model is called lab-equipment – e.g., Rivera-Batiz and Romer (1991) and Barro and Sala-i-Martin (2004, chaps. 6-7). Since Romer (1990), as a result of the chosen R&D production function, many endogenous R&D-based growth models suffer from some scale effects. This implies that a larger labor force causes greater technological-knowledge progress since there is more labor for R&D (e.g., Jones, 1999). Acemoglu (2002) shows that the R&D-based growth model also features market-size effects under which the technological knowledge is increasing in the labor level that uses the technological knowledge. Thus, the scale effects and the market-size effect

¹³In our case with two sectors, tradable and nontradable, we should use the index j ; i.e., $\dot{N}_j$, $j = T, D$. For simplification, in this process of justifying our R&D production function, we ignore the index j .

are closely related: the supply of research labor determines the scale effects, whereas the demand from production labor for technologies determines the market-size effects. Under knowledge-driven R&D that uses research labor as input, only the scale effect matters to innovation. Under lab-equipment R&D that uses final good as input, only the market-size effect matters to innovation. However, since there is little relationship between economic growth and the size of the economy (e.g., Backus et al., 1992; Jones 1995b), the inputs of the R&D production function should allow to remove or soften the effect of market size on the growth rate of the economy; i.e., the R&D technology should ensure that economic growth is relatively independent of labor.

In the knowledge-driven Romer (1990) model, the R&D technology is $\dot{N} = \delta L_N N$, where: δ is a scale parameter that can be interpreted as the success probability that any researcher has of inventing a new design in any period; L_N is the labor level dedicated to the R&D production (research labor); N is the accumulated technological knowledge. The new technological knowledge $\dot{N}$ is available to contribute to new progress. By rewriting this equation, we have $\frac{\dot{N}}{N} = \delta s$, where s is the fraction of labor employed in the R&D sector so that constant population is needed for a balanced growth path to exist, and for the same fraction of labor employed in the R&D sector, the economy with the highest population has the highest growth rate; i.e., the economy suffers from scale effects. In the knowledge-driven Jones (1995a) model, the R&D technology is $\frac{\dot{N}}{N} = \delta L_N N^\phi l_N^{\lambda-1}$, where: ϕ represents external returns and can have any sign; l_N represents an externality due to duplication in R&D such that in equilibrium $l_N = L_N$; $0 < \lambda \leq 1$.¹⁴ Hence, in equilibrium, we have $\frac{\dot{N}}{N} = \frac{\delta s^\lambda L^\lambda}{N^{1-\phi}}$ so that $L^\lambda N^{\phi-1}$ has to be constant for a balanced growth path to exist. If population grows at the rate n this is true whenever $\frac{\dot{N}}{N} = \frac{\lambda n}{1-\phi}$ so that when population is constant we have no growth at all. Further, in this semi-endogenous growth model, growth is independent of the R&D success probability and the researcher labor. However, the economy with the highest population growth rate has the highest growth rate and, in this way, it can be said that the economy also suffers from “dynamic scale / market-size effects”.

We consider that R&D production is done in *Innovator* countries and is done not only with accumulated technological knowledge and labor,¹⁵ but also with laboratories, microscopes, and a set of others goods that are purchased with a flow of aggregate final-good resources. Motivated by this point of view, but also by the desire to eliminate scale effects arising from the consideration of labor research, we follow Acemoglu and Zilibotti (2001) and Acemoglu (2002), among other seminal papers, and we propose the following R&D technology for each sector $j = T, D$ within the *Innovator* country: $\dot{N}_j^I(t) = \sigma_j^I \cdot Z_j^I(t)$,

¹⁴That is, Romer’s (1990) model is achieved considering $\phi = \lambda = 1$.

¹⁵Remember that in our case, as, for example, in Acemoglu and Zilibotti (2001) and Acemoglu (2002), labor supply is even assumed to be exogenous and, therefore, constant.

where: σ_j^I is the productivity of innovative R&D activity in the j -sector and we assume that $\sigma_T^I > \sigma_D^I$, $\frac{\sigma_D^I}{\sigma_T^I} < 1$, due to strong positive technology linkages on R&D performance in the tradable sector; Z_j^I – rather than L_N – is the flow of aggregate final-good resources devoted to R&D directed at discovering a new intermediate good to be used in the j -sector. Since our focus is not to explain the process of R&D, we choose the simplifying assumptions that there are constant returns to R&D expenditures – e.g., Romer (1993) and Barro and Sala-i-Martin (2004, chap. 6) –, which is also in line with the empirical evidence on returns to scale of R&D efforts – e.g., Bound et al. (1984), Kortum (1993) and Thompson (1996). Our assumption that R&D inputs are in terms of aggregate final-good resources runs away from the lab-equipment feature of our framework and ensures the removal of scale effects; however, does not necessarily get the economy out of the market-size effects. For this to happen, we need to introduce some type of externality. Thus, from now on, we consider that indeed innovations evolve over time according to the following equation of motion:

$$\dot{N}_j^I(t) = \sigma_j^I \cdot Z_j^I(t) \cdot (L_j^F + L_j^I)^{-\delta}, \quad (14)$$

where the externality $(L_j^F + L_j^I)^{-\delta}$, with $\delta \geq 0$, captures the effect of the worldwide market scale, measured by $L_j^F + L_j^I$, on the innovation rate; indeed, this externality can be interpreted as representative of the costs imposed by the market size due to coordination among agents, processing of ideas, informational, organizational, marketing, and transportation costs, as well as a diffusion externality such that the higher the market the lower the diffusion of the innovation among population (access of customers to the innovation, access of scientists to other scientific results, etc.), as suggested by works such as Becker and Murphy (1992), Alesina and Spolaore (1997), Dinopoulos and Segerstrom (1999), and Dinopoulos and Thompson (1999). That is, for simplicity, we reflect in R&D the costs imposed by the market size.¹⁶ Hence, through $(L_j^F + L_j^I)^{-\delta}$ the market size benefits on profits can be partially ($0 < \delta < 1$), totally ($\delta = 1$), or over counterbalanced ($\delta > 1$) and, therefore, allows us to remove market-size effects on the economic growth rate when $\delta = 1$.

Since there is perfect competition among entrants and free entry in the R&D business, the cost of discovering a new variety is the present value of monopoly profits $V_j^I(t) = \int_t^\infty \pi_j^I(v) \cdot e^{-\int_t^v r^I(\omega) d\omega} dv$, $j = T, D$. Since along the BGP $V_j^I(t)$ is constant for all t , $\dot{V}_j^I(t) = 0$, and the interest rate is constant, this results in $V_j^I(t) = \frac{\alpha \cdot [P_j^F \cdot (P_j^F)^{\frac{1}{\alpha}} L_j^F + (P_j^I)^{\frac{1}{\alpha}} L_j^I]}{r^I(t)}$, $j = T, D$. The present value of monopoly profits increases with both the product price (price channel), P_j^F and P_j^D , and the labor level (market-size channel),

¹⁶Dinopoulos and Thompson (1999), in particular, provided micro foundations for this effect. Dinopoulos and Segerstrom (1999) call this the ‘permanent-effects-on-growth’ specification.

L_j^F and L_j^I , in both countries, and it decreases with the rental price of capital, r^I . Since r^I is country specific, there are two forces determining the technological-knowledge bias – the price channel and the adjusted-market-size channel due to IPRs protection:

$$\frac{V_D^I}{V_T^I} = \frac{\pi_D^I}{\pi_T^I} = \sum_{i=F,I} \left[\underbrace{\left(\frac{P_D^i}{P_T^W} \right)^{\frac{1}{\alpha}}}_{\text{Price channel}} \cdot \underbrace{\left(\frac{\Re^{\lambda_i} \cdot L_D^i}{L_T^W} \right)}_{\text{Adjusted-market-size channel}} \right], \quad (15)$$

where: $\lambda_F = 1, \lambda_I = 0, L_T^W = \Re \cdot L_T^F + L_T^I, P_T^W = P_T^F = P_T^I$. Therefore, considering (9), we can also compute the equilibrium expression for relative profitability of developing technologies that complement the D -sector as $\frac{V_D^I}{V_T^I} = \frac{\pi_D^I}{\pi_T^I} = \sum_{i=F,I} \left\{ \left[\left(\frac{\chi_D^i}{\chi_T^i} \right)^\varepsilon \left(\frac{L_D^i}{L_T^i} \frac{N_D^I}{N_T^I} \right)^{-1} \right]^{\frac{1}{1+\Omega}} \frac{\Re^{\lambda_i} \cdot L_D^i}{L_T^W} \right\}$. Along the BGP, the relative profitability $\frac{V_D^I}{V_T^I} = \frac{\pi_D^I}{\pi_T^I}$ is equal to relative R&D cost, which from equation (14) is $\frac{Z_D^I(t)}{Z_T^I(t)} = \frac{\sigma_T^I}{\sigma_D^I} \left(\frac{L_T^F + L_T^I}{L_D^F + L_D^I} \right)^{-\delta}$; i.e., balanced growth (steady state) technology market clearing condition implies that $\pi_T^I(t) \cdot \sigma_T^I \cdot (L_j^F + L_j^I)^{-\delta} = \pi_D^I(t) \cdot \sigma_D^I \cdot (L_j^F + L_j^I)^{-\delta}$, obtaining the endogenous worldwide equilibrium technological-knowledge bias, which, recall, is the key result of the directed technical change literature and is still biased towards the more productive sector:

$$\frac{N_D^I}{N_T^I} = \mathcal{L} \cdot \left(\frac{\sigma_D^I}{\sigma_T^I} \right)^{1+\Omega} \cdot \left(\frac{L_D^F + L_D^I}{L_T^F + L_T^I} \right)^{-\delta(1+\Omega)}, \quad (16)$$

where:

$$\mathcal{L} \equiv \sum_{i=F,I} \left\{ \left(\frac{\chi_D^i}{\chi_T^i} \right)^\varepsilon \left(\frac{L_D^i}{L_T^i} \right)^{-1} \left(\frac{\Re^{\lambda_i} \cdot L_D^i}{L_T^W} \right)^{1+\Omega} \right\}. \quad (17)$$

From all labor level terms in (16) and (17), the scale effects can be almost removed when $\delta \rightarrow 1$.

Proposition 3. *The worldwide technological-knowledge bias, $\frac{N_D^I}{N_T^I}$, is positively related with: (i) the relative productivity of developing D -sector complementary intermediate goods in country I , $\frac{\sigma_D^I}{\sigma_T^I}$; (ii) the relative importance of the D -sector in the production of the final good in both countries, $\frac{\chi_D^F}{\chi_T^F}$ and $\frac{\chi_D^I}{\chi_T^I}$; (iii) the ratios between adjusted labor levels in the D -sector and in the worldwide labor level in the T -sector, $\frac{\Re \cdot L_D^F}{L_T^W}$ and $\frac{L_D^I}{L_T^I}$ – from these terms, as $\frac{\partial}{\partial \Re} \left(\frac{\Re \cdot L_D^F}{\Re \cdot L_T^F + L_T^I} \right) \geq 0$ and $\frac{\partial}{\partial \Re} \left(\frac{L_D^I}{\Re \cdot L_T^F + L_T^I} \right) \leq 0$, given that $\Re \in [0, 1]$, the effect of IPRs protection on $\frac{N_D^I}{N_T^I}$ is ambiguous. It is negatively related with: (i) the ratio between the worldwide labor level in the D -sector and in the T -sector, $\frac{L_D^F + L_D^I}{L_T^F + L_T^I}$, if $\delta > 0$; the ratios between the countries' labor levels in the D -sector and in the T -sector, $\frac{L_D^F}{L_T^F}$ and $\frac{L_D^I}{L_T^I}$.*

Proof. It results directly from (16) and (17). □

Considering (16) and (10), along the BGP, the relative price (real exchange rate or terms of trade) is:

$$\frac{P_D^i}{P_T^W} = \left[\mathcal{L}^{-\alpha} \left(\frac{\chi_D^i}{\chi_T^i} \right)^{\varepsilon\alpha} \left(\frac{L_D^i}{L_T^i} \right)^{-\alpha} \right]^{\frac{1}{1+\Omega}} \left(\frac{\sigma_D^I}{\sigma_T^I} \right)^{-\alpha} \left(\frac{L_D^F + L_D^I}{L_T^F + L_T^I} \right)^{\alpha\delta}, \quad i = I, F. \quad (18)$$

Hence, after the adjustment of the technological-knowledge bias, the relative advantage to entry through horizontal innovation in I , $\frac{\sigma_D^I}{\sigma_T^I}$, in equation (18) reflects the Balassa-Samuelson proposal: the relative price of nontradable goods is driven by intra-sector productivity growth differences, which depend particularly on the productivity of innovative R&D parameters σ_D^I and σ_T^I .

Proposition 4. *Also under trade, the “real exchange rate” in country i , $\frac{P_D^i}{P_T^W}$, depends on the degree of international protection of IPRs in F and on parameters and exogenous variables of both countries; it relies: (i) positively on the ratio between the worldwide labor levels in the D -sector and in the T -sector, $\frac{L_D^F + L_D^I}{L_T^F + L_T^I}$, on the ratio between the labor levels in the D -sector and in the T -sector in the other country; (ii) negatively on the relative advantage to entry through horizontal innovation in I , $\frac{\sigma_D^I}{\sigma_T^I}$, on the relative importance of the D -sector in the production of the final good in the other country, and on the ratios between adjusted labor levels in the D -sector and in the worldwide labor level in the T -sector, $\frac{\Re L_D^F}{L_T^W}$ and $\frac{L_D^I}{L_T^W}$ – and thus, from these terms, considering the range of $\Re$ between 0 and 1, the effect of IPRs protection on $\frac{P_D^i}{P_T^W}$ is ambiguous.*

Proof. Bearing in mind Proposition 3 and its proof, it is immediate from (18). □

Finally, bearing in mind (16) and (11), the endogenous intra-country wage inequality measures are, respectively:

$$\frac{w_D^i}{w_T^i} = \mathcal{L}^{\frac{\Omega}{1+\Omega}} \cdot \left(\frac{\sigma_D^I}{\sigma_T^I} \right)^{\Omega} \cdot \left(\frac{\chi_D^i}{\chi_T^i} \right)^{\frac{\varepsilon}{1+\Omega}} \cdot \left(\frac{L_D^F + L_D^I}{L_T^F + L_T^I} \right)^{-\delta\Omega} \cdot \left(\frac{L_D^i}{L_T^i} \right)^{-\frac{1}{1+\Omega}}, \quad i = I, F. \quad (19)$$

	$\delta = 0$	$\delta > 0$
$\varepsilon = 0$	$= 0$	> 0
$0 < \varepsilon < 1$	$= 0$	> 0
$\varepsilon = 1$	$= 0$	$= 0$
$\varepsilon > 1$	$= 0$	< 0

 Table 1: Elasticity of $\frac{w_D^i}{w_T^i}$ with respect to $\frac{L_D^F + L_D^I}{L_T^F + L_T^I}$.

