Inflation, Innovation, and Technology Transfer in an Open Economy with Variety Expansion

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Abstract

This study explores the cross-country effects of inflation on innovation and technology transfer in a North-South variety-expansion model with innovative northern R&D and adaptive southern R&D, in which R&D is subject to cash-in-advance constraints. In this model, higher southern inflation leads to a permanent increase in the North-South relative wage ratio, a temporary decrease in the northern innovation rate, and a permanent decrease in technology transfer. In contrast, higher northern inflation leads to a permanent decrease in the North-South relative wage ratio, a temporary decrease in the northern innovation rate, and a permanent decrease (increase) in technology transfer if the southern population is sufficiently small (large). Finally, a quantitative analysis is performed by calibrating the model to the China-US data, and the numerical results are consistent with these policy implications. Moreover, using country-pair panel data across OECD and emerging countries from 2003 to 2013, our model receives preliminary support in the predictions of nominal interest rate (inflation) effects on technology transfer from the North to the South.

Keywords: Inflation; Innovation; North-South product cycles; R&D; Technology transfer.
JEL classification: E41, F43, O30, O40.

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1 Introduction

How monetary policy affecting economic performance has long been an important issue in macroeconomics. The early studies of Stockman (1981) and Abel (1985) introduce a cash-in-advance (CIA) constraint into a macroeconomic economy by assuming that consumption/investment is subject to the CIA constraint to analyze the influence of monetary policy. Since then, the CIA model undergoes various modifications in several studies and becomes a popular model to examine the impact of monetary policy on economic growth, with the focus on its impact on accumulation of physical and human capital.[1] While accumulation of physical and human capital plays an important role in economic growth, recent studies have demonstrated that innovation resulting from research and development (R&D) is also an important engine for economic growth. Since existing empirical evidence suggests that cash flows affect R&D expenditures (e.g., Hall 1992, Himmelberg and Petersen 1994, and Opler *et al.* 1999), a growing literature concerns the role of R&D in a monetary economy with CIA constraints and how it affects the influence of monetary policy recently.

In order to analyze the effects of monetary policy on innovation and economic growth, most studies adopt a product-cycle model with CIA constraints. The product-cycle model was originally introduced by Vernon (1966) and subsequently developed by Segerstrom *et al.* (1990) and Grossman and Helpman (1991a,b). This strand of literature demonstrates that innovation improves quality of goods. Studies that carry out their analysis on the relation between monetary policy and innovation based on a closed economy include Chu and Cozzi (2014) and Huang *et al.* (2017, 2021). They analyze how monetary policy affects the market structure, employment, and innovation, respectively. Since international production through foreign direct investment (FDI) is common nowadays due to advances in technology and improvements in transportation, quite a few studies examine the cross-country effects of monetary policy based on a North-South model with technology transfer through FDI.[2] The availability of FDI allows firms to choose to produce goods domestically or abroad as a means of saving costs. As a result, monetary policy in one country have cross-country influences because firms adjust production patterns in response to policy changes.

Although an R&D model with quality improvement has been widely adopted in many studies to examine the cross-country influence of monetary policy, only very few studies examine this issue based on an R&D model with variety expansion.[3] To complement the literature, in this paper, we extend the variety-expansion model with multinational firms developed by Gustafsson

[1] For example, Suen and Yip (2005) show that indeterminacy may occur in a one-sector CIA model with an AK production function. A two-sector model with human capital accumulation and a CIA constraint is found in Marquis and Reffett (1991) and Mino (1997). Wang and Yip (1992) examine the impact of monetary policy under various monetary models, including a macroeconomic model with CIA constraints.

[2] For studies that examine the cross-country influences of monetary policy in a quality-ladder model, see Chu *et al.* (2015) and Chen (2018b,c). Chu *et al.* (2015) explore the growth and welfare effects of inflation in an open-economy Schumpeterian growth model with CIA constraints on consumption and R&D investment. Chen (2018b,c) respectively investigate the long-run impacts of monetary policy on growth and welfare in a North-South model with exogenous and endogenous rate of imitation. In particular, three separate CIA constraints applied to innovative R&D, adaptive R&D, and imitative R&D are considered.

[3] In line with the spirit of Romer (1990), Marquis and Reffett (1994) develop a variety-expanding R&D model with money and a costly accounting system that receives spillovers from new technologies to analyze the effects of inflation via a CIA constraint on consumption.

and Segerstrom (2011) by introducing CIA constraints applied to R&D investments to reexamine the cross-country effects of monetary policy on innovation, the North-South relative wage ratio, and international technology transfer, respectively. Our R&D model presents innovative R&D in the North (i.e., a high-wage country) which expands the variety of goods and adaptive R&D through FDI in the South (i.e., a low-wage country). Northern workers can work either in the innovative R&D sector or in the production sector. Northern production firms choose either to carry out the entire production of goods in the North or allow goods to be produced through FDI (i.e., technology transfer) in the South in order to take advantage of the lower southern wage rate. Multinational firms face the risk of imitation by southern firms since once southern firms succeed in imitation, they are then able to use the state-of-art technologies to produce goods.

By estimating a dynamic R&D model for high-tech firms, Hall and Lerner (2010) find that the wages and salaries of highly educated technology scientists and engineers count for fifty percent or more of R&D spending. Because highly educated workers are important determinants to the success of innovation and the departure of these workers will reduce a firm's profits, firms tend to hold cash to smooth their R&D spending over time and avoid having to lay off these workers. Brown and Petersen (2009, 2011) argue that it is very expensive for firms to adjust the flow of R&D in response to transitory finance shocks due to high adjustment costs for R&D. They show that during the 1998-2002 boom and bust in stock market returns, US firms depended heavily on cash reserves to smooth R&D expenditure.[4] To reflect this fact, we assume that innovative R&D and adaptive R&D are subject to CIA constraints. A fraction of innovative (adaptive) R&D investment is financed by borrowing money from households in the North (South).

We examine the respective impacts of northern monetary policy (i.e., an increase in the northern inflation/nominal interest rate) and southern monetary policy (i.e., an increase in the southern inflation/nominal interest rate). Since protection of intellectual property rights in the South tends to be much weaker than the one in the North and monetary policy (inflation) does not affect imitation, as a benchmark model, we assume that imitation is costless and the rate of imitation is exogenous. Increasing the southern nominal interest rate raises the cost of adaptive R&D for a foreign affiliate and reduces technology transfer from the North to the South. With a decrease in the demand for southern labor for adaptive R&D, the North-South relative wage ratio increases. The lower rate of technology transfer implies more products being produced in the North. Therefore, more northern workers are employed in the production sector, meaning that fewer northern workers are employed in the R&D sector. As a result, the rate of northern innovation decreases. By contrast, increasing the northern nominal interest rate raises R&D costs and reduces the demand for northern labor for R&D, causing the northern innovation rate and the North-South relative wage ratio to decrease. Regarding its impact on technology transfer, with a decrease in the North-South relative wage ratio, the costs of FDI become higher, which reduces the FDI rate. However, a higher northern nominal interest rate would raise technology transfer, since the decreased innovation rate reduces the difficulty level of transferring technology given the property of the semi-endogenous growth framework. We show that there will be an increase (decrease) in technology transfer if the southern population is sufficiently large (small).

[4] Brown *et al.* (2009) show that cash holdings have a significant impact on R&D in young firms. Brown *et al.* (2012) point out that R&D-incentive firms tend to hold cash to prevent themselves from financing R&D investment through debt or equity, because information friction and the lack of collateral value make R&D more sensitive to financing frictions.

In addition to theoretically examining the long-run effects of monetary policy on key macroeconomic variables, a quantitative analysis is performed by calibrating the model to the China-US data. Numerical results are consistent with our theoretical findings. Increasing the southern nominal interest rate by 10 percent points from 7.8% to 17.8% increases the North-South relative wage ratio by 1.5%, and it reduces the average R&D difficulty per worker in the North by 0.17% and international technology transfer by 3.6%, respectively. Moreover, increasing the northern nominal interest rate by 10 percent points from 7.1% to 17.1% reduces the North-South relative wage ratio by 1.5% and the average R&D difficulty per worker in the North by 3.3%. Since we calibrate the southern country to China which has a large population, such a change in the northern nominal interest rate induces an increase in technology transfer by 2.6%.[5] These results are qualitatively robust when we allow parameters representing the rate of imitation, productivity in adaptive R&D, and the tightness of CIA constraints to vary within a reasonable range.

As pointed out by Mansfield *et al.* (1981), an imitation-incentive firm, like an innovation-incentive firm, may also lean on cash reserves to smooth its imitation spending because of the requirement for hiring highly educated workers and high adjustment costs of imitation.[6] Consequently, we extend the benchmark model by endogenizing the rate of imitative R&D by assuming that southern firms can raise the rate of imitation by investing in imitation (imitative R&D).[7] Southern firms can imitate goods produced by firms in the North or goods produced by foreign affiliates in the South. Since taking into account costly imitation endogenizes a southern firm's imitation decision, changes in monetary policy induce a reallocation of southern labor between the production sector and the imitation sector. When producing goods in the South, foreign affiliates have higher production costs than southern firms. Moreover, R&D productivity for imitating northern-produced varieties is lower than southern-produced varieties by foreign affiliates due to the distance costs. Similar to innovative and adaptive R&D, imitative R&D is also subject to the cash constraint.

Due to the complexity of the model, we rely on numerical analysis for results. In order to compare the results in the generalized model with endogenous rate of imitation with the benchmark model with exogenous rate of imitation, we assign a high value for distance costs so that the imitation rate for northern-produced varieties is small. Our quantitative analysis indicates that the influences of northern and southern monetary policies on key macroeconomic variables in the generalized model are qualitatively the same as those found in the benchmark model, with one exception that now an increase in the northern nominal interest rate reduces international technology transfer.[8] We show that our results are qualitatively robust when allowing parame-

[5] In the numerical analysis, the threshold southern population ratio that determines the sign of the influence of a northern nominal interest rate on technology transfer is 0.56 under our parametrization. Since China's population is large, the parameter that represents China's population (relative to the global economy) is calibrated to 0.829, which is larger than the threshold southern population ratio.

[6] The survey data by Levin *et al.* (1987) indicate that for a major unpatented new product, the cost of duplication ranges from 51% to 75% of the innovator's R&D cost for more than half of firms. Mansfield *et al.* (1981) report that for 30 out of 48 products produced by firms in the chemical, drug, electronics, and machinery industries, the innovation cost exceeds $1 million, whereas for 12 products, it exceeds $5 million. They also note that on average the ratio of the imitation cost to the innovation cost is about 0.65.

[7] A closed-economy model with costly imitation is developed by Gallini (1992) to examine the effect of the length of patent protection on a rival's decision. Based on an R&D model with costly imitation, Chen (2018a) examines the effects of the strengthening of intellectual property rights in developing countries.

[8] This is because in the generalized model, the threshold southern population ratio becomes higher, so that the

ters representing the distance costs, the cost of southern production for foreign affiliates, and the tightness of CIA constraints in the North and in the South to vary within a reasonable range.[9]

A comparison of our results with Chu *et al.* (2019) indicates that higher northern (southern) inflation induces a permanent decrease (increase) in the North-South relative wage ratio, regardless of the type of an R&D model. In both types of R&D models, higher northern (southern) inflation also causes a temporary lower rate of northern innovation. Regarding technology transfer, higher southern inflation causes a permanent decrease in technology transfer in both types of models. However, while higher northern inflation causes an ambiguous effect on international technology transfer in Chu *et al.* (2019), the effect of northern inflation on technology transfer depends on the southern population size. Specifically, in our model, if the southern population is large (small) enough, higher northern inflation will result in a higher (lower) rate of technology transfer; this result is opposite to and well complements the counterpart in Chu *et al.* (2019). This is because in an R&D model with quality improvement, the manufacturing of products, which has been transferred to the South, can shift back to the North once goods with old quality are replaced by goods with new quality (namely a two-way product-cycle model). However, in an R&D model with variety expansion, the manufacturing of products, once transferred to the South, remains in the South and will never shift back to the North (namely a one-way product-cycle model).[10] Therefore, in a model with variety expansion, the magnitude of southern labor market plays a more important role in determining the effect of northern monetary policy on international technology transfer.

Finally, using country-pair panel data across OECD and emerging countries from 2003 to 2013, we find empirical support in the predictions of the nominal interest rate (inflation) effects on technology transfer. Specifically, both predictions — that an increase in southern nominal interest rate (southern inflation) leads to a lower rate of technology transfer and — that the effect of northern nominal interest rate (northern inflation) can be positive or negative depending on the relative size of southern to northern populations, are consistent with our empirical findings.

The remainder of this paper is organized as follows. Section 2 develops a North-South variety-expansion model with exogenous imitation in which northern innovative R&D and southern adaptive R&D are subject to CIA constraints. Section 3 The long-run equilibrium. Section 4 examines the effects of northern and southern monetary policies on key macroeconomic variables. Section 5 provides a numerical analysis. Section 6 analyzes an extended model with endogenous imitation. Section 7 presents the empirical results. Section 8 concludes this study.

calibrated value of the southern population ratio is lower than the threshold one.

[9]In our numerical analysis, there is one exception that increasing southern inflation causes northern innovation to slightly decrease if the cost of southern production is too high. The reason is that if the cost of southern production is too high, firms have less incentive to shift production to the South and more northern workers will be employed in the production sector. With few northern workers employed in the R&D sector, the rate of innovation decreases.

[10]There are two main reasons to consider a one-way product-cycle model. First, Gustafsson and Segerstrom (2010) argue that the production of old products (e.g., refrigerators, microwave ovens and air conditioners) used to be heavily concentrated in technologically advanced countries (the North), but today these products are mainly manufactured mainly in China and other developing countries (the South). Therefore, the one-way product-cycle model is more close to the spirit of Vernon's (1966) original discussion of product cycles. Second, as shown in Gustafsson and Segerstrom (2010, 2011), North-South trade models with two-way product cycles have difficulty explaining large North-South wage differences. Production shifting back to the North, when a northern firm innovates, requires the northern firm to have a lower effective marginal cost (in terms of wage) than its southern rival, which is constrained by the size of quality improvement. Nevertheless, the one-way product-cycle model does not have such a limitation on the size of quality improvement, so it can potentially account for much larger, empirically relevant wage differences.

2 The model

In this study, we extend the Gustafsson and Segerstrom (2011) North-South variety-expansion model with multinational firms, which is a recent variant of the North-South R&D-based model originating from the seminal work by Romer (1990). The model of Gustafsson and Segerstrom (2011) considers a global economy consisting of two countries: a high-wage North and a low-wage South. Labor in the two countries grow at the same rate and is the only production factor in manufacturing and R&D. Firms hire northern workers to engage in innovative R&D to expand varieties of new products, and such firms are called *northern firms* since all their production is located in the North. To take the advantage of lower production costs in the South, a northern firm can transfer its manufacturing operations to the South in the form of multinational firms by hiring southern workers to engage in adaptive R&D, and such a firm is called a *foreign affiliate* since all its production is located in the foreign country (i.e., the South). Adaptive R&D is considered as a measure of FDI because it represents the expenditures that multinational firms incur to transfer their technology to foreign affiliates. To model money demand, we incorporate cash-in-advance (CIA) constraints on investments in innovative R&D in the North and those in adaptive R&D in the South. Then we analyze the effects of northern inflation and southern inflation on innovation and international technology transfer, respectively. The benchmark model features exogenous imitation that happens in the South due to weaker protection of intellectual property rights in the South as compared to the North; therefore, inflation does not affect imitation.[11]

2.1 Households

At time t, the household in the North (South) has a population size of L_t^N (L_t^S). Each household member is endowed with one unit of labor, which is inelastically supplied. For simplicity, we assume that the population growth rates in both countries are identical and equal to g_L. Thus, the total population size in the world is $L_t = L_t^N + L_t^S$. Denote by $s \equiv L_t^S/L_t$ the share of southern population and $1 - s \equiv L_t^N/L_t$ the share of northern population in the global population, respectively.

Households in both the North and the South share identical preferences.[12] The lifetime utility of the representative household in country $k = \{N, S\}$ is given by

$$U = \int_0^\infty e^{-(\rho - g_L)t} \ln u_t^k dt, \tag{1}$$

where $\rho > g_L$ is the discount rate and u_t^k is the instantaneous utility of an individual in country k at time t. The instantaneous utility is given by the following constant elasticity substitution (CES) function:

$$u_t^k = \left[\int_0^{n_t} x_t^k(j)^\alpha dj \right]^{\frac{1}{\alpha}}, \tag{2}$$

where $x_t^k(j)$ is the per capita quantity demanded of product variety j in country k at time t. n_t is the number of varieties available in the world market, which is the sum of the number

[11] See Section 6 for the analysis of the cross-country effects of inflation on innovation and technology transfer in an extended model with endogenous imitation.

[12] The country superscript is omitted in this subsection unless it causes confusion.

of varieties n_t^N produced by northern firms, the counterpart n_t^F produced by foreign affiliates, and the counterpart n_t^S produced by southern firms who perform imitation, and hence $n_t = n_t^N + n_t^F + n_t^S$. The parameter $\alpha \in (0,1)$ measures the degree of product differentiation, given that the elasticity of substitution between product varieties is $\sigma \equiv 1/(1-\alpha) > 1$; therefore, the varieties in (2) are gross substitutes.

Denote by $E_t^k \equiv \tilde{p}_t^k c_t^k$ the individual expenditure of consumption c_t^k in country k, where $\tilde{p}_t^k$ is the price of consumption. Given zero transportation cost, the law of one price holds such that $\tilde{p}_t^N = \epsilon_t \tilde{p}_t^S$, where ϵ_t is the nominal exchange rate and $\tilde{p}_t^N$ ($\tilde{p}_t^S$) is the price of consumption in the North (South). In this study, all variables are expressed in real terms denominated by units of consumption that have the same value across the two countries. Then solving the static consumer optimization problem yields the familiar demand function for $x_t^k(j)$ such that

$$x_t^k(j) = \frac{p_t(j)^{-\sigma} E_t^k}{P_t^{1-\sigma}}, \tag{3}$$

where $p_t(j)$ is the price of variety j at time t and $P_t \equiv [\int_0^{n_t} p_t(j)^{1-\sigma} dj]^{1/(1-\sigma)}$ is an index of consumer prices.[13] The household maximizes (1) where (2) and (3) have been used to substitute for u_t^k and $x_t^k(j)$, respectively, subject to the following asset-accumulation equation:

$$\dot{a}_t^k + \dot{m}_t^k = (r_t^k - g_L)a_t^k - (\pi_t^k + g_L)m_t^k + i_t^k b_t^k + w_t^k + \tau_t^k - c_t^k, \tag{4}$$

where a_t^k is the real value of financial assets per capita, and r_t^k is the real interest rate in country k. π_t^k is the inflation rate of price $\tilde{p}_t^k$, so the nominal interest rate is $i_t^k = r_t^k + \pi_t^k$. m_t^k is the real value of domestic currency per capita. b_t^k is the real value of domestic currency borrowed by domestic R&D entrepreneurs, and the constraint is $b_t^k \leq m_t^k$. w_t^k is the real wage rate. τ_t^k is the real value of lump-sum transfer from the government (i.e., monetary authority). Following Dinopoulos and Segerstrom (2010) and Chu *et al.* (2019), we assume that the law of one price holds in this model, so the global financial market ensures that the real interest rates in both countries must be equal.[14] The standard dynamic optimization yields the familiar Euler equation:

$$\frac{\dot{c}_t^N}{c_t^N} = \frac{\dot{c}_t^S}{c_t^S} = r_t - \rho, \tag{5}$$

which implies that the growth rates of consumption in both countries are identical given that $r_t^N = r_t^S = r_t$.

