A North-South monetary model of endogenous growth with international trade

Óscar Afonso
CEF-UP, CEFAGE-UBI and Faculty of Economics of University of Porto

Tiago Miguel Guterres Neves Sequeira
University of Coimbra, Centre for Business and Economics Research, CeBER
and Faculty of Economics

CeBER Working Papers
No. 9 / 2020

A North-South monetary model of endogenous growth with international trade

Oscar Afonso*and Tiago Sequeira†

We devise a North-South endogenous growth model with international trade and money to study the effects of inflation (and monetary policy) on wage inequality, specialization, and growth. The relationship between monetary policy and wage inequality depends on the fact that skilled-production firms are less credit constrained than unskilled-production firms. Interestingly, inflation affects the structure of production by increasing the production share made by skilled-intensive firms, and decreases economic growth. Furthermore, inflation decreases the difference of wage inequality between countries; shrinking the skill premia difference. Moreover, inflation and trade have opposite effects on wage inequality and on specialization: while trade tends to decrease intra-South wage inequality, inflation tends to increase it; while trade tends to increase the number of different intermediate goods produced with unskilled technology in the South; inflation acts the other way around. Results are confirmed quantitatively.

Keywords: Inflation; Wage inequality; North-South trade; CIA constraints; Technological-knowledge bias.

JEL classification Codes: F16, F43, O31, O33, O40, E41.

*Please address correspondence to Oscar Afonso, Universidade do Porto, Faculdade de Economia, and CEFUP, Rua Roberto Frias 4200-464 Porto, Portugal; +351225571100 (phone); +351225505050 (fax).

†Universidade de Coimbra, Faculdade de Economia, and CeBER, Avenida Dr. Dias da Silva, 165, 3004-512 Coimbra.

1 Introduction

We devise a North-South endogenous growth model with a monetary sector in order to analyze the effects of both monetary and real trade-related technological diffusion shocks (primarily) on wage inequality. Additionally, using the same framework, we also analyze the effects of monetary policy in the technological-knowledge bias, international (trade) specialization, and economic growth. Although the study of the relationship between monetary policy and growth is not new, it has faced an exponential surge in recent years. Departing from the *superneutrality* result, Jones and Manuelli (1995) argued that according to economic growth theory, there should be negative effects of inflation on growth, but they should be small, however. Gillman and Kejak (2005) seem to confirm the negative effect of inflation on economic growth for a wide categories of endogenous growth models, but also with a wide range of quantitative estimates for the effects. In opposition to this result, Alogoskoufis and Ploeg (1994) showed that under certain circumstances, inflation may have positive effects on growth.

Since then the nonlinear effects of inflation on growth has been in the center of the discussion on the issue. In fact, López-Villavicencio and Mignon (2011) showed empirically that the initial level of inflation matters for the relationship between inflation and growth and discovered an inverted U-shaped relationship between inflation and economic growth, meaning that inflation may enhance economic growth for low levels of the inflation rate and then, after a given threshold level, it deters economic growth. However, this threshold effect differs considerably from country to country. In order to account for such an inverted-U relationship different types of heterogeneity have been proposed (e.g., Arawatari et al. 2018, and Chu et al. 2019).

In the context of the literature that studies the optimality of investments on R&D, some authors also study the effect of monetary policy on the allocations of resources between sectors of the economy and, in particular, the optimality of implementing a Friedman rule (e.g., Chu and Cozzi 2014, Chu et al. 2015, Ho et al. 2007, Hori 2019, Okawa and Ueda 2018). In all these contributions the monetary policy acts (typically through credit constraints) in the R&D sector, decreasing the R&D efforts. This follows the evidence according to which R&D is more credit constrained than the other sectors in the economy (as, e.g., Evers et al. 2007).

Few authors have studied the relationship between inflation and other variables that typically concern both economic growth economists and policy makers. There are two very recent exceptions: (i) Gil and Iglésias (2019), who studied the relationship between inflation and economic growth in the investment rate, R&D intensity, market structure (size of firms), and the velocity of money; (ii) and Chu et al. (2019), who besides the concern with the relationship between inflation on economic growth, also study the influence of inflation on income inequality. Chu et al. (2019) discovered that also theoretically the relationship between inflation and income inequality is of an inverted U, meaning that inequality rises until a certain level of inflation and then decreases above that level. However, neither Chu et al. (2019) nor Gil and Iglésias (2019) analyze the influence of inflation in an open economies setting and its iterations with trade.

We contribute to the explanation on the influence of monetary policy on income inequality in a North-South endogenous growth framework with trade. To begin with, we revisit the relationship empirically and show that once country and year effects are taken into account we should expect a linear relationship between inflation and income/wage inequality, i.e., inflation contributes to increase inequality. Then, we devise a North-South endogenous growth model that also predicts such a positive relationship. This relationship depends on the fact that skilled production firms are less credit constrained than unskilled production firms. Interestingly, inflation (or monetary policy) also affects the structure of production. In particular, higher inflation increases the share of production made by skilled-intensive producers. Furthermore, we show that inflation decreases the difference of wage inequality levels between the South and the North. This means that more inflation shrinks the difference between the skill premium in the North relatively to the skill premium in the South. It is also important to note that inflation and trade have opposite effects on wage inequality and on specialization: while trade tends to decrease wage inequality in the South, inflation tends to increase it; while trade tends to increase the number of different intermediate goods produced with unskilled technology in the South; inflation acts the other way around.

The remainder of this study proceeds as follows. The empirical evidence is spelled out in Section 2. The theoretical setup we develop is revealed in Section 3, bearing in mind consumers' decisions, monetary authority, the production and price decisions, R&D activity, and the international trade. Section 4 analyzes the dynamic general equilibrium, looking at equilibrium R&D and at the steady state or long-run analysis. Section 5 takes the model to data, through calibration, and presents quantitative effects of the inflation on wage inequality, specialization, and growth. Section 6 concludes the paper.

2 Empirical Evidence

In this Section we reassess the evidence concerning the determinants of income inequality (with special emphasis on wage inequality) and show that inflation appears to be an additional robust determinant of inequality, which has never been considered. Since Kuznets (1955) presented empirical evidence according to which income inequality has an inverted U-shaped relationship with GDP per capita, several contributions have appeared to highlight empirical determinants of income inequality. Barro (2000) presents cross-country evidence on several determinants of inequality (resembling the well-known Barro growth regressions, but for inequality). Despite the use of several institutional variables and fixed-effects, Barro does not include inflation or monetary-policy variables as possible determinants of inequality. Milanovic (1994) also considered the influence of institutional determinants of inequality, but without considering monetary variables.

Rodriguez-Pose and Tsellios (2009) present positive and robust signs for secondary and tertiary education in determining different inequality levels across European Union regions. Additionally, those authors found that population ageing, female participation, urbanization, agriculture, and industry specialization tend to decrease income inequality, while unemployment and specialization in the financial sector tend to raise inequality. Finally, income inequality is lower in social-democratic welfare states, in Protestant regions, and in regions with Nordic-type societies and institutions. Jaumotte et al. (2013) also assess the determinants of wage inequality and besides avoiding the Kuznets curve specification, conclude that trade globalization decreases inequality and financial globalization increases inequality. Also in their article, information and communication technologies and credit deepening increase inequality.

Thus, although the above-mentioned papers discovered some association with financial and credit institutions or measures with income inequality, none considered inflation or a direct target of the monetary policy as determinant of different levels of income inequality, as we do in this paper.

Many econometric methods have been applied to study the effect of several measures on income inequality. With the increase of panel data availability concerns with time and country fixed effects arise, as was typical in other fields of applied research. Both Rodriguez-Pose and Tsellios (2009) and Jaumotte et al. (2013) include evidence on fixed-effects panel data regressions. From all the empirical literature pertaining to the search for determinants of inequality, four sets of variables, apart from controls, have been taken into account and have shown significant results – e.g., Chusseau et al. (2008), McAdam and Willman (2018), and Song et al. (2019): human capital, skill ratios or correlates, technological level or correlates, and openness or globalization measures.

In this Section we regress inter-quantile wage ratios (in OECD countries) – this is the measure which best matches our theoretical approach – as do Gini coefficients (in a worldwide database) – on human capital or skill ratios and inflation. Finally, it is worth noting that country and year dummies are included in all the regressions. In order to motivate that the relationship between inflation and income inequality is not exclusive of the richer or most technologically advanced countries, we also regress the same inequality measures on subsamples excluding the most technologically advanced countries. Table 1 has the results.[1]

Table 1 shows that, despite the relationship with human capital (quantities) and other correlates, inflation rates tend to be positively associated with income or wage inequality. This seems to be a good reason to include inflation as a determinant of wage inequality when considered together with other already studied determinants of inequality, such as technology and trade. Additionally, the fact that this relationship seems to be preserved when the richest or the most technologically advanced countries are excluded[2] also motivates us to study this relationship in an open economy model that considers trade between the advanced North and the more technologically backward South.

Fact. *Inflation is positively related to inequality, even when considering the effects of human capital (skill ratio) and country and time dummies.*

In this paper we study the implications of this empirical fact.

3 Economic structure

In the standard endogenous North-South growth model, each economy produces final goods in perfect competition, intermediate goods under monopolistic competition, and R&D activities, when successful,

[1] We cannot obtain the nonlinear inverted-U relationship betwen income inequality and inflation shown in Chu et al. (2019) with our dependent variables, either in the case in which human capital or skills ratio are included in regressions and when they are not.

[2] The positive relationship is also kept when the dependent variable is the Inter-decile wage ratio 90-50 and technological leaders are excluded from the sample, although the regression is not shown in Table 1.

Dependent variable:	i-d 90-10	i-d 90-50	i-d 90-10	Gini	Gini	Gini
Skilled ratio or human capital	0.966***	0.085	1.434***	-0.322**	-0.299***	-0.217
	(0.309)	(0.225)	(0.343)	(0.044)	(0.046)	(0.161)
Inflation	0.971*	0.237**	1.196**	0.002**	0.003**	0.003**
	(0.564)	(0.118)	(0.543)	(0.001)	(0.001)	(0.001)
R^2	0.95	0.11	0.94	0.85	0.88	0.85
Number observations	328	328	245	3367	2986	2156
Time dummies	yes	yes	yes	yes	yes	yes
Country dummies	yes	no	yes	yes	yes	yes
Clustered standard-errors	no	yes	no	yes	yes	yes
Limited Sample	no	no	excludes leaders	no	no	excludes leaders

Table 1: Empirical Evidence on the influence of Inflation on Inequality. Notes: ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels respectivelly. Robust standard-errors are presented in parentheses below the coefficients. Inter-decile wage ratios (I-d) and skilled-unskilled ratios are from OECD. Gini coefficients (Gini) are net measures from SWIID (Solt, 2009). Human capital, TFP and Openness (inserted in logs) are from PWT 8.0 and Inflation (consumer prices) is from the World Bank. TFP and Openness are introduced as controls in regressions (4) and (5), where the dependent variable is the Gini coefficient. In the third regression excluded technological leaders are France, Germany, Norway, United Kingdom, United States, Sweden, and Japan. In the last regression excluded leaders are the countries in the first quartile of GDP *per capita*.

result in innovations (in the North) and imitations (in the South) that are used by the intermediate-goods sector and drive the economic growth (e.g., Barro and Sala-i-Matin, 2004, ch. 8). This framework has been extended by Afonso (2012) to include labor heterogeneity, such that the composite final good is then produced through skilled and unskilled labor, and a continuum of quality-adjusted intermediate goods used by each type of labor. This extension has allowed analyzing, on the one hand, the intra-country technological-knowledge bias toward a certain type of labor that directs the path of the intra-country wage inequality and, on the other hand, the inter-country technological-knowledge gap that affects inter-country wage inequality. This model is now extended again to include a monetary sector. Money demand is incorporated in the model via sector-specific cash-in-advance (CIA) constraint on production of intermediate goods and on R&D activities,[3] whereas the monetary authority (the only form of government in the model) determines the money supply. Infinitely-lived households inelastically supply labor, skilled and unskilled, maximize utility obtained with the consumption of the homogeneous final good, and earn income from labor and from investments in financial assets and money balances.

This is a dynamic general-equilibrium endogenous growth model in which the homogeneous final good can be thus used in consumption and investment (production of intermediate goods and R&D), and the dynamic general equilibrium implies that firms and households are rational and solve their problems, free-entry R&D conditions are met, and markets clear.

3.1 Consumers

The economy is populated by a fixed number of infinitely-lived households that consume and collect income from investments in financial assets and in money balances (as in, e.g., Chu and Cozzi 2014), and from labor. Households inelastically supply unskilled, L, or skilled labor, H, to final-good firms. Total labor supply, $L + H$, is therefore exogenous and constant. We assume that consumers have perfect foresight concerning the technological change over time and choose the path of final-good aggregate consumption $\{C(t), t \geq 0\}$ to maximize discounted lifetime utility. With a constant intertemporal elasticity of substitution (CIES) instantaneous utility function, the infinite horizon lifetime utility is $U = \int_0^\infty \left(\frac{C(t)^{1-\theta}-1}{1-\theta}\right) e^{-\rho t} dt$, where $\rho > 0$ is the subjective discount rate and $\theta > 0$ is the inverse of the

[3] In general, the contributions that introduced money demand in the R&D-driven growth model tend to consider money in the utility function (assuming that households or individuals like to hold money), and/or cash-in-advance (CIA) constraints (assuming that producers/entrepreneurs need money for making payments) – see e.g., Stockman (1981), Wang and Yip (1992). Both approaches – money in the utility or CIA – produce similar effects of money. As we wish to focus on the production and technology sectors of the model, we adopt the CIA approach.

intertemporal elasticity of substitution.