Proposition 5. *The intra-country wage inequality measures, $\frac{w_D^i}{w_T^i}$ with $i = I, F$, are positively related with: (i) the relative importance of the country specific D-sector in the production of the final good, $\frac{\chi_D^i}{\chi_T^i}$; (ii) under substitutability, $\varepsilon > 1$, (a) the country I relative productivity of developing D-sector complementary intermediate goods, $\frac{\sigma_D^I}{\sigma_T^I}$, (b) the relative importance of the D-sector in the production of the final good in the other country, (c) the ratios between adjusted labor levels in the D-sector and in the worldwide labor level in the T-sector, $\frac{\Re \cdot L_D^F}{L_T^W}$ and $\frac{L_D^I}{L_T^W}$ – thus, considering the range of $\Re$ between 0 and 1, the effect of IPRs protection on $\frac{w_D^i}{w_T^i}$ is ambiguous. They are negatively related with the ratio between the labor level in the D-sector and in the T-sector in the country, $\frac{L_D^i}{L_T^i}$, and in the other country under substitutability. Moreover, the effect of the ratio between the worldwide labor levels in the D-sector and in the T-sector, $\frac{L_D^F + L_D^I}{L_T^F + L_T^I}$, on $\frac{w_D^i}{w_T^i}$ is also ambiguous – see Table 1: (i) it is null if either $\varepsilon = 1$ or $\delta = 0$ (scale effects not removed); (ii) positive if there is complementarity, $0 \leq \varepsilon < 1$, and scale effects are (to some extent) removed, $\delta > 0$; (iii) negative if there is substitutability, $\varepsilon > 1$, and scale effects are (to some extent) removed, $\delta > 0$.*

Proof. It results directly from (19). □

[Table 1 goes about here]

For completeness, it is also useful to determine the long-run growth rate. In BGP the consumption, the technological knowledge, and the output grow at the same rate, g , and thus from (1) $r = \theta g + \rho$. Hence, along the BGP, the economic growth rate depends on the market interest rate and preference parameters. Using the expression for $V_j^I(t)$ above, the free-entry condition for the technology monopolists working to invent j -complementary intermediate goods implies that $V_j^I = Z_j^I$, which is equivalent to stating that $\sigma_j^I (L_j^F + L_j^I)^{-\delta} V_j^I = 1$ since $\sigma_j^I (L_j^F + L_j^I)^{-\delta} Z_j^I(t)$ units of composite final-good resources are required to invent a new design. In steady state, this condition implies that $\sigma_j^I (L_j^F + L_j^I)^{-\delta} V_j^I = \frac{\sigma_j^I \cdot (L_j^F + L_j^I)^{-\delta} \cdot \alpha \cdot \left[\Re \cdot (P_j^F)^{\frac{1}{\alpha}} L_j^F + (P_j^I)^{\frac{1}{\alpha}} L_j^I \right]}{r^I(t)} = 1$. Then, bearing in mind (3), (9), and (16), we have:

$$g = \frac{1}{\theta} \left\{ \alpha \sum_{i=F,I} \left[\left(\chi_D^i \right)^\varepsilon \left(\sigma_D^I \left(L_D^F + L_D^I \right)^{-\delta} \frac{\Re^{\lambda_i} L_D^i}{L_T^W} \right)^\Omega + \left(\chi_T^i \right)^\varepsilon \left(\sigma_T^I \left(L_T^F + L_T^I \right)^{-\delta} \frac{\Re^{\lambda_i} L_T^i}{L_T^W} \right)^\Omega \right]^{\frac{1}{\Omega}} - \rho \right\}, \quad (20)$$

which depends on parameters and exogenous variables and from which greater productivity in R&D innovative activity, σ_D^I and σ_T^I , makes the steady state growth rate of the economy higher, while the rate of time preference, ρ , and the elasticity of marginal utility of consumption, θ , have depressing effects on the steady state growth rate. Moreover, the market/scale effects can be present, $\delta = 0$, affecting positively the economic growth rate, or can be removed ($\delta > 0$), decreasing the economic growth rate. Moreover, it can be stated that:

Fact 2. *IPRs protection, $\Re \in [0, 1]$, can affect positively or negatively the worldwide steady-state growth rate, which under international trade can be higher or lower than in autarky.*

Proof. It results directly from (20) since $\frac{\partial}{\partial \Re} \left(\frac{\Re \cdot L_j^F}{\Re \cdot L_T^F + L_T^I} \right) > 0$ and $\frac{\partial}{\partial \Re} \left(\frac{L_j^I}{\Re \cdot L_T^F + L_T^I} \right) < 0$, $j = T, D$ with $\Re \neq 0$, being the sign reversed under complementarity. □

As stated above, concerning the degree of IPRs protection, it is assumed that producers of intermediate goods in the *Follower* country must pay a fixed royalty fee $\Re$ to the original innovator for the use of the design that the intermediate good embodies, in line with, e.g., Gancia and Bonfiglioli (2008). These authors showed that an increase in IPRs protection in the imitator country increases the (worldwide) economic growth rate when imitators compensate innovators in terms of final goods. The economic intuition is that better enforcement of IPRs strengthens the incentives to innovate and therefore fosters growth. In turn, in our model, IPRs protection can affect positively or negatively the worldwide growth rate. Mathematically, it depends on the degree of substitutability between sectors, T and D , captured by the parameter Ω , and on the terms $\frac{\Re \cdot L_j^F}{\Re \cdot L_T^F + L_T^I}$ and $\frac{L_j^I}{\Re \cdot L_T^F + L_T^I}$; in particular, $\frac{\partial}{\partial \Re} \left(\frac{\Re \cdot L_j^F}{\Re \cdot L_T^F + L_T^I} \right) > 0$ (< 0) and $\frac{\partial}{\partial \Re} \left(\frac{L_j^I}{\Re \cdot L_T^F + L_T^I} \right) < 0$ (> 0) under substitutability (complementarity) for $\Re \neq 0$ and $j = T, D$ – see (20). Hence, IPRs protection are applied to both sectors, tradable and nontradable, since, although only the tradable final good is internationally traded, the *Follower* country has access to all available technological knowledge in the *Innovator* country; i.e., the intermediate goods used in the production of the tradable and nontradable final goods in the *Follower* country embody the technological knowledge in

the *Innovator* country. The economic intuition underlying our case is as follows. Better enforcement of IPRs – by representing higher revenue from selling intermediate goods in F that is paid to the original innovator – strengthens the incentives to innovate due to the operation of the adjusted-market-size channel (present in 15) if: (i) under substitutability between sectors, the effects $\frac{\partial}{\partial \Re} \left(\frac{\Re \cdot L_j^F}{\Re \cdot L_T^F + L_T^I} \right) > 0$, $j = T, D$, dominate $\frac{\partial}{\partial \Re} \left(\frac{L_j^I}{\Re \cdot L_T^F + L_T^I} \right) < 0$, $j = T, D$; (ii) under complementarity between sectors, the effects $\frac{\partial}{\partial \Re} \left(\frac{L_j^I}{\Re \cdot L_T^F + L_T^I} \right) > 0$, $j = T, D$, dominate $\frac{\partial}{\partial \Re} \left(\frac{\Re \cdot L_j^F}{\Re \cdot L_T^F + L_T^I} \right) < 0$, $j = T, D$. To sum up, the effect of IPRs on the steady-state growth rate is ambiguous and, therefore, we can refute the idea that stronger IPRs is always better (in line with, for example, Helpman, 1993; Datta and Mohtadi, 2006; Furukawa, 2007; Eicher and Garcia-Penalosa, 2008).

Finally, it should be stated that outside the BGP, just one type of innovation arises: when $\frac{V_D^I(t)}{V_T^I(t)} > \frac{\sigma_T^I (L_T^F + L_T^I)^{-\delta}}{\sigma_D^I (L_D^F + L_D^I)^{-\delta}} \left(\frac{V_D^I(t)}{V_T^I(t)} < \frac{\sigma_T^I (L_T^F + L_T^I)^{-\delta}}{\sigma_D^I (L_D^F + L_D^I)^{-\delta}} \right)$ the R&D is directed to create new designs to produce D -complementary (T -complementary) intermediate goods. As (15) shows, $\frac{V_D^I(t)}{V_T^I(t)}$ is decreasing in $\frac{N_D^I}{N_T^I}$, which implies that the economy always returns to the BGP: when $\frac{N_D^I}{N_T^I}$ is higher (low) than in (16), the technological-knowledge change will be directed only to T -complementary (D -complementary) intermediate goods until the economy returns back to the BGP.

4 Quantitative results

In this section we calibrate the model and analyze quantitatively the sensitivity of the main aggregate ratios in steady state described in Propositions 1-5 and in Fact 2. The sensitivity analysis is evaluated for three key parameters: scale effects, δ , elasticity of substitution between sectors, ε , and IPRs, $\Re$. We then we analyze the effects of labor migration between countries and of labor mobility between sectors on the main aggregate ratios for any level of elasticity of substitution, ε , and for the particular cases of no and full IPRs protection, $\Re = 0$ and $\Re = 1$. Regarding the labor migration, we consider two labor movements: initially a movement of nontradable and then of tradable workers from the *Follower* to the *Innovator*; i.e., first an increase of $\frac{L_T^I}{L_T^F}$ and then of $\frac{L_D^I}{L_D^F}$. Regarding the labor mobility, we analyze the effect of a movement of workers from the nontradable to the tradable sector in the *Follower* country, i.e., a decrease of $\frac{L_D^F}{L_T^F}$.

4.1 Calibration

In order to analyze the model sensitivity we must calibrate the parameters α , ρ , θ , χ_D^i , χ_T^i , L_D^i , L_T^i , $\mathcal{B}^i$, $\forall i \in \{I, F\}$, $\frac{N_D^I}{N_T^I}$, $\frac{A^I}{A^F}$, $\frac{\sigma_D^I}{\sigma_T^I}$, Z_D^I and Z_T^I – see Table 2 for a summary of the values considered and that will be detailed below.

For the labor share in the tradable and nontradable final-goods production, α , inter-temporal elasticity of substitution, θ , and utility discount factor, ρ , we use the typical values considered in endogenous growth models; thus, we set $\alpha = 0.66$, $\theta = 2$, and $\rho = 0.02$ (e.g., Jones and Williams, 2000; Grossman et al., 2013; Gomez and Sequeira, 2013).

As the remaining parameters are country-specific – for the *Innovator* and the *Follower* – and sector-specific – for the tradable and the nontradable –, we must specify the countries and sectors included in each group. We define as *Innovators* 11 developed countries (Belgium, Canada, France, Germany, Italy, Japan, The Netherlands, Republic of Korea, Spain, The United Kingdom (The UK), and The United States(The US)) and as *Followers* 11 developing countries (Brazil, China, Hong Kong, The Kingdom of Saudi Arabia, India, Malaysia, Mexico, Russia, Singapore, Thailand, and The United Arab Emirates (UAE)). The countries selection is based on their importance in the world merchandise trade in 2014, bearing in mind that these 22 countries represent about 73% of world trade (see Table 3 in Appendix).¹⁷ Regarding the distinction between sectors, we follow the AMECO definition (Zeugner, 2013) and consider that the tradable sector includes Agriculture and Fishing, Mining and Utilities, Manufacturing, and Trade, Hotel and Transports, and the nontradable sector includes Construction, Financial and Real Estate, and Public and Social Services (see Table 4 in appendix). Thus, according to the ISIC rev. 3.1 classification system, the tradable sector includes the sectors A-E plus G-I, while the nontradable sector includes the sector F plus J-P.¹⁸

For χ_D^i and χ_T^i we use data from the UNCTAD National Accounts Main Aggregates Database. We collect the shares of the GDP by economic activity and country from 2010-2014 and calculate their average values for these five years. Next, we sum the average shares of the GDP for activities included in the tradable and nontradable sector for each country. Finally, we find the average of the tradable and nontradable shares for the set of *Innovator* and *Follower* countries getting $\frac{\chi_D^I}{\chi_T^I} = 1.25$ and $\frac{\chi_D^F}{\chi_T^F} = 0.65$

¹⁷The 11 *Innovator* countries represented 42% and 46% of world exports and imports, whereas the 11 *Follower* countries represented 31% and 27% of world exports and imports in 2014, respectively (see Table 3 in Appendix).

¹⁸However, “it is ... difficult to classify some sectors as either tradable or nontradable” (Zeugner, 2013, p. 2) and thus there is some moderate inconsistency in the classification provided by the literature – see, for example, the Schmillen (2013, Table A1) proposal.

Table 2: Parameter values

Description	Parameter	Value
Labor share	α	0.66
Discount factor	ρ	0.02
Intertemp.elasticity of Subst.	θ	2
D -sector share in I	χ_D^I	55.6
T -sector share in I	χ_T^I	44.5
D -sector share in F	χ_D^F	39.4
T -sector share in F	χ_T^F	60.6
T -labor in I	L_T^I	167338.1
D -labor in F	L_D^F	266855.9
D -labor in I	L_D^I	220593.4
T -labor in F	L_T^F	527688.1
T -sector share traded by F	$\mathcal{B}^F$	1.4
T -sector share traded by I	$\mathcal{B}^I$	0.89
Relative technological-knowledge in I	$\frac{N_D^I}{N_T^I}$	0.059
D -R&D expenditures in I	Z_D^I	502.771
T -R&D expenditures in I	Z_T^I	38.713
Technological-knowledge bias	$\frac{N_D^I}{N_T^I}$	0.07

(see Table 5 in Appendix).

For L_D^i and L_T^i we use the number of workers by economic activity available in the Key Indicators of the Labor Market (KILM) 2015 database from ILO. These data are available according to the ISIC rev. 3.1 classification system for some countries and according to the ISIC rev. 4 classification system for other countries. We convert the latter to the ISIC rev. 3.1 classification system in order to have homogenized data. We opt by the ISIC rev. 3.1 classification system to follow the classification system used to define tradable and nontradable sectors. Thus, for each country, we calculate the average number of workers over 2010-2014 included in tradable and nontradable sectors. To do that, we sum the average number of workers over 2010-2014 working in Agriculture and Fishing, Mining and Utilities, Manufacturing, and Trade, Hotel and Transports for the tradable sector and in Construction, Financial and Real Estate, and Public and Social Services for the nontradable sector. Finally, we calculate the average number of workers by sector, tradable and nontradable, for the set of *Innovator* and *Follower* countries (see Table 7 in Appendix). Note that for Brazil, Singapore, and The UAE no data are available in any classification system.

To evaluate the inter-country wage inequality, equations (12)-(13), we must know the inter-country productivity, $\frac{A^I}{A^F}$. In order to calibrate this productivity ratio we use the equation (7). Thus, we first collect the export shares of GDP by sector of activity and country for 2010-2014 from the UNCTAD National Accounts Main Aggregates. These shares are also available according to the ISIC rev. 3.1

classification system, which allows us to obtain information for all activities included in our tradable sector definition, and for all 22 countries of our sample. Then, we collect the total output share by sector of activity and country for 2010-2014 from the same database. Next, summing export and final output shares for all activities included within the tradable sector and dividing the former by the latter one, we obtain the fraction of exports of the tradable sector by country and year. Finally, we compute their annual average over the period 2010-2014 for each country and their average for the set of *Innovator* and *Follower* countries, i.e., $(\mathcal{B}^i, i = I, F)$. Once we have calibrated $\mathcal{B}^i$ (see Table 6 in Appendix) and $\frac{L_T^I}{L_T^F}$ (see Table 7 in Appendix), we directly apply the equation (7) in order to obtain the inter-country productivity ratio, $\frac{A^I}{A^F}$.