[13] The consumer price index P_t is an aggregate price of the prices across all varieties, which are produced by northern firms, southern affiliates, and southern firms.

[14] Under this assumption, even when the nominal interest rates in the two countries differ due to differences in their inflation rates, a small transaction cost on foreign exchange would make no incentive for the household to hold foreign currency. In this case, R&D performed in the North (South) is financed through northern (southern) savings, which is consistent with the finding in Feldstein and Horioka (1980) such that domestic investments are financed by domestic savings.

2.2 Product markets

Firms who produce differentiated varieties of products compete through prices. These firms with the know-how to produce a product variety uses one unit of labor to produce a unit of output, regardless of the location of production. Among these product varieties, some are produced in the North and the other are produced in the South. Products are mobile across countries, but labor is immobile. Therefore, the marginal cost of production for each northern firm is w_t^N, whereas the counterpart for each foreign affiliate and each southern firm is w_t^S. The marginal cost of production in the South is assumed to be lower than in the North, i.e., $w_t^S < w_t^N$, so that there is an incentive for production to shift from the North to the South in order to take advantage of cheaper labor force in the South.

The flow of global profits of a northern firm that produces variety $j \in [0, n_t^N]$ at time t is given by $\Pi_t^N(j) = [p_t^N(j) - w_t^N][x_t^{N,N}(j)L_t^N + x_t^{N,S}(j)L_t^S]$, where $p_t^N(j)$ is the price of northern firm j's product, $x_t^{N,N}(j) = [p_t^N(j)]^{-\sigma} E_t^N / P_t^{1-\sigma}$ is the quantity of the northern firm j's product demanded by each northern consumer, and $x_t^{N,S} = [p_t^N(j)]^{-\sigma} E_t^S / P_t^{1-\sigma}$ is the quantity of the northern firm j's product demanded by each southern consumer, according to the demand function in (3). Maximizing $\Pi_t^N(j)$ with respect to $p_t^N(j)$ yields the optimal price of this northern firm such that $p_t^N(j) = p_t^N = w_t^N/\alpha$, which implies that each northern firm charges the standard, unconstrained monopoly markup over the marginal cost. Therefore, it is straightforward to simplify the northern firm's profits as follows

$$\Pi_t^N = \Pi_t^N(j) = \frac{w_t^N \bar{x}_t^N L_t}{\sigma - 1}, \tag{6}$$

where

$$\bar{x}_t^N = \frac{(p_t^N)^{-\sigma}}{P_t^{1-\sigma}} \bar{E}_t \tag{7}$$

is the average quantity demanded of northern varieties by the world consumers and $\bar{E}_t \equiv (E_t^N L_t^N + E_t^S L_t^S)/L_t$ is the average consumer expenditure in the world. From (6), it can be seen that the symmetry in the monopolistic price implies the symmetry in firms' profits.

Analogously, the flow of global profits of a foreign affiliate who produces variety $j \in [0, n_t^F]$ at time t is given by $\Pi_t^F(j) = [p_t^F(j) - w_t^F][x_t^{F,N}(j)L_t^N + x_t^{F,S}(j)L_t^S]$, where $p_t^F(j)$ is the price of foreign affiliate j's product, $x_t^{F,N}(j) = [p_t^F(j)]^{-\sigma} E_t^N L_t^N / P_t^{1-\sigma}$ is the quantity of the foreign affiliate j's product demanded by each northern consumer, $x_t^{F,S}(j) = [p_t^F(j)]^{-\sigma} E_t^S L_t^S / P_t^{1-\sigma}$ is the quantity of the foreign affiliate j's product demanded by each southern consumer, according to the demand function in (3). Maximizing $\Pi_t^F(j)$ with respect to $p_t^F(j)$ yields the optimal price of this foreign affiliate such that $p_t^F(j) = p_t^F = w_t^S/\alpha$. Therefore, it is straightforward to simplify the foreign affiliate's profits as follows

$$\Pi_t^F = \Pi_t^F(j) = \frac{w_t^S \bar{x}_t^F L_t}{\sigma - 1}, \tag{8}$$

where

$$\bar{x}_t^F = \frac{(p_t^F)^{-\sigma}}{P_t^{1-\sigma}} \bar{E}_t \tag{9}$$

is the average quantity demanded of foreign affiliate varieties by the world consumers. Again, the profits in (8) and the average quantity demanded in (9) are symmetric across the foreign affiliates.

Technologies that have been transferred to foreign affiliates for production may be imitated by other southern firms. When this imitation occurs, the product varieties are produced competitively by firms in the South. Therefore, the price charged by southern firms equals the marginal cost of production such that $p_t^S = w_t^S$, implying a zero profit of these firms. For each southern variety, the quantity demanded by each northern consumer is $x_t^{S,N} = [p_t^S]^{-\sigma} E_t^N L_t^N / P_t^{1-\sigma}$, the quantity demanded by each southern consumer is $x_t^{S,S} = [p_t^S]^{-\sigma} E_t^S L_t^S / P_t^{1-\sigma}$, and the average quantity demanded by the world consumers is

$$\bar{x}_t^S = \frac{(p_t^S)^{-\sigma}}{P_t^{1-\sigma}} \bar{E}_t. \tag{10}$$

The analysis of the above product cycle shows $p_t^N > p_t^F > p_t^S$, implying that the optimal price of a product variety in equilibrium declines as the production of this variety is shifted from a northern firm to its foreign affiliate and finally to a southern firm.

2.3 Innovation, FDI and imitation

Innovative R&D is performed by entrepreneurs in the North. By employing an amount of $l_t^R(h)$ of northern labor to engage in innovation, a northern R&D entrepreneur (or R&D firm) will succeed in inventing a flow $\dot{n}_t(h)$ of new product varieties such that

$$\dot{n}_t(h) = \frac{l_t^R(h)}{a^N / n_t^\theta} = \frac{n_t^\theta l_t^R(h)}{a^N}, \tag{11}$$

where a^N / n_t^θ represents the productivity in innovative R&D and a^N is an exogenous parameter. The variable n_t represents the existing stock of knowledge, and the presence of n_t in (11) captures the intertemporal knowledge spillover externality, where the parameter θ measures the degree of this externality.[15] The expected benefit of a northern R&D entrepreneur is $v_t^N(h)\dot{n}_t(h)$, where $v_t^N(h)$ is the real value of expected discounted profits generated by each new product variety invented by entrepreneur h. To facilitate the wage payment to northern labor in R&D, the entrepreneurs borrow domestic currency from domestic households at the return rate of i_t^N. The strength of this CIA constraint is parametrized by ξ^N of which fraction R&D investment is financed by borrowing money from households in the North. Therefore, the total cost of innovative R&D is $(1 + \xi^N i_t^N) w_t^N l_t^R(h)$. Free entry into the innovative-R&D sector in the North implies the following condition:

$$v_t^N(h) = (1 + \xi^N i_t^N) \frac{w_t^N a^N}{n_t^\theta}, \tag{12}$$

where (11) has been used.

Adaptive R&D in the South is performed by local entrepreneurs and the foreign affiliates of a northern firm. By employing $l_t^F(h)$ units of southern labor into adaptive R&D, the foreign affiliate

[15] The sign of the parameter θ determines whether innovating becomes less or more difficult as the stock of knowledge increases, implying a positive or negative intertemporal knowledge spillover. For $\theta > 0$, it captures the effect of increasing research productivity as formulated in Grossman and Helpman (1991a) and Jones (1995), whereas for $\theta < 0$, it captures the effect of increasing research complexity as formulated in Segerstrom (1998, 2000).

of a northern firm will shift the production from the North to the South with the following number of product varieties:

$$\dot{n}_t^F(h) + \dot{n}_t^S(h) = \frac{l_t^F(h)}{a^F/n_t^\theta} = \frac{n_t^\theta l_t^F(h)}{a^F}, \tag{13}$$

where a^F/n_t^θ represents the productivity in adaptive R&D and $\dot{n}_t^F(h) + \dot{n}_t^S(h)$ is the total number of varieties that firm h moves to the South for production by the foreign affiliate and the potential imitators, following the definition of the FDI rate in Gustafsson and Segerstrom (2011).[16] Adaptive R&D is also subject to the intertemporal knowledge spillover n_t^θ, and a^F is an exogenous parameter that measures the level of the southern FDI friendliness. Denote by $v_t^F(h)$ the firm value of the foreign affiliate of a northern firm. Thus, the expected net benefit of a northern firm to invest in adaptive R&D is $[v_t^F(h) - v_t^N(h)][\dot{n}_t^F(h) + \dot{n}_t^S(h)]$. To facilitate the wage payment to southern labor in adaptive R&D, the foreign affiliates borrow domestic currency from domestic households at the return rate of i_t^S. The strength of this CIA constraint is parametrized by ξ^S of which fraction adaptive R&D investment is financed by borrowing money from households in the South. Therefore, the total cost of adaptive R&D is $(1+\xi^S i_t^S) w_t^S l_t^F(h)$. Free entry into the adaptive-R&D sector in the South implies the following condition:

$$v_t^F(h) - v_t^N(h) = (1+\xi^S i_t^S)\frac{w_t^S a^F}{n_t^\theta}, \tag{14}$$

where (13) has been used.

Finally, multinational firms that move their manufacturing to the South face the risk of imitation by other southern firms due to the lack of protection of their production technology in the South. Denote by $\varphi \equiv \dot{n}_t^S/n_t^F$ the (positive) imitation rate. We follow Helpman (1993) and Lai (1998) to assume that this imitation rate is exogenously given such that a decrease in φ corresponds to a strengthening of IPR protection in the South.[17]

2.4 Stock markets

The no-arbitrage condition that determines the value of a northern firm $v_t^N(h)$ is given by

$$r_t v_t^N(h) = \Pi_t^N(h) - (1+\xi^S i_t^S) w_t^S l_t^F(h) + \dot{v}_t^N(h) + [\dot{n}_t^F(h) + \dot{n}_t^S(h)][v_t^F(h) - v_t^N(h)]. \tag{15}$$

This condition implies that the real asset return $r_t v_t^N(h)$ equals the sum of (i) the monopolistic profit flow Π_t^N in the North net of the adaptive R&D expenditure flow $(1+\xi^S i_t^S) w_t^S l_t^F(h)$, (ii) the potential capital gain $\dot{v}_t^N(h)$, and (iii) the expected change in asset value $[\dot{n}_t^F(h) + \dot{n}_t^S(h)][v_t^F(h) - v_t^N(h)]$ when adaptive R&D for transferring production to the South is successful. Using (13) and

[16] The reason for the term $\dot{n}_t^S(h)$ to be included in (13) is explained by Gustafsson and Segerstrom (2011) by using a bathtub with an open drain that is being filled with water from a faucet, such that "the flow of water coming out of the faucet into the bathtub equals the rate of change in the volume of water in the bathtub plus the flow of water going down the open drain." Hence, the flow number of varieties that are transferred to the South through FDI (i.e., $\dot{n}_t^F(h) + \dot{n}_t^S(h)$) equals the rate of change in the number of varieties produced by foreign affiliates (i.e., $\dot{n}_t^F(h)$) plus the flow number of foreign affiliate varieties that are imitated by southern firms (i.e., $\dot{n}_t^S(h)$).

[17] See Section 6 for the extension in which endogenous imitation is considered.

(14), equation (15) can be simplified to a more familiar expression such that

$$r_t v_t^N(h) = \Pi_t^N(h) + \dot{v}_t^N(h). \tag{16}$$

The no-arbitrage condition that determines the value of a foreign affiliate $v_t^F(h)$ is given by

$$r_t v_t^F(h) = \Pi_t^F(h) + \dot{v}_t^F(h) - \varphi v_t^F(h). \tag{17}$$

This condition implies that the real asset return $r_t v_t^F(h)$ equals the sum of (i) the monopolistic profit flow $\Pi_t^F(h)$ in the South, (ii) the potential capital gain $\dot{v}_t^F(h)$, and (iii) the expected capital loss $-\varphi v_t^F(h)$ when imitation occurs.

From the free-entry conditions (12) and (14), it can be seen that the value of a successful innovation $v_t^N(h)$ and the value of a successful adaption $v_t^F(h)$ are independent of the index h. Therefore, we follow the standard treatment in this class of models (such as Gustafsson and Segerstrom 2010, 2011) to focus on the symmetric equilibrium in which $v_t^F(h) = v_t^F$ and $v_t^N(h) = v_t^N$. Furthermore, aggregating the flow of new varieties $\dot{n}_t(h)$ developed in the North and the flow of varieties $\dot{n}_t^F(h) + \dot{n}_t^S(h)$ shifted to the South yields $(n_t^\theta L_t^R)/a^N$ and $(n_t^\theta L_t^F)/a^F$, respectively, where $L_t^R = \int l_t^R(h)dh$ is the total amount of northern labor employed in innovative activities and $L_t^F = \int l_t^F(h)dh$ is the total amount of southern labor employed in adaptive R&D activities.

2.5 Labor markets

Labor markets are perfectly competitive, in which labor demand equals labor supply through the adjustment of wages in each country. The market-clearing condition for labor in the North is given by $L_t^N = L_t^R + \bar{x}_t^N L_t n_t^N$, where L_t^R is the level of northern R&D labor and $\bar{x}_t^N L_t n_t^N$ is the level of northern manufacturing labor, given that northern firms use $\bar{x}_t^N L_t$ to produce each variety and there are n_t^N varieties produced by northern firms. Therefore, using (11), this labor-market-clearing condition can be rewritten as

$$L_t^N = \frac{a^N \dot{n}_t}{n_t^\theta} + x_t^N L_t, \tag{18}$$

where $x_t^N \equiv \bar{x}_t^N n_t^N$ is the per capita world demand for northern varieties.

Similarly, the market-clearing condition for labor in the South is given by $L_t^S = L_t^F + \bar{x}_t^F L_t n_t^F + \bar{x}_t^S L_t n_t^S$, where L_t^F is the level of southern labor conducting adaptive R&D and and $\bar{x}_t^F L_t n_t^F$ ($\bar{x}_t^S L_t n_t^S$) is the level of manufacturing labor in foreign affiliates (southern firms), given that foreign affiliates (southern firms) use $\bar{x}_t^F L_t$ ($\bar{x}_t^S L_t$) to produce each variety and there are n_t^F (n_t^S) varieties produced by foreign affiliates (southern firms). Therefore, using (13), this labor-market-clearing condition can be rewritten as

$$L_t^S = \frac{a^F(\dot{n}_t^F + \dot{n}_t^S)}{n_t^\theta} + x_t^F L_t + x_t^S L_t, \tag{19}$$

where $x_t^F \equiv \bar{x}_t^F n_t^F$ ($x_t^S \equiv \bar{x}_t^S n_t^S$) is the per capita world demand for varieties produced by foreign affiliates (southern firms).

2.6 Monetary authority

Consider that the inflation rate π_t^N in the North (π_t^S in the South) is the policy instrument that can be controlled by the northern (southern) monetary authority. Given π_t^N (π_t^S), the nominal interest rate in the North (South) is endogenously determined by the Fisher equation such that $i_t^N = \pi_t^N + r_t$ ($i_t^S = \pi_t^S + r_t$), where r_t is the global real interest rate. Denote by M_t^N (M_t^S) the nominal money supply per capita in the North (South). Moreover, the real money balance per capita in the North (South) is given by $m_t^N = M_t^N / \tilde{p}_t^N$ ($m_t^S = M_t^S / \tilde{p}_t^S$), where $\tilde{p}_t^N$ ($\tilde{p}_t^S$) is the price of consumption in the North (South). Therefore, the growth rate of M_t^N (M_t^S) is endogenously determined by $\dot{M}_t^N / M_t^N = \pi_t^N + \dot{m}_t^N / m_t^N$ ($\dot{M}_t^S / M_t^S = \pi_t^S + \dot{m}_t^S / m_t^S$). The northern (southern) monetary authority returns to each member of domestic households in the North (South) the seigniorage revenue as a lump-sum transfer, whose real value is $\tau_t^N = (\dot{M}_t^N + g_L M_t^N)/P_t^N$ ($\tau_t^S = (\dot{M}_t^S + g_L M_t^S)/P_t^S$).

The semi-endogenous-growth property of this model implies that the steady-state growth rate of consumption c_t^N in the North (and c_t^S in the South) is given by $g_L[\sigma/(1-\theta)]$ (see (20)). Therefore, using the Euler equation in (5) yields the steady-state rate of real interest such that $r = \rho + g_L[\sigma/(1-\theta)]$. Combining this expression and the Fisher equation shows a one-to-one relationship between the nominal interest rate and the inflation rate in the long run, i.e., $i^N = \pi^N + \rho + g_L[\sigma/(1-\theta)]$ and $i^S = \pi^S + \rho + g_L[\sigma/(1-\theta)]$. Given this result, throughout the rest of this study, we will use i^N (i^S) to represent the instrument of northern (southern) monetary policy for simplicity.

3 Steady-state equilibrium

In this section, we first define the decentralized equilibrium. Second, we solve the steady-state equilibrium of the model by deriving (a) the steady-state number of varieties produced by each type of firms, and (b) the steady-state conditions of innovation and technology transfer.

3.1 Decentralized equilibrium

The equilibrium consists of a sequence of allocations $[c_t^N, c_t^S, x_t^{N,N}(j), x_t^{F,N}(j), x_t^{S,N}(j), x_t^{N,S}(j), x_t^{F,S}(j), x_t^{S,S}(j), l_t^R(h), l_r^F(h)]_{t=0}^{\infty}$, a sequence of prices $[w_t^N, w_t^S, \tilde{p}_t^N, \tilde{p}_t^S, p_t^N, p_t^F, p_t^S, v_t^N, v_t^F]_{t=0}^{\infty}$, and a sequence of monetary policies $[i_t^N, i_t^S]_{t=0}^{\infty}$. At each instant of time,

• the representative household in the North chooses $[x_t^{N,N}(j), x_t^{F,N}(j), x_t^{S,N}(j)]$ to maximize static utility taking $[p_t^N, p_t^F, p_t^S]$ as given and chooses $[c_t^N]$ to maximize lifetime utility taking $[\tilde{p}_t^N, r_t, i_t^N, w_t^N]$ as given;

• the representative household in the South chooses $[x_t^{N,S}(j), x_t^{F,S}(j), x_t^{S,S}(j)]$ to maximize static utility taking $[p_t^N, p_t^F, p_t^S]$ as given and chooses $[c_t^S]$ to maximize lifetime utility taking $[\tilde{p}_t^S, r_t, i_t^S, w_t^S]$ as given;

• monopolistic intermediate-good firms in the North choose $[p_t^N(j)]$ and produce $[x_t^{N,N}(j), x_t^{N,S}(j)]$ to maximize profits taking w_t^N as given;

• foreign affiliates in the South choose $[p_t^F(j)]$ and produce $[x_t^{F,N}(j), x_t^{F,S}(j)]$ to maximize profits taking w_t^S as given;

• competitive firms in the South produce $[x_t^{S,N}(j), x_t^{S,S}(j)]$ to maximize profits taking $[p_t^S(j), w_t^S]$ as given;

• R&D entrepreneurs in the North employ $l_r^R(h)$ to perform innovative R&D taking $[i_t^N, w_t^N, v_t^N]$ as given;

• monopolistic firms in the North and their affiliates in the South employ $l_r^F(h)$ to perform adaptive R&D taking $[i_t^S, w_t^S, v_t^F]$ as given;

• the product-market-clearing condition holds;

• the labor-market-clearing conditions hold in both countries; and

• the nominal exchange rate is determined by the law of one price such that $\epsilon = \tilde{p}_t^N / \tilde{p}_t^S$.