The maximization is subject to the flow budget constraint $\dot{a}(t) + \dot{m}(t) = r(t) \cdot a(t) + w_L(t) \cdot L + w_H(t) \cdot H - C(t) + \tau(t) - \pi(t) \cdot m(t) + i(t) \cdot b(t)$, where: $a(t)$ denotes the households' real financial assets (equity); $m(t)$ is the households' real money balances; $r(t)$ is the real interest rate; w_L and w_H are the wages paid to L and H, respectively; $\tau(t)$ denotes a lump-sum transfer/tax from the monetary authority; $\pi(t)$ is the inflation rate, which determines the cost of holding money; and $b(t)$ is the amount of money borrowed from households to firms (final-good firms, intermediate-good firms, and R&D investments) and its return is $i(t)$. Thus, the CIA constraints imply that $b(t) \leq m(t)$. From standard dynamic optimization, we derive a no-arbitrage condition between real money balances and real financial assets (this amounts to the well-known Fisher equation) and the optimal path of consumption (the households' Euler equation),

$$i(t) = r(t) + \pi(t), \tag{1}$$

$$\dot{C}(t) = \frac{1}{\theta} \cdot (r(t) - \rho) \cdot C(t), \tag{2}$$

whereas the transversality conditions are $\lim_{t\to+\infty} e^{-\rho t} \cdot C(t)^{-\theta} \cdot a(t) = 0$ and $\lim_{t\to+\infty} e^{-\rho t} \cdot C(t)^{-\theta} \cdot m(t) = 0$.

3.2 Monetary authority

The monetary sector is considered as in, e.g., Chu and Cozzi (2014). The nominal money supply is denoted by $M(t)$ and its growth rate is $\mu(t) \equiv \frac{\dot{M}(t)}{M(t)}$. Real money balances are then $m(t) = \frac{M(t)}{P(t)}$, where $P(t)$ is the nominal price of the final good. Since the growth rate of $P(t)$ is the inflation rate, $\pi(t) \equiv \frac{\dot{P}(t)}{P(t)}$, the growth rate of $m(t)$ is $\frac{\dot{m}(t)}{m(t)} = \mu(t) - \pi(t)$. We consider that the monetary authority adopts an inflation targeting framework, in which the monetary policy instrument is the nominal interest rate. In this context, we follow the literature and assume that the nominal interest rate is exogenously chosen by the monetary authority (e.g., Chu and Cozzi 2014, Chu and Ji 2016, Chu et al. 2017, and Chu et al. 2019), so that $i(t) = i$, and thus $\pi(t)$ is endogenously determined according to the Fisher equation (1), for each $r(t)$: $\pi(t) = i - r(t)$. Then, given $\pi(t)$, the growth rate of the nominal money supply will be endogenously determined according to $\mu(t) = \frac{\dot{m}(t)}{m(t)} + \pi(t)$. That is, the monetary authority will endogenously adjust the money growth rate to whatever level is needed for the interest rate i to prevail. As usual in the literature, we consider that, to balance its budget, the monetary authority returns the seigniorage revenues to households as a lump-sum transfer, i.e., $\tau(t) = \frac{\dot{M}(t)}{P(t)} = \frac{(m(t)\dot{\cdot} P(t))}{P(t)} = \frac{\dot{m}(t) \cdot P(t) + \dot{P}(t) \cdot m(t)}{P(t)} = \dot{m}(t) + \pi(t) \cdot m(t)$.

The long-run (steady-state) equilibrium relationships will reveal that there is a relationship between the inflation rate, π, and the nominal interest rate, i, implying that we can extend all the comparative-statics results pertaining to shifts in i also to shifts in the steady-state inflation rate, π^*. Therefore, one can consider the inflation rate or even the growth rate of money supply as the policy variable directly controlled by the monetary authority. The consideration of the nominal interest rate as the policy instrument, however, simplifies the analytical derivation of the steady-state equilibrium of the model without changing the comparative-statics results.

3.3 Production and price decisions

Final-goods sector. Following Acemoglu and Zilibotti (2001) and Afonso (2012), in each country, North and South, each final good, indexed by $n \in [0, 1]$, is produced by one of two technologies. The L-technology uses L complemented with a continuum of L-specific intermediate goods indexed by $j \in [0, J]$. The H-technology's inputs are H complemented with a continuum of H-specific intermediate goods indexed by $j \in [J, 1]$. Both productions are affected by a scaling variable A, common to both technologies, representing the productivity level dependent on the country's domestic institutions, namely property rights, tax laws, and government services. The constant returns to scale production function at time t is:

$$Y_n(t) = \begin{cases} A \left[\int_0^J z_n(j,t)^{1-\alpha} dj\right] [(1-n) \cdot l \cdot L_n]^\alpha & , if\ n \leq \overline{n}(t) \\ A \left[\int_J^1 z_n(j,t)^{1-\alpha} dj\right] (n \cdot h \cdot H_n)^\alpha & , if\ n > \overline{n}(t) \end{cases} . \tag{3}$$

By considering $z_n(j,t) = q^{k(j,t)} x_n(j,t)$ in (3), the integral terms are the contributions to production of quality-adjusted intermediate goods. The size of each quality upgrade obtained with each success in R&D

is q, an exogenous constant greater than 1. The rungs of the quality ladder are indexed by k, with higher ks denoting higher quality. At time 0 the top quality good in each intermediate good has a quality index $k=0$. At t the highest quality good produced by j has a quality index $k(j,t)$, which is used due to profit maximizing limit pricing by the monopolist producers of intermediate goods. The quantity $x_n(j,t)$ of j is used, together with its specific labor, to produce $Y_n(t)$. The term $(1-\alpha)$ is the intermediate-goods input share, and $\alpha \in (0,1)$ is the labor share.

In (3), the labor terms include the quantities employed in the production of the n^{th} final good, L_n and H_n, and two corrective, but important, factors accounting for productivity differentials. An absolute productivity advantage of skilled over unskilled labor is accounted for by assuming $h > l \geq 1$. A relative productivity advantage of either labor type is captured by the adjustment terms n and $(1-n)$. These adjustment terms transform the index n into an ordering index, meaning that final goods indexed by larger ns are relatively more intensive in skilled labor. Since $n \in [0,1]$, there is a threshold final good, $\overline{n}(t)$, endogenously determined, at which the switch from one technology to another becomes advantageous.

The production function (3) combines complementarity between inputs in each technology, L and H, and substitutability between the two technologies since optimally only the L-technology is used to produce final goods indexed by $n \leq \overline{n}(t)$, and only the H-technology is used to produce goods with $n > \overline{n}(t)$ – e.g., Afonso (2012). That is, $\overline{n}(t)$ defines the structure of final-goods production: at each time t, there are $\overline{n}(t)$ final goods produced with the L-technology and $1-\overline{n}(t)$ final goods produced with the H-technology. Hence, in production function (3), $H_n(t) = x_n(j,t) = 0$, for $0 \leq j \leq J$, $\forall 0 \leq n \leq \overline{n}(t)$ and $L_n(t) = x_n(j,t) = 0$, for $J < j \leq 1$, $\forall \overline{n}(t) \leq n \leq 1$, and from the competitive profit maximization conditions by the representative producer of n^{th} final good, $\pi_n = p_n \cdot Y_n - \int_0^J p(j) \cdot x_n(j)dj - \int_0^J p(j) \cdot x_n(j)dj - w_L \cdot L_n - w_H \cdot H_n$, the demand for each intermediate good j by this producer is $x_n(j,t) = (1-n) \cdot l \cdot L_n \left[\frac{Ap_n(t)\cdot(1-\alpha)}{p(j,t)|_{0<j\leq J}}\right]^{\frac{1}{\alpha}} q^{k(j,t)\left[\frac{1-\alpha}{\alpha}\right]}$ if $0 < j \leq J$, $\forall\, 0 \leq n \leq \overline{n}(t)$, and $x_n(j,t) = n \cdot h \cdot H_n \left[\frac{Ap_n(t)\cdot(1-\alpha)}{p(j,t)|_{J<j\leq 1}}\right]^{\frac{1}{\alpha}} q^{k(j,t)\left[\frac{1-\alpha}{\alpha}\right]}$ if $J < j \leq 1$, $\forall\, \overline{n}(t) \leq n \leq 1$, where $p_n(t)$ is the price of final good n and $p(j,t)$ is the price of intermediate good j (prices given for the perfectly competitive producers of final goods). The higher the $\overline{n}$, the higher the number of varieties produced with the unskilled technologies and, since L is exogenous, lower the average quantity produced of each L variety.

Intermediate-goods sector without trade. Firms in the intermediate-goods sector use one unit of aggregate output to produce one unit of j whereby its marginal cost is one. However, for intermediate goods used in L-technology and in H-technology, a CIA constraint is introduced on the production by assuming that firms use money, borrowed from households subject to the nominal interest rate $i(t)$, to pay for a fraction $\Omega_m \in [0,1]$, where $m = L$ or $m = H$, of the input. Since firms cannot repay this amount to households until they earn revenue from production, households are effectively providing credit to these firms (e.g., Feenstra 1986, Gil and Iglésias 2019). Hence, the cost of intermediate good j has the following operational and financial component $(1-\Omega_m)\cdot 1 + \Omega_m \cdot (1+i(t)) \cdot 1$ if j is used in the m-technology, and thus the cost functions are $(1+\Omega_m \cdot i(t))$.[4]

Each quality of j is exclusively produced by the owner of its patent and, at time t, this monopolist obtains the profit flow $\pi(j,t)|_{0<j\leq J} = [p(j,t)|_{0<j\leq J} - (1+\Omega_L \cdot i(t))]\, X(j,t)|_{0<j\leq J}$ or $\pi(j,t)|_{J<j\leq 1} = [p(j,t)|_{J<j\leq 1} - (1+\Omega_H \cdot i(t))]\, X(j,t)|_{J<j\leq 1}$, where $X(j,t)|_{0<j\leq J} = \int_0^{\overline{n}(t)} x_n(j,t)\, dn$ and $X(j,t)|_{J<j\leq 1} = \int_{\overline{n}(t)}^1 x_n(j,t)\, dn$ represent the aggregate demand for the top quality, obtained from the demand by the respective final-goods producers at each t. Since intermediate goods, bought by the producers of final goods, fully depreciate at the end of each t, the monopolist faces no dynamic constraints and every t chooses $p(j,t)$ in order to maximize π, obtaining: $p(j,t)|_{0<j\leq J} = \frac{1+\Omega_L \cdot i(t)}{1-\alpha}$ or $p(j,t)|_{J<j\leq 1} = \frac{1+\Omega_H \cdot i(t)}{1-\alpha}$, which, in any case, is a mark-up over the marginal cost since $0 < \alpha < 1$. Hence, in each range of j, each mark-up is constant across t, k, and j (e.g., Afonso 2012). As the leader is the only one legally allowed to produce the highest quality, it will use pricing to wipe out sales of lower quality. Following Grossman and Helpman (1991, chs. 4 and 12) it is assumed that limit pricing by each leading monopolist is optimal such that $q \equiv \frac{1}{1-\alpha}$ and to capture the entire market (Barro and Sala-i-Martin 2004, ch. 7), $p(j,t)|_{0<j\leq J} = q\,[1+\Omega_L \cdot i(t)]$ or $p(j,t)|_{J<j\leq 1} = q\,[1+\Omega_H \cdot i(t)]$.

Economic structure given the inputs. The optimal choice of L- or H-technology is thus reflected in $\overline{n}(t)$, obtained from profit maximization (by perfectly competitive final-goods producers and by intermediate-goods monopolists) and full-employment equilibrium in factor markets, given the labor supply and the current state of technological knowledge,

[4] In other words, Ω_m measures the intensity of the CIA constraint on intermediate-goods production used by the m-technology, respectively.

$$\overline{n}(t)=\left\{1+\left[G(t)\left(\frac{h\cdot H}{l\cdot L}\right)\left(\frac{1+\Omega_L\cdot i}{1+\Omega_H\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}}\right\}^{-1}, \tag{4}$$

$$\text{where: } G(t)\equiv\frac{Q_H(t)}{Q_L(t)},\; Q_L(t)\equiv\int_0^J q^{k(j,t)\left[\frac{1-\alpha}{\alpha}\right]}\,dj,\; Q_H(t)\equiv\int_J^1 q^{k(j,t)\left[\frac{1-\alpha}{\alpha}\right]}\,dj, \tag{5}$$

i.e., Q_L and Q_L are aggregate quality indexes of the technological-knowledge stocks, and the ratio $G\equiv\frac{Q_H}{Q_L}$ is the appropriate measure of the technological-knowledge bias. From (4), the threshold final good, $\overline{n}(t)$, is small, meaning that the fraction of final goods using the H-technology in (3) is large, when the technological knowledge, G, is highly H-biased, the relative supply of H, $\frac{H}{L}$, is large, the absolute advantage of the skilled labor, $\frac{h}{l}$, is strong, and the relative intensity of the CIA constraints on intermediate-goods used by the H-technology, $\frac{\Omega_H}{\Omega_L}$, is smaller. The threshold final good $\overline{n}(t)$ can be implicitly expressed in terms of price indexes, which is achieved by considering that in the production of the threshold $n=\overline{n}(t)$ a firm that uses L-technology and a firm that uses H-technology should break even, resulting in the following ratio of index prices of goods produced with H and L technologies:

$$\frac{p_H(t)}{p_L(t)}=\left(\frac{\overline{n}(t)}{1-\overline{n}(t)}\right)^{\alpha}. \tag{6}$$

The relative price of final goods produced with the H-technology, $\frac{p_H}{p_L}$, is low when the threshold final good, $\overline{n}$, is small. In this case, the demand for H-intermediate goods is low, which, as we see below, discourages R&D activities aimed at improving their quality by the *price channel*.