Next, we need to calibrate the relative productivity of *D*-sector in country *I*, $\frac{\sigma_D^I}{\sigma_T^I}$, to evaluate the real exchange rate and the intra-country wage inequality (equations 18 and 19). To do so, we use equation (14) and define $\frac{\sigma_D^I}{\sigma_T^I} = \frac{\dot{N}_D^I(t)}{\dot{N}_T^I(t)} \cdot \frac{Z_T^I}{Z_D^I} \cdot \frac{(L_T^F + L_T^I)^{-\delta}}{(L_D^F + L_D^I)^{-\delta}}$. To apply this math definition, we first collect data in order to calibrate the ratios $\frac{N_D^i}{N_T^i}$, $\frac{Z_D^I}{Z_T^I}$ and δ . To calibrate $\frac{N_D^i}{N_T^i}$, we collect the number of patents by technology and International Patent Classification (IPC) from 2010-2013 and for the 22 countries of our sample (OECD, 2015). After that, as we are interested in patents by sector of activity, we convert patents by technology and IPC to patents by sector of activity using the Algorithm Links with Probabilities' (ALP) developed by Lybbert and Zolas (2014). This conversion is also performed for the ISIC rev. 3.1 classification system. Then, we find the average number of patents by sector of activity and country over the period 2010-2013. Finally, we sum the number of patents for all activities included in the tradable sector and find their average value for the set of *Innovator* and *Follower* countries obtaining N_D^I and N_T^I , and therefore $\frac{N_D^I}{N_T^I}$ (Table 8 in Appendix).

To calibrate $\frac{Z_D^I}{Z_T^I}$ we collect the business enterprise R&D expenditure (BERD) by economic activity and type of costs from the Eurostat,¹⁹ from 2010-2013 for the set of *Innovator* countries. Then, we sum the R&D expenditures for all sectors included in the tradable and nontradable sectors definition and find the average R&D expenditure carried out by the set of *Innovator* countries over 2010-2013 (see Table 9 in Appendix).²⁰ Recall that we always follow the ISIC rev. 3.1 classification system and the traditional AMECO definition of tradable (A-E and G-I) and nontradable (F, J-P) sectors.

Finally, as we are analyzing the sensitivity of our model aggregate ratios to scale effects, we consider different values for δ obtaining the following R&D productivity ratio values:

¹⁹For patents and R&D expenditure there are no available data for 2014.

²⁰These data are available for only seven of our 11 countries. However, as we are using average values for the *Innovator* country, we assume that the missing data have the same average as the available data.

$$\{\delta, \frac{\sigma_D^I}{\sigma_T^I}\} = \{(0, 0.296), (0.25, 0.279), (0.5, 0.2475), (0.75, 0.227), (1, 5.98)\}$$

The set $\{\delta, \frac{\sigma_D^I}{\sigma_T^I}\}$ illustrates that the R&D productivity of nontradable goods is, in general, smaller than the R&D productivity of tradable goods, which is in conformity with our assumption that $\frac{\sigma_D^I}{\sigma_T^I} < 1$ in equation (14). Moreover, the relative R&D productivity of nontradable goods decreases when the scale effects also decrease, $\delta \rightarrow 1$. However, when there are no scale effects, $\delta = 1$, the R&D productivity of tradable goods is greater than the R&D productivity of nontradable goods since $\frac{L_D^F + L_D^I}{L_T^F + L_T^I} < 1$ and $\frac{Z_D^I}{Z_T^I} > 1$.

4.2 Sensitivity analysis

In this section, we analyze the sensitivity of the inter-country relative price of the D -sector, $\frac{P_D^I}{P_D^F}$, inter-country wage inequality in both sectors, D -sector and T -sector, $\frac{w_D^I}{w_D^F}$ and $\frac{w_T^I}{w_T^F}$, worldwide technological-knowledge bias, $\frac{N_D^I}{N_T^I}$, real exchange rate in both countries, *Innovator* and *Follower*, $\frac{P_D^I}{P_T^F}$ and $\frac{P_D^F}{P_T^F}$, intra-country wage inequality, $\frac{w_D^I}{w_T^I}$ and $\frac{w_D^F}{w_T^F}$, and economic growth rate, g , to variations in parameters ε (elasticity of substitution), δ (scale effects) and $\Re$ (royalty fees) as well as to the migration of tradable and nontradable workers from the *Follower* to the *Innovator*, $\frac{L_T^I}{L_T^F} \uparrow$ and $\frac{L_D^I}{L_D^F} \uparrow$.

4.2.1 The impact of the elasticity of substitution, scale effects and IPRs

We start this analysis by simultaneously analyzing the effects of elasticity of substitution, scale, and royalty fees (or IPRs). In order to better understand the effects of IPRs, we also compare, throughout the analysis, the values of the main aggregate ratios when there is IPRs protection, $\Re > 0$, and when there is no IPRs protection, $\Re = 0$.

Figure 1 presents the results for our main aggregate ratios in steady state. The first observation is that scale effects have no relevant effect over the aggregate ratios. As we have already shown in Section 3, the scale effects have no direct effect over the inter-country relative price of D -sector (equation 10) and inter-country wage inequality (equations 12-13). An increase of δ directly and negatively affects the technological-knowledge bias (equation 16), intra-country inequality (equation 19), and economic growth (equation 20), and directly and positively affects the exchange rate (equation 18) via the worldwide labor ratio; however, the direct effect is offset by an opposite effect of scale effects on the relative productivity of R&D sector of nontradable goods, $\frac{\sigma_D^I}{\sigma_T^I}$. That is, since in our calibration exercise the ratio of innovations,

$\frac{\dot{N}_D^I(t)}{\dot{N}_T^I(t)}$, is calibrated to match the data and, thereby, it is fixed,²¹ variations on the parameter of scale effects, δ , are offset by variations on the evolution of $\frac{\sigma_D^I}{\sigma_T^I}$.

The elasticity of substitution presents a positive relationship with the inter-country relative price of D -sector, $\frac{P_D^I}{P_F^I}$, equation (10), and inter-country wage inequality in D -sector, $\frac{w_D^I}{w_F^I}$, equation (12), (Figures 1a-1b). In I , the nontradable sector is relatively more important, $\frac{\chi_D^I}{\chi_T^I} > 1$, and thus an increase in ε favors the D -sector: the relative demand for nontradable intermediate goods and workers rises, leading to an increase of $\frac{P_D^I}{P_F^I}$ and $\frac{w_D^I}{w_F^I}$. These effects of ε in $\frac{P_D^I}{P_F^I}$ and $\frac{w_D^I}{w_F^I}$ are independent of IPRs; i.e., there is no effect of IPR on $\frac{P_D^I}{P_F^I}$ and $\frac{w_D^I}{w_F^I}$, as shown by Propositions 1 and 2 - see also equations (10)-(12). Yet, the inter-country wage inequality in T -sector, $\frac{w_T^I}{w_F^I}$, depends only on the quality of institutions of both countries and thus no effects are observed with changes on ε (Figure 1c and equation 13).

The effect of the elasticity of substitution on the technological-knowledge bias, $\frac{N_D^I}{N_T^I}$, depends on the relative world importance of D -sector. An increase of ε favors the D -sector in I since, as stated above, $\frac{\chi_D^I}{\chi_T^I} > 1$, and favors the T -sector in F since $\frac{\chi_F^I}{\chi_T^I} < 1$. Bearing in mind the relatively small importance of the D -sector in the world; i.e., $\frac{\chi_D^I + \chi_F^I}{\chi_T^I + \chi_F^I} < 1$ (see Table 2), the effect of ε on the technological-knowledge bias is negative (Figure 1d); i.e., an increase of ε directs the technological-knowledge in favor of the T -sector. For example, Afonso and Sequeira (2016) found a positive relationship between the elasticity of substitution and the technological-knowledge bias in a model calibrated for Germany, where the nontradable sector is relatively more important than the tradable, which is not observed when we look at a representative sample of countries in the international trade. The essential idea is that the same economic forces (profitability of innovative R&D) that affect the amount of technological-knowledge progress will also shape the technological-knowledge bias.

This negative relationship between ε and $\frac{N_D^I}{N_T^I}$ is true for any value of IPRs, $\forall \Re \geq 0$. Moreover, a positive IPRs policy, $\Re > 0$, tends to reinforce (weaken) the bias in favor of the T -sector under substitutability (complementarity) between sectors via adjusted market-size channel. This is in line with Proposition 3, which states that IPRs effects in $\frac{N_D^I}{N_T^I}$ can be either positive or negative, depending on the adjusted labor of the D -sector in F and in I relatively to the adjusted worldwide labor.²² In our calibration exercise the sum of these two opposite effects is negative, reinforcing, under substitutability, the technological-knowledge bias in favor of the T -sector.

²¹We need to take into account that $\frac{\sigma_D^I}{\sigma_T^I} = \frac{\dot{N}_D^I(t)}{\dot{N}_T^I(t)} \cdot \frac{Z_T^I}{Z_D^I} \cdot \frac{(L_T^F + L_T^I)^{-\delta}}{(L_D^F + L_D^I)^{-\delta}}$.

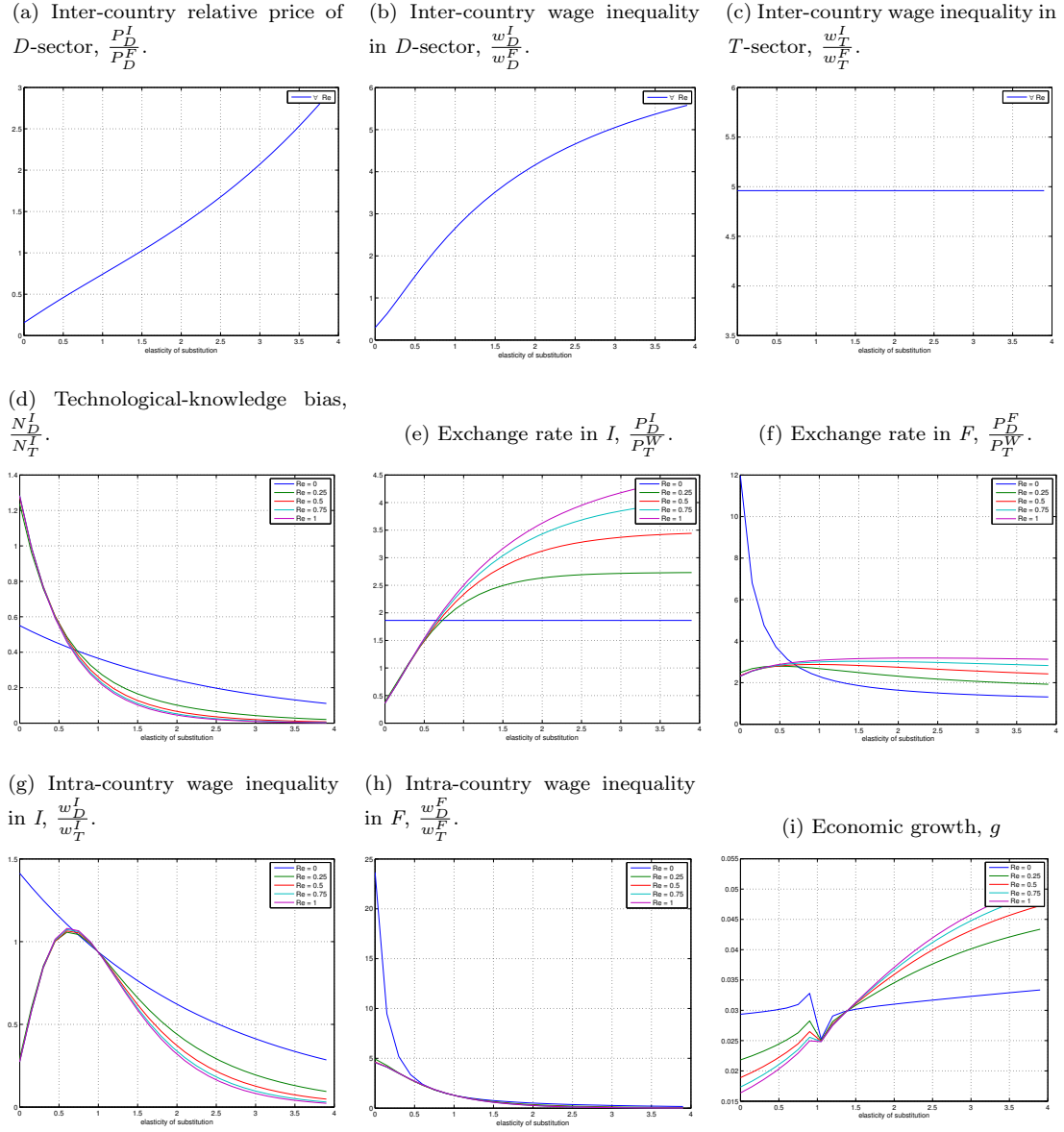
²²Remember that $\frac{\partial}{\partial \Re} \left(\frac{\Re \cdot L_j^F}{\Re \cdot L_T^F + L_T^I} \right) > 0$ and $\frac{\partial}{\partial \Re} \left(\frac{L_j^I}{\Re \cdot L_T^F + L_T^I} \right) < 0$, $j = T, D$.

As the elasticity of substitution favors the T -sector in final-goods production, biasing the technological knowledge in favor of the T -sector, intra-country wage inequality, $\frac{w_D}{w_T}$, decreases. Indeed, the technological-knowledge bias in favor of the T -sector stimulates the relative demand for labor in the T -sector: by reason of complementarity between inputs in (4) – there is a combination of the two types of technological knowledge with the respective labor –, changes in intra-country wages are closely related to the technological-knowledge bias, as (11) clearly shows. Thus, the relationship between elasticity of substitution and intra-country wage inequality is also negative in both countries (Figures 1g-1h). As explained above, the IPRs, $\Re > 0$, reinforce the technological-knowledge bias in favor of the T -sector. Hence, under substitutability, the decrease of $\frac{w_D}{w_T}$ in F is greater than in I . The effects of the elasticity of substitution and of IPRs on intra-country wage inequality are thus intrinsically related with the effects on technological-knowledge bias. Since IPRs reinforce the technological-knowledge bias, which drives intra-country wage inequality, in favor of T , it can be stated that IPRs benefit the tradable workers in both countries.

Due to complementarity between inputs in the production of tradable and nontradable final goods – equation (4) – the effect of the elasticity of substitution on the exchange rates, $\frac{P_D^I}{P_T^I}$ and $\frac{P_D^F}{P_T^F}$, depends directly on the country's relative importance of D -sector and on the technological-knowledge bias, as equation (9) shows. Thus, through $\frac{N_D^I}{N_T^I}$, the effect depends indirectly on both IPRs and the relative world importance of the D -sector. Since $\frac{\chi_D^I}{\chi_T^I} > 1$, $\frac{P_D^I}{P_T^I}$ is positively related with the elasticity of substitution, the effect being smoothed by the impact of $\frac{N_D^I}{N_T^I}$, which, recall, is negatively affected by ε and is true for any positive value of IPRs, $\Re > 0$ (Figure 1e); in particular, under no IPRs protection, $\Re = 0$, the positive effect of $\frac{\chi_D^I}{\chi_T^I}$ on $\frac{P_D^I}{P_T^I}$ is exactly offset by the negative effect of $\frac{N_D^I}{N_T^I}$ on $\frac{P_D^I}{P_T^I}$. In contrast $\frac{P_D^F}{P_T^F}$ can be positively or negatively related with ε (Figure 1f): it is negatively (positively) affected by the impact of ε in $\frac{\chi_D^F}{\chi_T^F} < 1$ ($\frac{N_D^I}{N_T^I}$); for example, when there is no IPRs protection, $\Re = 0$, the negative effect dominates, whereas under IPRs protection, $\Re > 0$, the exchange rate tends to slightly increase (decrease) with ε under complementary (substitutability) between sectors. To sum up, in general, under IPRs protection, $\Re > 0$, the exchange rate always increases in I and increases in F over substitutability and strong protection of IPRs.