3.2 Industry composition and variety dynamics

Before proceeding to analyze the industry composition and variety dynamics, we first derive the steady-state growth rate of innovation, denoted by g, in this model. Using the flow of new product varieties in (11), the growth rate of the number of varieties is $\dot{n}_t / n_t = n_t^{\theta-1} l_r^R / a^N$. Hence, the steady-state growth rate of innovation g is given by

$$g \equiv \frac{\dot{n}_t}{n_t} = \frac{g_L}{1-\theta}, \tag{20}$$

which is completely determined by the exogenous population growth rate due to the feature of semi-endogenous growth as in Jones (1995).

Next, there are three types of firms in the intermediate-good sector: northern monopolistic firms, foreign affiliates of northern firms, and southern competitive firms. Denote by $\gamma^N \equiv n_t^N / n_t$, $\gamma^F \equiv n_t^F / n_t$, and $\gamma^S \equiv n_t^S / n_t$ the steady-state share of product varieties produced by these types of firms, respectively. Then the variety condition $n_t^N + n_t^F + n_t^S = n_t$ implies the following condition of varieties shares:

$$\gamma^N + \gamma^F + \gamma^S = 1. \tag{21}$$

Denote by $\phi_t \equiv (\dot{n}_t^F + \dot{n}_t^S)/n_t^N$ the FDI rate; this is the rate at which northern varieties are shifted to the South because of adaptive R&D. In addition, the FDI rate ϕ is constant in the steady-state equilibrium since $\phi = \dot{n}_t^F / n_t^N + \dot{n}_t^S / n_t^N = (\dot{n}_t^F / n_t^F)(n_t^F / n_t^N) + (\dot{n}_t^S / n_t^S)(n_t^S / n_t^N) = g(n_t^F / n_t^N + n_t^S / n_t^N)$, given that the number of varieties in different industries grow at the same rate of g. Using the definitions of g, ϕ, and variety shares, we obtain $g = \dot{n}_t / n_t = (\dot{n}_t^N + \dot{n}_t^F + \dot{n}_t^S)/n_t = (\dot{n}_t^N / n_t^N)(n_t^N / n_t) + [(\dot{n}_t^F + \dot{n}_t^S)/n_t^N](n_t^N / n_t) = g\gamma^N + \phi\gamma^N$. Solving for γ^N yields

$$\gamma^N = \frac{g}{g+\phi}. \tag{22}$$

Then the definition of imitation rate φ implies $\varphi = \dot{n}_t^S / n_t^F = (\dot{n}_t^S / n_t^S)(n_t^S / n_t^F) = g(\gamma^S / \gamma^F)$, yielding the relationship between γ^F and γ^S such that $\gamma^F = (g/\varphi)\gamma^S$. Accordingly, substituting this equation and (22) into (21) yields

$$\gamma^F = \left(\frac{\phi}{g+\phi}\right)\left(\frac{g}{g+\varphi}\right), \tag{23}$$

and

$$\gamma^S = \left(\frac{\phi}{g+\phi}\right)\left(\frac{\varphi}{g+\varphi}\right). \tag{24}$$

Moreover, define the average R&D difficulty per northern worker δ^N such that

$$\delta^N \equiv \frac{n_t^{1-\theta}}{L_t^N}, \tag{25}$$

which is constant over time given that n_t grows at the rate of $g_L/(1-\theta)$. As will be shown, solving the steady-state equilibrium of this model can be reduced to solving a system of two equations with two endogenous variables $\{\phi, \delta^N\}$.

3.3 Steady-state conditions

To solve the steady-state equilibrium, we first derive the balanced-growth values of assets. Given the Euler equation (5), using (16) and (17) yields

$$v_t^N = \frac{\Pi_t^N}{\rho + \theta g}, \tag{26}$$

and

$$v_t^F = \frac{\Pi_t^F}{\rho + \theta g + \varphi}. \tag{27}$$

Substituting (6), (25), and (26) into (12) yields the following *steady-state innovative R&D condition*:

$$\frac{\frac{x^N}{(\sigma-1)\gamma^N(1-s)}}{\rho + \theta g} = (1 + \xi^N i^N) a^N \delta^N, \tag{28}$$

where $s = L_0^S / L_0$ is the share of southern population over the world population. Furthermore, the northern labor-market-clearing condition in (18) can be reexpressed as $1 = a^N \delta^N g + x^N/(1-s)$, where $g = \dot{n}_t/n_t$, $\delta^N = n_t^{1-\theta}/L_t^N$, and $1 - s = L_t^N/L_t$. Substituting this labor-market-clearing condition into (28) yields the *northern steady-state condition* such that

$$1 = a^N \delta^N g \left[1 + (1 + \xi^N i^N)\left(\frac{\rho + \theta g}{g + \phi}\right)(\sigma - 1)\right], \tag{29}$$

where $\gamma^N = g/(g+\phi)$ is applied. Equation (29), which contains two endogenous variables $\{\phi, \delta^N\}$, is positively sloped and has a positive δ^N intercept in the $\{\phi, \delta^N\}$ space as shown in Figure 1, where "North" represents the northern steady-state condition. The intuition behind the positive slope of the northern steady-state condition can be explained as follows. An increase in the FDI rate ϕ implies that more varieties of products are shifted for manufacturing from the North to the South, which in turn leads to a reallocation of labor in the North from manufacturing to innovative R&D due to the resource constraint on northern labor. Therefore, the average R&D difficulty δ^N increases in response to more research labor in the North in order to maintain the steady-state innovation rate g.

Similarly, substituting (6), (8), (26), and (27) into (14) yields the following *steady-state adaptive R&D condition*:

$$\frac{\frac{x^F}{(\sigma-1)\gamma^F(1-s)}}{\rho+\theta g+\varphi} - (1+\xi^N i^N)\omega a^N \delta^N = (1+\xi^S i^S) a^F \delta^N, \tag{30}$$

where $1-s \equiv L_0^N/L_0$ is the share of northern population over the world population and $\omega \equiv w_t^N/w_t^S$ is the steady-state relative North-South wage ratio, which will be shown to be determined by monetary instruments $\{i^N, i^S\}$. Furthermore, the southern labor-market-clearing condition in (19) can be reexpressed as $L_t^S = a^F \phi \gamma^N \delta^N L_t^N + x_t^F L_t + x_t^S L_t$, where $\phi = (\dot{n}_t^F + \dot{n}_t^S)/n_t^N$. Using (3), (23), and (24), it is straightforward to verify that $x_t^S/x_t^F = (p_t^F/p_t^S)^\sigma(\gamma^S/\gamma^F) = (1/\alpha)^\sigma \varphi/g$. Then substituting this expression and the southern labor-market-clearing condition into (30) yields *southern steady-state condition* such that

$$1 = \frac{1-s}{s}\left(\frac{\delta^N \phi}{g+\phi}\right)\left\{a^F g + \left[(1+\xi^S i^S)a^F + (1+\xi^N i^N)\omega a^N\right](\rho+\theta g+\varphi)(\sigma-1)\Phi(\varphi)\right\}, \tag{31}$$

where $\Phi(\varphi) \equiv g/(g+\varphi) + (1/\alpha)^\sigma \varphi/(g+\varphi)$ and the relation $L_t^N/L_t^S = (1-s)/s$ is used. This condition also contains two endogenous variables $\{\phi, \delta^N\}$, but it features a negative slope and no intercepts in the $\{\phi, \delta^N\}$ space as shown in Figure 1, where "South" represents the southern steady-state condition. Intuitively, an increase in the FDI rate ϕ implies that more varieties of products are manufactured in the South, which in turn reallocates labor in the South from adaptive R&D to production due to the resource constraint on southern labor. Therefore, the average R&D difficulty δ^N decreases (i.e., technologies become easier to be transferred to the South) in response to less research labor in the South in order to maintain the given FDI rate ϕ.

In summary, equations (29) and (31) are the two conditions that implicitly solve for the steady-state values of $\{\phi, \delta^N\}$. The intersection at point O in Figure 1 determines the unique steady-state values of ϕ and δ^N.

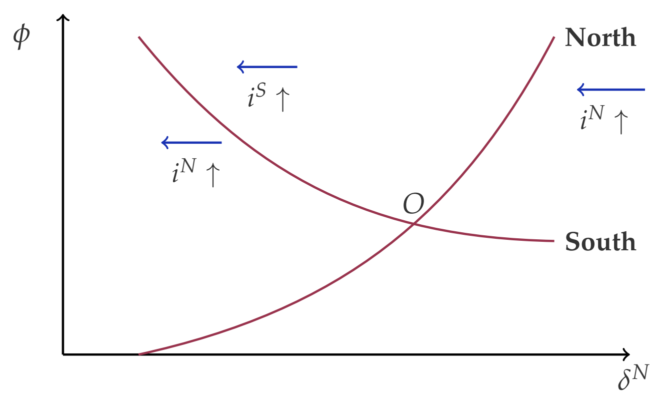


Figure 1: The steady-state equilibrium.

4 Inflation, innovation, and technology transfer

In this section, we explore the effects of southern and northern monetary policy $\{i^S, i^N\}$ on the technology transfer rate ϕ and the innovation rate $\dot{n}_t/n_t$, respectively. To facilitate this analysis, we first examine the effects of these monetary-policy tools on the relative wage ω. Using (7) and (9) yields $x_t^N = \omega^{-\sigma}[(g+\varphi)/\phi]x_t^F$. Substituting this equation and (28) into (30) yields the *steady-state relative-wage condition*:

$$\omega^{\sigma}\left(\frac{\rho+\theta g}{\rho+\theta g+\varphi}\right)-\omega=\frac{(1+\xi^S i^S)a^F}{(1+\xi^N i^N)a^N}, \tag{32}$$

which is an implicit function that pins down the steady-state equilibrium value of the relative wage $\omega(i^N, i^S)$. The following proposition illustrates the effects of the nominal interest rate in each country on the relative wage.

Proposition 1. *The steady-state relative wage rate between the North and the South increases with the nominal interest rate in the South and decreases with the nominal interest rate in the North.*

Proof. See Appendix A.1. □

Proposition 1 can be explained as follows. Increasing the inflation rate π^S or the nominal interest rate i^S in the South raises the adaptive R&D cost of being a foreign affiliate as shown in (14). This yields a negative effect on the demand for southern R&D labor, thereby raising the wage rate in the North relative to the South. In contrast, increasing the inflation rate π^N or the nominal interest rate i^N in the North raises the innovative R&D cost of being a northern firm as shown in (12). This yields a negative effect on the demand for northern R&D labor, thereby lowering the wage rate in the North relative to the South. This mechanism on the cross-country effects of inflation (or the nominal interest rate) on relative wage is similar to the counterparts in Chen (2018c) and Chu *et al.* (2019).

Given the effects of southern and northern monetary policy $\{i^S, i^N\}$ on the relative wage rate ω, we are now in a position to analyze their effects on the rate of innovation $\dot{n}_t/n_t$ and the rate of international technology transfer ϕ. First, the following proposition summarizes the results with regard to the impacts of an increase in i^S on $\dot{n}_t/n_t$ and ϕ.

Proposition 2. *Increasing the nominal interest rate in the South yields (i) a temporary lower rate of innovation in the North, and (ii) a permanent lower rate of technology transfer from the North to the South.*

Proof. See Appendix A.2. □

Proposition 2 can be explained as follows. In Figure 1, a higher i^S shifts the South curve to the left, whereas this change in i^S does not affect the North curve. As a result, both δ^N and ϕ decline. Intuitively, an increase in i^S raises adaptive R&D costs of foreign affiliates in (14), reducing the incentives for firms in the South to engage in adaptive R&D by lowering the allocation of adaptive R&D labor. In the case, less adaptive R&D will be performed, so a higher i^S yields a negative effect on the rate of international technology transfer ϕ. Furthermore, since the lower rate of technology transfer to the South implies that a larger number of products will be manufactured in the North, the higher demand for northern production labor causes a reallocation of labor in the North from innovative R&D to manufacturing. As a result, the rate of northern innovation $\dot{n}_t/n_t$ decreases in the short run, which is associated with a lower average R&D difficulty per northern worker δ^N in the long run, as implied by (25).

Next, the following proposition summarizes the results with regard to the impacts of an increase in i^N on $\dot{n}_t/n_t$ and ϕ.

Proposition 3. *Increasing the nominal interest rate in the North yields (i) a temporary lower rate of innovation in the North, and (ii) a permanent lower (higher) rate of technology transfer from the North to the South if the southern population size is sufficiently small (large).*

Proof. See Appendix A.3. □

Proposition 3 can be explained as follows. Graphically, a higher i^N shifts both the North curve and the South curve to the left simultaneously, resulting in an unambiguously decreasing effect on δ^N and an ambiguous effect on ϕ.[18] Intuitively, for the impact on δ^N, a higher i^N increases innovative R&D costs of northern firms in (12), reducing the incentives for firms in the North to perform R&D activities by lowering the allocation of innovative R&D labor. In the case, less innovative R&D will be conducted, so the rate of northern innovation $\dot{n}_t/n_t$ declines in the short run, in association with a decline in the average R&D difficulty per northern worker δ^N in the long run.

For the impact on ϕ, a higher northern nominal interest rate i^N causes two contrasting effects. To see this, we rearrange the definition of the FDI rate ϕ_t as follows:

$$\phi_t = \frac{\dot{n}_t^F + \dot{n}_t^S}{n_t^N} = \frac{1}{n_t^N}\frac{n_t^\theta L_t^F}{a^F} = \frac{1}{a^F \delta^N}\frac{L_t^F}{(1-s)L_t}\frac{n_t}{n_t^N}, \tag{33}$$

where the second equality uses (13) and the third equality uses (25). In the steady state, n_t/n_t^N is given by (22). Hence, (33) can be reexpressed as

$$\frac{g\phi}{g+\phi} = \underbrace{\frac{1}{a^F \delta^N}}_{A}\underbrace{\frac{L_t^F}{(1-s)L_t}}_{B}, \tag{34}$$

where the left-hand side is monotonically increasing in ϕ given g. Observing (34) implies that the northern nominal interest rate i^N affects the technology transfer rate ϕ through the average R&D difficulty per worker δ^N and the number of adaptive R&D labor L_t^F. On the one hand, a higher i^N decreases the difficulty level of adaptive R&D δ^N (according to Proposition 3 (i)), which yields a positive effect on the FDI rate ϕ. On the other hand, a higher i^N decreases the incentives for adaptive R&D by altering the relative asset value between the northern firm and its foreign affiliate (i.e., v_t^F/v_t^N). This can be seen by combining (26) and (27) and substituting (6) and (8)

[18] If an increase in i^N shifts the North curve to the left in a larger (smaller) magnitude than the South to the left, then there will be an increase (decrease) in ϕ in response.

into the resulting equation such that

$$\frac{v_t^F}{v_t^N} = \frac{\rho + \theta g}{\rho + \theta g + \varphi}\frac{\Pi_t^F}{\Pi_t^N} = \frac{\rho + \theta g}{\rho + \theta g + \varphi}\left(\frac{w_t^N}{w_t^S}\right)^{\sigma - 1}, \tag{35}$$

where (7) and (9) are used in the second equality. Recalling that a higher i^N decreases the relative wage rate ω, it also decreases the relative asset value v_t^F/v_t^N. In this case, there will be a decline in adaptive R&D in the South, yielding a negative effect on the FDI rate ϕ. Accordingly, whether a higher northern nominal interest rate i^N increases (or decreases) the technology transfer rate ϕ in the long run depends on the interplay between the positive effect through adaptive R&D difficulty (captured by the term A in (34)) and the negative effect through adaptive R&D labor (captured by the term B in (34)).

We find that this interplay is determined by the size of southern population s (relative to the total population). When the size of southern population s is sufficiently small, the impact of the decrease in the relative asset value v_t^F/v_t^N is not significant, implying a small decline in adaptive R&D. Hence, the negative effect B via adaptive R&D labor becomes relatively weak and is dominated by the positive effect A via adaptive R&D difficulty. As a result, the rate of technology transfer ϕ increases in the long run. By contrast, if the size of southern population s is sufficiently large, the impact of the decrease in the relative asset value v_t^F/v_t^N is significant. In the case of a large decline in adaptive R&D, the negative effect B through adaptive R&D labor becomes relatively strong to dominate the positive effect A through adaptive R&D difficulty. Consequently, the rate of technology transfer ϕ decreases in the long run.

One can see that comparing to Chu *et al.* (2019) who consider the effect of northern inflation on the technology transfer rate in a North-South quality-ladder model, this effect in the current North-South variety-expansion model becomes opposite. Specifically, for a sufficiently large (small) size of southern population, a higher rate of northern inflation leads to a permanent lower (higher) FDI rate in the Chu *et al.* (2019) quality-ladder model, whereas a higher rate of northern inflation leads to a permanent higher (lower) FDI rate in our variety-expansion model. The main reason for the above difference may be that the current model relies on the setting of one-way product cycle, instead of the setting of two-way product cycle in Chu *et al.* (2019). Under one-way product cycle, the manufacturing of products, once transferred to the South, remains in the South therefrom and will never shift back to the North. Therefore, the role of the southern labor market becomes more important. In this case, the negative effect of a higher northern inflation rate via the number of adaptive R&D workers in the South becomes relatively strong (weak) when the southern population size is large (small). Nevertheless, under two-way product cycle in Chu *et al.* (2019), the above mechanism reverses, leading to the opposite role of the southern labor market. Overall, the above result reveals the importance of the process of innovation (variety expansion versus quality improvement) regarding the effect of northern inflation on technology transfer.

5 Quantitative analysis

In this section, we numerically investigate the impacts of raising nominal interest rates in northern and southern countries on the three variables of interest: the relative wage ratio ω, the rate of international technological transfer ϕ, and the average R&D difficulty per worker in the North δ^N. The purpose of our numerical analysis is to verify the theoretical results obtained in Propositions 1–3. Moreover, we perform sensitivity checks for the robustness of the propositions by varying benchmark parameter values.