The composite final good, Y, is produced by a continuum of firms, indexed by $n\in[0,1]$, such that $Y(t)=\int_0^1 p_n(t)\,Y_n(t)\,dn$, where $p_n(t)$ and $Y_n(t)$ are, respectively, the price and the output of the final good n. Plugging the demand functions $x_n(j,t)$ into (3) the supply of n is obtained,

$$Y_n=A^{\frac{1}{\alpha}}\left[\frac{p_n\cdot(1-\alpha)}{q}\right]^{\frac{1-\alpha}{\alpha}}\left\{(1+\Omega_L\cdot i)^{\left(\frac{\alpha-1}{\alpha}\right)}\cdot(1-n)\cdot l\cdot L_n\cdot Q_L+(1+\Omega_H\cdot i)^{\left(\frac{\alpha-1}{\alpha}\right)}\cdot n\cdot h\cdot H_n\cdot Q_H\right\}, \tag{7}$$

Following Acemoglu and Zilibotti (2001), among others, we choose the composite final good as the numeraire, so that the appropriate price (index) is one at each time t, $\exp\int_0^1 \ln p_n(t)\,dn=1$, and thus bearing also in mind (4) and (6), the price-indexes of L and H final goods are, respectively, $p_L(t)=p_n\,(1-n)^{\alpha}=\exp(-\alpha)\overline{n}(t)^{-\alpha}$ and $p_H(t)=p_n n^{\alpha}=\exp(-\alpha)\,[1-\overline{n}(t)]^{-\alpha}$; therefore,

$$Y=\exp(-1)\left[\frac{(1-\alpha)}{q}\right]^{\frac{1-\alpha}{\alpha}}\left\{\left\{(1+\Omega_L\cdot i)^{\frac{\alpha-1}{\alpha}}\cdot l\cdot L\cdot Q_L\right\}^{\frac{1}{2}}+\left\{(1+\Omega_H\cdot i)^{\frac{\alpha-1}{\alpha}}\cdot h\cdot H\cdot Q_H\right\}^{\frac{1}{2}}\right\}^{2}, \tag{8}$$

which clearly shows how final-production growth – the economic growth rate – is driven by the technological-knowledge progress. From the profit maximization conditions of final-goods production full employment in the labor market is guaranteed, which is also implicit in $\overline{n}$, and results that the marginal productivity of each labor type equals its cost. The equilibrium skilled premium, measuring intra-country wage inequality, yields:

$$\frac{w_H(t)}{w_L(t)}=\left[G(t)\left(\frac{h}{l}\frac{L}{H}\right)\left(\frac{1+\Omega_L\cdot i}{1+\Omega_H\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}}. \tag{9}$$

From (9), the skill premium, $\frac{w_H}{w_L}$, is greater when the technological knowledge, $G\equiv\frac{Q_H}{Q_L}$, is more skill-biased, the absolute advantage of the skilled labor, $\frac{h}{l}$, is strong, skilled labor, $\frac{H}{L}$, is relatively scarcer, and the relative intensity of the CIA constraints on intermediate-goods used by the H-technology, $\frac{\Omega_H}{\Omega_L}$, is smaller. The wage ratio depends on the nominal interest rate positively if and only if financial restrictions affecting the unskilled production are higher than those affecting the skilled production, $\Omega_L>\Omega_H$.

Equations (4), (6), and (9) are useful in foreseeing the operation of the *price (of final goods) channel* from the stocks (of labor, technological knowledge, and CIA constraints) to the flows of resources used in R&D and to wage inequality. For example, in a country relatively H-abundant and (or) with a large technological-knowledge bias and (or) with a strong CIA constraint in intermediate goods used by the L-technology, $\overline{n}(t)$ is small, i.e., many final goods are produced with the H-technology and thus final goods produced with the H-technology are sold at a relatively low price. Profit opportunities in the production of intermediate-goods used by the relatively high-priced L-technology final goods induce a change in the direction of R&D against the technological-knowledge bias and in favor of unskilled wages, i.e., there are stronger incentives to develop technologies when the final goods produced by these technologies command higher prices.[5] The overall effect on the technological-knowledge bias thus depends on the magnitude of the two contradictory channels – *price channel* and *market-size channel*. For example, an increase in skilled labor causes an immediate steep drop in the skilled premium since its relative supply decreases its relative wage (see 9), but this immediate effect can be reversed in the transitional dynamics toward the (constant) steady-state skilled premium if the stimulus to the demand for skilled labor resulting from the technological-knowledge bias dominates, which occurs with a sufficiently strong *market-size channel*.

3.4 Research and development sector

Research and development drives the North and South economic growth. A more detailed description of the technology of R&D activities is therefore in order, with the purpose of closing the characterization of the North and South domestic economies. The R&D activities result in innovative designs for the manufacture of intermediate goods, which increase their quality, in the North and in imitation of Northern designs in the South (through reverse engineering). As already stated, designs are domestically patented and the leader firm in each intermediate-goods industry – the one that produces according to the latest patent – uses limit pricing to assure monopoly. The value of the leading-edge patent depends on the profit-yields accruing during each period t to the monopolist, and on the duration of the monopoly power. The duration, in turn, depends (i) on the probability of an innovation in the North, which creatively destroys the current leading-edge design or (ii) on the probability of an imitation in the South. The probabilities of successful innovation and imitations are, thus, at the heart of R&D.

Let $I_N(j,t)$ denote the instantaneous probability at time t – a Poisson arrival rate – of Northern successful innovation in the next higher quality $[k(j,t)+1]$ in intermediate-goods industry j,

$$I_N(j,t) = y_N(j,t) \cdot \beta_N q^{k(j,t)} \cdot \zeta_N^{-1} q^{-\alpha^{-1} k(j,t)} \cdot (m_N + m_S)^{-\xi_N}, \tag{10}$$

where: (i) $y_N(j,t)$ is the flow of domestic final-good resources devoted to R&D in intermediate good j, which defines our framework as a lab equipment model (Rivera-Batiz and Romer 1991); (ii) β_N $q^{k(j,t)}$, $\beta_N > 0$, represents learning-by-past domestic R&D, as a positive learning effect of accumulated public knowledge from past successful R&D (Romer 1990, Grossman and Helpman 1991, ch. 12, and Afonso 2012); (iii) $\zeta_N^{-1} q^{-\alpha^{-1} k(j,t)}$, $\zeta_N > 0$, is the adverse effect – cost of complexity – caused by the increasing complexity of quality improvements (Kortum 1997, and Afonso 2012);[6] (iv) $(m_N + m_S)^{-\xi_N}$, $m = L$ when $0 \leq j \leq J$ and $m = H$ when $J < j \leq 1$, $\xi_N > 0$, is the adverse effect of market size, capturing the idea that the difficulty of introducing new quality intermediate goods and replacing old ones is proportional to the size of the market measured by the respective labor. That is, for reasons of simplicity, we reflect in R&D the costs of scale increasing, due to coordination among agents, processing of ideas, informational, organizational, marketing, and transportation costs, as reported by works such as Dinopoulos and Segerstrom (1999), and Dinopoulos and Thompson (1999).

In the absence of international trade, the South mimics the R&D process of the North, but less efficiently, i.e., with $k_S \leq k$ in expression (10). Since the South is less developed, but not too backward, we assume that there are some intermediate goods j, but not all, for which $k_S < k$, implying that even in the absence of trade there are some state-of-the-art intermediate goods produced in both countries (i.e., for which $k_S = k$).

Once the South has access to all the best quality intermediate goods through international trade, it becomes an imitator, improving the probability of successful R&D. Hence, the South's R&D activities, when successful, result in imitation of current worldwide best qualities. Denoting the probability of successful imitation by $I_S(j,t)$ – the instantaneous probability of successful imitation of the current

[5] This *price channel* shows up in various papers by Acemoglu (2002), although always dominated by the market-size channel, which, in our case, can be removed through the *cost-of-the-market size* – see below the equilibrium R&D.

[6] This complexity cost is modeled in such a way that, together with the positive learning effect (ii), exactly offsets the positive influence of the quality rung on the profits of each leader intermediate good firm – calculated below; this is the technical reason for the presence of the production function parameter α in the expression – see also Barro and Sala-i-Martin (2004, ch. 7).

higher quality $k(j,t)$ in intermediate-goods industry j,

$$I_S(j,t) = \begin{array}{c} y_S(j,t) \cdot \beta_S q^{k_S(j,t)} \cdot \zeta_S^{-1} q^{-\alpha^{-1}k(j,t)} \cdot (m_S + m_N)^{-\xi_S} \\ B_D(j,t) \cdot B_T(j,t) \cdot f(\widetilde{Q}_m(t), d)^{-\sigma + \widetilde{Q}_m(t)} \end{array}, \tag{11}$$

where: (i) $y_S(j,t)$ is the flow of domestic final-good resources devoted to R&D in intermediate good j; (ii) $\beta_S q^{k_S(j,t)}$, $0 < \beta_S < \beta_N$, $k_S \leq k$; i.e., we consider that the learning-by-past imitations is lower than the learning-by-past innovations; (iii) $\zeta_S^{-1} q^{-\alpha^{-1}k(j,t)}$, $\zeta_N > \zeta_S > 0$; i.e., we assume that the complexity cost of imitation is lower than the innovation's in line with Mansfield et al. (1981) and Teece (1977); (iv) $(m_S + m_N)^{-\xi_S}$, $\xi_S > 0$, is the adverse effect of market size; (v) $B_D(j,t) \cdot B_T(j,t) \cdot f(\widetilde{Q}_m(t), d)^{-\sigma + \widetilde{Q}_m(t)}$, $0 < \widetilde{Q}_m(t) < 1$, $\sigma > 0$; this is a catching-up term, specific to the South, which sums up positive effects of imitation capacity and backwardness. Terms $B_D(j,t)$ and $B_T(j,t)$ are positive exogenous variables, which capture important determinants of imitation capacity. The former represents the level of imitation productivity dependent on domestic causes, which includes domestic policies promoting R&D (Aghion et al., 2001, 2004). The latter embodies the level of imitation productivity dependent on external causes, and thus comprises the degree of openness to international trade (Coe and Helpman, 1995; Coe et al. 1997) and other trade policies, namely international integration (Grossman and Helpman, 1991, ch. 11), as well as the South's relative level of labor. Therefore, we assume that labor enhances the imitation capacity, thereby speeding up convergence with the North – as argued by Nelson and Phelps (1966), Benhabib and Spiegel (1994), and Aghion et al. (2004), among others. In order to capture the benefits of relative backwardness, function $f(\widetilde{Q}_m(t), d)$ – similar to Papageorgiou (2002) and Afonso (2012) – is

$$f(\widetilde{Q}_m(t), d) = \begin{cases} 0 & \text{, if } 0 < \widetilde{Q}_m(t) \leq d \\ -\widetilde{Q}_m(t)^2 + (1+d) \cdot \widetilde{Q}_m(t) - d & \text{, if } d < \widetilde{Q}_m(t) < 1 \end{cases}, \tag{12}$$

where $\widetilde{Q}_m(t) \equiv \frac{Q_{m,S}(t)}{Q_m(t)}$ is the relative technological-knowledge level of the South's m-specific intermediate goods.[7] Provided that the gap is not large – i.e., if $\widetilde{Q}_m(t)$ is above threshold d – then the country can benefit from an advantage of backwardness, as in Barro and Sala-i-Martin (2004, ch. 8). When the gap is wider – so that $\widetilde{Q}_m(t)$ is below threshold d – backwardness is no longer an advantage (in line with Verspagen, 1993, and Papageorgiou, 2002, for example). Function $f(\widetilde{Q}_m(t), d)$ is quadratic over the range of main interest, and, once affected by the exponent function $(-\sigma + \widetilde{Q}_m)$ in (11)-(v), yields an increasing (in the technological-knowledge gap) advantage of backwardness – where the size of σ affects how quickly the probability of successful imitation falls as the technological-knowledge gap falls.

In addition to the direct effect of openness on the capacity of imitation, the level effect of entry into international trade also involves immediate changes in the allocation of resources to R&D. In particular, the amount of Southern resources devoted to R&D increases for two reasons. On the one hand, incentives to imitation increase through the positive effect of openness on the probability of successful imitation (11-v); and, on the other hand, access to enlarged markets requires more resources due to the adverse effect of market size on the probability of successful imitation (11-iv).[8]

3.5 International trade

Under international trade, the state-of-the-art intermediate goods, available internationally, embody the North's technological knowledge – Q_H and Q_L. Assuming that endowments of labor are such that the North is relatively H abundant, i.e.,

$$\frac{H_N}{L_N} > \frac{H_S}{L_S}, \tag{13}$$

and also that:[9]

[7] Thus, we assume that the probability of successful imitation in intermediate good j is state dependent on all past successful R&D in all intermediate goods of its type in both countries, contrary to the probability of successful innovation, which is state dependent only on the stock of past successful R&D in intermediate good j in the North.

[8] Resources devoted to R&D immediately increase in the North as well, but only for the second reason, i.e., the adverse effect of market size on the probability of successful innovation (10-iv). Northern resources are reallocated at the expense of current consumption, differently from the South, where consumption increases with the immediate increase in income.