In terms of growth rate, g , we start by recalling that, due to our calibration procedure, variations in the parameter of scale effects, δ , are offset by variations in the evolution of $\frac{\sigma_D^I}{\sigma_T^I}$ and thus scale effects have no effect on g . In turn, the elasticity of substitution and IPRs protection affect the BGP growth rate (Figure 1i), resulting that better enforcement of IPRs under substitutability generates stronger incentives to innovate – see Fact 2 and equation (20).

Figure 1: Impact of elasticity of substitution, scale effects, and IPRs



4.2.2 Migration of tradable workers from the *Follower* to the *Innovator*

In this section, we analyze the effects on steady-state ratios of a movement of tradable workers from F to I ; i.e., the effects induced by an increase in $\frac{L_T^I}{L_F^I}$. These effects are described in Figures 2-3 for $\forall \varepsilon$ and for the cases of no and full protection of IPRs, $\Re = 0$ and $\Re = 1$. We consider two movements, a

movement of 10,000 workers (green line) and a movement of 50,000 workers (red line). The blue line describes the results for the real level of tradable workers (see Table 2).

The migration of tradable workers from F to I leads to a shift of the relative labor supply in the two countries: the $\frac{L_D^I}{L_T^I}$ shifts downward and $\frac{L_D^F}{L_T^F}$ shifts upwards. Regardless of the IPRs policy, these shifts increase the inter-country relative price of the D -sector, as I becomes relatively more competitive – Figures 2a and 3a, Proposition 1 and equation (10).

The variation of inter-country wage inequality depends on whether the adjustment – see equation (7) – is achieved through the relative productivity $\frac{A^I}{A^F}$ or through the international trade via $\frac{B^F}{B^I}$.²³ In the case of productivity adjustment ($\frac{L_T^I}{L_T^F} \uparrow \Rightarrow \frac{A^I}{A^F} \downarrow$), the fall of the relative productivity is mirrored in the reduction of the inter-country wage inequality in the T -sector – Figures 2c and 3c, and equation (13) – as well as in the D -sector under substitutability – Figures 2b and 3b, and equation (12). Note that the effects on the inter-country wage inequality in the D -sector depend on the strength of $\frac{A^I}{A^F}$ and $\frac{L_T^I}{L_T^F}$, such that in cases of complementarity the $\frac{w_D^I}{w_D^F}$ rises. In the case of trade adjustment ($\frac{L_T^I}{L_T^F} \uparrow \Rightarrow \frac{B^F}{B^I} \uparrow$), there is no effect on the relative productivity and the only effect on the inter-country wage inequality is via the relative labor supply of tradable workers in I , thus positively affecting just the D -sector; i.e., $\frac{w_D^I}{w_D^F}$ increases – Figures 4b and 5b, and equation (12). Indeed, inter-country wage inequality in the T -sector is not affected – Figures 4c and 5c, and equation (13). Inter-country wage inequality is also independent of the IPRs policy.

The effect of migration of tradable workers from F to I on technological-knowledge bias is insignificant in the case of full IPRs protection (Figure 3d), since, as is clear from equation (16) and is stated by Proposition 3, trade: (i) enlarges the market and thus encourages innovative R&D activities directed towards the T -sector by positively affecting the respective profitability – effect captured by $\frac{\partial}{\partial \mathfrak{R}} \left(\frac{\mathfrak{R} \cdot L_j^F}{\mathfrak{R} \cdot L_T^F + L_T^I} \right) > 0$, $j = T, D$ in equation (16); (ii) makes possible the adoption activity in F and thus discourages innovative R&D activities directed towards the T -sector by negatively affecting the respective profitability – effect captured by $\frac{\partial}{\partial \mathfrak{R}} \left(\frac{L_j^I}{\mathfrak{R} \cdot L_T^F + L_T^I} \right) < 0$, $j = T, D$ in equation (16). These two contradictory effects compensate themselves and thus cancel out. In the case of no IPRs protection, the negative effect of the adoption activity on innovative activity directed towards the T -sector remains, which together with the increase in L_T^I decreases (increases) the technological-knowledge bias if the two intermediate goods are substitutes (complements) – Figure 2d and equation (16).

²³Remember that for relative productivity we use the international trade relationship $\frac{B^F}{B^I} = \frac{A^I \cdot L_T^I}{A^F \cdot L_T^F}$. Thus, an increase in $\frac{L_T^I}{L_T^F}$ might be adjusted by an increase in $\frac{B^F}{B^I}$ or by a decrease in $\frac{A^I}{A^F}$.

Regarding the effects on exchange rate, we observe opposite effects on I and F due to the immediate consequence of the workers' movement. The exchange rate in I increases with immigration of tradable workers and this rise is stronger in the case of no IPRs protection. In this case, the dominant negative effect of IPRs protection through $\frac{\Re \cdot L_j^F}{L_T^W}$, $j = T, D$ is absent, which is usually stronger than the positive effect via $\frac{L_j^I}{L_T^W}$, $j = T, D$. Yet in F , the exchange rate falls and this effect is stronger when there is full protection of IPRs, due to the explanation made for I : since the exchange rate relies negatively on $\frac{\Re \cdot L_j^F}{L_T^W}$, $j = T, D$ and positively on $\frac{L_j^I}{L_T^W}$, $j = T, D$, the fall is more pronounced when $\Re = 1$ – Figures 2e, 2f, 3e, and 3f.

As the migration movement of tradable workers from F to I shifts the relative labor supply of nontradable workers downward in I , $\frac{L_D^I}{L_T^I} \downarrow$, and upward in F , $\frac{L_D^F}{L_T^F} \uparrow$, there is an increase in $\frac{w_D^I}{w_T^I}$ (decrease in $\frac{w_D^F}{w_T^F}$); i.e., the decrease in $\frac{L_D^I}{L_T^I}$ (increase in $\frac{L_D^F}{L_T^F}$) increases (decreases) the relative wage, $\frac{w_D^I}{w_T^I} \uparrow$ and $\frac{w_D^F}{w_T^F} \downarrow$ – see, for example, equation (6). However, this effect is reversed in I and reinforced in F due to the stimulus in the demand for labor in the T -sector, which is a result of the technological-knowledge bias and which is the path of intra-country wage inequality observed in both the case of no IPRs and full IPRs protection (Figures 2g, 2h, 3g, and 3h). Thus, as stated above, by reason of complementarity between inputs in equation (2), changes in intra-country wage inequality are closely related to the technological-knowledge bias as, for example, equation 6 clearly shows. To sum up, the stimulus in the demand for labor in the T -sector, arising from the technological-knowledge bias, tends to decrease the intra-country wage inequality.

Finally, the economic growth rate is negatively affected by the tradable workers movement from F to I ; i.e., *per se* the adoption activity favors economic growth and, consequently, this movement reduces the revenue for producers of intermediate goods, although naturally less when $\Re = 1$ than in the case of $\Re = 0$ – see equation (20).

Figure 2: Migration of tradable workers from the *Follower* to the *Innovator* country for $\mathfrak{R} = 0$ and productivity adjustment

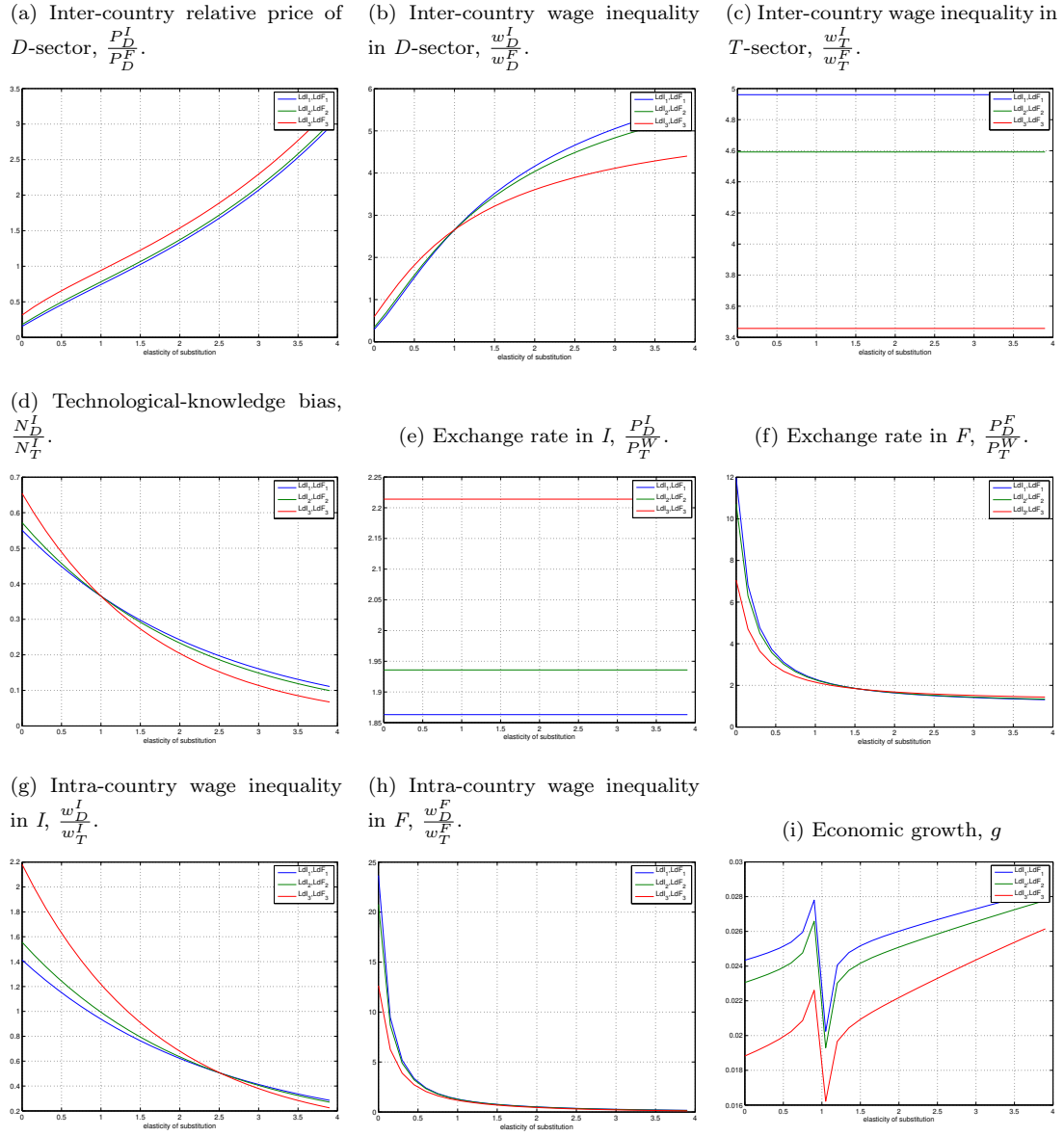


Figure 3: Migration of tradable workers from the *Follower* to the *Innovator* country for $\mathfrak{R} = 1$ and productivity adjustment

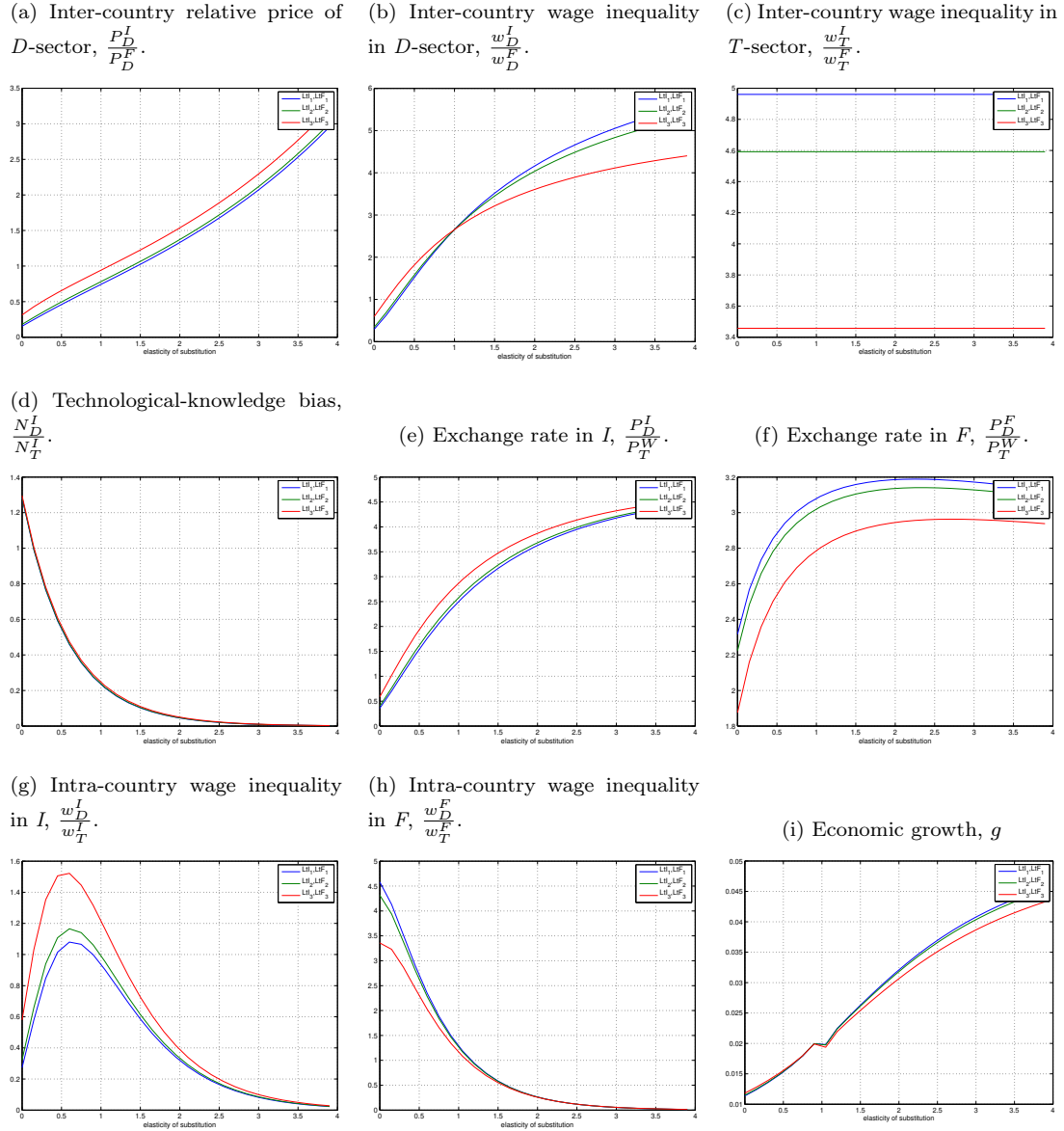


Figure 4: Migration of tradable workers from the *Follower* to the *Innovator* country for $\Re = 0$ and trade adjustment