5.1 Calibration

Our model features the following parameters $\{\rho, \sigma, s, \alpha, \varphi, \xi^N, \xi^S, a^N, a^F, \theta, i^N, i^S\}$. We calibrate our model by matching these parameters to the current data found in China (i.e., the South) and the US (i.e., the North). We assign a standard value of 0.03 for the discount factor ρ.[19] We set the elasticity of substitution σ to 2.5, which yields a calibrated value for α at 0.6 by using the expression $\alpha = 1 - 1/\sigma$. This pair of calibrated values reaches a markup estimate at 66.7%; this is an intermediate value that lies between 50% and 80%, which is a feasible range supported by the up-to-date markup estimation of US firms in De Loecker *et al.* (2020).[20] We follow Gustafsson and Segerstrom (2011) to assign an exogenous imitation rate φ at 5% in our baseline model and set g at 2% to meet the long-run US average growth rate. For the relative southern population s, we use the data from the World Development Indicators on the labor force sizes of the US and China to set s to 0.829. In addition, we restrict our wage data within the period 2013 to 2021, implying that the US wage rate is approximately 4.1 times higher than the Chinese counterpart.[21] By normalizing the northern productivity a^N to unity, we use (32) to calibrate the southern productivity a^F to match the relative wage rate 4.1 and other parameters, yielding a value of 10.025 for a^F. For the CIA parameters, we follow Chu *et al.* (2019) to set 0.5 for the CIA constraints ξ^N and ξ^S on both northern innovative R&D and the southern adaptive R&D. Finally, by applying the Fisher equation,[22] we calibrate the degree of knowledge spillover externality θ at a value of 0.28, given that the US average long-run population growth rate is 0.8% according to Federal Reserve Economic Data (FRED) and that the US average inflation and nominal interest rates are $\pi^N = 2\%$ and $i^N = 7.8\%$, respectively, from the same FRED source, where $i_N = 7.8\%$ is close to the 10-year US Treasury rate from 1970 to 2020 after taking into account the convenience yields of Treasury bonds.[23] With the same procedure, we apply Fisher equation with the inflation rate in China ($\pi^S = 2.7\%$) to back up the southern interest rate around $i^S = 8.5\%$.[24] The calibrated parameter values in our baseline model are reported in Table 1.

[19]See Scholz *et al.* (2006) for the value of ρ.

[20]Using more current US firm-level data, De Loecker *et al.* (2020) find that the markup shows a growing trend since 1980 and reached about 61% in average around 2016. In particular, the average markup for the publicly traded firms in manufacturing industries, which are the main source of R&D activities, from 1977 onward is between 55% to 80%. The value assigned to σ in our calibration matches a markup at 67%; it is slightly above the cross-industry average of 61%, but remains at the intermediate value within manufacturing industry.

[21]The data of the relative wage is computed by using the average and the projection values of the latest period (2013–2021) from the US Bureau of Labor Statistics and National Bureau of Statistics China, with the annual exchange rates. The China and US wage rates have significantly converged since 2000 and the US-China wage ratio has reached around 3.8 in 2019.

[22]With the calibrated parameters, we underpin the value of θ by using the Fisher equation that shows a one-to-one relation between the nominal interest rate and the inflation rate in the long run, i.e., $i^N = \pi^N + \rho + g_L[\sigma/(1-\theta)]$.

[23]The average Moody's Seasoned AAA corporate bond yield over this period is 7.36%. See Huang *et al.* (2023).

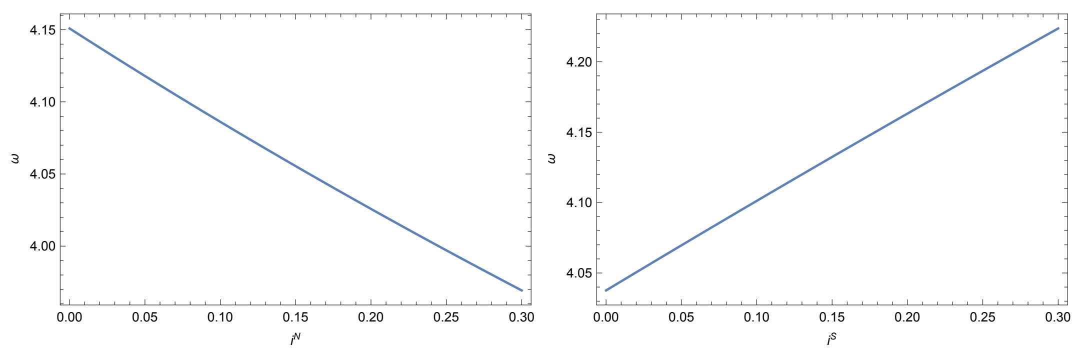
[24]The value of $i^S = 8.5\%$ is an intermediate value between the average annual lending rate around 7% from 1988 to 2020 and the estimate in Chu *et al.* (2019) (i.e., 9.8%) who use FRED.

ρ	σ	s	α	φ	ξ^N	ξ^S	a^N	a^F	θ	i^N	i^S
0.03	2.5	0.829	0.6	0.05	0.5	0.5	1	10.02	0.28	0.078	0.085

Table 1: Calibrated parameters (baseline model)

5.2 Benchmark results

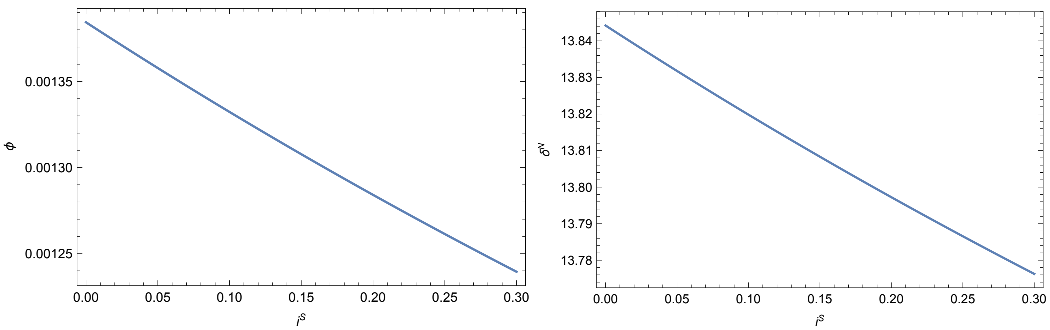
Based on the benchmark calibrated parameters, we proceed to evaluate the effects of the northern (i.e., the US) and the southern (i.e., China) monetary policies on the relative wage rate ω, the rate of innovation in the North $\dot{n}/n$, (i.e., the average R&D difficulty per northern worker δ^N), and the rate of international technology transfer to the South ϕ, respectively. Figure 2a and 2b indicate that a higher northern (southern) nominal interest rate in the US (and China) is associated with a decrease (increase) in the relative wage rate ω, In particular, increasing the northern (southern) nominal interest rate by 10 percentage points from 7.8% to 17.8% (8.5% to 18.5%) decreases (increases) ω by 1.5%. The intuition of this result is straightforward. A rise in i^S increases the southern inflation rate π^S, which raises the cost of adaptive R&D for a foreign affiliate as shown in (14). This yields a negative effect on the demand for southern R&D labor, thereby raising the wage rate in the North relative to the South. By contrast, a rise in i^N increases the northern inflation rate π^N, which raises the cost of innovative R&D for a northern firm as shown in (12). This yields a negative effect on the demand for northern R&D labor, thereby lowering the wage rate in the North relative to the South. These results conform well to Proposition 1.



(a) i^N and ω (b) i^S and ω

Figure 2: Effects of nominal interest rate on the relative wage

Figure 3a shows that an increase in the southern nominal interest rate i^S in China is associated with a decrease in the rate of international technology transfer ϕ. In particular, increasing i^S by 10 percentage points from 8.5% to 18.5% decreases ϕ by 3.6%. Figure 3b shows that a higher i^S in China is associated with a decrease in the average R&D difficulty per worker in the North δ^N. In particular, increasing i^S by 10 percentage points from 8.5% to 18.5% decreases δ^N by 0.17%. Intuitively, an rise in i^S reduces the incentives for southern affiliates to engage in adaptive R&D due to a higher adaptive R&D cost. When facing higher inflation, the rate of international technology transfer ϕ decreases. Thereafter, the lower rate of technology transfer implies more products being manufactured in the North, reallocating northern labor from innovative R&D to manufacturing as such. This decreases the rate of northern innovation $\dot{n}/n$ in the short run, which leads to a lower average R&D difficulty per northern worker δ^N in the long run, as implied by (25). This set of results is consistent with Proposition 2.



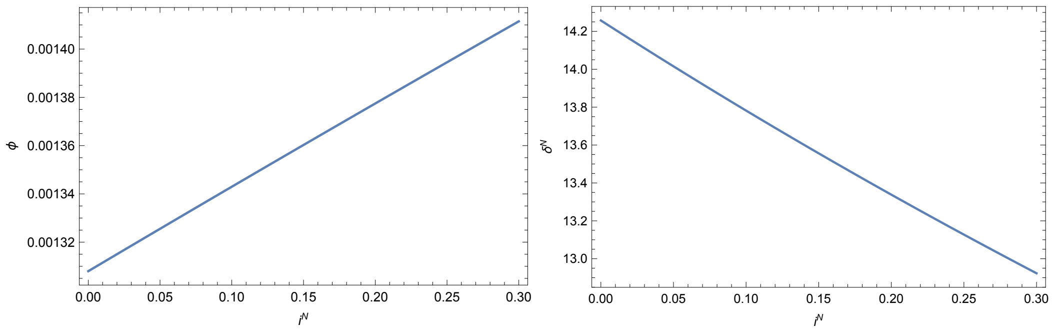
(a) i^S and ϕ

(b) i^S and δ^N

Figure 3: Effects of southern nominal interest rate on technology transfer and R&D difficulty

By contrast, Figure 4a shows that a rise in northern nominal interest rate i^N in the US is associated with an increase in the rate of international technology transfer ϕ. In particular, increasing i^N by 10 percentage points from 7.8% to 17.8% increases ϕ by 2.6%. Figure 4b shows that an increase in i^N leads to a decrease in the average R&D difficulty per worker δ^N in the North. In particular, increasing i^N by 10 percentage points decreases δ^N by 3.2%. Intuitively, for the impact on δ^N, a higher i^N increases the innovative R&D costs of northern firms, which decreases northern R&D. A lower level of northern R&D reduces the rate of northern innovation $\dot{n}/n$ in the short run. As a result, the average R&D difficulty per northern worker δ^N declines in the long run.

Concerning the impact on ϕ, on the one hand, the negative impact of a higher i^N on δ^N increases the FDI rate, since the difficulty level of transferring technology becomes lower. On the other hand, a higher i^N decreases the incentives for adaptive R&D by decreasing the relative wage ω (i.e., a higher i^N increases the southern wage rate relative to the northern counterpart), which results in a lower FDI rate due to higher costs of technology transfer. In our benchmark case, we find that the interplay between these two effects shows that the negative effect through the decline in adaptive R&D labor is *weaker* than the positive effect through a lower R&D difficulty, leading to a *net positive* impact on the rate of international technology transfer, ϕ. This result justifies part (ii) in Proposition 3, provided that the southern population (i.e., China's population) is sufficiently large as commonly perceived. We further compute the threshold southern population ratio $\bar{s}$ according to (A.5) in Appendix A. The benchmark set of parameters implies that the value of $\bar{s}$ is roughly 0.56. Therefore, our benchmark ratio of southern population $s = 0.829$ exceeds $\bar{s}$, implying that the southern population is large enough to guarantee the result that i^N is positively correlated with ϕ.



(a) i^N and ϕ

(b) i^N and δ^N

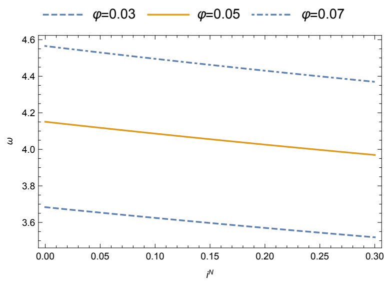
Figure 4: Effects of northern nominal interest rate on technology transfer and R&D difficulty

5.3 Sensitivity analysis

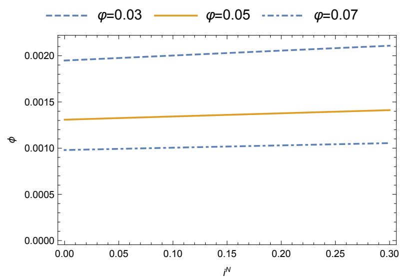
In this subsection, we show that the results in Propositions 1–3 are robust given the variation of some parameters of interest. Figures 5a, 5b, and 5c show the impacts of the northern nominal interest rate i^N on the relative wage ω, the technology transfer rate ϕ, and the R&D difficulty per worker, δ^N, by varying the exogenous imitation rate φ to 0.03, 0.05 (the benchmark) and 0.07, respectively. These figures display the same monotonic patterns as in the benchmark case. Similarly, Figures 5d, 5e, and 5f show the impacts of the southern nominal interest rate i^S on the three endogenous variables by varying φ to the same alternative values. Again, all three figures display the same monotonic patterns as in the benchmark case. The sensitivity analysis around φ confirms that our the results obtained in the three propositions are robust.

Figures 6 consists of a set of six figures, where Figures 6a, 6b, and 6c show how the northern nominal interest rate i^N is correlated with the three endogenous variables of interest by varying the southern CIA constraint ξ^S to 0.3, 0.5 (benchmark) and 0.7, respectively. These figures display the same monotonic relations as in the benchmark cases. Moreover, Figures 6d, 6e, and 6f show the impacts of i^N on the three variables by varying the northern CIA constraint ξ^N to 0.3, 0.5 (benchmark) and 0.7, respectively. Not surprisingly, it can be seen that the relations between i^N and the three variables remain monotonic. The difference in 6d, 6e, and 6f from 6a, 6b, and 6c is that the magnitude of the effects from i_N are amplified when the CIA constraint within the same country (i.e., ξ^N) increases, making the three lines radiate out from the origin instead of three parallel lines in 6a, 6b, and 6c.

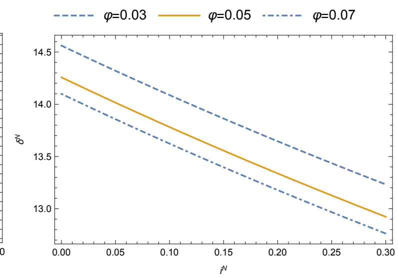
Figure 7 consists of the alternative counterpart of six figures, where Figures 7a, 7b, and 7c show the relations between southern nominal interest rate i^S and the three endogenous variables of interest by varying the northern CIA constraint ξ^N to 0.3, 0.5 (benchmark) and 0.7, respectively. Again, all these figures show the same monotonic relations as in the benchmark cases. Moreover, Figures 7d, 7e, and 7f show the nexuses between i^S and the three variables by varying ξ^S to 0.3, 0.5 (benchmark) and 0.7, respectively. Similarly, one can see that the relations between i^S and the three variables again show that the three lines radiate out from the origin instead of three parallel lines as in 7a, 7b, and 7c. The results in Figure 6 and Figure 7 also confirm that the results we obtained in Propositions 1–3 are robust.



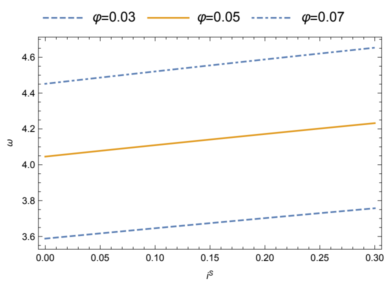
(a) i^N and ω (varying φ)



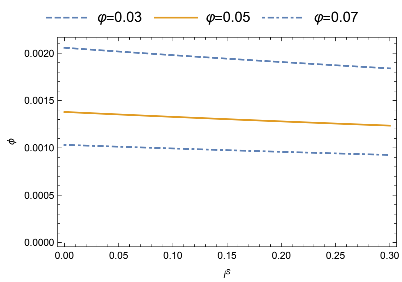
(b) i^N and ϕ (varying φ)



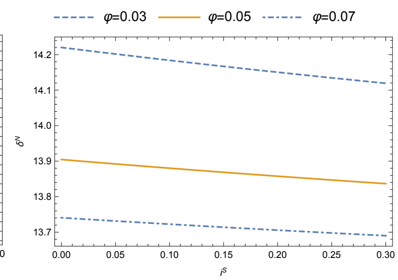
(c) i^N and δ^N (varying φ)



(d) i^S and ω (varying φ)

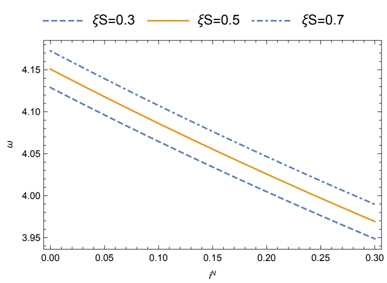


(e) i^S and ϕ (varying φ)

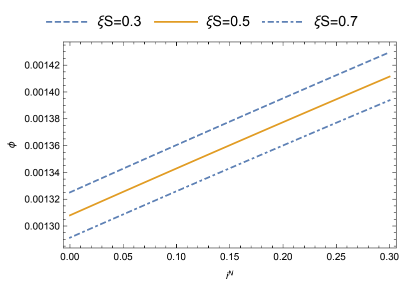


(f) i^S and δ^N (varying φ)

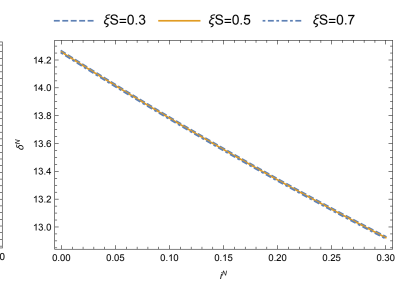
Figure 5: Sensitivity analysis by varying φ



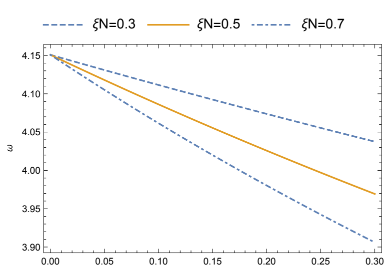
(a) i^N and ω (varying ξ^S)



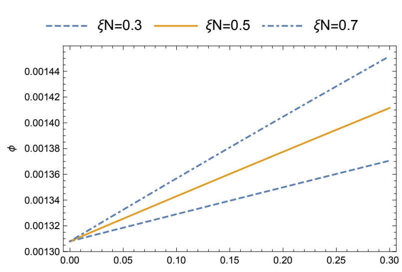
(b) i^N and ϕ (varying ξ^S)



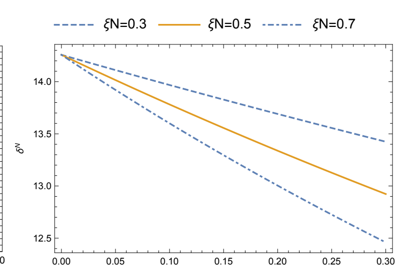
(c) i^N and δ^N (varying ξ^S)



(d) i^N and ω (varying ξ^N)