[9] We are assuming equal nominal interest rates in the North and in the South, without loss of generalization.

$$\frac{H_N}{L_N}\left(\frac{1+\Omega_{L,N}\cdot i}{1+\Omega_{H,N}\cdot i}\right)^{\frac{1-\alpha}{\alpha}} > \frac{H_S}{L_S}\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\frac{1-\alpha}{\alpha}}, \quad (14)$$

the comparison of inter-country threshold final goods in (31) shows that $\overline{n}_S > \overline{n}_N$. In other words, since Northern and Southern producers have access to the same state-of-the-art intermediate goods under trade, and differences in the structure of final-goods production is determined by differences in domestic labor endowments and in CIA constraints on the production of intermediate goods, which imply that, under international trade, the North produces more *H*-technology final goods than the South. Notice that, through the operation of the *price channel*, the $\overline{n}_S$ is larger than in pre-trade. This is because, as discussed above, labor endowments influence the direction of R&D in such a way that there are stronger incentives to improve technological knowledge that saves the relatively scarce type of labor. Since the South is H-scarce, its pre-trade technological-knowledge bias is $\frac{Q_{H,S}}{Q_{L,S}} > \frac{Q_H}{Q_L} \Longleftrightarrow G_S > G$.[10]

Concerning the level effect on wages, the access to more productive intermediate goods shifts upwards the demand for both labor types in the South. The resulting absolute (and relative to the North) benefit to both Southern labor types is not balanced. Indeed, the level effect reduces intra-South wage inequality (the skilled-labor premium), as shown by plugging the technological-knowledge bias implied by the assumed relative labor endowments (13) into (9),

$$\frac{w_{H,S}(t_0)}{w_{L,S}(t_0)} = \left[G(t_0)\left(\frac{h}{l}\frac{L_S}{H_S}\right)\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}} < \left.\frac{w_{H,S}(t_0)}{w_{L,S}(t_0)}\right|_{pre-trade} = \left[G_S(t_0)\left(\frac{h}{l}\frac{L_S}{H_S}\right)\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}}. \quad (15)$$

It is important to note that a shock on inflation and, thus, on the inflation rate depend on the relative unskilled-skilled financial constraints and on the change in the technological-knowledge bias.

Proposition 1. An increase in the inflation rate increases (decreases) wage inequality if the unskilled (skilled) sector is more financially constrained than the skilled (unskilled) sector, which happens both in the North and in the South.

Proof. Derive $\frac{\partial \frac{w_{H,o}}{w_{L,o}}}{\partial i}$ and observe that this is positive if and only if $\Omega_{L,o} > \Omega_{H,o}$ for $o = N, S$. □

From this proposition an interesting corollary can be observed.

Corollary. *(a) After an inflation shock that raises wage inequality due to a more constrained unskilled sector, openness to trade may counter-influence the effect of that shock; and also (b) if* $\frac{\Omega_{L,S}}{\Omega_{H,S}} > \frac{\Omega_{L,N}}{\Omega_{H,S}}$, *a monetary shock that increases inflation, leads wage inequality to increase more in the South than in the North; the effect of trade is opposite to the effect of a monetary shock leading to converging wage inequalities.*

Figure 1 illustrates this result, highlighting the effect of an inflation shock in wage inequality that is followed by the effect of openness to trade.

4 General equilibrium

As the countries' economic structure has been characterized for given states of technological knowledge, we now proceed to include the general equilibrium dynamics of technological knowledge, which drives economic growth and wage dynamics.

[10] This is in contrast with what would be predicted by the *market-size channel*, through which the opposite would occur and implies that after trade the South produces a higher number of varieties of the intermediate goods that use *L*-technology (but also high quantity of such goods).

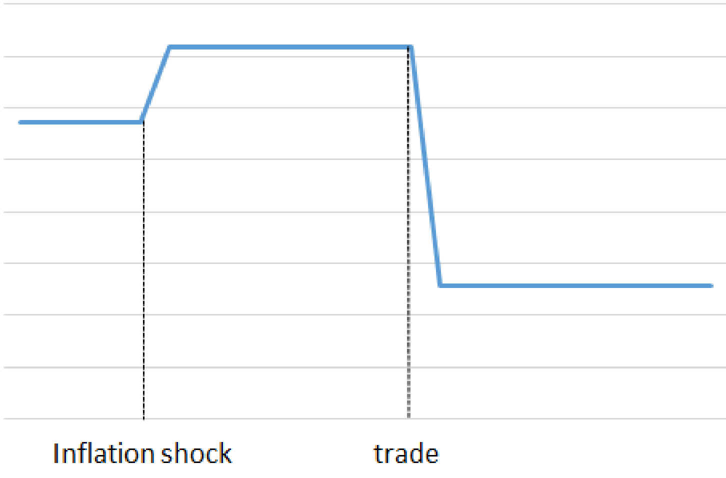

Figure 1: Ilustration of the effect of an inflation shock followed by openness to trade in Southern wage inequality.

4.1 Equilibrium R&D

4.1.1 International Limit pricing

We turn now to the production and international pricing of intermediate goods. Since, by assumption, the production of intermediate goods and R&D are financed by the resources saved after consumption of the composite final good, the simplest hypothesis is to consider that, in each country, the production function of intermediate goods is identical to the production function of the composite final good specified by equations (3) and (8).[11] Given this convenient simplification, the marginal cost of producing an intermediate good equals the marginal cost of producing the composite final good, MC, which, due to perfect competition in the final-goods sector, equals the price of the composite final good. Thus, in each country, the marginal cost of producing an intermediate good is independent of its quality level and is identical across all domestic industries.

Regarding inter-country differences, we assume that the marginal cost of producing the composite final good in the South is smaller than in the North, in order to allow for the entry of the South's intermediate goods in international markets (recall that the composite final good is the input to the production of intermediate goods). Normalizing to one the marginal cost in the North, the assumption is $0 < MC_S < MC_N = 1$, allowing the Southern producer of the same quality rung, k, to underprice its Northern competitor.

The manufacture of an intermediate good requires a start-up cost of R&D, either in a new design invented in the North or in its imitation by a Southern researcher. This investment in a blueprint can only be recovered if profits are positive within a certain period in the future. This is guaranteed by costly R&D together with domestically enforced patents, i.e., there is a domestic system of intellectual property rights (IPRs), which protect domestically, but not internationally, the leader firm's monopoly of that quality good, while at the same time disseminating acquired knowledge to other domestic firms. Under these assumptions, knowledge of how to produce the latest quality good is public (non-rival and non-excludable) within each country and semi-public internationally (non-rival and partially non-excludable).

Even without international protection of patents, the current producer of each intermediate good enjoys some international monopoly power: for example, if the current producer is from the North, thus being challenged by either another Northerner or a Southerner imitator, monopoly is temporarily assured by IPRs in the North and costly imitation in the South. Notice that the length and magnitude (measured by the mark-up) of the monopoly power are shortened by international competition – without international trade of intermediate goods the current producer in the North is challenged only by other Northerner and not by a Southern imitator with lower marginal cost. In general, there are three possible sequences of successful R&D outcomes and their limit pricing consequences, at time t, for given quality k at time $t - dt$, are depicted in Table 2:[12]

[11] Or, equivalently, that the composite final good is the input in the production of each intermediate good, as in Barro and Sala-i-Martin (2004, ch. 8), for example.

[12] We follow Grossman and Helpman (1991, ch. 12), by assuming that limit pricing by each leading monopolist

The first mark-up is the highest: the Northern entrant (N) competes with a Northern incumbent (N)

$t-dt$	t	Share in intermediate goods production at t	$p(j)$
N produces and exports quality k	N produces and exports quality $k+1$	$\Phi_m \cdot (1-\Psi_m)$	$p_{m,N-N}(j) = q \cdot MC_N \cdot [1+\Omega_{m,N} \cdot i]$
N produces and exports quality k	S produces and exports quality k	$1-\Phi_m$	$p_{m,S-N}(j) = MC_N \cdot [1+\Omega_{m,S} \cdot i]$
S produces and exports quality k	N produces and exports quality $k+1$	$\Phi_m \cdot \Psi_m$	$p_{m,N-S}(j) = q \cdot MC_S \cdot [1+\Omega_{m,N} \cdot i]$

Table 2: Limit pricing of each intermediate good

at the same marginal cost but with better quality. The second one is smaller: the Southern entrant (S), with lower marginal cost, competes in the same quality rung with a Northern incumbent (N). Compared with the first, the third mark-up is again smaller, but due to a different reason: the Northern entrant improves quality as in the first case, but competes with an incumbent with lower marginal cost.

In order to pin down which intermediate goods are produced in each country at each moment in time, let: (i) Φ_m and $(1-\Phi_m)$ be the proportion of intermediate goods of m-type with production in the North and in the South, respectively; (ii) Ψ_m be the proportion of intermediate goods of m-type produced in the North having overcome imitator competition; (iii) $(1-\Psi_m)$ be the proportion of intermediate goods of m-type produced in the North having overcome innovator competition. The specification of these proportions as functions of the probabilities of successful R&D follows Afonso (2012), such that the proportion of intermediate goods produced in the North increases with the probability of innovation and decreases with the probability of imitation. It is possible to define a price index for the m-type intermediate goods – at each moment in time – as a weighted average of the limit prices in Table 2:

$$\overline{p}_m = \Phi_m \cdot q \cdot [1-\Psi_m\ (1-MC_S)] \cdot [1+\Omega_{m,N} \cdot i] + (1-\Phi_m) \cdot [1+\Omega_{m,S} \cdot i]. \tag{16}$$

The price index in equation (16) is affected by the costs imposed by the CIA constraints.

4.1.2 Free-entry and non-arbitrage conditions in R&D

Given the functional forms (10) and (11) of the probabilities of success in R&D, which rely on the resources – composite final goods – allocated to it, free-entry equilibrium is defined by the equality between expected revenue and resources spent. We assume that the financing of R&D costs also requires money borrowed from households, such that a CIA constraint on R&D activities also exists alongside that on manufacturing of intermediate goods. Therefore, the R&D cost has an operational and a financial component, that is, $y(j,t) + \Upsilon_m \cdot i(t) \cdot y(j,t)$, where $\Upsilon_m \in [0,1]$, $m=L$ or $m=H$, is the share of the R&D cost that requires the borrowing of money from households. By considering free entry in R&D activities, free access to the R&D technology, and a proportional relationship between successful R&D and the share of R&D effort, the R&D spending aimed at, for example, imitating j should equal the expected payoff generated by the imitation; i.e.,

$$I_S(j,t)\ V_S(j,t) = y_S(j,t) \cdot (1+\Upsilon_{m,S} \cdot i) \tag{17}$$

where $V_S(k,j,t)$ is the expected current value of the flow of profits to the monopolist producer of intermediate good j, the market value of the patent, or the value of the monopolist firm owned by domestic consumers.

is optimal. In general, depending on whether $q(1-\alpha)$ is greater or less than MC, the leader of each industry would, respectively, use the monopoly pricing $p = \frac{MC}{1-\alpha}$ or the limit pricing $p = q\ MC$ to capture the entire domestic market (Barro and Sala-i-Martin 2004, ch. 7). In order to rule out monopoly pricing, we assume that the size of each quality improvement, q, is not large enough.

The expected flow of profits depends on the amount in each period, the interest rate, and the expected duration of the flow, which is the expected duration of the imitator's technological-knowledge leadership. Such duration, in turn, depends on the probability of a successful innovation in the North, which is the potential challenger.[13] The expression for V_S is

$$V_S(j,t) = \int_t^{\infty} \Pi_S(j,t) \exp\left[-\int_t^s (r_S(\nu) + I_N(j,\nu))\, d\nu\right] ds \frac{\Pi_S(j,t)}{r_S(t) + I_N(j,t)} \tag{18}$$

Differentiating (18) using Leibniz's rule, we obtain the dynamic arbitrage equation:

$$r_S(\nu) + I_N(j,\nu) = \frac{\dot{V}_S(j,t)}{V_S(j,t)} + \frac{\Pi_S(j,t)}{V_S(j,t)} - \dot{k}(j,t)\left(\frac{1-\alpha}{\alpha}\right)\ln q \tag{19}$$

Bearing in mind (11), considering that the market-size scale effects are removed, $\xi_S = 1$, taking into account the amount of profits, Π_S, at time t, for the monopolist producer of intermediate good j, using an imitation of quality k, which depends on the marginal cost, the mark-up, the world demand for the intermediate good j by final-goods producers, and the price in the second sequence in Table 2, then plugging (19) into (17), and solving for I_N, the equilibrium probability of a successful innovation in a H-specific intermediate good – given the interest rate and the price indexes of final goods – is

$$\begin{aligned} I_{H,N}(t) = &\underbrace{\beta_S \cdot \zeta_S^{-1} \cdot B_D \cdot B_T \cdot h \cdot (1-\alpha)^{\alpha^{-1}} \cdot (1 - MC_S)\cdot}_{Technology\, channel} \quad \underbrace{D_H(t)}_{Price\, channel} \\ &\underbrace{f(\widetilde{Q}_H(t), d)^{-\sigma + \widetilde{Q}_H(t)} \cdot \widetilde{Q}_H(t)\cdot}_{backwardness\, channel} \underbrace{\frac{(1 + \Omega_{H,S} \cdot i)^{\left(\frac{\alpha-1}{\alpha}\right)}}{1 + \Upsilon_{H,S} \cdot i}}_{CIA-constraint\, channel} - r_S(t) \end{aligned} \quad ; \tag{20}$$

where: $D_H(t) = \frac{H_S}{H_S + H_N}\left[A_S \cdot p_{H,S}(t)\right]^{\alpha^{-1}} + \frac{H_N}{H_S + H_N}\left[A_N \cdot p_{H,N}(t)\right]^{\alpha^{-1}}$,where $A_N > A_S$and $H_N > H_S$ measuring respectively the institutional quality and skilled-labor levels in the North and in the South. The equilibrium m-specific $I_{m,N}$ in (20) turns out to be independent of j and k. There are two reasons behind this independence. The first and most substantial one is the removal of scale of technological-knowledge effects – the positive influence of the quality rung on profits and on the learning effect is exactly offset by its influence on the complexity cost – see the exponents of q in the demand of intermediate goods above, which impacts in the expression of profits, and in (11)-(ii) and (iii). The second reason is the simplifying assumption that the determinants of imitation capacity, B_D and B_T in the catching-up term in (11)-(v), are not specific to each intermediate good.