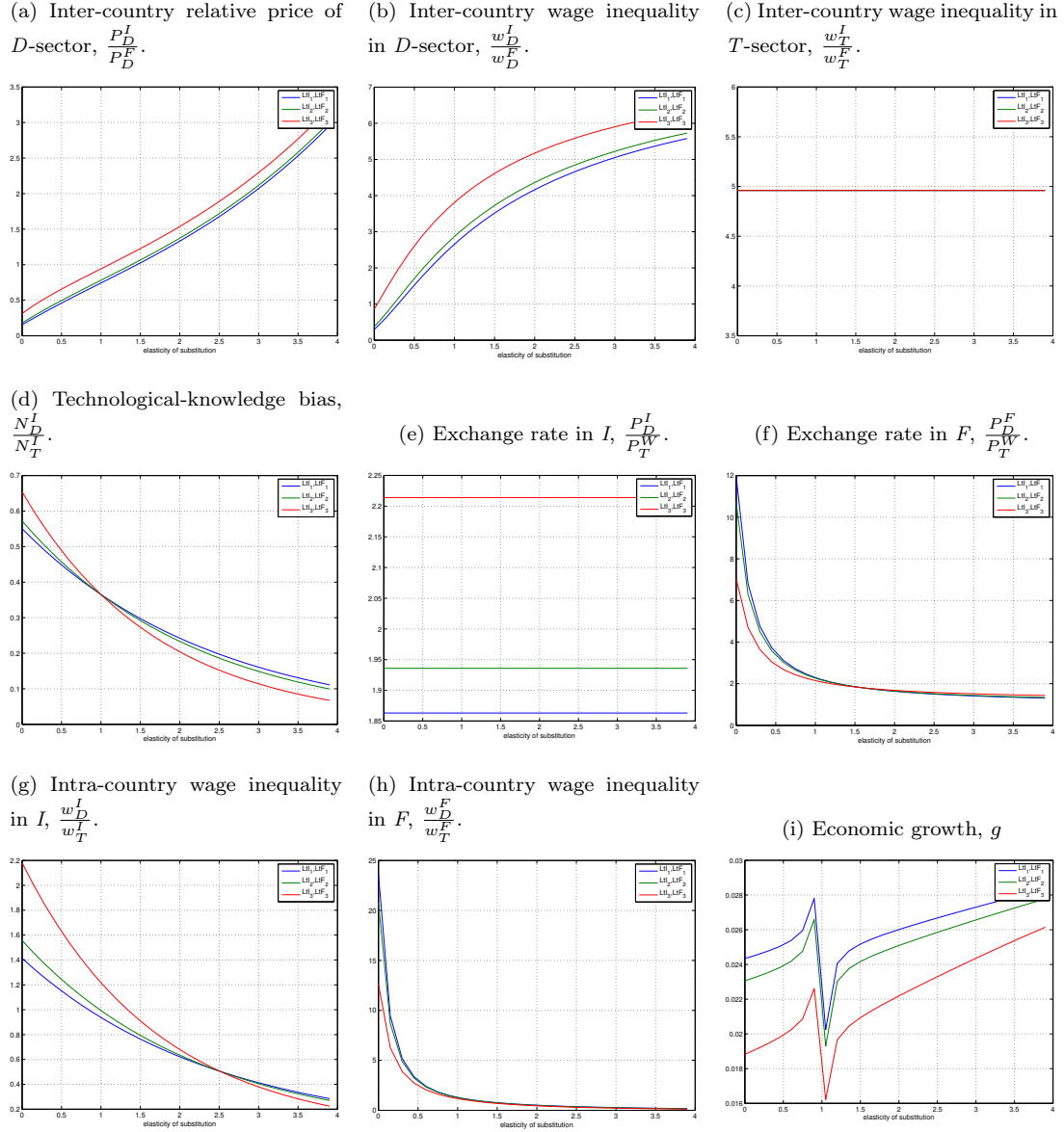
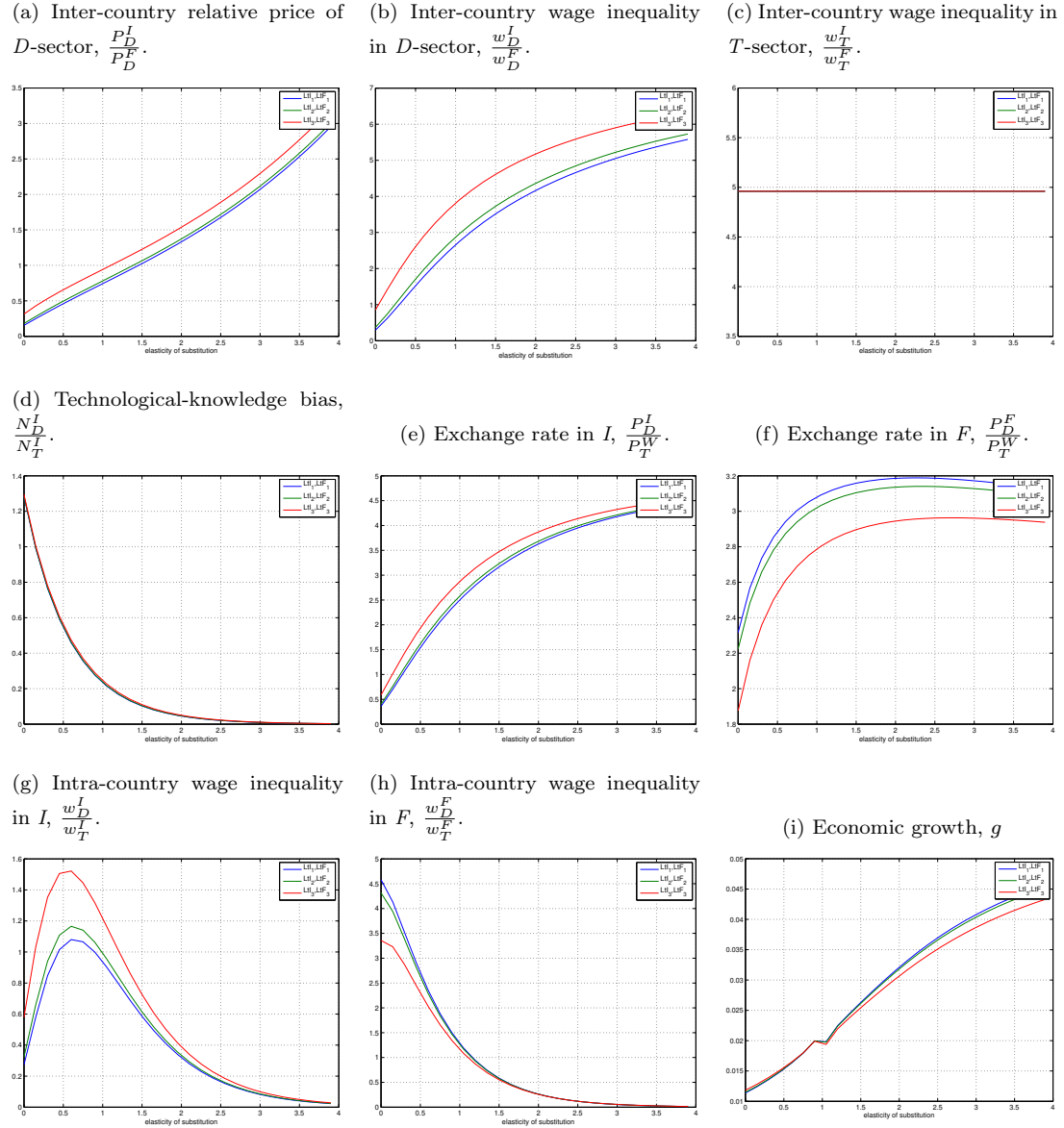


Figure 5: Migration of tradable workers from the *Follower* to the *Innovator* country for $\mathfrak{R} = 1$ and trade adjustment



4.2.3 Migration of nontradable workers from the *Follower* to the *Innovator*

In this section we analyze the effects on steady-state ratios of a movement of nontradable workers from F to I ; i.e., the effects induced by an increase in $\frac{L_D^I}{L_F^I}$. These effects are described in Figures 6 – 7 for any value of elasticity of substitution and for the cases of no and full protection of IPRs, $\Re = 0$ and $\Re = 1$. Here we follow the line of reasoning present in the previous Subsection and thus the same mechanisms to understand the chain of effects, and therefore provide explanations.

We consider again two movements, a movement of 10,000 workers (green line) and a movement of 50,000 workers (red line). As in the previous Subsection, the blue line describes the results for the real level of tradable workers (see Table 2).

The immediate consequence of a migration of nontradable workers from F to I is the shift of the relative labor supply: $\frac{L_D^I}{L_T^I}$ increases whereas $\frac{L_D^F}{L_T^F}$ decreases. Regardless of the IPRs policy and the elasticity of substitution, these shifts decrease both the inter-country relative price of the D -sector, $\frac{P_D^I}{P_F^I}$, since the relative production of this sector increases in I , and the inter-country wage inequality in the D -sector, $\frac{w_D^I}{w_F^I}$ – Figures 6a, 7a, 6b, 7b, and Propositions 1-2. As the inter-country wage inequality in the T -sector, $\frac{w_T^I}{w_F^I}$, depends on only the relative productivity, $\frac{A^I}{A^F}$, no effects are observed – see equation 13.

This upward shift of $\frac{L_D^I}{L_T^I}$ increases (decreases) the profitability of innovative R&D in the D -sector under substitutability (complementarity) and thus drives the technological-knowledge bias in favor of the D -sector (T -sector). The effect on the technological-knowledge bias is observed, however, only if there is no IPRs protection, $\Re = 0$. In the case of full IPRs protection, $\Re = 1$, the profitability of innovative R&D in the D -sector is cancelled out by the effects induced by the adjusted-market-size ratios, and the migration of nontradable workers from F to I has no effect on $\frac{N_D^I}{N_T^I}$ – Figures 6c and 7c.

Also the effects on the exchange rate are an immediate consequence of the nontradable labor supply in the two countries. Thus, as expected, we can state that the exchange rate $\frac{P_D^i}{P_T^i}$ depreciates in I and appreciates in F – Figures 6e, 7e, 6e, and 7f. However, the size of the effects in $\frac{P_D^i}{P_T^i}$ is influenced by the IPRs protection policy. Recall that in the case of full IPRs protection, $\Re = 1$, the fall of $\frac{P_D^I}{P_F^I}$ and $\frac{w_D^I}{w_F^I}$ have no repercussions on the profitability of innovative R&D in the D -sector and thus in $\frac{N_D^I}{N_T^I}$. The migration effects of nontradable workers to the *Innovator* are therefore weaker in the case of full IPRs protection.

Finally, migration effects of nontradable workers on the labor supply; i.e., the upward shift of $\frac{L_D^I}{L_T^I}$ and the downward shift of $\frac{L_D^F}{L_T^F}$, tends to decrease (increase) $\frac{w_D^i}{w_T^i}$ in I (F) – Figures 6g, 7g, 6h, and 7h

– since the greater the elasticity of substitution between the two sectors, the smaller the effects on intra-country wage inequality due to the behavior of the technological-knowledge bias. Additionally, in the case of no IPRs protection the effects on intra-country wage inequality are stronger than under full IPRs protection: in the former case, under substitutability, the upwards shift of $\frac{L_D^I}{L_T^I}$ also biases the technological-knowledge in favor of the T -sector, moderating the effects on intra-country wage inequality. Note that in our particular calibration exercise and in the case of $\Re = 1$, the $\frac{w_D^I}{w_T^I}$ tends to be always smaller than 1. Thus, the decline of the intra-country wage ratio means an increase of inequality in favor of tradable workers.

Once again, the economic growth rate is negatively affected by the nontradable workers' movement from F to I due to decreased adoptative activity by F , a fact that penalizes the profitability of intermediate goods producers in I , although, as in the previous case, naturally less with $\Re = 1$ than with $\Re = 0$.