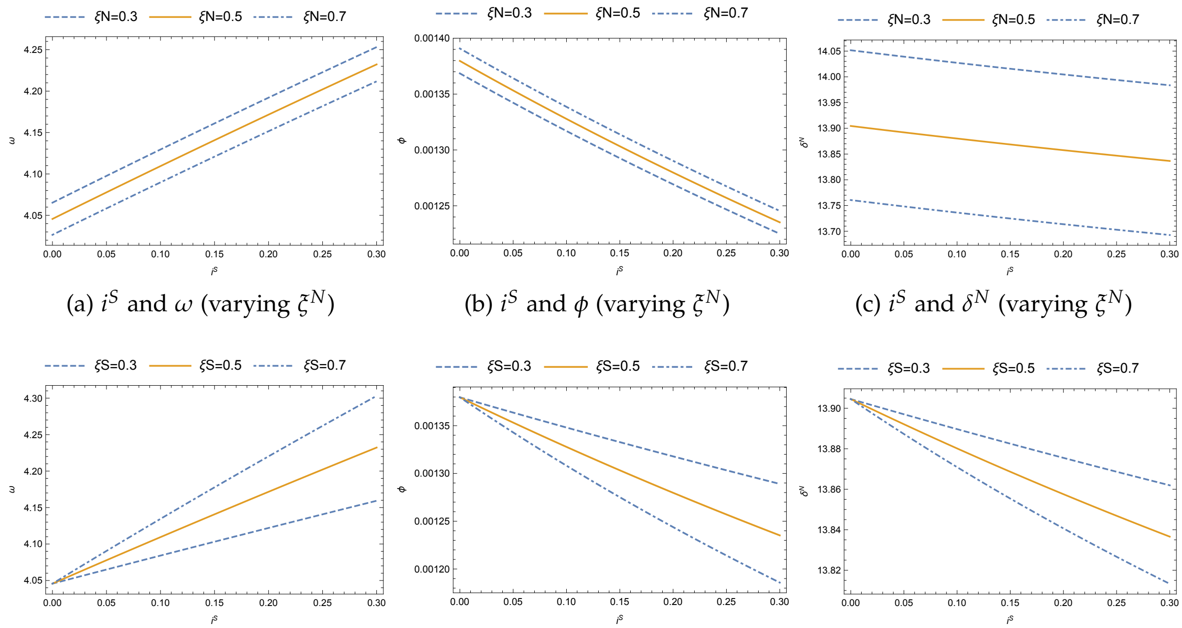


(e) i^N and ϕ (varying ξ^N)



(f) i^N and δ^N (varying ξ^N)

Figure 6: Sensitivity analysis for i^N by varying ξ^N and ξ^S



(a) i^S and ω (varying ξ^N) (b) i^S and ϕ (varying ξ^N) (c) i^S and δ^N (varying ξ^N)

(d) i^S and ω (varying ξ^S) (e) i^S and ϕ (varying ξ^S) (f) i^S and δ^N (varying ξ^S)

Figure 7: Sensitivity analysis for i^S by varying ξ^S and ξ^N

6 Endogenous imitation

In this section, we consider an extension of the baseline model in which imitation is costly. Imitators maximize profits by copying products produced in the South or those produced in the North. In addition to our main model with exogenous imitation, we also extend our numerical analysis by considering this generalized model with endogenous imitation.

6.1 New setup

We follow Gustafsson and Segerstrom (2011) to assume that foreign affiliates have higher production costs than southern firms, because the former are less familiar with the southern economic environment than the latter. Specifically, to produce one unit of product, foreign affiliates use one unit of labor whereas southern firms use $\zeta \in (0,1)$ unit of labor. Therefore, the marginal cost of production for a northern firm, a foreign affiliate, and a southern firm is w_t^N, w_t^S, and ζw_t^S, respectively, and these marginal costs satisfy $w_t^N > w_t^S > \zeta w_t^S$.

For a southern firm who imitates the product variety produced by a foreign affiliate (denoted by I), its profit flow is $\Pi_t^I = (p_t^I - \zeta w_t^S)(x_t^{I,N} L_t^N + x_t^{I,S} L_t^S)$, where $x_t^{I,N} = (p_t^I)^{-\sigma} E_t^N / P_t^{1-\sigma}$ is the quantity demanded by each northern consumer and $x_t^{I,S} = (p_t^I)^{-\sigma} E_t^S / P_t^{1-\sigma}$ is the quantity demanded by each southern consumer. Assuming $\zeta > \alpha$ ensures that the limit price w_t^S is smaller than the unconstrained monopoly price $\zeta w_t^S / \alpha$, so $p_t^I = w_t^S$. Then it is straightforward to simplify this southern firm's profit as follows

$$\Pi_t^I = w_t^S (1 - \zeta) \bar{x}_t^I L_t, \tag{36}$$

where $\bar{x}_t^I = (p_t^I)^{-\sigma}\bar{E}_t/P_t^{1-\sigma}$.

For a southern firm who copies the product variety produced by a northern firm (denoted by C), its profit flow is $\Pi_t^C = (p_t^C - \zeta w_t^S)(x_t^{C,N}L_t^N + x_t^{C,S}L_t^S)$, where $x_t^{C,N} = (p_t^C)^{-\sigma}E_t^N/P_t^{1-\sigma}$ is the quantity demanded by each northern consumer and $x_t^{C,S} = (p_t^C)^{-\sigma}E_t^S/P_t^{1-\sigma}$ is the quantity demanded by each southern consumer. Assuming $w_t^N/w_t^S > \zeta/\alpha$ ensures that the limit price w_t^N is greater than the unconstrained monopoly price $\zeta w_t^S/\alpha$, so $p_t^C = \zeta w_t^S/\alpha$. Then it is straightforward to simplify this southern firm's profit as follows

$$\Pi_t^C = \frac{\zeta w_t^S}{\sigma - 1}\bar{x}_t^C L_t, \tag{37}$$

where $\bar{x}_t^C = (p_t^C)^{-\sigma}\bar{E}_t/P_t^{1-\sigma}$.

Next, denote by n_t^N the number of varieties produced by northern firms, n_t^F the number of varieties produced by foreign affiliates, n_t^I the number of varieties produced by southern firms that have imitated foreign affiliates, and n_t^C the number of varieties produced by southern firms that have copied northern firms, respectively. Therefore, the total number of varieties is given by $n_t = n_t^N + n_t^F + n_t^I + n_t^C$. In the steady state, the innovation rate is $g \equiv \dot{n}_t/n_t$, the FDI rate is $\phi \equiv (\dot{n}_t^F + \dot{n}_t^I)/n_t^N$, the imitation rate of southern-produced varieties is $\varphi^S \equiv \dot{n}_t^I/n_t^F$, and the imitation rate of northern-produced varieties is $\varphi^N \equiv \dot{n}_t^C/n_t^N$, respectively.

In addition, the (aggregate) flow of new varieties invented in the North is given by

$$\dot{n}_t = \frac{n_t^\theta L_t^R}{a^N g^\beta}, \tag{38}$$

where L_t^R is the total amount of innovative R&D labor in the North. The term g^β captures the fact of increasing research complexity and $\beta > 0$ is the parameter representing the degree of such nature. The (aggregate) flow of varieties transferred through adaptive R&D from the North to the South is given by

$$\dot{n}_t^F + \dot{n}_t^I = \frac{n_t^\theta L_t^F}{a^F \phi^\beta}, \tag{39}$$

where L_t^F is the total amount of adaptive R&D labor in the South. The (aggregate) flow of varieties imitated from foreign affiliates to southern firms is given by

$$\dot{n}_t^I = \frac{n_t^\theta L_t^I}{a^I (\varphi^S)^\beta}, \tag{40}$$

where L_t^I is the total amount of southern R&D labor imitating foreign affiliates' varieties and a^I is the parameter for imitative R&D productivity. The (aggregate) flow of varieties imitated from northern firms to southern firms is given by

$$\dot{n}_t^C = \frac{n_t^\theta L_t^C}{d a^I (\varphi^N)^\beta}, \tag{41}$$

where L_t^C is the total amount of southern R&D labor imitating northern firms' varieties and $d > 1$ is a distance parameter that represents a lower R&D productivity for imitating northern-produced varieties.

Next, we solve the model with endogenous imitation. Denote by v_t^I (v_t^C) the real value of the expected discounted profits associated with imitating a variety of a foreign affiliate (a northern firm). Using a similar approach as in Section 3, we can obtain the following no-arbitrage conditions in the steady state as follows:

$$
\begin{aligned}
v_t^N &= \frac{\Pi_t^N}{\rho + \theta g + \varphi^N} = (1+\xi^N i^N)\frac{w_t^N a^N g^\beta}{n_t^\theta} \\
v_t^F - v_t^N &= \frac{\Pi_t^F}{\rho + \theta g + \varphi^S} - (1+\xi^N i^N)\frac{w_t^N a^N g^\beta}{n_t^\theta} = (1+\xi^S i^S)\frac{w_t^S a^F \phi^\beta}{n_t^\theta} \\
v_t^I &= \frac{\Pi_t^I}{\rho + \theta g} = (1+\xi^S i^S)\frac{w_t^S a^I (\varphi^S)^\beta}{n_t^\theta} \\
v_t^C &= \frac{\Pi_t^C}{\rho + \theta g} = (1+\xi^S i^S)\frac{w_t^S d a^I (\varphi^N)^\beta}{n_t^\theta}.
\end{aligned}
$$

For the labor markets, the northern labor-market-clearing condition becomes $L_t^N = (a^N g^\beta \dot{n}_t)/n_t^\theta + x_t^N L_t$, where $x_t^N = \bar{x}_t^N n_t^N$. Evaluating this equation at $t = 0$ and rearranging it yields the steady-state labor-market-clearing condition in the North such that

$$1 = a^N g^{1+\beta}\delta^N + \frac{x^N}{1-s}, \tag{42}$$

where $\delta^N = n_t^{1-\theta}/L_t^N = n_0^{1-\theta}/L_0^N$ and $L_0^N/L_0 = 1-s$. Moreover, the southern labor-market-clearing condition becomes $L_t^S = [a^F(\dot{n}_t^F + \dot{n}_t^I)\phi^\beta + a^I \dot{n}_t^I (\varphi^S)^\beta + d a^I \dot{n}_t^C (\varphi^N)^\beta]/n^\theta + (x_t^F + \zeta x_t^I + \zeta x_t^C)L_t$, where $x_t^F = \bar{x}_t^F n_t^F$, $x_t^I = \bar{x}_t^I n_t^I$, and $x_t^C = \bar{x}_t^C n_t^C$. Evaluating this equation at $t = 0$ and rearranging it yields the steady-state labor-market-clearing condition in the South such that

$$1 = \delta^N \left(\frac{1-s}{s}\right)[a^F\gamma^N \phi^{1+\beta} + a^I \gamma^F (\varphi^S)^{1+\beta} + d a^I \gamma^N (\varphi^N)^{1+\beta}] + \frac{1}{s}(x^F + \zeta x^I + \zeta x^C), \tag{43}$$

where $L_0^S/L_0 = s$, $\gamma^N \equiv n_t^N/n_t$, and $\gamma^F \equiv n_t^F/n_t$.

Analogous to the approach used in Section 3.2 shows that the steady-state rate of innovation is given by $g = \dot{n}_t/n_t = g_L/(1-\theta)$. Furthermore, the steady-state shares of varieties are given by

$$
\begin{aligned}
\gamma^N &\equiv \frac{n_t^N}{n_t} = \frac{g}{g+\phi+\varphi^N} & \gamma^C &\equiv \frac{n_t^C}{n_t} = \frac{\varphi^N}{g+\phi+\varphi^N} \\
\gamma^F &\equiv \frac{n_t^F}{n_t} = \left(\frac{\phi}{g+\phi+\varphi^N}\right)\left(\frac{g}{g+\varphi^S}\right) & \gamma^I &\equiv \frac{n_t^I}{n_t} = \left(\frac{\phi}{g+\phi+\varphi^N}\right)\left(\frac{\varphi^S}{g+\varphi^S}\right).
\end{aligned}
$$

Then the above result implies that the steady-state value of the average R&D difficulty per northern work δ^N is stationary, since differentiating the logarithm of δ_t^N with respect to time yields $\dot{\delta}_t^N/\delta_t^N = (1-\theta)g - g_L = 0$. Accordingly, we can solve the steady-state version of the four no-arbitrage conditions as follows:

$$\frac{\frac{x^N}{(\sigma-1)\gamma^N(1-s)}}{\rho+\theta g+\varphi^N} = (1+\xi^N i^N)a^N\delta^N g^\beta, \tag{44}$$

$$\frac{\frac{x^F}{(\sigma-1)\gamma^F(1-s)}}{\rho+\theta g+\varphi^S} - (1+\xi^N i^N)\omega a^N\delta^N g^\beta = (1+\xi^S i^S)a^F\delta^N\phi^\beta, \tag{45}$$

$$\frac{\frac{(1-\zeta)x^I}{\gamma^I(1-s)}}{\rho+\theta g} = (1+\xi^S i^S)a^I\delta^N(\varphi^S)^\beta, \tag{46}$$

$$\frac{\frac{\zeta x^C}{(\sigma-1)\gamma^C(1-s)}}{\rho+\theta g} = (1+\xi^S i^S)da^I\delta^N(\varphi^N)^\beta. \tag{47}$$

In addition, since $x^I/x^F = (\bar{x}_t^I n_t^I)/(\bar{x}_t^F n_t^F) = (1/\alpha)^\sigma\varphi^S/g$, $x^C/x^F = (\bar{x}_t^C n_t^C)/(\bar{x}_t^F n_t^F) = (1/\zeta)^\sigma\varphi^N(g+\varphi^S)/(g\phi)$, $x^N/x^F = (\bar{x}_t^N n_t^N)/(\bar{x}_t^F n_t^F) = \omega^{-\sigma}(g+\varphi^S)/\phi$, the steady-state values of x^I, x^C, and x^N can be written as a function of x^F given by

$$x^I = x^F\frac{\alpha^{-\sigma}\varphi^S}{g} \qquad x^C = x^F\frac{\zeta^{-\sigma}\varphi^N(g+\varphi^S)}{\phi g} \qquad x^N = x^F\frac{\omega^{-\sigma}(g+\varphi^S)}{\phi}.$$

Finally, given stationary values of i^N and i^S, solving a steady-state equilibrium reduces to solving a system of six equations (42)-(47) in six unknowns $\{\omega, \delta^N, \phi, \varphi^S, \varphi^N, x^F\}$.

6.2 Quantitative analysis: endogenous imitation

In this subsection, we consider the generalized case by extending the baseline model to feature costly endogenous imitation as in Gustafsson and Segerstrom (2011) and assume that foreign affiliates have higher production costs than southern firms as shown in Section 6.1.

6.3 Calibration: endogenous imitation

We recalibrate the model with the following set of parameters $\{\rho,\sigma,s,\alpha,\xi^N,\xi^S,a^N,a^I,a^F,\theta,i^N,i^S,\beta,\zeta,d,\varphi^S,\varphi^N\}$, where $\{\beta,\zeta,d,\varphi^S,\varphi^N,a^I\}$ are the additional parameters in this extended model.

We preserve the same values for $\{\rho,\sigma,s,\alpha,\xi^N,\xi^S,\theta,i^N,i^S\}$ as in our benchmark case with exogenous imitation by applying the same calibration procedure as above. For the rest of the parameters, we proceed with a similar calibration strategy as in Gustafsson and Segerstrom (2011). First, given that the parameter β determines the degree of decreasing returns by R&D duplication, we assign a value of 1 to β such that the point estimate $1/(1+\beta)$ lies in the range found in the empirical literature on patents and R&D.[25] Next, the northern productivity, a^N, is calibrated by normalizing $a^N g\beta \equiv 1$ and using the US long-run growth rate $g = 0.02$, which yields $a^N = 50$. Similarly, the cost parameter ζ is set to 0.9 (which lies between 0 and 1), since this value allows

[25]The point estimates of $1/(1+\beta)$ lie between 0.1 and 0.6 in the empirical literature on patents and R&D as suggested in Gustafsson and Segerstrom (2011), and this estimate in Jones and Williams (2000) is 0.5. Therefore, we use the intermediate value of $1/(1+\beta) = 0.5$ to calibrate $\beta = 1$.

southern firms to entail 10% lower production costs than foreign affiliates as in Gustafsson and Segerstrom (2011).

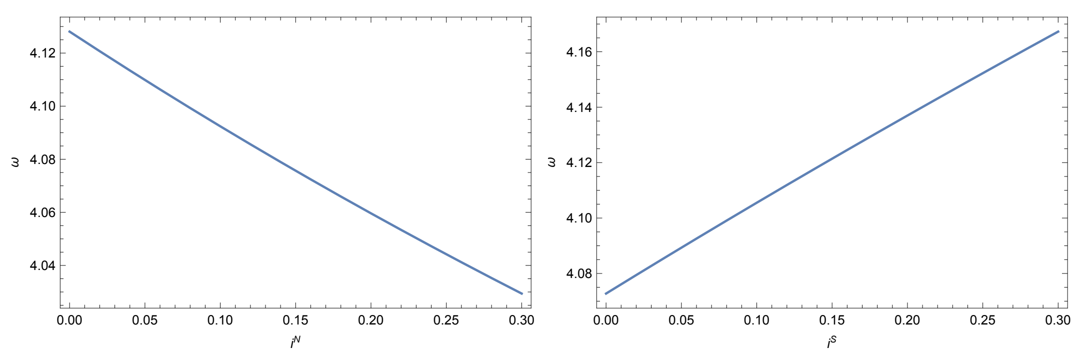
For the measure of distant parameter d, in order to facilitate the comparison with the exogenous imitation model, we choose a high value of $d = 10000$ to guarantee that the imitation rate φ^N of northern-produced varieties is very close to zero.[26] Moreover, the southern copying rate, φ^S, is set to 0.05, which equals to the above benchmark imitation rate. Finally, we calibrate a^I and a^F by jointly solving the equilibrium system equations from (42) to (46) together with the other three endogenous variables. Along with China-US relative wage ratio of 4.1 and other data moments, the solution to the system equations yields the values of 366.2 and 8999.3 for a^I and a^F respectively. Table 2 below reports the calibrated parameters:

ρ	σ	s	α	ξ^N	ξ^S	a^N	a^I	a^F	θ	i^N	i^S	β	ζ	d	φ^S	φ^N
0.03	2.5	0.829	0.6	0.5	0.5	50	366.2	8999.3	0.28	0.078	0.085	1	0.9	10000	0.05	0

Table 2: Calibrated parameters (generalized case)

6.4 The results

We find that the results in this endogenous imitation case also support what we obtained in the exogenous case in Propositions 1–3 in most cases with a few exceptions. Figure 8a and 8b indicate that the relation between northern (southern) nominal interest rate i^N (i^S) and the relative wage rate ω is negative (positive). A similar intuition applies here as in the baseline model, therefore, the results in Figure 8 remain in line with Proposition 1.