Additional scale effects could arise through market size, as has been intensely discussed in the R&D endogenous growth literature since Jones' (1995) critique. Due to the technological complementarity in the production function (3), the size of the market for m-specific intermediate goods is the m-type labor. Then, the scale effect is apparent in the size of the profits – see *per se* the labor terms, m_S and m_N, within the term D_m. Since we aim at understanding international trade effects other than market size, the removal of scale is in order. The adverse effect of market size due to the scale-proportional difficulty of introducing new quality intermediate goods – term (iv) in equations (10) and (11) – is designed to offset the scale effect on profits. With $\xi = 1$, the offsetting is such that the influence of market size becomes negligible, as is apparent in expression D_H in (20) – see the final labor terms $\frac{H_S}{H_S+H_N}$ and $\frac{H_N}{H_S+H_N}$.

Since the probability of successful innovation, as a Poisson arrival rate, determines the speed of technological-knowledge progress, equilibrium can be translated into the path of Northern technological knowledge, from which free trade in intermediate goods allows the South to benefit as well. The relationship turns out to yield the expression, where (20) is plugged in, for the equilibrium rate of growth of, for example, H-specific technological knowledge:

$$\frac{\dot{Q}_H(t)}{Q_H(t)} = \left[I_{H,N}(t) - r_S(t)\right]\left[q^{(1-\alpha)\alpha^{-1}} - 1\right] \quad . \tag{21}$$

It should be stressed that after removing the market-size channel, four channels remain – see (20): the *technology channel* related with parameters from the productive side of the economy, the *backwardness channel* related with the North-South technological-knowledge gap, the *price channel* through which the trade and the inter-sectors, L and H, CIA constraints on the production of intermediate goods operate,

[13] In the case of the value of a patented innovation, V_N, the challenge comes from both a new Northern innovation and a Southern imitation.

and the intra-sectors, L or H, *CIA-constraint channel* that is also affected by trade. From the observation of (20), it should be noted that the CIA constraint channel tends to decrease the probability of innovation both when constraints affect the manufacturing sector through $\Omega_{H,S}$, or through the R&D sector, $\Upsilon_{H,S}$. However, given the fact that the financial constraints linked with R&D are (empirically) higher and are not affected by the relative labor shares, this means that, as probably was expected, that CIA constraints linked with R&D have greater influence in the probability of innovation. It is clear in (21) that there are trade feedback effects from imitation to innovation. That is, the positive level effect from the innovator to the imitator – the access to the state-of-the-art intermediate goods increases production and, thus, the resources available to imitation R&D – feeds back into the innovator, affecting the Northern technological knowledge through creative destruction.

Due to the technological complementarity in the production of final goods, the rate of growth of m-specific technological knowledge – equation (21) for the South and $m = H$ – translates into the growth of demand for m-type labor interrelated with the dynamics of the price indexes of final and intermediate goods ($p_{m,S}$ and $\overline{p}_m$, respectively), such that

$$\frac{\dot{w}_{m,S}(t)}{w_{m,S}(t)} = \frac{1}{\alpha} \cdot \frac{\dot{p}_{m,S}(t)}{p_{m,S}(t)} + \frac{\alpha - 1}{\alpha} \cdot \frac{\dot{\overline{p}}_m(t)}{\overline{p}_m(t)} + \frac{\dot{Q}_m(t)}{Q_m(t)}. \tag{22}$$

Thus, the path of m-wages in each country relies on the path of domestic demand for m-type labor, which, in turn, relies on the path of: (i) the domestic range of the m-technology, established by threshold $\overline{n}$, which determines prices of (non-tradable) final goods; (ii) the world demand for m-specific intermediate goods, reflected in international prices and driven by technological knowledge.

4.2 Steady-state

Since, by assumption, both countries have access through free trade to the same state-of-the-art intermediate goods and the same technology of production of final goods,[14] the steady-state growth rate must be the same as well. This implies, through the Euler equation (2), that interest rates are also equalized between countries in steady state. As for the sectorial growth rates, we note first that the instantaneous aggregate resources constraint in the South, for example, is

$$Y_S(t) = C_S(t) + X_S(t) + R_S(t), \tag{23}$$

where: (i) $Y_S(t)$ is total resources, the composite final good; (ii) $C_S(t) = \int_0^1 c_S(i,t)di$ is aggregate consumption; (iii) $X_S(t) = \int_0^1 \int_0^1 x_{n,S}(j,t)dndj$ is aggregate intermediate goods; (iv) $R_S(t) = \int_0^1 y_S(j,t)dj$ is total resources spent on R&D. In other words, the aggregate final good is used for consumption and savings, which, in turn, are allocated between production of intermediate goods and R&D.[15] This implies that the steady-state growth rate of each of these variables is equal to the North's growth rate of technological knowledge. Since the composite final-good production is constant returns to scale in the inputs from equations (7) and (8), the constant, common to both countries, unique steady-state growth rate, designated by g^*, is

$$\left(\frac{\dot{Q}_H}{Q_H}\right)^* = \left(\frac{\dot{Q}_L}{Q_L}\right)^* = \left(\frac{\dot{Y}}{Y}\right)^* = \left(\frac{\dot{X}}{X}\right)^* = \left(\frac{\dot{R}}{R}\right)^* = \left(\frac{\dot{C}}{C}\right)^* = \left(\frac{\dot{c}}{c}\right)^* = \theta^{-1}\left(r^* - \rho\right) = g^*, \tag{24}$$

implying constant steady-state levels of threshold final goods, final and intermediate goods price indexes, wage premia, and North-South gaps in both technological-knowledge types.[16] Although levels remain different (due to international immobility of labor and differences in exogenous productivity and marginal costs), the steady-state growth of wages is equalized between countries as derived by plugging in constant steady-state prices in (22), which is a Schumpeterian dynamic result equivalent to the static factor-price equalization Samuelson's result.

From (21) and (20) for H- and L-technology, as well as from (4) and (6), $\frac{\dot{Q}_H}{Q_H}$ and $\frac{\dot{Q}_L}{Q_L}$ rise at the same rate if

[14]Except for the levels of exogenous productivity, A, and labor, m, in production function (3), implying differences in the levels, but not in the growth rates.

[15]Net exports are always zero since, by assumption, international trade is balanced.

[16]Indeed, while complete convergence in available technological knowledge is instantaneous with international trade (level effect), domestic levels may not converge completely, that is, the ratio between $\widetilde{Q}_H$ and $\widetilde{Q}_L$ may remain below one.

$$\frac{\left(1+\left[G^*\frac{h}{l}\frac{H_S}{L_S}\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{1/2}\right)\left[G^*\frac{h}{l}\frac{H_N}{L_N}\left(\frac{1+\Omega_{L,N}\cdot i}{1+\Omega_{H,N}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{1/2}}{\left(1+\left[G^*\frac{h}{l}\frac{H_N}{L_N}\left(\frac{1+\Omega_{L,N}\cdot i}{1+\Omega_{H,N}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{1/2}\right)\left[G^*\frac{h}{l}\frac{H_S}{L_S}\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{1/2}} -$$

$$-\frac{\frac{H_N A_N^{\alpha-1}}{H_S+H_N}-\frac{f(\widetilde{Q}^*_L,d)^{-\sigma+\widetilde{Q}^*_{L},\cdot\widetilde{Q}^*_L}}{f(\widetilde{Q}^*_H,d)^{-\sigma+\widetilde{Q}^*_{H},\cdot\widetilde{Q}^*_H}}\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\left(\frac{1+\Upsilon_{L,S}\cdot i}{1+\Upsilon_{H,S}\cdot i}\right)\frac{L_N A_N^{\alpha-1}}{L_S+L_N}\left[G^*\frac{h}{l}\frac{H_N}{L_N}\left(\frac{1+\Omega_{L,N}\cdot i}{1+\Omega_{H,N}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{1/2}}{\frac{f(\widetilde{Q}^*_L,d)^{-\sigma+\widetilde{Q}^*_{L},\cdot\widetilde{Q}^*_L}}{f(\widetilde{Q}^*_H,d)^{-\sigma+\widetilde{Q}^*_{H},\cdot\widetilde{Q}^*_H}}\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\left(\frac{1+\Upsilon_{L,S}\cdot i}{1+\Upsilon_{H,S}\cdot i}\right)\frac{L_S A_S^{\alpha-1}}{L_S+L_N}\left[G^*\frac{h}{l}\frac{H_S}{L_S}\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{1/2}-\frac{H_S A_S^{\alpha-1}}{H_S+H_N}} = 0. \tag{25}$$

Equation (25) can be found since $\frac{\dot{\widetilde{Q}}^*_H}{\widetilde{Q}^*_H} = \frac{\dot{\widetilde{Q}}^*_L}{\widetilde{Q}^*_L} = 0$. In steady state, the stable and unique endogenous technological-knowledge bias, D^*, depends (in this case, implicitly) on h, l, A_N, A_S, H_N, H_S, L_N, L_S, $\Omega_{L,S}$, $\Omega_{H,S}$, $\Omega_{L,N}$, $\Omega_{H,N}$, $\Upsilon_{L,N}$, $\Upsilon_{H,N}$, and i. For simplification and since our main interest is in the effect of credit constraints and nominal interest rate, we rewrite (25) as

$$F(G^*, i) = F_1(G^*, i) - F_2(G^*, i) = 0. \tag{26}$$

It is straightforward to see that $F_1(G^*, i) > 0$ and, then, for (25) to hold, $F_2(G^*, i) > 0$. Thus, the numerator and the denominator of $F_2(G^*, i)$ are both positive or both negative. Note that$\Omega_{L,o} > \Omega_{H,o}$ and $\Upsilon_{L,o} >\Upsilon_{H,o}$, means that credit requirements by unskilled production firms are higher than those of the skilled production firms. As will be seen below, these CIA constraints relationships are essential to drive the main results. In some sense that we detail further below, the consideration of monetary constraints are essential to derive some well-known empirical facts about wage inequality as well as the empirical relationship with the inflation rate highlighted above.

Proposition 2. Let $\Omega_{L,o} > \Omega_{H,o}$ ($\Omega_{L,o} < \Omega_{H,o}$) and $\Upsilon_{L,o} >\Upsilon_{H,o}$ ($\Upsilon_{L,o} <\Upsilon_{H,o}$). *An increase in the nominal interest rate i (and also in the inflation rate) decreases (increases)*G^*.

Proof. Define (25) implicitly as $F(G^*, i) = 0$ and, thus, $\frac{\partial G^*}{\partial i} = -\frac{\frac{\partial F}{\partial i}}{\frac{\partial F}{\partial G^*}} = -\frac{\frac{\partial(F_1(G^*,i)-F_2(G^*,i))}{\partial i}}{\frac{\partial(F_1(G^*,i)-F_2(G^*,i))}{\partial G^*}}$. Let $\Omega_{L,o} > \Omega_{H,o}$ and $\Upsilon_{L,o} > \Upsilon_{H,o}$; as is straighforward to see $sign\left(\frac{\partial F}{\partial G^*}\right) = sign\left(\frac{\partial F}{\partial i}\right)$, which implies that $\frac{\partial G^*}{\partial i} < 0$. Now, let $\Omega_{L,o} < \Omega_{H,o}$ and $\Upsilon_{L,o} < \Upsilon_{H,o}$; in this case, we have $sign\left(\frac{\partial F}{\partial G^*}\right) \neq sign\left(\frac{\partial F}{\partial i}\right)$ and so $\frac{\partial G^*}{\partial i} > 0$.

□

The theoretical study of the influence of other variables on the technological-knowledge bias is beyond the scope of this article (as was approached in the previous literature) due to the fact that our focus is the influence of credit constraints and inflation on wage inequality. In the next paragraph we go through intuition.

By removing scale effects, the *price channel* dominates the *market-size channel*. However, since $\frac{p_{H,N}}{p_{L,N}}$ remains always lower than $\frac{p_{H,S}}{p_{L,S}}$ due to relative labor endowments, the North-South average (the one that becomes relevant under international trade) relative price of H-technology final goods is higher than the one prevailing in the North alone. As a result, the price channel – discussed above in 3.3 – enhances the relative demand for H-specific new designs, biasing innovation R&D in that direction; i.e., G^* increases and this bias increases the world supply of H-specific intermediate goods; an increase in Ω_L (Ω_H) raises costs in the L-technology (H-technology), therefore diverting, direct or indirectly, resources from R&D activities directed to the L-technology (H-technology) and, thus, improving (penalizing) the steady-state technological-knowledge bias. This also happens with $\frac{h}{l}$, which *ceteris paribus*, increases the relative cost of the H-technology and, in turn, decreases the technological-knowledge bias.