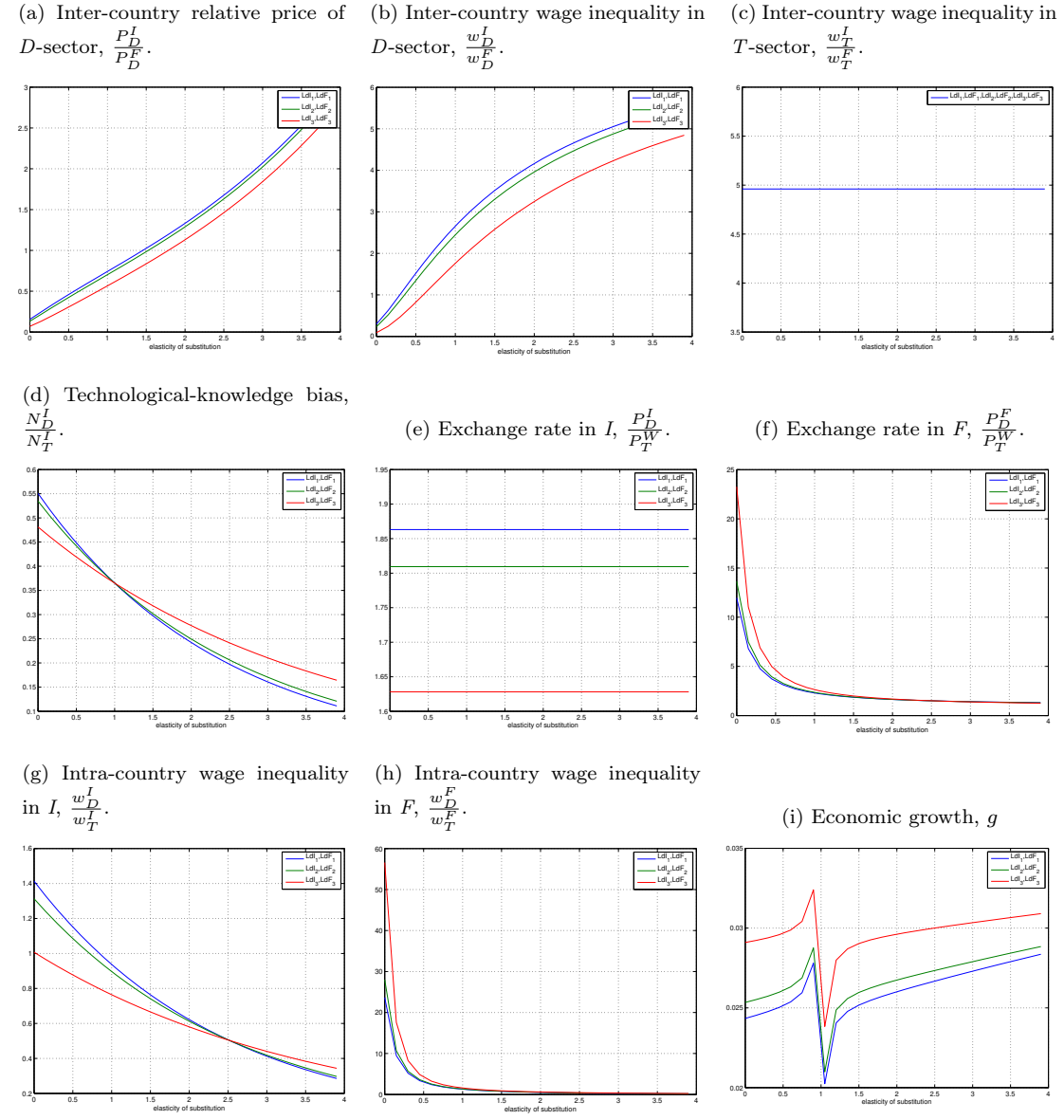
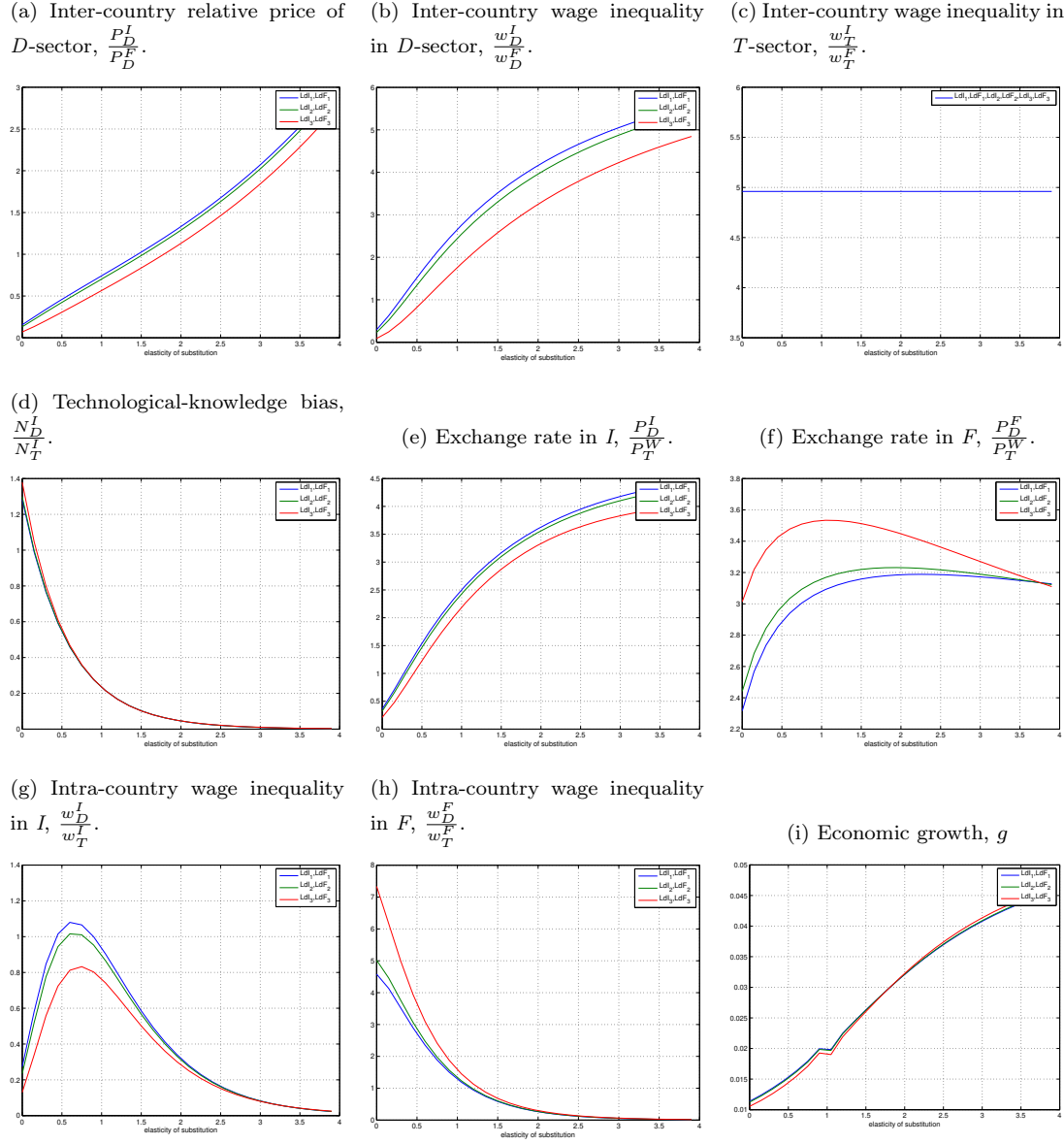
Figure 6: Migration of nontradable workers from the *Follower* to the *Innovator* country for $\mathfrak{R} = 0$ 

Figure 7: Migration of nontradable workers from the *Follower* to the *Innovator* country for $\mathfrak{R} = 1$ 

5 Concluding remarks

The purpose of this paper is to propose mechanisms that are able to accommodate some important observed trends: the enlarged trade flows between developed/*Innovator* and developing/*Follower* countries and the worldwide strong technological-knowledge progress, as well as the behavior of inter-country

prices, real exchange rates, inter-country wages, and intra-country wages between tradable and nontradable sectors.

We propose a general equilibrium endogenous growth model that merges two (main) literatures – the directed technical change and the international trade – and considers two groups of countries, *Innovator* and *Follower*, and two sectors, tradable and nontradable. Moreover, it is flexible concerning the dominance of either the price channel or the market-size channel in driving/directing the technological knowledge, as well as regarding the degree of IPRs in the costless process of technological-knowledge adoption.

With perfect competition in final goods, as in standard directed technical change set-ups, economic viability of each sector relative to the other depends on the: output price, importance in production, degree of substitutability (with the other sector), labor price, and intermediate-goods prices. The technological-knowledge bias mechanism emerges as the driving force of the real exchange rate and the intra-country wage inequality affected by six factors: (i) sectoral labor supply; (ii) sectoral importance in production; (iii) sectoral elasticity of substitution; (iv) sectoral relative advantage to entry through horizontal R&D; (v) degree of scale effects and; (vi) degree of international IPRs protection.

In general, we found that the main variables depend on parameters and exogenous variables of both countries. In particular, the inter-country relative price of the nontradable sector also depends on the labor levels in the tradable sector and tends to be higher in the *Innovator*. Inter-country wage inequality also tends to be higher in the *Innovator* since by assumption the positive exogenous productivity reflecting the country's institutions is greater in this country; however, it is balanced between sectors and greater in the nontradable sector especially under substitutability. In turn, the worldwide technological-knowledge bias towards the nontradable sector depends positively on the relative productivity of developing nontradable complementary intermediate goods, on the relative importance of the nontradable sectors in production, and on the ratios between adjusted labor levels in the nontradable sectors and in the worldwide labor level in the tradable sectors. It depends ambiguously on the degree of IPRs protection, considering the range from no to full protection of international IPRs. Moreover, it is negatively related to the relative worldwide ratio and country-specific nontradable labor level.

Basically, the real exchange rate of each country relies positively on the relative importance of the nontradable sector in production, and relies negatively on both the relative nontradable labor level and the technological-knowledge bias. The intra-country wage inequality in each country is generally positively related to the relative importance of the nontradable sector in production, negatively related

to the relative supply of nontradable labor, and is also driven by the technological-knowledge bias. The effect of the technological-knowledge bias on exchange rate and on intra-country wage inequality operates due to complementarity between inputs in production, and is influenced by the degree of substitutability between sectors. Through the bias these variables depend ambiguously on the degree of IPRs protection, which, in turn, can affect positively or negatively the worldwide steady-state growth rate. It should also be emphasized that the real exchange rates also depend negatively on the relative advantage to entry through horizontal innovation, in line with the Balassa-Samuelson proposal.

Our calibrated exercise for 11 developed countries (*Innovator* group) and 11 developing countries (*Follower* group) confirms the above results when sensitivity analysis is performed and the impact of the elasticity of substitution, scale effects, royalty fees (i.e., international IPRs protection), migration of tradable workers from the *Follower* to the *Innovator*, and migration of nontradable workers from the *Follower* to the *Innovator* is analyzed.

It should be also emphasized that while related papers have illustrated some important aspects of the complex relationship between trade, IPRs, innovative R&D, prices, and wages, our approach seems at least equally plausible and is useful in explaining a number of empirical observations as well as in understanding mechanisms that justify policy measures. For example, the results indicate that, in terms of economic growth rate, the *Follower* may benefit from the enforcement of IPRs and thus can use this instrument to affect innovative R&D activity in the desired direction.

Our framework is still quite stylized and encourages extensions in several directions. For example, it should be extended to accommodate the role played by multinationals and other organizational forms of production. It can be also extended to consider that the *Follower* also innovates since developing countries such as the ones considered in our calibrated exercise also invest in innovative R&D. The elasticity of substitution between tradable and nontradable sectors is a key parameter of the analysis and that in future research needs to be properly estimated. Although R&D is a key driver of economic growth, our framework can also be extended to include human-capital accumulation. Moreover, the model can be extended to include trade in intermediate goods along with the imitative R&D activity, in order to discuss the technological-knowledge gap between countries. Also a formal welfare analysis of IPRs, which can or cannot be sector specific, for workers in both countries and in both sectors can be performed in future research. Incorporating these elements into the analysis would certainly improve our understanding of the complex interactions between trade, prices, wages, and growth in a global economy and seems a fruitful direction for future research.

A Data construction and sources

Table 3: Share of exports and imports by country in the world merchandise trade in 2014

Countries	Rank	Exports %	Rank	Imports %
<i>Innovators</i>				
The US	2	8.5	1	12.6
Germany	3	7.9	3	6.4
Japan	4	3.6	4	4.3
The Netherlands	5	3.5	8	3.1
France	6	3.1	6	3.5
Korea, Republic of	7	3.0	9	2.8
Italy	8	2.8	11	2.5
The UK	10	2.7	5	3.6
Canada	12	2.5	10	2.5
Belgium	13	2.5	13	2.4
Spain	18	1.7	16	1.9
<i>Followers</i>				
China	1	12.3	2	10.3
Hong Kong, China	9	2.8	7	3.1
Russian Federation	11	2.6	17	1.6
Singapore	14	2.2	15	1.9
Mexico	15	2.1	14	2.2
The UAE	16	1.9	20	1.4
Saudi Arabia	17	1.9	29	0.9
India	19	1.7	12	2.4
Malaysia	23	1.2	26	1.1
Thailand	24	1.2	24	1.2
Brazil	25	1.2	22	1.3
Total of developed countries		41.8		45.5
Total of developing countries		31.0		27.3
Total		72.8		72.8

Source: WTO, International Trade Statistics 2015.

Table 4: Sectors classification

Sectors	Tradable				Nontradable	
	Agriculture, hunting, forestry, fishing	Mining, Manufacturing, utilities	Wholesale, retail trade, restaurants & hotels	Transport, storage & communications	Finance & Real State Public & Social Services	Construction
ISIC rev.3.1	A-B	C-E	G-H	I	J-P	F

Table 5: Share of tradable and nontradable goods by sector (2010-2014 averages)

Sector	Tradable				Nontradable	
	Agriculture, hunting, forestry, fishing	Mining, Manufacturing, utilities	Wholesale, retail trade, restaurants & hotels	Transport, storage & communications	Construction	Other activities
ISIC code	A-B	C-E	G-H	I	F	J-P
<i>Innovators</i>						
Belgium	.8	16.98	14.34	9.96	5.64	52.34
Canada	1.68	20.72	12.58	7.2	7.5	50.3
France	1.74	13.74	13.14	9.66	5.94	55.84
Germany	.76	25.98	11.1	9.36	4.46	48.38
Italy	2.16	18.58	14.76	9.38	5.32	49.84
Japan	1.2	20.86	14.34	10.48	5.72	47.46
The Netherlands	1.82	17.1	14.94	9.58	4.88	51.72
Republic of Korea	2.42	33.34	11.54	7.5	4.9	40.28
Spain	2.56	17.3	18.84	8.94	6.74	45.62
The UK	.7	14.94	16.24	8.04	6.02	54.06
The US	1.24	16.68	14.46	9.3	3.64	54.7
<i>Followers</i>						
Brazil	5.3	19.2	14.88	7.52	6.36	46.78
China	9.74	38.06	11.08	4.48	6.84	29.74
China, Hong Kong SAR	.08	3.32	28.42	9.92	3.7	54.56
India	18.02	23.08	11.38	6.62	8.7	32.22
Malaysia	10.24	37.24	16.8	6.48	3.86	25.36
Mexico	3.28	30.66	17.86	8.74	7.94	31.48
Russian Federation	4.06	29.18	19.62	8.88	7.2	31.04
Saudi Arabia	1.98	55.84	8.56	4.82	4.68	24.14
Singapore	0	21.2	21.06	11.06	4.84	41.82
Thailand	11.1	35.18	17.6	7.04	2.7	26.4
The UAE	.7	45.72	12.6	7.82	9.06	24.1
<i>Innovators</i> (mean)	tradable		44.5		nontradable	55.6
<i>Followers</i> (mean)	tradable		60.6		nontradable	39.4

Source: Own construction, data from UNCTAD National Accounts Main Aggregates Database and following the ISIC. Rev.3 classification.

Table 6: Share of exports in the tradable sector by year and country

Country	2010	2011	2012	2013	2014	Mean 2010-14
<i>Innovators</i>						
Belgium	1.77	1.92	1.96	1.98	2.04	1.93
Canada	0.69	0.72	0.72	0.72	0.75	0.72
France	0.68	0.72	0.74	0.75	0.76	0.73
Germany	0.90	0.94	0.97	0.97	0.98	0.95
Italy	0.56	0.60	0.64	0.65	0.66	0.62
Japan	0.32	0.33	0.32	0.35	0.37	0.34
The Netherlands	1.67	1.78	1.87	1.89	1.91	1.83
Republic of Korea	0.90	1.01	1.03	0.98	0.93	0.97
Spain	0.55	0.61	0.64	0.66	0.68	0.63
The UK	0.72	0.77	0.76	0.74	0.71	0.74
The US	0.30	0.33	0.33	0.32	0.32	0.32
<i>Followers</i>						
Brazil	0.23	0.23	0.26	0.26	0.25	0.25
China	0.45	0.43	0.42	0.41	0.39	0.42
China. Hong Kong	5.24	5.32	5.38	5.50	5.34	5.36
India	0.37	0.41	0.41	0.43	0.40	0.40
Malaysia	1.31	1.27	1.21	1.17	1.13	1.22
Mexico	0.50	0.52	0.54	0.52	0.53	0.52
Russian Federation	0.47	0.48	0.48	0.47	0.49	0.48
Saudi Arabia	0.71	0.76	0.75	0.74	0.71	0.73
Singapore	3.55	3.67	3.65	3.71	3.72	3.66
Thailand	0.92	0.98	0.97	0.96	1.00	0.97
The UAE	1.23	1.32	1.42	1.51	1.50	1.40
<i>Innovators (mean)</i>						0.89
<i>Followers (mean)</i>						1.40

Source: Own construction, data from UNCTAD National Accounts Main Aggregates Database.