(a) i^N and ω

(b) i^S and ω

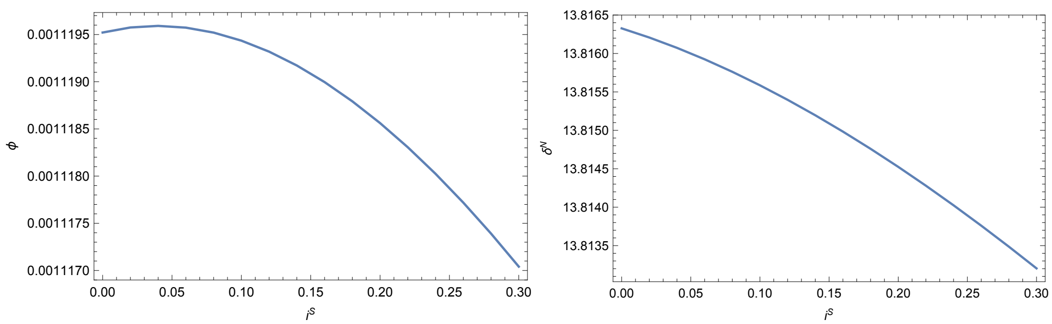
Figure 8: Effects of nominal interest rates on the relative wage: endogenous imitation

Figure 9 displays the impacts of the southern nominal interest rate i^S on the international technological transfer rate ϕ and the average R&D difficulty per worker in the North δ^N. Interestingly, Figure 9a shows an inverted-U relation between i^S and ϕ in contrast to the exogenous imitation case. The intuition behind is that there are two opposing forces jointly in play. On the one hand, as in the exogenous model, increasing i^S directly raises the cost of adaptive R&D and

[26] By combining (46) and (47), we obtain the expression $1/d = (1-\zeta)/\zeta^{1-\sigma}\alpha^{1-\sigma}(\varphi^N/\varphi^S)^\beta$. Given the value of φ^S, the value of d has to be sufficiently high to ensure that φ^N is close to zero.

makes production relocation more costly, leading to a lower rate of technology transfer. On the other hand, in this endogenous imitation model, a higher i^S increases the cost of imitative R&D in the South, which lowers the southern imitation rate. A lower imitation rate implies a more secure environment in intellectual property rights protection, which would encourage multinational firms to perform technology transfer. In our simulation, when i^S is low, the latter force dominates the former one, leading to a net increase in ϕ. Nevertheless, when i^S reaches a higher level, the opposite would occur, leading to a net decrease in ϕ. This implies that although we may observe an initial increase in ϕ in response to i^S in this generalized model, in response to the continual rise in i^S, ϕ will eventually decrease; this result generalizes our finding in the baseline model with exogenous imitation.

Furthermore, Figure 9b shows that a nonlinear negative relation between i^S and δ^N; raising i^S decreases δ^N with an increasing rate. The intuition is similar to the one in the baseline model with exogenous imitation. Thus, this set of results is consistent with Proposition 2.



(a) i^S and ϕ

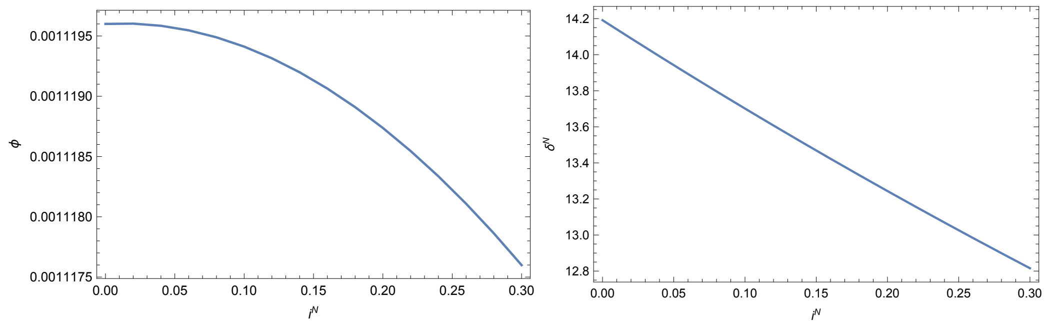
(b) i^S and δ^N

Figure 9: Effects of southern nominal interest rate on technology transfer and R&D difficulty: endogenous imitation

Figure 10a displays that a rise in the northern nominal interest rate i^N is associated with a decrease in the technology transfer rate ϕ. Interestingly, this result is in contrast to the positive relation found in the baseline exogenous imitation model. Figure 10b shows that an increase in i^N leads to a decrease in the average R&D difficulty per worker in the North δ^N, as in the baseline model. The intuition of these results is as follows. For the impact on δ^N, a higher i^N increases innovative R&D costs of northern firms, which decreases the rate of northern innovation $\dot{n}/n$ in the short run. As a result, the average R&D difficulty per northern worker δ^N declines in the long run. For the impact on ϕ, recall that a higher i^N, on the one hand, decreases R&D difficulty per worker δ^N, which yields a positive effect on the FDI rate. On the other hand, a higher i^N decreases the incentives for adaptive R&D by decreasing the relative wage ω, which leads to a lower FDI rate. In contrast to the baseline model, we find that endogenous imitation tends to significantly reduce the incentives for adaptive R&D, so that the negative effect through a lower adaptive R&D labor becomes *stronger* than the positive effect through a lower R&D difficulty, leading to a *net negative* impact on ϕ.[27]

Additionally, this generalized model allows us to report the effects of nominal interest rate

[27]This result holds for a wide range of the southern population size ($s \geq 0.45$).



(a) i^N and ϕ

(b) i^N and δ^N

Figure 10: Effects of northern nominal interest rate on technology transfer and R&D difficulty: endogenous imitation

on both northern and southern imitation rates. Figures 11a to 11d display that a rise in the northern nominal interest rate increases both northern and southern imitation rates, whereas a rise in the southern nominal interest rate decreases them. The intuition for the impacts of i^S on φ^N and φ^S are straightforward: a rise in the southern nominal interest rate simply raises the cost of imitative firms in the South, regardless of imitations against northern or southern products, which reduces both northern and southern imitation rates. The impacts of i^N on φ^N and φ^S, however, are a bit indirect. A rise in the northern nominal interest rate raises the cost of innovative R&D in the North. This shifts labor away from R&D sector, leading to a lower technology transfer and thus fewer products being transferred to the South. As a result, a smaller amount of products in both the North and the South are present for imitation. According to the definition of imitation rates, injecting fewer products in the imitative pool (which decreases the denominator of imitation rates) while keeping the same amount of imitation efforts in the South (which makes the numerator of imitation rates unchanged) would result in a higher probability of succeeding in imitations, thus leading to higher imitation rates for both northern and southern products.

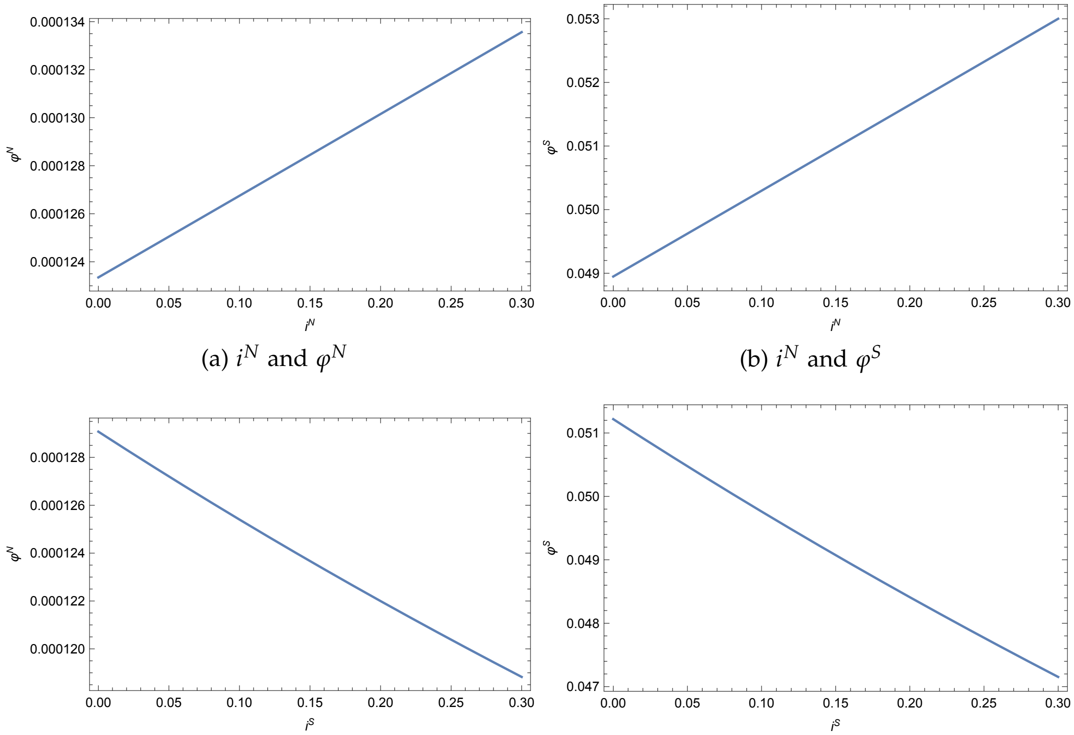
7 Empirical analysis

In this section we conduct empirical analysis using country-level panel data to examine the relationship between technology transfer (i.e., FDI) and the nominal interest rates (inflation).

7.1 Data

The data is collected from various sources. FDI flows are obtained from a country-pair panel obtained from OECD International Direct Investment Statistics. Nominal interest rates and other country-level control variables are obtained from the World Development Indicators (WDI). Our study period expands from 2003 to 2013.

We define the group of OECD countries as northern countries, which stands for the technological frontier who joined the organization before 2003, and the group of emerging economies



(a) i^N and φ^N

(b) i^N and φ^S

(c) i^S and φ^N

(d) i^S and φ^S

Figure 11: Nominal interest rates and imitation rates

as southern countries because they received most of the FDI from northern OECD countries during the past several decades. There are 34 OECD countries and 15 emerging economies in our sample.

The total observations amounting to 3955 count for outward FDI flows from the North to the South over the sample period, and we exclude observations in the missing data in the nominal interest rates. Consequently, there are 1844 observations in total involved. FDI flows and GDP are measured in constant 2015 U.S. dollars, and they have been adjusted by inflation to represent real variables in terms of goods and services.

To save space, the summary statistics, including the main variables of interests (i.e., outward FDI flows, nominal interest rates, and population sizes) and other control variables (i.e., real GDP, exchange rates and the measure of trade openness), is shown in the appendix.

7.2 Model specification and estimation methodology

One notable prediction in our model shows that an increase in nominal interest rate in the southern country leads to a lower rate of international technology transfer, whereas the effect of northern nominal interest rate can be positive or negative depending on the relative size of southern to northern populations.[28]

[28] It is worth to note that the parameter in Proposition 3 that matters for the effect of northern nominal interest rate on technology transfer is the share of southern population s. It is easy to derive that the relative size of southern to

We use the outward FDI flow from the North to the South divided by the northern country's GDP as a proxy measure for the magnitude of the technological transfer from the North.[29] [30] To estimate the effects of northern and southern interest rates on FDI shares, we extend a gravity type of specification as our first regression:[31]

$$fd_{n,s,t} = \alpha + \beta_1 i_{n,t} + \beta_2 i_{s,t} + \gamma_1 Z_{n,t} + \gamma_2 Z_{s,t} + \gamma_3 Z_{n,s,t} + \delta_{n,s} + \eta_t + \varepsilon_{n,s,t}, \tag{48}$$

where n denotes the northern country and s denotes the southern counterpart. $fd_{n,s,t}$ is the FDI to GDP share in the northern country n that outflows to the southern country s. $i_{n,t}$ and $i_{s,t}$ are nominal interest rates in the northern and southern countries, respectively. $Z_{n,t}$ and $Z_{s,t}$ are country level control variables including real GDP and trade openness. $Z_{n,s,t}$ include the log of exchange rate between south and north countries. The regression also controls for the country-pair fixed effect $\delta_{n,s}$ and the year fixed effect η_t. Standard errors are clustered at the country-pair level.

Since the model predict that an increase of south interest rate is associated with a decline in technology transfer from the North to the South, we expect β_2 to be negative. The sign of β_1 is ambiguous implied by the theory because the effect of northern interest rate on FDI share depends on the relative size of southern to northern populations. The effect of northern interest rate on FDI share is positive if the relative size of southern population is sufficiently large, and is negative if the relative size of southern population is sufficiently small.

Moreover, to account for the heterogeneous (the opposite) effect of the northern interest rate on technology transfer, we add in our second regression an interaction term between the relative population and northern nominal interest rate $i_{n,t} \times Size_{n,s,t}$ to capture this heterogeneous effect depending on relative population size as follows:

$$fd_{n,s,t} = \alpha + \beta_1 i_{n,t} + \beta_2 i_{s,t} + \beta_3 i_{n,t} \times Size_{n,s,t} + \gamma_1 Z_{n,t} + \gamma_2 Z_{s,t} + \gamma_3 Z_{n,s,t} + \delta_{n,s} + \eta_t + \varepsilon_{n,s,t}, \tag{49}$$

where $Size_{n,s,t} = ln(N_{s,t}/N_{n,t})$ is the log of relative size of population between southern and northern countries. To reflect the signs of coefficients under our model prediction, it is worth to note that $Size_{n,s,t}$ is positive when southern population is larger than the northern population, and is negative when the southern population is smaller. In particular, the marginal effect of northern interest rate on FDI share is given by $\beta_1 + \beta_3 \times Size_{n,s,t}$. The term β_1 denotes the marginal effect of northern interest rate when the southern population equals to the northern population, so its sign would be ambiguous.

Again, since the model predicts that the effect of the northern interest rate increases (decreases) technology transfer when the relative size of southern to northern population is large

northern population is equal to $s/(1\text{-}\ s)$, which is monotonically increasing function of s and thereby represents an one-to-one corresponding match to the change in s.

[29] Due to the difficulty of a direct measure of technology transfer, using FDI flow as a proxy is standard in the literature. See Findlay (1978), Blomström (1986), Das (1987), Wang (1990), Wang and Blomström (1992), Kokko and Blomström (1995), Harrison *et al.* (1999), and Keller (2004) for the survey of the relationship between FDI and technology transfer.

[30] In the literature, the inflow FDI share to GDP in host countries (southern countries) is a commonly-used measure, because those studies focus on the impact of inflow FDI in host countries, for example, see Demir and Duan (2018). Since our study focuses on a direct interest rate effect on technology transfer from the North, it is arguably reasonable to use outward FDI to GDP ratio in northern countries as the measure.

[31] See Anderson *et al.* (2019) and Dorakh (2020) for extending the gravity model approach to study FDI.

(small), this implies that the marginal effect of the northern interest rate increases with the relative size of southern to northern population (i.e., $\beta_1 + \beta_3 \times Size_{n,s,t}$ is increasing in $Size_{n,s,t}$). Thus, the key prediction here is that β_3 would be positive.

7.3 Empirical results

The results of northern and southern interest rate on technology transfer are shown in Table 7.3. The first three columns show the results running the first regression. In column 1, we only control for the northern and southern GDP levels. The estimates show that a one percentage point increase in the southern interest rate is significantly associated with a 0.0015% decrease in FDI share, whereas a one percentage point increase in the northern interest rate has no significant effect on FDI share.[32] Column 2 adds all control variables and the estimate of the coefficient on the south interest rate remain similar. However, after controlling for trade openness and exchange rate, the coefficient of the north interest rate becomes positive and significant, which means that a rise of interest rate in the north country increases the technological transfer from north to south countries in our sample.

To check the robustness of the result, we notice that our sample period covers the extreme periods with the financial crisis starting from 2008. In column 3, we follow the literature to further control for the effect of global financial crisis by adding a financial crisis dummy GFC that covers the periods from 2008 to 2010.[33] In practice, we include a global financial crisis dummy variable which takes the value of one in between year 2008 and 2010 and its interaction with the interest rate in northern countries for controlling its effect that mainly prevails among the OECD countries. Again, our main results remain robust: the FDI share is significant and negative in association with the southern nominal interest rate and is positively associated with northern interest rate. The results in all first three columns corroborate our model predictions in the first regression. .

The last three columns test the heterogeneous effects of northern interest rate on technology transfer using our second regression in (49). Recall that the effect of northern interest rate on technology transfer is contingent on the relative size of the population, implying that $\beta_1 + \beta_3 \times Size_{n,s,t}$ is increasing in $Size_{n,s,t}$. This means that the coefficient of the interaction term β_3 in our second regression would be positive. In columns 4 and 5, the estimates of the coefficient on the interaction term is positive and significant, which support our model prediction. This result is also robust after taking into account the financial crisis during 2008 to 2010 as shown in column 6.

8 Conclusion

In this paper we examine the effects of monetary policy on innovation, the North-South relative wage ratio, and technology transfer from the North to the South, respectively, based on a variety-expansion model with CIA constraints applied to northern innovative R&D and southern adaptive R&D. Our analysis reveals that regardless of the imitation rate being exogenous

[32]This result is similar to that in Karahan and Bayır (2022), who find that low-interest rates encourage FDI inflows to the South using the data of some developing countries (such as Brazil, China, Turkey, and Poland).

[33]See, for example, Jinjarak and Wignaraja (2016), Liu *et al.* (2019), and Kim (2019)

Table 3: Nominal interest rates and FDI between OECD countries and emerging economies

	(1) FDI share	(2) FDI share	(3) FDI share	(4) FDI share	(5) FDI share	(6) FDI share
North interest rate	0.0019	0.0019*	0.0028*	-0.0015	-0.0012	-0.0005
	(0.0012)	(0.0011)	(0.0017)	(0.0020)	(0.0020)	(0.0020)
South interest rate	-0.0015**	-0.0013*	-0.0013*	-0.0016***	-0.0013*	-0.0013*
	(0.0006)	(0.0007)	(0.0008)	(0.0006)	(0.0007)	(0.0007)
North interest rate× Size				0.0008**	0.0007**	0.0008**
				(0.0004)	(0.0004)	(0.0004)
Size				0.1351	0.1462	0.1356
				(0.1253)	(0.1038)	(0.1025)
Ln(north GDP)	0.0535	0.0923*	0.0909*	0.0718	0.1136*	0.1104*
	(0.0477)	(0.0556)	(0.0547)	(0.0559)	(0.0636)	(0.0621)
Ln(south GDP)	0.1003***	0.0864**	0.0841**	0.1140***	0.0976**	0.0951**
	(0.0359)	(0.0404)	(0.0403)	(0.0372)	(0.0388)	(0.0389)
North Openness level		-0.0271	-0.0219		-0.0421	-0.0362
		(0.0403)	(0.0393)		(0.0450)	(0.0439)
South Openness level		0.0004	0.0023		0.0145	0.0156
		(0.0216)	(0.0215)		(0.0254)	(0.0255)
Relative exchange rate		-0.0143	-0.0192		-0.0215	-0.0260
		(0.0152)	(0.0174)		(0.0164)	(0.0185)
GFC			-0.0117			-0.0205
			(0.0188)			(0.0193)
GFC× North interest rate			-0.0011			-0.0011
			(0.0013)			(0.0013)
Constant	-1.9815**	-2.2809**	-2.2403**	-2.6411**	-2.9779**	-2.8898**
	(0.8761)	(0.9582)	(0.9392)	(1.1796)	(1.1621)	(1.1345)
Observations	1383	1145	1145	1383	1145	1145
R^2	0.033	0.043	0.045	0.039	0.051	0.052

Standard errors are clustered at the country-pair level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

or endogenous, a higher southern nominal interest causes the North-South relative wage ratio to increase permanently, the northern innovation rate to decrease temporarily, and technology transfer to decrease permanently. However, a higher northern nominal interest rate causes a permanent decrease in the North-South relative wage ratio, a temporary decrease in the northern innovation rate, and a permanent decrease (increase) in technology transfer if the southern population is sufficiently small (large). In addition, using country-pair panel data across OECD and emerging countries from 2003 to 2013, our model receives empirical support in the predictions of nominal interest rate (inflation) effects on technology transfer.