Moreover, from (31)

$$\overline{n}_S^* = \left\{ 1 + \left[G^* \left(\frac{h}{l} \frac{H_S}{L_S} \right) \left(\frac{1+\Omega_{L,S} \cdot i}{1+\Omega_{H,S} \cdot i} \right)^{\left(\frac{1-\alpha}{\alpha} \right)} \right]^{\frac{1}{2}} \right\}^{-1} > \overline{n}_N^* = \left\{ 1 + \left[G^* \left(\frac{h}{l} \frac{H_N}{L_N} \right) \left(\frac{1+\Omega_{L,N} \cdot i}{1+\Omega_{H,N} \cdot i} \right)^{\left(\frac{1-\alpha}{\alpha} \right)} \right]^{\frac{1}{2}} \right\}^{-1}, \tag{27}$$

in steady state, the stable and unique endogenous threshold final good, $\overline{n}^*$ in each country, for a given value of the endogenous technological-knowledge bias, G^*, relies on the (structural) level of the nominal interest rate, i, on parameters and variables related to the technology, l, h, L, H, and α, and on the CIA constraints, Ω_L and Ω_H. An increase in l, L, and Ω_H or a decrease in h, H, α, and Ω_L increases $\overline{n}^*$. The sign of the effect of i on $\overline{n}^*$ depends on the values assumed by Ω_L and Ω_H. Note that the difference between the threshold final good in the North and in the South is not especially dependent on the technological-knowledge bias, G^*.

Proposition 3. *Let $\Omega_{L,o} > \Omega_{H,o}$ ($\Omega_{L,o} < \Omega_{H,o}$). Then a higher nominal interest rate (and, thus, an higher inflation) contributes to decrease the threshold final good, $\overline{n}^*$, in each country, tending to increase (decrease) the relative production of the skilled intensive goods.*

Proof. For a constant technological-knowledge bias, this is straightforward to see, because $\frac{\partial n_o}{\partial i} \lesseqgtr 0$ for $\Omega_{L,o} \gtreqless \Omega_{H,o}$. Taking into account the effect through the technological-knowledge bias, the proof is cumbersome, but it can be shown that the effect through G^* is of second-order.

□

From (15), since $\frac{L_S}{H_S} > \frac{L_N}{H_N}$, the steady-state skill premium in each country is:

$$\left(\frac{w_{H,S}}{w_{L,S}} \right)^* = \left[G^* \left(\frac{h}{l} \frac{L_S}{H_S} \right) \left(\frac{1+\Omega_{L,S} \cdot i}{1+\Omega_{H,S} \cdot i} \right)^{\left(\frac{1-\alpha}{\alpha} \right)} \right]^{\frac{1}{2}} > \left(\frac{w_{H,N}}{w_{L,N}} \right)^* = \left[G^* \left(\frac{h}{l} \frac{L_N}{H_N} \right) \left(\frac{1+\Omega_{L,N} \cdot i}{1+\Omega_{H,N} \cdot i} \right)^{\left(\frac{1-\alpha}{\alpha} \right)} \right]^{\frac{1}{2}}, \tag{28}$$

i.e., the stable and unique steady-state endogenous skill premium depends on G^*, $\frac{h}{l}$, $\frac{H}{L}$, Ω_L, Ω_H, and i. If the (unskilled-) relative financial constraints in the South are higher than in the North, this contributes to obtain a higher skill premium in the South than in the North. This also implies a relationship in inter-country wage ratio such as $\left(\frac{w_{H,N}}{w_{H,S}} \right) < \left(\frac{w_{L,N}}{w_{L,S}} \right)$. The higher the difference between (unskilled-) relative financial constraints in the South when compared to the North, the higher the difference in inter-country wage ratios by skills.

Proposition 4. *An increase in the unskilled financial costs in the intermediate goods production, $\Omega_{L,o}$, and in the R&D activities, $\Upsilon_{L,o}$, increases $\frac{w_{H,o}}{w_{L,o}}$, whereas an increase in the skilled financial costs in the intermediate-goods production, $\Omega_{H,o}$, and in the R&D activities, $\Upsilon_{H,o}$, decreases $\frac{w_{H,o}}{w_{L,o}}$. An increase in the nominal interest rate i (and also in the inflation rate) decreases $\frac{w_{H,o}}{w_{L,o}}$ if $\Omega_{H,o} > \Omega_{L,o}$, or increases $\frac{w_{H,o}}{w_{L,o}}$ if $\Omega_{H,o} < \Omega_{L,o}$. Moreover, effects are quantitatively higher than those described in Proposition 2.*

Proof. Partially derive (28) in order to $\Omega_{L,S}$, $\Omega_{H,S}$, $\Omega_{L,N}$, $\Omega_{H,N}$, $\Upsilon_{L,N}$, $\Upsilon_{H,N}$, and i and evaluate the sign of the derivatives, taking into account (25).

□

It is worth noting that, as we expect, skilled producers will be less financially constrained than unskilled producers, $\Omega_{H,o} < \Omega_{L,o}$, and that inflation increases wage inequality as the empirical evidence presented above highlighted. Note also that $\left(\frac{\dot{w}_H}{w_H} \right)^* - \left(\frac{\dot{w}_L}{w_L} \right)^* = 0$ and wages rise steadily in line with the technological-knowledge progress; i.e., $\left(\frac{\dot{w}_H}{w_H} \right)^* = \left(\frac{\dot{w}_L}{w_L} \right)^* = \left(\frac{\dot{Q}_H}{Q_H} \right)^* = \left(\frac{\dot{Q}_L}{Q_L} \right)^*$. From the previous analysis, for example, an increase in β as well as a decrease in θ, ρ, and ζ increases g^* and has no impact on $\left(\frac{w_H}{w_L} \right)^*$. Hence, any change in these parameters in the sense referred to implies that all workers will earn higher wages in the new steady state (i.e., welfare gains emerge).

As follows from, for example, (8) and (24), R&D drives steady-state endogenous growth. The intensity of the driving force is, in turn, influenced by international trade and CIA constraints. In order to look at the steady-state effects of international trade in a context with CIA constraints we must investigate g^*

further. To this end, since g^* results directly from plugging r^* into the Euler equation (2), it is sufficient to compare the steady-state interest rate

$$r^* = \left\{ \left[q^{\left(\frac{1-\alpha}{\alpha}\right)} - 1 \right] \theta + 1 \right\}^{-1} \left\{ \beta_S \cdot \zeta_S^{-1} \cdot B_D \cdot B_T \cdot f(\widetilde{Q}_H^*, d)^{-\sigma + \widetilde{Q}_{H,}^*} \cdot \widetilde{Q}_H^* \cdot h \right. \\ \left. (1-\alpha)^{\alpha^{-1}} \cdot (1 - MC_S) \cdot \cdot \frac{D_H^*}{(1+\Omega_{H,S} \cdot i)^{\left(\frac{1-\alpha}{\alpha}\right)} (1+\Upsilon_{H,S} \cdot i)} \left[q^{\left(\frac{1-\alpha}{\alpha}\right)} - 1 \right] \theta + \rho \right\} \quad ; \tag{29}$$

obtained by setting the growth rate of consumption in (2) equal to the growth rate of Northern technological knowledge in (21) with the one that would prevail in a pre-trade steady state and where $D_H(t) = \frac{H_S}{H_S+H_N} \left[A_S \cdot p_{H,S}(t) \right]^{\alpha^{-1}} + \frac{H_N}{H_S+H_N} \left[A_N \cdot p_{H,N}(t) \right]^{\alpha^{-1}}$, and prices are given by $p_H(t) = p_n n^\alpha = \exp(-\alpha) \left[1 - \overline{n}(t) \right]^{-\alpha}$. The long-run real interest rate, r^*, and economic growth rate, g^*, depend on preferences parameters, on the (structural) level of the nominal interest rate, on parameters related to the technology, and on the CIA constraints. It should be emphasized that r^* depends positively on the discount rate, ρ, and on the inverse of the intertemporal elasticity of substitution, θ, whereas g^* depends negatively on ρ and on θ. The impact of ρ and θ on g^* is consistent with the fact that if present consumption is more highly valued than future consumption (following the properties of the utility function), then this will lead to less need for private investment and, thus, to less dispersion over time. In other words, the more patient – i.e., the smaller the value of ρ – and the less keen the individuals are on consumption smoothing – i.e., the smaller the value of θ – the higher the steady-state growth rate.

Proposition 5. *The real interest rate, r^*, and, consequently, the economic growth rate, g^*, decrease when Υ_H or Υ_L (Ω_H or Ω_L – acting through p_H) increase. The sign of the effect of i on r^* and g^* is negative.*

Proof. Partially derive (29) in order to $\Omega_{L,S}$, $\Omega_{H,S}$, $\Omega_{L,N}$, $\Omega_{H,N}$, $\Upsilon_{L,N}$, $\Upsilon_{H,N}$, taking the expression for p_H into account. For the effect of i, taking D_H as given, it is directely seen that $\left.\frac{\partial r^*}{\partial i}\right|_{D_H} < 0$. Additionally, note that $\frac{\partial D_H}{\partial i} < 0$ as $sign\left(\frac{\partial D_H}{\partial i}\right) = sign\left(\frac{\partial p_{H,j}}{\partial i}\right) = sign\left(\frac{\partial \bar{n}}{\partial i}\right) < 0$.

□

Therefore, our theoretical results are consistent with the recent empirical evidence suggesting that both the economic growth rate and the real interest rate are negatively related to long-run inflation (e.g., Valdovinos 2003, Chu et al. 2015, Akinsola and Odhiambo 2017), and that those effects can be nonlinear and differ greatly across countries (e.g., López-Villavicencio and Mignon 2011). These effects will be evaluated through a calibration exercise below.

Considering that in the absence of international trade, the advantages of backwardness and openness terms vanish from the probability of successful imitation (11) and that the relevant market size in each country is its own domestic labor, the increment in the steady-state interest rate from pre-trade to international trade in intermediate goods relies on the difference

$$B_T \cdot f(\widetilde{Q}_H^*, d)^{-\sigma + \widetilde{Q}_{H,}^*} \cdot \widetilde{Q}_H^* \cdot (1 - MC_S) \cdot D_H^* - \\ - \left(\frac{q-1}{q}\right) \left[A_S \cdot p_{H,S}^*\big|_{pre-trade} \right]^{\alpha^{-1}} \cdot MC_S^{(\alpha-1)\alpha^{-1}} \quad . \tag{30}$$

While evaluation of equation (30) requires solving for transitional dynamics through calibration and simulation, we can, however, emphasize five ways, in addition to the level effects, through which international trade and CIA constraints influences in opposite directions, steady-state growth. It should be stressed that, although CIA constraints are not explicit in (30), they work through D_H^* and $P_{H,S}^*$.

The first way in which international trade influences steady-state growth is the positive catching-up effect on the probability of successful imitation. Imitation capacity increases with the degree of openness, which is captured by B_T, and the advantages of backwardness are obtained only in the presence of international trade. Through the feedback effect described above, the probability of successful innovation, and thus the steady-state growth rate, are also affected – see equations (20) and (21).

The second way is the positive spillovers from North to South. Each innovation in the North tends to lower the cost of Southern imitation because the backwardness advantage is strengthened with each improvement of the technological-knowledge frontier.

The third – counteracting – channel reflects the effect of CIA constraints on the production of intermediate goods. Since $D_H^* = \frac{H_S}{H_S+H_N} \left[A_S \cdot p_{H,S}^* \right]^{\alpha^{-1}} + \frac{H_N}{H_S+H_N} \left[A_N \cdot p_{H,N}^* \right]^{\alpha^{-1}}$ any change in $\Omega_{L;S}$, $\Omega_{H,S}$, or i that affects $p_{H,S}^*$ has negative influence on (30). Indeed, under international trade the cost of introducing new qualities of intermediate goods also in the South has to be considered, which feeds back into the North by making the R&D innovative activity more difficult.

The fourth – counteracting as well – channel is the monopolistic competition mark-up. The Northern monopolist loses profits with the entry into international trade: the average mark-up between the first and third situations in Table 2 above is smaller than $(q-1)$, which is the pre-trade mark-up. The reason for this is that in pre-trade successful innovators are protected from international competition. Once engaged in international trade and imitation becomes profitable (provided that the technological-knowledge threshold d is overcome), profit margins in the North are reduced, which discourages R&D activities.[17]

The fifth – counteracting as well – way through which trade influences steady-state growth, is that Southern firms have to support the R&D imitative cost of state-of-the-art intermediate goods, possibly several quality rungs above (and thus more complex) their own experience level in pre-trade. This is captured by the presence of the technological-knowledge ratio, $\widetilde{Q}_H^*$, in (30).

The effect of trade on the steady-state growth rate is, thus, ambiguous. However, the comparative statics (numerically computed based on the calibration in Table 3, appendix) are not affected by such ambiguity because changes in g^* refer to steady-state growth under trade. This rate is affected by the levels of exogenous variables and parameters, which is to be expected in an endogenous growth model. In particular, both countries' exogenous levels of productivity (A_N and A_S) and parameters of R&D technology (β, B_D and B_T) improve the common growth rate through their positive effect on the profitability of R&D, as (20) demonstrates. The impact on steady-state growth of an increase in the Southern marginal cost of final-goods production, MC_S, results from the combination of typical Schumpeterian R&D effects: (i) by reducing productivity, it reduces resources available to R&D, and, consequently, both imitation and innovation (feedback effect); it also implies a smaller mark-up for the intermediate-goods producers in the South, thereby (ii) discouraging imitative R&D and (iii) encouraging innovative R&D; in our numerical calculations, the effects (i) and (ii) clearly dominate (iii).