Table 7: Employment by economic sector and country (2010-2014 averages)

Sector ISIC code	Tradable				Nontradable		Total		T/D
	A-B	C-E	G-H	I	F	J-P	Tradable	Nontradable	
<i>Innovators</i>									
Belgium	54.4	690.9	743.2	255.1	325.5	2430.8	1743.5	2756.3	0.63
Canada	360.8	2272.1	4063.0	1131.8	1323.7	8635.5	7827.7	9959.2	0.79
France	731.6	3727.6	4232.0	1364.4	1827.7	13663.5	10055.6	15491.2	0.65
Germany	550.2	8312.2	6733.6	1832.2	2589.3	18422.2	17428.1	21011.4	0.83
Italy	771.1	4494.4	4397.1	1038.9	1657.9	9700.5	10701.6	11358.4	0.94
Japan	2426.7	11184.4	14573.3	3610.0	5020.0	25420.5	31794.4	30440.5	1.04
Korea	1539.0	4286.5	5546.8	1351.2	1757.6	10018.4	12723.5	11776.0	1.08
The Netherlands	181.2	849.3	1458.5	367.8	422.8	4170.0	2856.8	4592.8	0.62
Spain	738.0	2497.1	4231.7	866.5	1242.7	8179.0	8333.3	9421.7	0.88
The UK	295.3	3349.4	5352.1	1411.3	2130.2	15993.9	10408.1	18124.1	0.57
The US	2206.0	14822.6	29303.0	7134.0	9077.0	76584.8	53465.6	85661.8	0.62
<i>Followers</i>									
Brazil	14148.7	12894.0	21416.7	5260.0	8309.7	32837.3	53719.3	41147.0	1.31
China	3676.0	47756.2	8172.5	6469.5	14961.5	51129.2	66074.2	66090.7	1.00
India	186516.2	56043.1	45236.8	16840.5	41956.7	49067.1	304636.6	91023.8	3.35
Malaysia	1565.7	2391.7	3054.6	595.0	1157.2	3864.1	7606.9	5021.3	1.51
Mexico	6457.4	7848.9	13019.0	1954.7	3653.7	14738.8	29280.0	18392.5	1.59
Russian Fed.	5203.8	14370.6	12865.4	6688.8	5254.2	26646.6	39128.6	31900.8	1.23
Saudi Arabia	477.6	951.3	1971.0	414.5	1501.9	4984.8	3814.4	6486.7	0.59
Thailand	11982.9	4344.3	6364.7	736.1	1851.2	4941.8	23428.0	6793.0	3.45
<i>Tot. Innovators</i>	9854.4	56486.5	80634.3	20363.0	27374.4	193219.0	167338.1	220593.4	0.76
<i>Tot. Followers</i>	230028.3	146600.1	112100.6	38959.1	78646.1	188209.8	527688.1	266855.9	1.98
<i>Innov./Followers</i>	0.04	0.39	0.72	0.52	0.35	1.03	0.32	0.83	

Source: Own construction, data from KILM, 2015 database (ILO). Thailand and Brazil data available organized according ISIC. Rev. 3.1 classification. The remaining data were organized according ISIC rev. 4 revision. Thus, we carried out the necessary rearrangements and rearrange data following the ISIC rev. 3.1 classification. We compute employment averages for 2010-2014, except for Brazil (2011-2013), Saudi Arabia (2013), Canada (2013), China (2010-2011), India (2012), Japan (2010-2013), Mexico (2010-2013), Thailand (2010-2013), and the US (2010) because of unavailability of data.

Table 8: Patents by activity sector (2010-2013 averages)

Country	A	B	C	D	E	F	Tradable	Non Tradable	NT/T
<i>Innovators</i>									
Belgium	111.35	2.07	106.30	911.88	12.38	68.28	1143.96	68.28	0.06
Canada	268.87	4.79	201.98	2263.89	26.28	230.17	2765.80	230.17	0.08
France	652.45	11.49	569.79	5572.49	85.17	418.82	6891.38	418.82	0.06
Germany	1271.31	19.77	1530.41	13184.54	291.98	1114.60	16298.02	1114.60	0.07
Italy	336.46	6.58	235.93	2311.15	38.36	231.97	2928.48	231.97	0.08
Japan	2537.12	35.69	2705.60	31940.68	343.94	1729.70	37563.03	1729.70	0.05
Korea	867.10	14.63	597.10	8526.25	68.88	565.72	10073.95	565.72	0.06
The Netherlands	381.84	7.51	222.91	2450.62	29.62	184.37	3092.51	184.37	0.06
Spain	201.66	4.02	128.81	1270.85	17.37	122.35	1622.71	122.35	0.08
The UK	608.50	11.56	409.63	4278.22	59.94	408.22	5367.86	408.22	0.08
The US	5286.89	99.78	3330.17	38172.48	392.44	2840.64	47281.76	2840.64	0.06
<i>Followers</i>									
Brazil	77.34	1.57	52.15	450.12	8.93	45.17	590.11	45.17	0.08
China	1075.71	14.68	774.20	14509.31	77.39	875.72	16451.29	875.72	0.05
Hong Kong	39.17	0.78	18.38	247.24	2.78	16.97	308.35	16.97	0.06
India	210.60	4.10	156.11	1444.75	16.76	68.44	1832.32	68.44	0.04
Malaysia	26.15	0.42	22.17	274.54	2.01	19.27	325.28	19.27	0.06
Mexico	30.92	0.65	17.34	155.61	2.37	22.27	206.89	22.27	0.11
Russia	100.00	1.81	81.71	773.78	12.42	82.47	969.72	82.47	0.09
Saudi Arabia	7.91	0.09	20.01	126.42	1.80	22.49	156.23	22.49	0.14
Singapore	60.00	1.05	49.94	539.10	4.71	37.52	654.80	37.52	0.06
Thailand	9.36	0.19	6.71	60.41	0.76	4.90	77.43	4.90	0.06
The UAE	4.15	0.07	3.55	36.41	0.42	4.12	44.60	4.12	0.09
<i>Innovators</i> (mean)									0.07
<i>Followers</i> (mean)									0.06

Source: Own construction, data from OECD, 2015 converted from International Patent Classification (IPC) to ISIC rev 3.1 classification system through the concordance algorithm developed in Lybbert and Zolas, 2014.

Table 9: Business enterprise R&D expenditures by sector and country for 2010-2013

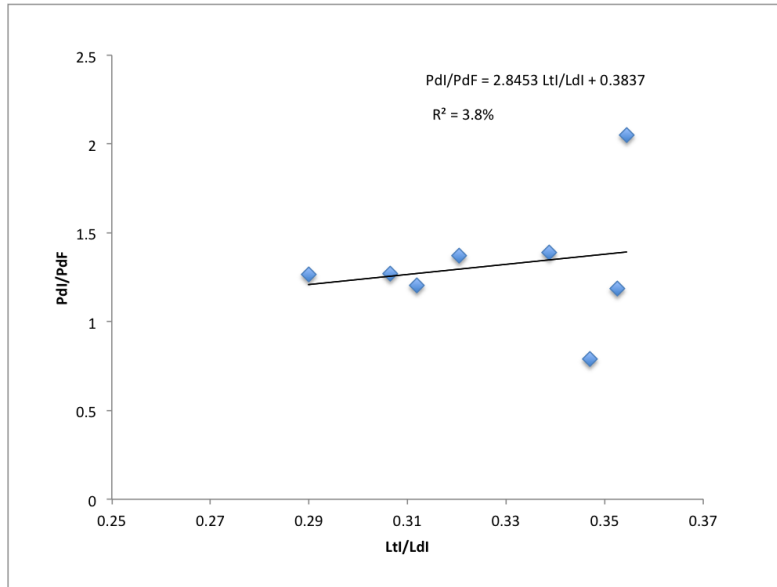
Countries	Tradable				Nontradable				Tradable	Nontradable
	2010	2011	2012	2013	2010	2011	2012	2013	mean	mean
<i>Innovators</i>										
Belgium	345.3	393.6	441.4	452.5	118.4	116.5	143.7	151.7	408.20	132.6
France	289.3	301.6	317.3	330.6	134.8	141.8	142.3	137.0	309.70	139.0
Germany	532.1	580.1	614.0	608.9	41.3	44.3	42.9	44.0	583.78	43.1
Italy	156.5	159.6	164.5	168.2	22.0	22.5	22.2	23.8	162.20	22.6
The Netherlands	274.4	329.8	334.2	333.9	36.8	84.8	86.8	87.0	318.08	73.9
Spain	103.3	103.6	98.6	95.0	57.6	54.0	52.5	52.3	100.13	54.1
The UK	168.6	179.2	199.4	202.8	127.6	134.9	128.6	132.4	187.50	130.9
Mean									295.65	85.16

B Empirical facts

This section includes some available data in order to be compared with the model predictions. Note that now we also collect data for wages and prices, and thereby, our sample is constrained by the availability of data.

In Figure 8 we observe the relationship between the inter-country relative price of the D -sector against the relative tradable labor in country I . First, as shown by the model, $\frac{P_D^I}{P_D^F}$ tends to be greater than 1, that is, the inter-country relative price tends to be higher in the *Innovator* country. Second, the inter-country relative price of the D -sector increases with relative tradable labor supply of country I , as found in our results.

Figure 8: Inter-country relative price of the D -sector versus relative tradable labor in country I



Note: Prices for tradable and nontradable goods were obtained from the Social Economics Accounts (SEA) of the World Input-Output database for the average between 1995-2009 and for 8 *Innovator* countries (Belgium, Canada, Germany, Spain, France, The UK, The Netherlands, and The US) and 8 *Follower* countries (Brazil, China, India, Latvia, Mexico, Malta, Russia, and Slovenia), following the AMECO definition for tradable and nontradable sector classification, (Zeugner, 2013) and converted to US dollars. Tradable and nontradable labor were also obtained from SEA. The period and country sample is based on data availability.

As observed in 9a, the inter-country wage inequality in both the D and T -sectors is higher in the country, and as is shown by the 45-degree line; and higher in the nontradable sector, reinforcing the presence of substitutability between goods, $\frac{W_D^I}{W_D^F} > \frac{W_T^I}{W_T^F} > 1$. Additionally, the intra-country wage inequality in

country I is negatively related to the technological-knowledge bias, see Figure 9b.

Figure 9: Inter-country wage inequality in the T and D -sectors.

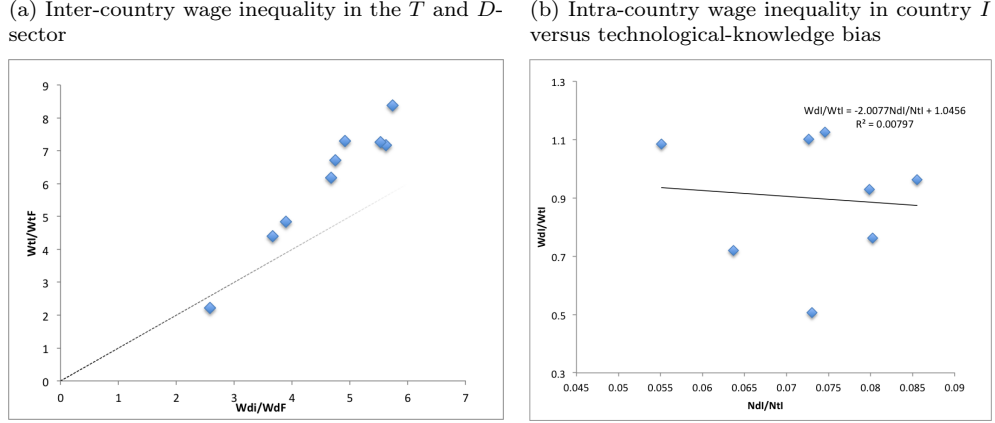
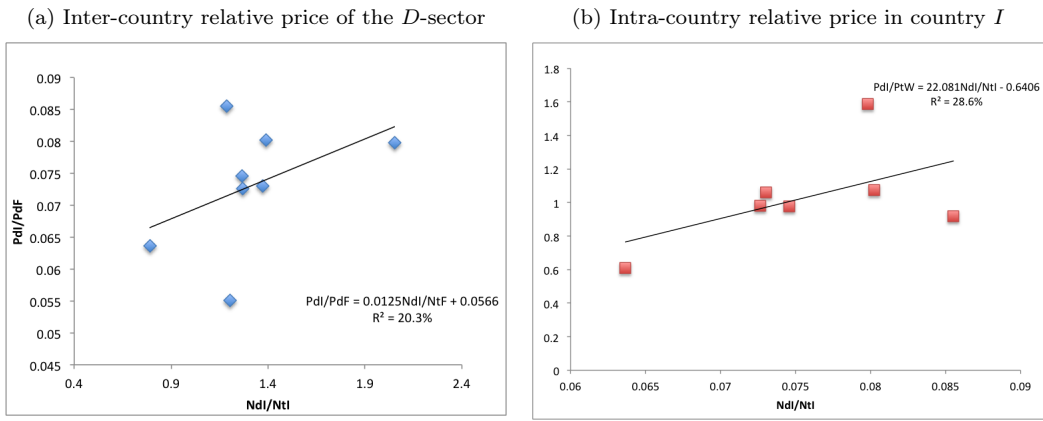


Figure 10 shows a positive relationship between inter (10a) and intra-country (10b) relative prices of the D -sector and the technological-knowledge bias, as stated in our findings. Moreover, according to this evidence, the technological-knowledge bias explains around 20% and 29% of the variability of the inter and intra-country relative prices.

Figure 10: Inter and intra-country prices versus technological-knowledge bias.



Note: Wages and prices were obtained from the SEA from the WIOD for the average between 1995-2009 and for 8 *Innovator* countries (Belgium, Canada, Germany, Spain, France, The UK, The Netherlands and The US) and 8 *Follower* countries (Brazil, China, India, Latvia, Mexico, Malta, Russia and Slovenia), following the AMECO definition for the tradable and nontradable sector classification, Zeugner (2013).

References

- Acemoglu, D. (2002). "Directed technical change." *Review of Economic Studies* 69(4), 781-809.
- Acemoglu, D. (2003). "Patterns of skill premia." *Review of Economic Studies* 70, 199-230.
- Acemoglu, D. (2008). *Introduction to modern economic growth*. Princeton University Press.
- Acemoglu, D., and Ventura, J. (2002). "The world income distribution." *Quarterly Journal of Economics* 117, 659-694.
- Acemoglu, D., and Zilibotti, F. (2001). "Productivity differences." *Quarterly Journal of Economics* 116, 563-606.
- Adams, S. (2008). "Globalization and income inequality: implications for Intellectual Property Rights." *Journal of Policy Modeling* 30, 725-735.
- Afonso, O. (2012). "Scale-independent North-South trade effects on the technological-knowledge bias and on wage inequality." *Review of World Economics* 148 (1), 181-207.
- Afonso, O., and Sequeira, T. (2016). "Tradable and nontradable directed technical change". Mimeo.
- Akiyama, T., and Furukawa, Y. (2009). "Intellectual property rights and appropriability of innovation." *Economics Letters* 103, 138-141.
- Alesina, A., and Spolaore, E. (1997). "On the number and size of nations." *Quarterly Journal of Economics* 112(4), 1027-1056.
- Amiti, M., and Davis, D.R. 2008. "Trade, firms, and wages: Theory and evidence", NBER Working Paper No. W14106 (Cambridge, MA, National Bureau of Economic Research).
- Atkinson, A.B., and Brandolini, A. (2010). "On analyzing the World distribution of income." *World Bank Economic Review* 24(1): 1-37.
- Backus, D.K., Kehoe, P.J., and Kehoe, T.J. (1992). "In search of scale effects in trade and growth." *Journal of Economic Theory* 58(2), 377-409.
- Balassa, B. (1964). "The purchasing-power parity doctrine: a reappraisal." *Journal of Political Economy* 72(6), 584-596.