In this paper, we do not consider skill choices and changes in monetary policy do not affect agent's decisions on the acquisition of skills. Therefore, one direction for future research is to extend our model by endogenizing skill choices to examine the wage ratio of skilled workers to unskilled workers within the country.[34] The heterogeneity among agents will allow us to study how monetary policy affects global production and a country's wage inequality between skilled and unskilled workers. Furthermore, it would be interesting to investigate the effects of monetary policy on innovation and technology transfer in a framework with different modes of international technology transfer that abstract from FDI, such as licensing in Yang and Maskus (2001) and Tanaka *et al.* (2007) and imitation in Gustafsson and Segerstrom (2010) and Lorenczik and Newiak (2012).

References

Abel, A. B. (1985). Dynamic behavior of capital accumulation in a cash-in-advance model. *Journal of Monetary Economics*, **16** (1), 55–71.

Anderson, J. E., Larch, M. and Yotov, Y. V. (2019). Trade and investment in the global economy: A multi-country dynamic analysis. *European Economic Review*, **120**, 103311.

Blomström, M. (1986). Foreign investment and productive efficiency: the case of mexico. *Journal of Industrial Economics*, pp. 97–110.

Brown, J. R., Fazzari, S. M. and Petersen, B. C. (2009). Financing innovation and growth: Cash flow, external equity, and the 1990s R&D boom. *Journal of Finance*, **64** (1), 151–185.

—, Martinsson, G. and Petersen, B. C. (2012). Do financing constraints matter for R&D? *European Economic Review*, **56** (8), 1512–1529.

— and Petersen, B. C. (2009). Why has the investment-cash flow sensitivity declined so sharply? rising R&D and equity market developments. *Journal of Banking & Finance*, **33** (5), 971–984.

— and — (2011). Cash holdings and R&D smoothing. *Journal of Corporate Finance*, **17** (3), 694–709.

Chen, H.-J. (2015). Intellectual property rights and skills accumulation: A product-cycle model of FDI and outsourcing. *Journal of Macroeconomics*, **46** (C), 328–343.

— (2018a). Innovation and imitation: Effects of intellectual property rights in a product-cycle model of skills accumulation. *Macroeconomic Dynamics*, **22** (06), 1475–1509.

[34] Parello (2008) and Chen (2015) introduce skill choices into a North-South product-cycle model to examine the effects of a stronger IPR protection on skill accumulation.

— (2018b). Innovation and imitation in a product-cycle model with FDI and cash-in-advance constraints. *Journal of Macroeconomics*, **58** (C), 91–114.

— (2018c). Innovation, FDI, and the long-run effects of monetary policy. *Review of International Economics*, **26** (5), 1101–1129.

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.

—, —, Furukawa, Y. and Liao, C. (2019). Inflation and innovation in a schumpeterian economy with north-south technology transfer. *Journal of Money, Credit and Banking*, **51** (2-3), 683–719.

—, —, 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.

Das, S. (1987). Externalities, and technology transfer through multinational corporations a theoretical analysis. *Journal of International Economics*, **22** (1-2), 171–182.

De Loecker, J., Eeckhout, J. and Unger, G. (2020). The rise of market power and the macroeconomic implications. *Quarterly Journal of Economics*, **135** (2), 561–644.

Demir, F. and Duan, Y. (2018). Bilateral fdi flows, productivity growth, and convergence: The north vs. the south. *World Development*, **101**, 235–249.

Dinopoulos, E. and Segerstrom, P. (2010). Intellectual property rights, multinational firms and economic growth. *Journal of Development Economics*, **92** (1), 13–27.

Dorakh, A. (2020). A gravity model analysis of fdi across eu member states. *Journal of Economic Integration*, **35** (3), 426–456.

Feldstein, M. and Horioka, C. (1980). Domestic saving and international capital flows. *Economic Journal*, **90** (358), 314–329.

Findlay, R. (1978). Relative backwardness, direct foreign investment, and the transfer of technology: a simple dynamic model. *Quarterly Journal of Economics*, **92** (1), 1–16.

Gallini, N. T. (1992). Patent policy and costly imitation. *RAND Journal of Economics*, **23** (1), 52–63.

Grossman, G. M. and Helpman, E. (1991a). Endogenous product cycles. *Economic Journal*, **101** (408), 1214–1229.

— and — (1991b). Quality ladders and product cycles. *Quarterly Journal of Economics*, **106** (2), 557–586.

Gustafsson, P. and Segerstrom, P. S. (2010). North-south trade with increasing product variety. *Journal of Development Economics*, **92** (2), 97–106.

— and — (2011). North-south trade with multinational firms and increasing product variety. *International Economic Review*, **52** (4), 1123–1155.

Hall, B. H. (1992). *Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?* NBER Working Papers 4096, National Bureau of Economic Research.

— and Lerner, J. (2010). The financing of R&D and innovation. In B. H. Hall and N. Rosenberg (eds.), *Handbook of the Economics of Innovation*, *Handbook of the Economics of Innovation*, vol. 1, pp. 609–639.

Harrison, A. E., Aitken, B. J. *et al.* (1999). Do domestic firms benefit from direct foreign investment? evidence from venezuela. *American Economic Review*, **89** (3), 605–618.

Helpman, E. (1993). Innovation, imitation, and intellectual property rights. *Econometrica*, **61** (6), 1247–1280.

Himmelberg, C. P. and Petersen, B. C. (1994). R&D and internal finance: A panel study of small firms in high-tech industries. *Review of Economics and Statistics*, **76** (1), 38–51.

Huang, C.-Y., Chang, J.-J. and Ji, L. (2021). Inflation, market structure, and innovation-driven growth with distinct cash constraints. *Oxford Economic Papers*, **73** (3), 1270–1303.

—, Wu, Y., Yang, Y. and Zheng, Z. (2023). Monetary policy in a schumpeterian growth model with vertical r&d sectors. *Journal of Money, Credit and Banking*, **55** (6), 1569–1607.

—, Yang, Y. and Cheng, C.-C. (2017). The growth and welfare analysis of patent and monetary policies in a schumpeterian economy. *International Review of Economics and Finance*, **52** (C), 409–426.

Jinjarak, Y. and Wignaraja, G. (2016). An empirical assessment of the export—financial constraint relationship: How different are small and medium enterprises? *World Development*, **79**, 152–163.

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

— and Williams, J. C. (2000). Too much of a good thing? the economics of investment in R&D. *Journal of Economic Growth*, **5** (1), 65–85.

Karahan, Ö. and Bayir, M. (2022). The effects of monetary policies on foreign direct investment inflows in emerging economies: some policy implications for post-covid-19. *Future Business Journal*, **8** (1), 1–14.

Keller, W. (2004). International technology diffusion. *Journal of economic literature*, **42** (3), 752–782.

Kim, M. (2019). Financial constraints on export market exit of domestic firms versus foreign multinational corporation subsidiaries in south korea. *Applied Economics Letters*, **26** (9), 750–754.

Kokko, A. and Blomström, M. (1995). Policies to encourage inflows of technology through foreign multinationals. *World Development*, **23** (3), 459–468.

Lai, E. L. C. (1998). International intellectual property rights protection and the rate of product innovation. *Journal of Development Economics*, **55** (1), 133–153.

Levin, R. C., Klevorick, A. K., Nelson, R. and Winter, S. (1987). Appropriating the returns from industrial R&D. *Brookings Papers on Economic Activity*, **3**, 783–831.

Liu, M.-H., Margaritis, D. and Zhang, Y. (2019). The global financial crisis and the export-led economic growth in china. *The Chinese Economy*, **52** (3), 232–248.

Lorenczik, C. and Newiak, M. (2012). Imitation and innovation driven development under imperfect intellectual property rights. *European Economic Review*, **56** (7), 1361–1375.

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

Marquis, M. H. and Reffett, K. L. (1991). Real interest rates and endogenous growth in a monetary economy. *Economics Letters*, **37** (2), 105–109.

— and — (1994). New technology spillovers into the payment system. *Economic Journal*, **104** (426), 1123–1138.

Mino, K. (1997). Long-run effects of monetary expansion in a two-sector model of endogenous growth. *Journal of Macroeconomics*, **19** (4), 635–655.

Opler, T., Pinkowitz, L., Stulz, R. and Williamson, R. (1999). The determinants and implications of corporate cash holdings. *Journal of Financial Economics*, **52** (1), 3–46.

Parello, C. P. (2008). A north-south model of intellectual property rights protection and skill accumulation. *Journal of Development Economics*, **85** (1-2), 253–281.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, **98** (5), 71–102.

Scholz, J. K., Seshadri, A. and Khitatrakun, S. (2006). Are americans saving "optimally"; for retirement? *Journal of Political Economy*, **114** (4), 607–643.

Segerstrom, P. S. (1998). Endogenous growth without scale effects. *American Economic Review*, **88** (5), 1290–1310.

— (2000). The long-run growth effects of R&D subsidies. *Journal of Economic Growth*, **5** (3), 277–305.

—, Anant, T. C. A. and Dinopoulos, E. (1990). A schumpeterian model of the product life cycle. *American Economic Review*, **80** (5), 1077–1091.

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

Suen, M.-H. and Yip, C. K. (2005). Superneutrality, indeterminacy and endogenous growth. *Journal of Macroeconomics*, **27** (4), 579–595.

Tanaka, H., Iwaisako, T. and Futagami, K. (2007). Dynamic analysis of innovation and international transfer of technology through licensing. *Journal of International Economics*, **73** (1), 189–212.

Vernon, R. (1966). International investment and international trade in the product cycle. *Quarterly Journal of Economics*, **80** (2), 190–207.

Wang, J.-Y. (1990). Growth, technology transfer, and the long-run theory of international capital movements. *Journal of International Economics*, **29** (3-4), 255–271.

— and Blomström, M. (1992). Foreign investment and technology transfer: A simple model. *European Economic Review*, **36** (1), 137–155.

Wang, P. and Yip, C. K. (1992). Alternative approaches to money and growth. *Journal of Money, Credit and Banking*, **24** (4), 553–562.

Yang, G. and Maskus, K. E. (2001). Intellectual property rights, licensing, and innovation in an endogenous product-cycle model. *Journal of International Economics*, **53** (1), 169–187.

Appendix A

A.1 Proof of Proposition 1

First, we examine the effect of i^N on ω. Rewrite (32) as

$$\omega^{\sigma}\left(\frac{\rho+\theta g}{\rho+\theta g+\varphi}\right)-\omega-\frac{(1+\xi^S i^S)a^F}{(1+\xi^N i^N)a^N}=0.$$

Define the left-hand side of this expression as $f(\omega; i^N, i^S)$. Making use of the implicit function theorem, we obtain

$$\frac{d\omega}{di^N}=-\frac{\frac{\partial f}{\partial i^N}}{\frac{\partial f}{\partial \omega}}=-\frac{\left[\frac{(1+\xi^S i^S)a^F\xi^N}{(1+\xi^N i^N)^2 a^N}\right]\omega}{\sigma\left(\frac{\rho+\theta g}{\rho+\theta g+\varphi}\right)\omega^{\sigma}-\omega}. \tag{A.1}$$

It is obvious that the numerator of (A.1) is positive. Furthermore, since $\sigma>1$, using (32) implies that the denominator of (A.1) is also positive. Thus, we obtain $d\omega/di^N<0$, implying that an increase in i^N leads to a lower ω. In addition, because (32) shows that a higher i^S has an opposite effect against a higher i^N on ω, an increase in i^S leads to a higher ω.

A.2 Proof of Proposition 2

According to Proposition 1, $\omega(i^N, i^S)$ is increasing in i^S, so it is straightforward to show that, in Figure 1, a rise in i^S shifts the South curve (31) to the left, whereas it has no impact on the North curve (29). As a result, both δ^N and ϕ decline in response. Furthermore, given the definition of the average R&D difficulty per northern worker δ^N in (25), a permanent decrease in δ^N must be associated with a temporary decrease in the innovation rate $\dot{n}_t/n_t$ below its steady-state level $\dot{n}_t/n_t=g_L/(1-\theta)$. This completes the proof of Proposition 2.

A.3 Proof of Proposition 3

First, according to (29) and (31), we can show graphically in Figure 1 that an increase in i^N shifts both the North curve and the South curve to the left, leading to an unambiguously negative effect on δ^N. This completes the proof for (ii).

For (i), combine (29) and (31) and redefine the resulting expression as a function of $\{\phi, i^N\}$ given by

$$\begin{aligned}F(\phi,i^N)\equiv\, & a^N g\left[1+(1+\xi^N i^N)\left(\frac{\rho+\theta g}{g+\phi}\right)(\sigma-1)\right]\\ & -\left(\frac{1-s}{s}\right)\frac{\phi}{g+\phi}\underbrace{\left\{a^F g+[(1+\xi^S i^S)a^F+(1+\xi^N i^N)a^N\omega](\rho+\theta g+\varphi)(\sigma-1)\Phi(\varphi)\right\}}_{\Omega}=0,\end{aligned} \tag{A.2}$$

where $\Omega\equiv a^F g+[(1+\xi^S i^S)a^F+(1+\xi^N i^N)a^N\omega](\rho+\theta g+\varphi)(\sigma-1)\Phi(\varphi)$. The implicit function $F(\phi, i^N)=0$ determines the steady-state equilibrium as shown in Figure 1. Therefore, we use the implicit function theorem to show the impact of i^N on ϕ such that

$$\frac{d\phi}{di^N} = -\frac{\frac{\partial F(\phi, i^N)}{\partial i^N}}{\frac{\partial F(\phi, i^N)}{\partial \phi}}. \tag{A.3}$$

It is straightforward to see that the denominator of (A.3) is negative such that

$$\frac{\partial F(\phi, i^N)}{\partial \phi} = -a^N g(1+\xi^N i^N)(\sigma-1)(\rho+\theta g)\frac{1}{(g+\phi)^2} - \left(\frac{1-s}{s}\right)\frac{\Omega g}{(g+\phi)^2} < 0. \tag{A.4}$$

Therefore, the sign of (A.3) is determined by the sign of its numerator given by

$$\frac{\partial F(\phi, i^N)}{\partial i^N} = \xi^N a^N g(\sigma-1)\left(\frac{\rho+\theta g}{g+\phi}\right) - \left(\frac{1-s}{s}\right)\frac{a^N \Phi(\varphi)(\rho+\theta g+\varphi)(\sigma-1)\phi}{g+\phi}\left[\xi^N\omega + (1+\xi^N i^N)\frac{d\omega}{di^N}\right], \tag{A.5}$$

where $d\omega/di^N < 0$ as previously proved. Then using (A.1), we obtain

$$\xi^N\omega + (1+\xi^N i^N)\frac{d\omega}{di^N} = \xi^N\omega\left[\frac{(\sigma-1)\omega^\sigma\left(\frac{\rho+\theta g}{\rho+\theta g+\varphi}\right)}{\sigma\omega^\sigma\left(\frac{\rho+\theta g}{\rho+\theta g+\varphi}\right) - \omega}\right],$$

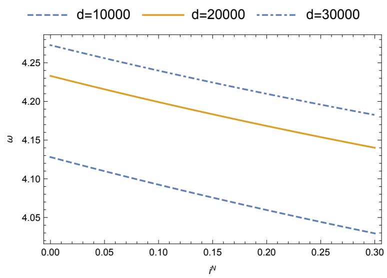
which is positive as shown in Appendix A.1. Notice that in (A.5), neither $\Phi(\varphi)$ nor ω is a function of s. In this case, $\partial F(\phi, i^N)/\partial i^N$ is monotonically increasing in s. Additionally, as $s \to 0$, we have $\partial F(\phi, i^N)/\partial i^N \to -\infty$, whereas as $s \to 1$, we have $\partial F(\phi, i^N)/\partial i^N > 0$. According to the intermediate value theorem, there exists a threshold value $\bar{s} \in (0,1)$ that satisfies $\partial F(\phi, i^N)/\partial i^N = 0$, so that $\partial F(\phi, i^N)/\partial i^N < (>)0$ when $s < (>)\bar{s}$. Therefore, this implies that $d\phi/di^N < (>)0$ holds for a sufficiently small (large) value of s.

A.4 Sensitivity analysis: endogenous imitation

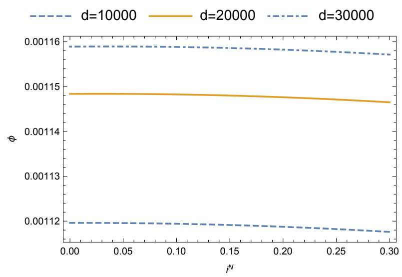
In this subsection, we show that the results we obtained in this generalized model with endogenous imitation are robust when varying various parameters including the distance parameter d, the cost of southern production parameter ζ, and the parameters of both Northern and Southern CIA constraints ξ^N and ξ^S.

Figures 12a to 12e show the impacts of the northern nominal interest rate i^N on the relative wage ω, the rate of technology transfer ϕ, the R&D difficulty per worker δ^N and the northern (southern) imitation rate φ^N (φ^S) by varying the distance parameter d to 10000 (the benchmark), 20000, and 30000, respectively. One can see that the same monotonic relation is preserved in these exercises as previously. Similarly, Figures 12f to 12j show that the impacts of the southern nominal interest rate i^S on the five variables of interest by varying the distance parameter d to the same alternative values. Again, we observe that all five figures exhibit the same monotonic relations as in benchmark result of the generalized model. This sensitivity analysis on d confirms that our results obtained in Subsection 6.4 are thus consistent with Propositions 1–3 for most variables.