To prove that the steady state is stable, let us consider that the economy is initially out of the steady state whereby, for example, $I_{H,N} > I_{L,N}$. In particular, this implies that $\frac{P_H}{P_L} > \left(\frac{P_H}{P_L}\right)^*$; i.e., that $\overline{n} > \overline{n}^*$, meaning that $\frac{\dot{Q}_H}{Q_H} > \frac{\dot{Q}_L}{Q_L}$ and, since from (6) $\frac{P_H}{P_L} = \left\{ D\left(\frac{h \cdot H}{l \cdot L}\right)\left(\frac{1+\Omega_{L,N}\cdot i}{1+\Omega_{H,N}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right\}^{-\frac{\alpha}{2}}$, $\frac{\dot{P}_H}{P_H} - \frac{\dot{P}_L}{P_L} < 0$. Thus, $\frac{P_H}{P_L}$ (or $\overline{n}$) is decreasing toward $\frac{P_H^*}{P_L^*}$ (or $\overline{n}^*$). Notice that the decrease in $\frac{P_H}{P_L}$ (or $\overline{n}$) attenuates the rate at which the technological-knowledge bias is increasing. Thus, due to market incentives, while $\frac{\dot{Q}_H}{Q_H} > \frac{\dot{Q}_L}{Q_L}$, $\frac{\dot{Q}_H}{Q_H} - \frac{\dot{Q}_L}{Q_L}$ is decreasing until the unique and stable steady state is achieved, at which $\left(\frac{\dot{Q}_H}{Q_H}\right)^* - \left(\frac{\dot{Q}_L}{Q_L}\right)^* = 0$. The argument to show that the economy starting with $I_{H,N} < I_{L,N}$ converges to $\left(\frac{P_H}{P_L}\right)^*$ is identical. Hence, the economy starting out at the steady state converges to this state and, without any exogenous disturbance, it remains there.

Finally, we can extend all the above comparative-statics results pertaining to shifts in i also to shifts in the long-run inflation rate, π^*. The long-run inflation rate, π^*, is an increasing function of the exogenous monetary-policy variable, i. Bearing in mind the Fisher equation (1) and the equilibrium relationship $\pi(t) = \pi^*$, with $\pi^* = i - r^*$, since r^* is a decreasing function of i, then, for a given exogenous shift in i, Δi, implies that $\text{sgn}(\Delta\pi^*) = \text{sgn}(\Delta i)$ and $\Delta\pi^* > \Delta i$.

5 Quantitative effects

5.1 Calibration

Most of the parameters have common values in the macroeconomics growth literature, such as the labor share, $\alpha = 0.6$, the discount rate, $\rho = 0.03$, the intertemporal elasticity of substitution, $\theta = 1.05$ – see, e.g., Jones (1995) and Jones and Williams (2000). Spillovers or the standing-on-the-shoulders effects, β, take the value 1.6 for the North and 1.0 for the South,[18], the complexity effects, ζ, take the value 4 for the North and 2.5 for the South, consistent with a higher complexity for more developed countries as argued, e.g., by Sequeira et al. (2018). The other parameters of the technology channel, B_D and B_T,

[17]Contrary to the previous models in which the reduction of margins is offset by market enlargement, e.g., Rivera-Batiz and Romer (1991), we have removed the scale effect, as explained above.

[18]This means that the North has a spillover 0.6 higher than the South and are in line with estimates from Neves and Sequeira (2018).

and those of the backwardness channel, σ and d, as well as variables $\widetilde{Q}_L(t_0)$ and $\widetilde{Q}_H(t_0)$, in equation (20) are taken from Afonso (2012). The same is done considering the relative productivity advantage of the skilled over unskilled workers $\frac{h}{l} = 1.2$. Some others reflect empirical facts such as A_N and A_S, reflecting the institutional quality advantage of North relative to the South in more 1.4 institutional quality. If we consider that the North (say the USA) has been seven times richer that the South (say China)[19] – considering GDP *per capita*, this is roughly consistent with the Hall and Jones (1999) finding that 1% increase in institutional quality implies an increase in 5% in GDP *per capita*. We will present robustness analysis to show that some reasonable changes in these values do not affect our main results. Furthermore, we adjust σ and q such that we replicate reasonable values for both the skill premium (near 2.5 in the North with zero inflation) and the economic growth rate (near 3% with zero inflation).

Skilled and unskilled labor endowments as well as CIA constraints are essential elements in our model. First, for skilled and unskilled labor we use the Barro and Lee education attainment dataset (update June 2018) – Barro and Lee (2013) – considering for unskilled labor the number of people in population aged 15 or above with total primary and secondary education and for skilled labor the number of people in population aged 15 or above with total tertiary education. As Northern countries, we consider the ones that are leading in research.[20] As Southern countries we included those that imitate or adopt Northern technologies.[21] This yields a skilled-unskilled labor of 0.57 in the North and 0.12 in the South, also yielding a much higher skill premium in the South than in the North, as we will show below and consistent with empirical evidence. For CIA constraints in the North, we follow Gómez (2018) and consider $\Omega_{H,N} = 0.2$. As expected, low-skilled production firms are more financially constrained than the skilled production function (see, e.g., Gómez, 2018; and Popov, 2013). It is worth noting that in his calculations Gómez (2018) does not consider the extensive margin, i.e., the firms that can exit the markets once hit by a financial constraint. Also, Beck et al. (2005) present results according to which smaller firms are more financially constrained than big ones. It is, thus, natural to assume that unskilled production firms are smaller and more prone to exit than skilled production firms when hit by a financial constraint. This leads us to assume that $\Omega_{L,N} = 0.4$, taking the average estimate in Popov (2013). For the financial constraints in the South, we use the higher value in Popov (2013) for setting $\Omega_{L,S} = 0.8$ and an intermediate value for setting $\Omega_{H,S} = 0.6$. Finally, R&D firms – and by the same reasons also firms that adapt technologies in the South – need higher cash-flow for payments than intermediate goods firms (see, e.g., Chu and Cozzi 2014). Thus, we assume $\Upsilon_{L,S} = 0.9$ and $\Upsilon_{H,S} = 0.7$. Table 3 summarizes the calibrated values for parameters and predetermined variables.

Parameter	Value		Parameter	Value		Variables	Value
α	0.66		B_D	1.28		A_N	1.60
h	1.20		B_T	1.85		A_S	1.00
MC_S	0.80		σ	1.70		$\frac{H_N}{L_N}$	0.57
β_N	1.60		d	0.10		$\frac{H_S}{L_S}$	0.12
β_S	1.00		q	1.10		$\frac{Q_H(t_0)}{Q_L(t_0)}$	1.00
ζ_N	4.00		θ	1.05		$\widetilde{Q}_H(t_0)$	0.35
ζ_S	2.50		ρ	0.02		$\widetilde{Q}_L(t_0)$	0.30
$\Omega_{L,N}$	0.4		$\Omega_{H,N}$	0.2		$\Omega_{L,S}$	0.8
$\Omega_{H,S}$	0.6		$\Upsilon_{L,S}$	0.9		$\Upsilon_{H,S}$	0.7

Table 3: Baseline parameter and initial values

5.2 Comparative steady-state effects of inflation on wage inequality, production specialization, and growth

After using equation (25) to calculate the endogenous technological-knowledge bias, we can use equation (27) to calculate the unskilled threshold variety for the North and the South, equation (28) to calculate

[19]For this comparison we considered differences in GDP per capita, averaged between 1990 and 2017, from the PWT 9.1. If this comparison would be between the USA and India, the USA would be around 11 times richer than India, considering the period after 2000. In this case a higher $\frac{A_N}{A_S}$ would be appropriate.

[20]Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands New Zealand, Norway, Sweden, Switzerland, the United Kingdom, and the USA.

[21]China, India, Indonesia, Russian Federation, Brazil, and South Africa.

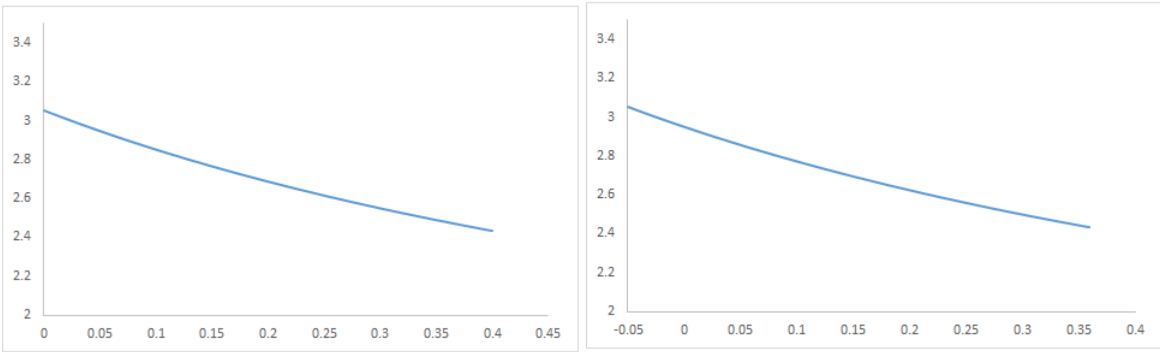

Figure 2: Changes in the endogenous technological-knowledge bias for different nominal interest rates, panel (a), and inflation rates, panel (b).

wage inequality in the North and in the South, and equation (29) to calculate economic growth.

First, we plot the endogenous technological-knowledge bias (on the Y-axis of Figure 2), G^*, which is negatively related to the nominal interest (panel (a), on the left side) and inflation rates (panel (b), on the right side), as stated by Proposition 2.

Next, we plot the threshold final good for the North and the South (Figure 3: panel (a), on the left side), the skill premium in the North and in the South (Figure 3: panel (b), on the right side), the skill premium in the South related to the skill premium in the North (Figure 3: panel (c), on the left side) and economic growth (Figure 3: panel (d), on the right side). There are several results that can be highlighted by this quantitative exercise, even to compare them with available empirical evidence. First, as expected, the number of varieties produced with unskilled technologies is greater in the South than in the North (compare the right- with the left-hand scale in the panel (a), Figure 3). However, due to the effect of inflation, the number of varieties produced with skilled technologies increases in both the South and in the North. Despite the quantitative effects being relatively small, effects on the North seem to be higher. In Figure 3, panel (b) we observe the skill premia for the North and the South. As expected, both theoretically and empirically, the skill premium is higher in the South than in the North. Both increase with inflation as Proposition 4 predicted. However, the magnitude of the effects are greater in the South, where, quantitatively, the skill premium is also higher. However, the distance between skill premia regarding skill premia in the North and in the South seem to shrink with increasing inflation – see panel (c) in Figure 3. Finally, panel (d) in Figure 3 shows the responsiveness of economic growth to inflation rate. As pointed out by the majority of the previous contributions (e.g., Gillman and Kejak 2005, for a survey), there is a negative effect of (non-hyper) inflation rates on economic growth that tends to become slightly smoother for higher levels of inflation – note the slightly convex negatively sloped curve.

We also note that an increase in the inflation rate decreases the real interest rates, which, in fact, can be observed by the path in the economic growth rate in Figure 3, panel (c) given the Euler condition. This would imply the verification of the Tobin effects mentioned in Gillman and Kejak (2005), i.e., an increase in the investment and an increase in capital-labor ratios, as also a decrease in the consumption share in output.

6 Concluding remarks

The effects of inflation on economic growth have been studied just after the endogenous growth theory advent, but superneutrality of money seems then to be the overwhelming result. In the light of this result, interest in studying the effects of inflation within the endogenous growth theory has been almost neglected over nearly 30 years of theory. However, given the recent interest in studying the real effects of monetary policy, several contributions have been made in the past few years concerning the effects of inflation on growth both empirical and theoretically.

In this paper we focus on an almost overlooked issue within the inflation economic development nexus: we highlight the study of the effect of inflation on wage inequality. To that end, we devise a North-South model of endogenous growth in which there is international trade between

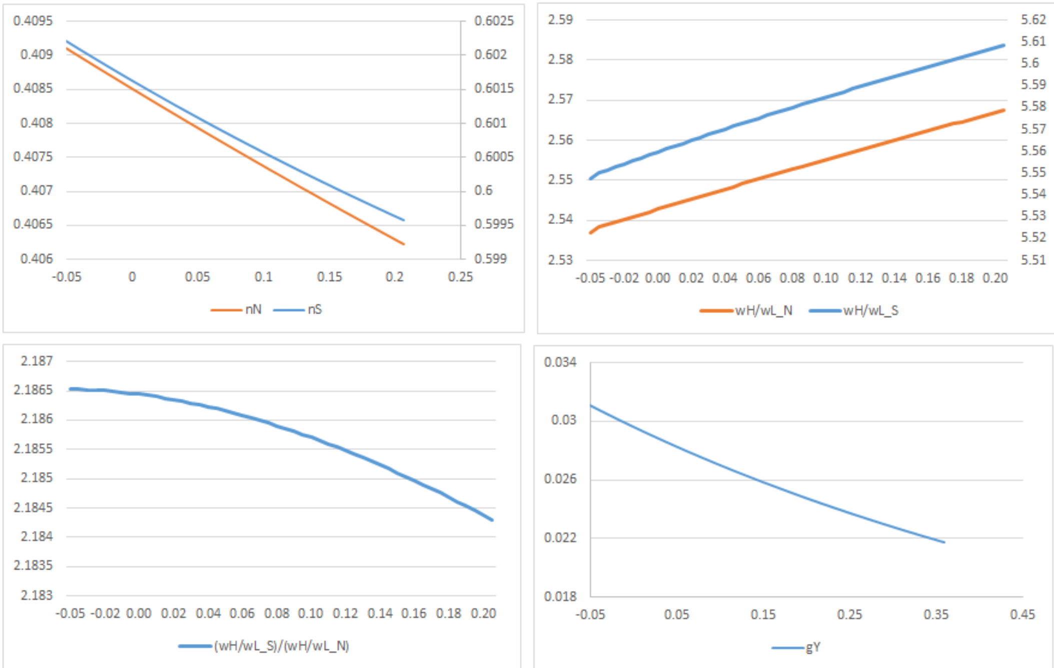

Figure 3: Changes in the endogenous threshold final good, panel (a), skill premium, panel (b), relative South-North skill premium, panel (c), and economic growth rate, panel (d), for different inflation rates.

both regions. We first present compelling evidence according to which the relationship between inflation and inequality is a negative one. Then, we study the theoretical effect of inflation in different macroeconomic variables, namely, the wage inequality, the specialization pattern, nominal and real interest rates, and economic growth. For plausible relationships between financial constraints of the different sectors in the economy, we obtain that an increase in the nominal interest rate (and also in the inflation rate) decreases the technological-knowledge bias, tending to increase the relative specialization in skilled intensive goods and wage inequality. Thus, the model confirms the empirical prediction according to which inflation tends to increase inequality. Also, inflation undoubtedly decreases economic growth, in which the model also follows the existing empirical evidence. All the results are confirmed quantitatively.