- Barro, R., and Sala-i-Martin, X. (1997). "Technological diffusion, convergence, and growth." *Journal of Economic Growth* 2(1), 1-26.
- Barro, R., and Sala-i-Martin, X. (2004). *Economic Growth*. 2nd Edt. Cambridge, Massachusetts: MIT Press.
- Becker, G.S., and Murphy, K.M. (1992). "The division of labor, coordination costs, and knowledge." *Quarterly Journal of Economics* 107(4), 1137-1160.
- Bergin, P., Glick, R., and Taylor, A. (2006). "Productivity, tradability, and the long-run price puzzle." *Journal of Monetary Economics* 53, 2041-2066.
- Berka, M., and Devereux, M.B. (2010). "What determines European real exchange rates?" NBER Working Paper 15753.
- Berka, M., and Devereux, M.B. (2013). "Trends in European real exchange rates." *Economic Policy* 28(74), 193-242.
- Bernard, A.B., and Jensen, J.B. (1995). "Exporters, jobs, and wages in U.S. manufacturing: 1976-1987." *Brookings Papers on Economic Activity. Microeconomics*, 67-119.
- Bernard, A.B., and Jensen, J.B. (1999). "Exceptional exporter performance: cause, effect, or both?" *Journal of International Economics* 47, 1-25.
- Bernard, A.B., and Jensen, J.B. (2004). "Why some firms export." *Review of Economics and Statistics* 86, 561-569.
- Bernard, A.B., Jensen, J.B., Redding, S.J., and Schott, P.K. (2007). "Firms in international trade." *Journal of Economic Perspectives* 12, 105-130.
- Blonigen, B.A., and Wilson, W.W. (1999). "Explaining Armington: what determines substitutability between home and foreign goods?" *Canadian Journal of Economics* 32(1), 1-21.
- Borensztein, E., Gregorio, J.D., and Lee, J.-W. (1998). "How does foreign direct investment affect economic growth?" *Journal of International Economics* 45, 115-135.
- Bound, J., Cummins, C., Griliches, Z., Hall, B., and Jaffe, A. (1984). "Who does R&D and who patents?" In Zvi Griliches (ed.), *R&D, Patent and Productivity*, pp. 21-54, University of Chicago Press, Chicago, IL.

- Broda, C., and Weinstein, D.E. (2006). "Globalization and the gains from variety." *Quarterly Journal of Economics* 121(2), 541-585.
- Burstein, A., and Vogel, J. (2010). "Globalization, technology, and the skill premium: a quantitative analysis." NBER Working paper, 16459. Cambridge, MA: National Bureau of Economic Research.
- Carvalho, C., and Nechio, F. (2011). "Aggregation and the PPP puzzle in a sticky-price model." *American Economic Review* 101, 2391-2424.
- Caselli, F., and Wilson, D. (2004). "Importing technology." *Journal of Monetary Economics* 51, 1-32.
- Caselli, F., and Coleman, W.J. (2006). "The world technology frontier." *American Economic Review* 96(3), 499-522.
- Chong, Y., Jordi, O., and Taylor, A.M. (2012). "The Harrod-Balassa-Samuelson hypothesis: real exchange rates and their long-run equilibrium." *International Economic Review* 53(2), 609-633.
- Chin, J.C., and Grossman, J.M. (1990). "Intellectual property rights and North-South trade in the political economy of international trade: essays in honor of Robert E. Baldwin." Ed. by R.W. Jones and A.O. Krueger. Cambridge, MA, Basil Blackwell.
- Chu, A.C., Cozzi, G., and Furukawa, Y. (2015). "Effects of economic development in China on skill-biased technical change in the US." *Review of Economic Dynamics* 18, 227-242.
- Cozzi, G., and Galli, S.J. (2014). "Sequential R&D and blocking patents in the dynamics of growth." *Journal of Economic Growth* 19(2), 183-219.
- Datta, A., and Mohtadi, H. (2006). "Endogenous imitation and technology absorption in a model of North-South trade." *International Economic Journal* 20(4), 431-459.
- Dicken, P. (2015). *Global shift: mapping the changing contours of the world economy*. Seventh Edition. Sage Publications Ltd., London, UK.
- Dickens, W.T., and Katz, L.F. (1987). "Interindustry wage differences and industry characteristics." In: Lang K. and Leonard, J. *Unemployment and the Structure of Labor Markets*. Blackwell, 48-89.
- Dinopoulos, E., and Segerstrom, P. (1999). "A Schumpeterian model of protection and relative wages." *American Economic Review* 89(3), 450-473.

- Dinopoulos, E., and Segerstrom, P. (2004). "A theory of North-South trade and globalization." Stockholm School of Economics, mimeo.
- Dinopoulos, E., and Thompson, P. (1999). "Scale effects in Schumpeterian models of economic growth." *Journal of Evolutionary Economics*, vol. 9, issue 2, April, pp. 157-185.
- Dinopoulos, E., and Thompson, P. (2000). "Endogenous growth in a cross-section of countries." *Journal of International Economics* 51, 335-362.
- Eaton, J., and Kortum, S. (2001). "Trade in capital goods." *European Economic Review* 45, 1195-1235.
- Egger, H., and Kreickemeier, U. (2009). "Firm heterogeneity and the labor market effects of trade liberalization." *International Economic Review* 50, 187-216.
- Eicher, T., and Garcia-Penalosa, C. (2008). "Endogenous strength of intellectual property rights: implications for economic development and growth." *European Economic Review* 52, 237-258.
- Epifani, P., and G. Gancia (2009). "Openness, government size and the terms of trade." *Review of Economic Studies* 76(2), 629-668.
- Fadinger, H., and K. Mayr (2014). "Skill-biased technological change, unemployment, and brain drain." *Journal of the European Economic Association* 12(2), 397-431.
- Freeman, R.B., and Oostendorp, R. (2000). "Wages around the world: pay across occupations and countries." NBER Working Paper 8058, National Bureau of Economic Research (NBER), Cambridge, MA, December.
- Feenstra, R.C., Luck, P.A., Obstfeld, M. and Russ, K.N. (2014). "In search of the Armington elasticity." NBER Working Papers 20063, National Bureau of Economic Research, Inc.
- Frias, J.A., Kaplan, D.S., and Verhoogen, A.E. (2012). "Exports and within-plant wage distributions: evidence from Mexico." *American Economic Review: Papers & Proceedings* 102(3), 435-440.
- Furukawa, Y. (2007). "The protection of intellectual property rights and endogenous growth: Is stronger always better?" *Journal of Economic Dynamic and Control* 31, 3644-3670.
- Gallaway, M.P., McDaniel, C.A., and Rivera, S.A. (2003). "Short-run and long-run industry-level estimates of US Armington elasticities." *North American Journal of Economics and Finance* 14, 49-68.

- Gancia, G., and Bonfiglioli, A. (2008). "North-South trade and directed technical change." *Journal of International Economics* 76(2), 276-295.
- Gancia, G., Muller, A., and Zilibotti, F. (2013). "Structural development accounting." In *Advances in Economics and Econometrics: Tenth World Congress* (Vol. 2, p. 373). Cambridge University Press. Chicago.
- Ghironi, F., and Melitz, M. (2005). "International trade and macroeconomic dynamics with heterogeneous firms." *Quarterly Journal of Economics* 120(3), 865-915.
- Glass, A., and Saggi, K. (2002). "Intellectual property rights and foreign direct investment." *Journal of International Economics* 56, 387-410.
- Goh, A.-T., and Olivier, J. (2002). "Free trade and protection of intellectual property rights: can we have one without the other?" CEPR Discussion Paper No. 3127.
- Gomez, M.A., and Sequeira, T.N. (2013). "Should the US increase subsidies to R&D? Lessons from an endogenous growth theory." *Oxford Economic Papers* 66(1), 254-282.
- Grossman, G., and Lai, E. (2004). "International protection of intellectual property." *American Economic Review* 94, 1635-1653.
- Grossmann, V., Steger, T., and Trimborn, T. (2013). "Dynamically optimal R&D subsidization." *Journal of Economic Dynamics and Control* 37(3), 516-534.
- Helpman, E. (1993). "Innovation, imitation and intellectual property rights." *Econometrica* 61(6), 1247-1280.
- Helpman, E., Itskhoki, O., and Redding, S. (2010). "Inequality and unemployment in a global economy." *Econometrica* 78(4), 1239-1283.
- Ivus, O. (2011). "Trade-related intellectual property rights: industry variation and technology diffusion." *Canadian Journal of Economics* 44(1), 201-226.
- Jones, C.I. (1995a). "R&D based models of economic growth." *Journal of Political Economy* 103(4), 759-784.
- Jones, C.I. (1995b). "Time series tests of endogenous growth models." *Quarterly Journal of Economics* 110(2), 495-525.

- Jones, C.I. (1999). "Growth: with or without scale effects." *American Economic Review* 89, 139-144.
- Jones, C.I., and Williams, J.C. (2000). "Too much of a good thing? The economics of investment in R&D." *Journal of Economic Growth* 5(1), 65-85.
- Juhn, C., Murphy, K., and Pierce, B. (1993). "Wage inequality and the rise in returns to skill." *Journal of Political Economy* 101(3), 410-442.
- Kehoe, T., and Ruhl, K. (2009). "Sudden stops, sectoral reallocations, and the real exchange rate." *Journal of Development Economics* 89, 235-249.
- Kortum, S. (1993). "Equilibrium R&D and the patent-R&D ratio: U.S. evidence." *American Economic Review* 83, 450-457.
- Krishna, P., Sense, M., and Poole, J. (2011). "Trade liberalization, firm heterogeneity, and wages: new evidence from matched employer-employee data." *The World Bank, Policy Research Working Papers*, doi: 10.1596/1813-9450-5711
- Krueger, A., and Summers, L. (1987). "Efficiency wages and the inter-industry wage structure." *Econometrica* 56, 259-293.
- Krugman, P. (2008). "Trade and wages, reconsidered." *Brookings Papers on Economic Activity*, Spring, 103-154.
- Lai, E. (1998). "International intellectual property rights protection and the rate of product innovation." *Journal of Development Economics* 55, 115-130.
- Leamer, E. (1996). "Wage inequality from international competition and technological change: theory and country experience." *American Economic Review* 86(2), 309-314.
- Lothian, R., and Taylor, M.P. (2008). "Real exchange rates over the past two centuries: how important is the Harrod-Balassa-Samuelson effect?" *Economic Journal* 118(532), 1742-1763.
- Lybbert, T.J., and Zolas, N.J. (2014). "Getting patents and economic data to speak to each other: An algorithmic links with probabilities approach for joint analyses of patenting and economic activity." *Research Policy* 43(3), 530-542.
- MacDonald, R., and Ricci, L. A.(2007). "Real exchange rates, imperfect substitutability, and imperfect competition." *Journal of Macroeconomics* 29(4), 639-664.

- Mondal, D., and Gupta, M. (2009). "Endogenous imitation and endogenous growth in a North-South model: A theoretical analysis." *Journal of Macroeconomics* 31, 668-684.
- Nair-Reichert, U. and Duncan, R. (2008). "Patent regimes, host country policies and the nature of MNE activities." *Review of International Economics* 16(4), 783-797.
- OECD Patent Statistics (2015). "Patents by main technology and by international patent classification (ipc)" (edition 2015).
- Park, W., and Lippoldt, D. (2005). "International licensing and the strengthening of intellectual property rights in developing countries during the 1990s." *OECD Economic Studies* 40, 7-48.
- Rabanal, P., and Tuesta, V. (2013). "Nontradable goods and the real exchange rate." *Open Economies Review* 24(3), 495-535.
- Rivera-Batiz, L.A., and Romer, P.M. (1991). "Economic Integration and endogenous growth." *Quarterly Journal of Economics* 106(2), 531-555.
- Romer, P. (1990). "Endogenous technological change." *Journal of Political Economy*, 98, S71-S102.
- Romer, P. (1993). "Ideas gaps and object gaps in economic development." *Journal of Monetary Economics* 32(3), 543-573.
- Samuelson, P. (1964). "Theoretical notes on trade problems." *Review of Economics and Statistics* 46(2), 145-154.
- Sa, N., Connolly, M., and Peretto, P. (2009). "Sustaining the goose that lays the golden egg: a continuous treatment of technological transfer." *Scottish Journal of Political Economy* 56(4), 492-507.
- Schmillen, A. (2013). "Are wages equal across sectors of production? A panel data analysis for tradable and nontradable goods." *Economics of Transition* 21(4), 655-682.
- Summers, R., and Heston, A. (1991). "The Penn World Table (Mark 5): an expanded set of international comparisons, 1950-1988." *Quarterly Journal of Economics* 106(2), 327-368.
- Thompson, P. (1996). "Technological opportunity and the growth of knowledge: a schumpeterian approach to measurement ." *Journal of Evolutionary Economics* 6(1), 77-97.
- Trommetter, M. (2010). "Flexibility in the implementation of intellectual property rights in agricultural biotechnology." *European Journal of Law and Economics* 30, 223-245.

- Vandenbussche, J., Aghion, P., and Meghir, C. (2006). "Growth, distance to frontier and composition of human capital." *Journal of Economic Growth* 11, 97-127.
- Verhoogen, E. (2008). "Trade, quality upgrading, and wage inequality in the Mexican manufacturing sector." *Quarterly Journal of Economics* 123(2), 489-530.
- Wood, A. (1998). "Globalisation and the rise in labour market inequalities." *Economic Journal* 108(450), 1463-1482.
- World Trade Organization (2013a). *World Trade Report*. Available online at (accessed in March 2014): https://www.wto.org/english/res_e/booksp_e/anrep_e/anrep13_e.pdf
- World Trade Organization (2013b). *International Trade Statistics*. Available online at (accessed in March 2014): https://www.wto.org/english/res_e/statis_e/its2013_e/its13_toc_e.htm
- World Trade Organization (2014a). *World Trade Report*. Available online at (accessed in January 2014): https://www.wto.org/english/res_e/booksp_e/anrep_e/anrep14_e.pdf
- World Trade Organization (2014b). *International Trade Statistics*. Available online at (accessed in January 2014): https://www.wto.org/english/res_e/statis_e/its2014_e/its14_toc_e.htm
- World Trade Organization (2015a). *World Trade Report*. Available online at (accessed in September 2015): https://www.wto.org/english/res_e/booksp_e/anrep_e/anrep15_e.pdf
- World Trade Organization (2015b). *International Trade Statistics*. Available online at (accessed in September 2015): https://www.wto.org/english/res_e/statis_e/its2015_e/its15_toc_e.htm
- Wu, H. (2010). "Distance to frontier, intellectual property rights, and economic growth." *Economics of Innovation and New Technology* 19(2), 165-183.
- Yang, G., and Maskus, K. (2001). "Intellectual property rights, licensing, and innovation in an endogenous product-cycle model." *Journal of International Economics* 53, 169-187.
- Zeugner, S. (2013). "Tradable vs. nontradable: an empirical approach to the classification of sectors". Technical report, European Commission.