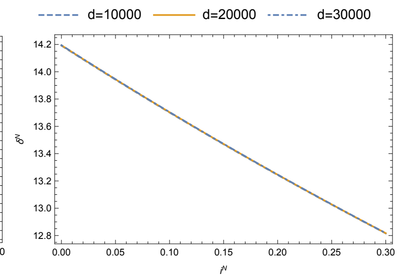
Figures 13a to 13e show the impacts of the northern nominal interest rate i^N on the relative



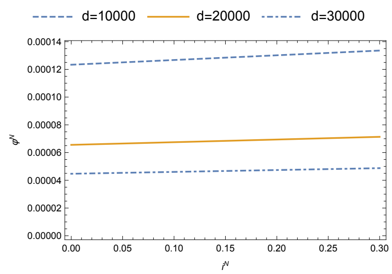
(a) i^N and ω (varying d)



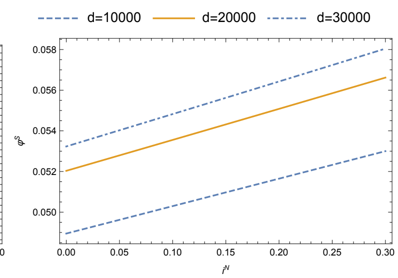
(b) i^N and ϕ (varying d)



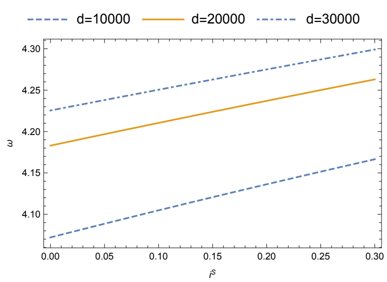
(c) i^N and δ^N (varying d)



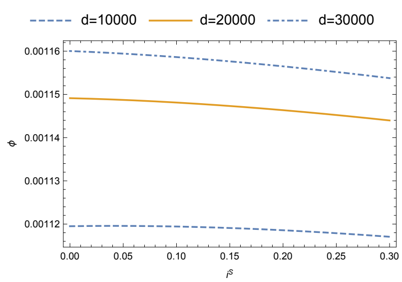
(d) i^N and φ^N(varying d)



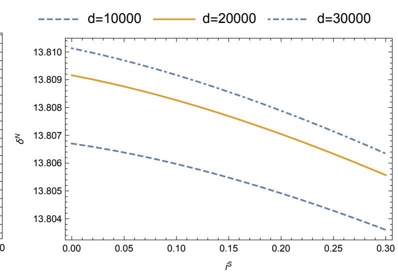
(e) i^N and φ^S (varying d)



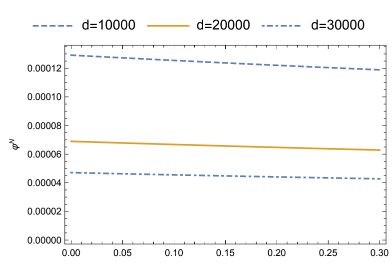
(f) i^S and ω (varying d)



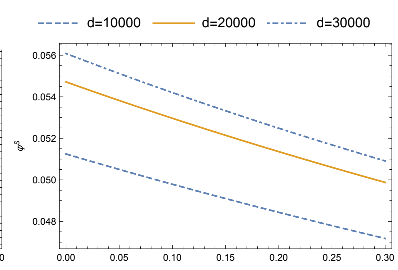
(g) i^S and ϕ (varying d)



(h) i^S and δ^N (varying d)



(i) i^S and φ^N (varying d)



(j) i^S and φ^S (varying d)

Figure 12: Sensitivity analysis by varying d

wage ω, the rate of technology transfer ϕ, the R&D difficulty per worker δ^N and the two imitation rates φ^N and φ^S, by varying the cost parameter ζ to 0.9 (the benchmark), 0.8, and 0.7, respectively. One can see all figures display the same monotonically decreasing relations as in the benchmark. Figures 13f to 13j show the relations between the southern nominal interest rate i^S and the five variables of interest by varying the cost parameter ζ to the same alternative values. Interestingly, one can see that the benchmark case of $\zeta = 0.9$ shows a slightly negative correlation between i^S and δ^N, whereas the variant cases with $\zeta = 0.8$ and $\zeta = 0.7$ display a positive correlation between i^S and δ^N. This sensitivity exercise implies that although the negative relation between i^S and δ^N obtained in the generalized model is not robust by varying ζ, the current results remain consistent with Proposition 3 in the sense that the relation between i^S and δ^N can be positive or negative under different conditions.

Finally, we also conduct sensitivity analysis by varying both CIA constraints. Figures 14 consists of a set of ten figures where Figures 14a to 14e show the relations between the northern nominal interest rate i^N and the five endogenous variables of interest by varying the southern CIA constraint ξ^S to 0.3, 0.5 (benchmark) and 0.7, respectively. These exercises all display the similar monotonic relations as in the benchmark case. In addition, Figures 14f to 14j display the nexuses between i^N and the five variables by varying the northern CIA constraint ξ^N to 0.3, 0.5 (benchmark) and 0.7, respectively. Not surprisingly, we again can see that the relations between i^N and the five variables remain monotonic.

Figure 15 consists of the alternative counterpart of ten figures where Figures 15a to 15e show the relations between the southern nominal interest rate i^S and the five endogenous variables of interest by varying the northern CIA constraint ξ^N to 0.3, 0.5 (benchmark) and 0.7, respectively. Again, these exercises all display the similar monotonic relation as in the benchmark case. Figures 15f to 15j display the nexuses between the southern CIA constraint i^S and the five variables by varying ξ^S to 0.3, 0.5 (benchmark) and 0.7, respectively. Similarly, we can see that the relations between i^S and the five variables of interest remain monotonic. The results in Figure 14 and Figure 15 also confirm that the results we obtained in Propositions 1–3 and the numerical exercises in Subsection 5.2 are quite robust.

A.5 Summary statistics for our regression variables

FDI flows and GDP are measured in constant 2005 U.S. dollars, and have been adjusted by inflation to represent real variables in terms of goods and services. The mean of the FDI flows equals 301.4 million (2005 base constant US dollars), and the FDI flows account for 0.06% of the GDP in northern countries. Moreover, the nominal interest rate and thus the inflation rate in the southern countries are higher than those in the northern countries. Northern countries have higher real GDPs and higher level of trade openness. The southern countries exhibits a relatively larger population.

The summary statistics, including the main variables of interests (i.e., outward FDI flows, nominal interest rates, and population sizes) and other control variables (i.e., real GDP, exchange rates and the measure of trade openness), is shown below

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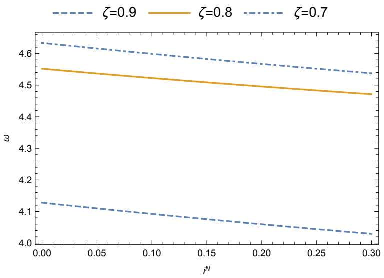
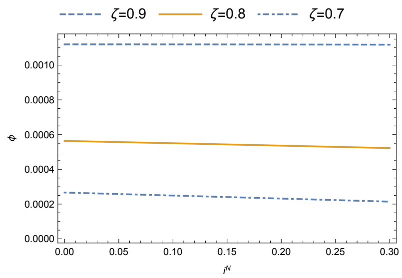
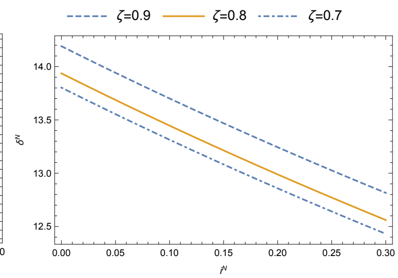


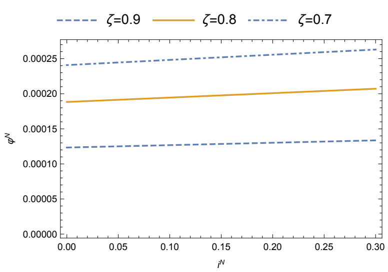
(a) i^N and ω (varying ζ)



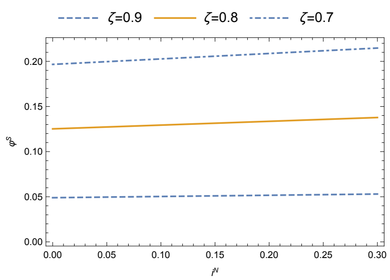
(b) i^N and ϕ (varying ζ)



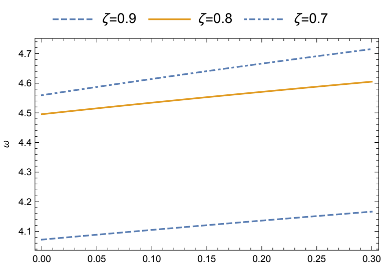
(c) i^N and δ^N (varying ζ)



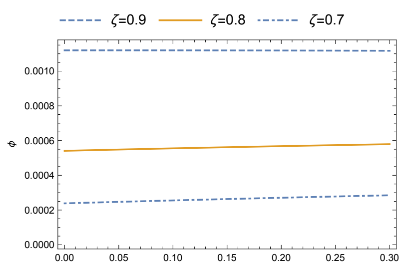
(d) i_N and φ_N (varying ζ)



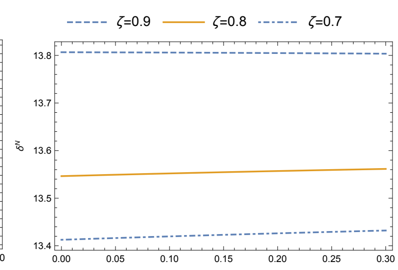
(e) i_N and φ_S (varying ζ)



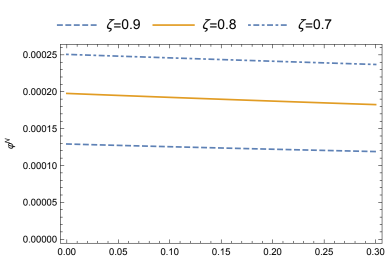
(f) i^S and ω (varying ζ)



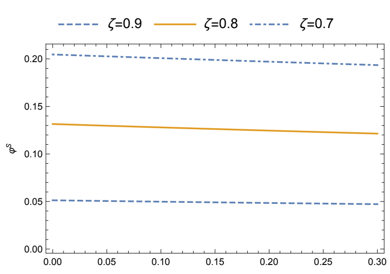
(g) i^S and ϕ (varying ζ)



(h) i^S and δ^N (varying ζ)

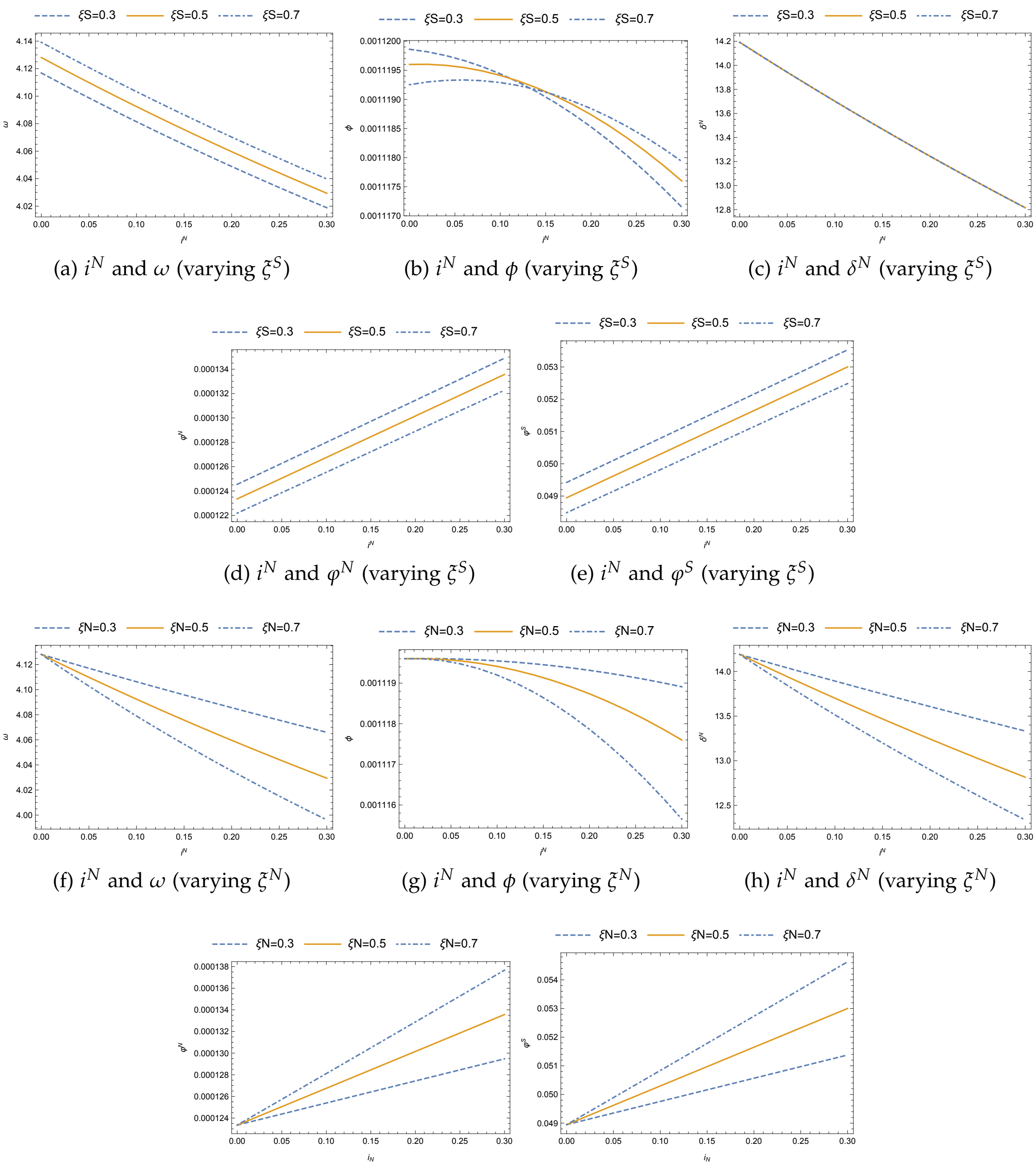


(i) i_S and φ_N (varying ζ)



(j) i_S and φ_S (varying ζ)

Figure 13: Sensitivity analysis by varying ζ



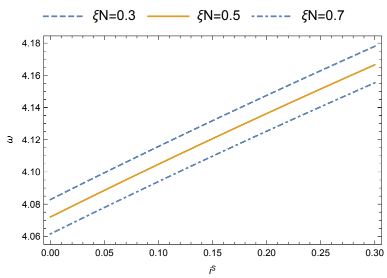
(a) i^N and ω (varying ξ^S) (b) i^N and ϕ (varying ξ^S) (c) i^N and δ^N (varying ξ^S)

(d) i^N and φ^N (varying ξ^S) (e) i^N and φ^S (varying ξ^S)

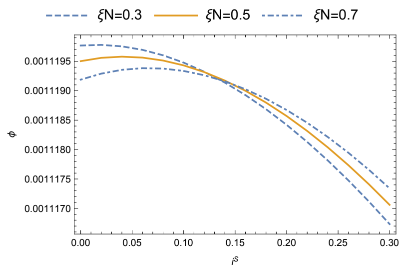
(f) i^N and ω (varying ξ^N) (g) i^N and ϕ (varying ξ^N) (h) i^N and δ^N (varying ξ^N)

(i) i^S and φ^N(varying ξ^N) (j) i^N and φ^S(varying ξ^N)

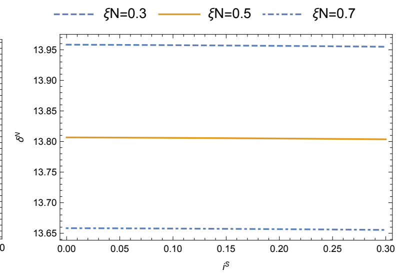
Figure 14: Sensitivity analysis for i^N by varying ξ^N and ξ^S: endogenous imitation



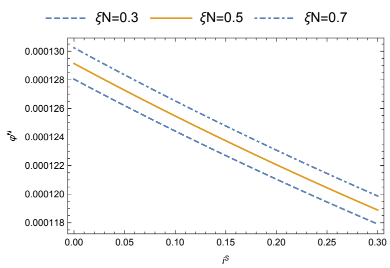
(a) i^S and ω (varying ξ^N)



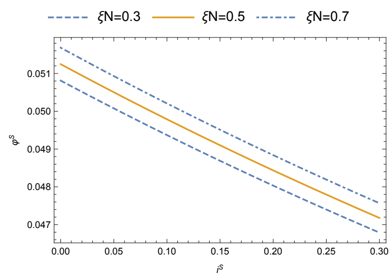
(b) i^S and ϕ (varying ξ^N)



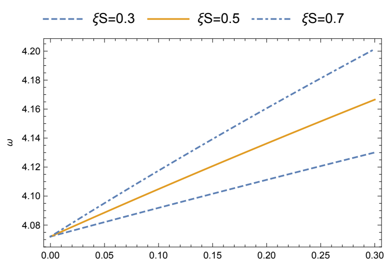
(c) i^S and δ^N (varying ξ^N)



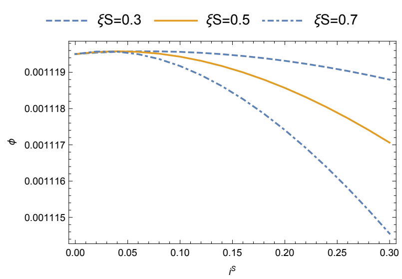
(d) i^S and φ^N (varying ξ^N)



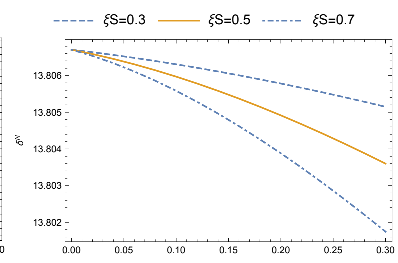
(e) i^S and φ^S (varying ξ^N)



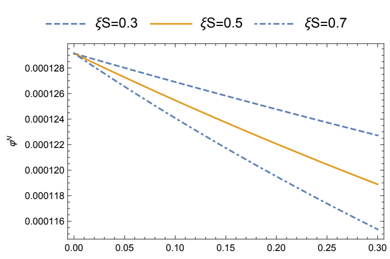
(f) i^S and ω (varying ξ^S)



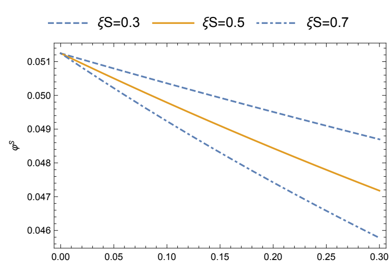
(g) i^S and ϕ (varying ξ^S)



(h) i^S and δ^N (varying ξ^S)



(i) i^S and φ^N(varying ξ^S)



(j) i^S and φ^S(varying ξ^S)

Figure 15: Sensitivity analysis for i^S by varying ξ^S and ξ^N: endogenous imitation

Table 4: Summary statistics

	count	mean	sd	max	min
FDI(million)	3955	301.40	1129.22	18027.97	-8276.21
FDI/GDP (%)	3955	0.06	0.74	31.38	-7.45
South interest Rate(%)	3622	13.30	11.12	67.08	4.33
North interest rate (%)	1844	6.08	3.63	20.15	0.50
South Inflation(%)	3996	6.40	5.02	36.60	-0.85
North Inflation(%)	4408	2.82	2.40	21.60	-4.48
South GDP(million)	4408	958,860.26	1575512.78	9619581.22	160382.39
North GDP(million)	4408	1,294,177.15	2931606.72	17016393.93	12670.53
South Trade Openness	4408	0.61	0.41	1.86	0.17
North Trade Openness	4408	0.70	0.36	1.81	0.18
South exchange rate	4408	1,418.35	3267.63	18414.45	1.67
North exchange rate	2567	108.44	261.88	1277.25	0.50
South Population(million)	4408	248.05	412.29	1363.24	3.81
North Population(million)	4408	34.97	58.20	313.88	0.29

[1] FDI and GDP are measured in 2015 US dollars.

[2] Trade openness is defined as $(Import + Export)/GDP$.

[3] Data sources: FDI data are from OECD International Direct Investment Statistics; Other data are from World Development Indicators.