Furthermore, we show that inflation decreases the difference of wage inequality levels between the South and the North. This means that more inflation shrinks the difference between the skill premium in the North relatively to the skill premium in the South. It is also important to note that inflation and trade have opposite effects on wage inequality and on specialization: while trade tends to decrease wage inequality in the South, inflation tends to increase it; while trade tends to increase the number of different intermediate goods produced with unskilled technology in the South, inflation acts the other way around. This counter effect of inflation (in comparison to trade) in wage inequality in the developing South could indicate that the monetary policy may have a role in counterbalancing the negative effects of a potential decrease in international trade due to escalating protectionism. Thus, in face of a drop in international trade, inflation should decrease.

Appendix: more on trade and level effects in the South

Some empirical studies provide strong evidence that imports of intermediate goods improve productivity in developing countries (Amiti and Konings, 2007; Goldberg et al., 2008). Thus, in order to emphasize the diffusion of technological knowledge embodied in intermediate goods, we assume that only these goods are internationally traded, while final goods and assets are internationally immobile.[22] Each intermediate good in the international market is produced either in the North or in the South. In the former case, it embodies the latest innovation, while in the latter it results from the imitation, at a lower cost, of the latest innovation. In either case, internationally traded intermediate goods embody the state-of-the-art technological knowledge accumulated in the North, which is summarized in $Q_H(t)$ and $Q_L(t)$.

Level effects in the South

When compared with a pre-trade situation, the improvement in the level of technological knowledge available to the South – through access to the state-of-the-art intermediate goods – is a static benefit of international trade. Indeed, the technological-knowledge gap is always favorable to the North in either specific knowledge, i.e., $Q_m > Q_{m,S}$, since even under trade, at each t not all innovations have been imitated yet and, thus, the South enjoys an immediate absolute and relative (to the North) benefit in terms of aggregate product and factor prices. In fact, both the level of the composite final good – see (8) – and the marginal productivity of H and L increase with Q_m.

The structure of final-goods production in the South is also affected, as the North's technological-knowledge bias, $\frac{Q_H}{Q_L}$, is transmitted to the South. In fact, comparing the threshold final good in the South – given, in general, by (4) – immediately before and immediately after entry into trade at time t_0,

$$\begin{gathered}\overline{n}_S(t_0)|_{pre-trade} = \left\{1 + \left[G_S(t_0)\left(\frac{h}{l}\frac{H_S}{L_S}\right)\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}}\right\}^{-1} < \overline{n}_S(t_0) = \left\{1 + \left[G(t_0)\left(\frac{h}{l}\frac{H_S}{L_S}\right)\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}}\right\}^{-1} \\ versus \\ \overline{n}_S(t_0) = \left\{1 + \left[G(t_0)\left(\frac{h}{l}\frac{H_S}{L_S}\right)\left(\frac{1+\Omega_{L,S}\cdot i}{1+\Omega_{H,S}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}}\right\}^{-1} > \overline{n}_N(t_0) = \left\{1 + \left[G(t_0)\left(\frac{h}{l}\frac{H_N}{L_N}\right)\left(\frac{1+\Omega_{L,N}\cdot i}{1+\Omega_{H,N}\cdot i}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}\right]^{\frac{1}{2}}\right\}^{-1}\end{gathered}, \quad (31)$$

where $G_S(t_0) \equiv \frac{Q_{H,S}(t_0)}{Q_{L,S}(t_0)}$ is the South's technological-knowledge bias at time t_0 and $G(t_0) \equiv \frac{Q_H(t_0)}{Q_L(t_0)}$ is the North's technological-knowledge bias at time t_0. That is, while before trade the level of technological knowledge available to the South is just the domestic technological knowledge – $Q_{H,S}$ and $Q_{L,S}$ –, under trade the state-of-the-art intermediate goods available internationally embody the North's technological knowledge – Q_H and Q_L.[23]

References

Acemoglu, D. (2002). Directed technical change. *Review of Economic Studies* 69(4), 781-809.

Acemoglu, D., and Zilibotti, F. (2001). Productivity differences. *Quarterly Journal of Economics* 116(2), 563-606.

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.

Aghion, P., Garcia-Penalosa, C., and Howitt, P. (2004). Knowledge and development: a Schumpeterian approach. In S. Dowrick, R. Pitchford and S. Turnovsky, eds., *Economic Growth and Macroeconomic Dynamics: some Recent Developments*. Cambridge University Press, Cambridge.

Aghion, P., Harris, C., Howitt, P., and Vickers, J. (2001). Competition, imitation and growth with step-by-step innovation. *Review of Economic Studies* 68(3), 467-492.

Akinsola, F., and Odhiambo, N.M. (2017). Inflation and economic growth: a review of the international literature. *Comparative Economic Research* 20(3), 41-56.

Alogoskoufis, G., and Ploeg, F. (1994). Money and endogenous growth. *Journal of Money, Credit and Banking* 26(4), 771-791.

Amiti, M., and Konings, J. (2007). Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia. *American Economic Review* 97(5), 1611–1638.

Arawatari, R., Hori, T., and Mino, K. (2018). On the nonlinear relationship between inflation and growth: a theoretical exposition. *Journal of Monetary Economics* 94, 79-93.

Barro, R., and Sala-i-Martin, X. (2004). *Economic Growth.* Second edition, Cambridge, MA: MIT Press.

[22] Thus, in order to import some intermediate goods, the South has to be able to export other intermediate goods, since we consider balanced trade.

[23] We are assuming equal nominal interest rates in the North and in the South, without loss of generalization.

Barro, R. (2000). Inequality and Growth in a Panel of Countries. *Journal of Economic Growth* 5(1), 5-32.

Barro, R., and Lee, J. (2013). A new data set of educational attainment in the world, 1950-2010. *Journal of Development Economics* 104, 184-198.

Beck, T., A. Demirgüç-Kunt, L. Laeven, and V. Maksimovic (2005). Financial and Legal Constraints to Firm Growth: Does Firm Size Matter?, *Journal of Finance*, Vol. 60, No 1, pp. 137-177.

Benhabib, J., and Spiegel, M. (1994). The role of human capital in economic development: evidence from aggregate cross-country and regional U.S. data. *Journal of Monetary Economics* 34(2), 143-174.

Chu, A., and Ji, L. (2016). Monetary policy and endogenous market structure in a Schumpeterian economy. *Macroeconomics Dynamics* 20(5), 1127-1145.

Chu, A., Cozzi, G., Furukawa, Y., and Liao, C.H. (2017). Inflation and economic growth in a Schumpeterian model with endogenous entry of heterogeneous firms. *European Economic Review* 98, 392-409.

Chu, A.C., and Cozzi, G. (2014). R&D and economic growth in a cash-in-advance economy. *International Economic Review* 55(2), 507-524.

Chu, A.C., Cozzi, G., Lai, C.C., and Liao, C.H. (2015). Inflation, R&D and growth in an open economy. *Journal of International Economics* 96(2), 360-374.

Chu, A.C., Ning, L., and Zhu, D. (2019). Human capital and innovation in a monetary Schumpeterian growth model. *Macroeconomic Dynamics* 23(5), 1875-1894.

Coe, D., and Helpman, E. (1995). International R&D spillovers. *European Economic Review* 39(5), 859-897.

Coe, D., Helpman, E., and Hoffmaister, A. (1997). North-South R&D spillovers. *Economic Journal* 107(440), 134-149.

Chusseau, N., Dumont, M., and Hellier, J. (2008). Explaining rising inequality: Skill-biased technical change and North-South trade. *Journal of Economic Surveys* 22(3), 409-457.

Dinopoulos, E., and Segerstrom, P. (1999). A Schumpeterian model of protection and relative wages. *American Economic Review* 89(3), 450-473.

Dinopoulos, E., and Thompson, P. (1999). Scale effects in Schumpeterian models of economic growth. *Journal of Evolutionary Economics* 9(2), 157-185.

Grossman, G., and Helpman, E. (1991). *Innovation and growth in the global economy*. Cambridge, MA: MIT Press.

Goldberg, P., Khandelwal, A., Pavcnik, N., and Topalova, P. (2008). Imported intermediate inputs and domestic product growth: evidence from India. NBER Working Paper 14416. Cambridge, MA: National Bureau of Economic Research.

Evers, M., Niemann, S., and Schiffbauer, M. (2007). Inflation, investment composition and total factor productivity. University of Essex Economics Discussion Paper, number 632.

Gil, P., and Iglésias, G. (2019). Endogenous growth and real effects of monetary policy: R&D and physical capital complementarities. *Journal of Money, Credit and Banking,* forthcoming.

Gillman, M., and Kejak, M. (2005). Contrasting models of the effects of inflation on growth. *Journal of Economic Surveys* 19, 113-136.

Gómez, M. (2018). Credit constraints, firm investment and growth: evidence from survey data. European Central Bank Working Paper series, number 2126.

Ho, W., Zeng, J., and Zhang, J. (2017). Inflation taxation and welfare with externalities and leisure. *Journal of Money, Credit and Banking* 39(1), 105-131.

Hori, T. (2019). Monetary policy, financial frictions, and heterogeneous R&D firms in an Endogenous Growth Model. *Scandinavian Journal of Economics* online first: https://doi.org/10.1111/sjoe.12387.

Jaumotte, F., Lall, S., and Papageorgiou, C. (2009). Rising income inequality: technology, or trade and financial globalization. Working paper. Available at (December 2009): http://www.chrispapageorgiou.com/

Jones, C. (1995). R&D-based models of economic growth. *Journal of Political Economy* 103(4), 759-784.

Jones, L.E., and Manuelli, R.E. (1995) Growth and the Effects of Inflation. *Journal of Economic Dynamics and Control*, 19, 1405-1428.

Kortum, S. (1997). Research, patenting and technological change. *Econometrica* 65(6), 1389-1419.

Kuznets, S. (1955). Economic Growth and Income Inequality. *American Economic Review* 45, 1-28.

López-Villavicencio, A., and V. Mignon (2011). On the impact of Inflation on Output Growth: does the level of Inflation matter? *Journal of Macroeconomics* 33, 455-464.

Mansfield, E., Swartz, M., and Wagner, S. (1981). Imitation costs and patents: an empirical study. *Economic Journal* 91(364), 907-918.

Milanovic, B. (1994). Determinants of cross-country income inequality: an augmented kuznets hypothesis. Policy Research Working-Paper 1246, World Bank, Washington DC.

McAdam, P., and Willman, A. (2018). Unraveling the skill premium. *Macroeconomic Dynamics* 22(1), 33-62.

Nelson, R., and Phelps, E. (1966). Investment in humans, technological diffusion, and economic growth. *American Economic Review* 56(1/2), 69-75.

Okawa, K., and Ueda, K. (2018). The optimal inflation rate under Schumpeterian growth. *Journal of Monetary Economics* 100, 114-125.

Papageorgiou, C. (2002). Technology adoption, human capital, and growth theory. *Review of Development Economics* 6(3), 351-368.

Popov, A. (2013). Credit constraints and investment in human capital. European Central Bank Working Paper series, number 1606.

Rivera-Batiz, L., and Romer, P. (1991). Economic Integration and endogenous growth. *Quarterly Journal of Economics* 106(2), 531-555.

Rodriguez-Pose, V., and Tselios, V. (2009). Education and income inequality in the regions of the European Union. *Journal of Regional Sciences* 49(3), 411-437.

Romer, P. (1990). Endogenous technological change. *Journal of Political Economy* 98(5), S71-S102.

Sequeira, T., Gil, P., and Afonso, O. (2018). Endogenous growth and entropy. *Journal of Economic Behavior and Organization* 154, 100-120.

Song, J., Price, D., Guvenen, F., and Bloom, N. (2019). Firming up inequality. *Quarterly Journal of Economics* 134(1), 1-50.

Stockman, A. (1981). Anticipated inflation and the capital stock in a cash in-advance economy. *Journal of Monetary Economics*, 8(3), 387-393.

Teece, D. (1977). Technology transfer by multinational firms: the resource cost of transferring technological know-how. *Economic Journal* 87(346), 242-261.

Valdovinos, C.G.F. (2003). Inflation and economic growth in the long run. *Economics Letters* 80(2), 167-173.

Verspagen, B. (1993). *Uneven Growth Between Interdependent Economies: An Evolutionary View on Technology Gaps, Trade and Growth*. Avebury, Aldershot.

Wang, P., and Yip, C. (1992). Alternative Approaches to Money and Growth. *Journal of Money, Credit and Banking* 24(4), 553-562.