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ABSTRACT

This paper analyzes the effects of stronger intellectual property rights (IPR) protection in the South on innovation, imitation, the pattern of production and wage inequality based on a North-South product-cycle model with foreign direct investment (FDI) and skills accumulation. This quality-ladder model features innovative R&D in the North and imitative R&D in the South. Two types of innovation are considered: innovation targeting all products and innovation targeting only imitated products. We find that for both types of innovation, strengthening IPR protection reduces the innovation rate and raises the imitation rate. There is also an increase in the proportion of Northern unskilled labor and a decrease in Northern wage inequality. As for the pattern of production, the extent of FDI may decrease while the extent of Northern production may increase.

Keywords: Imitation; IPR; R&D; Skills; Wage inequality.

JEL Classification: F11; F23; O31.

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1. INTRODUCTION

Given that it is now very common for international production to be achieved through foreign direct investment (FDI), firms can choose to produce goods domestically or abroad as a means of saving costs. However, due to inadequate protection of intellectual property rights (IPR) in many developing countries, firms need to take the risk of imitation into account when producing goods abroad. This phenomenon has made developed countries like the U.S. and some European countries put forth efforts at improving IPR protection in developing countries during the 1980s, leading to the approval of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) for the Uruguay Round.

Supporters of strengthening IPR protection claim that not only developed countries, but also developing countries can benefit from such strengthening. For developed countries, stronger IPR protection mitigates imitation risk and encourages innovation, while at the same time reducing production cost. Developing countries can benefit from stronger IPR protection by attracting firms to shift their production bases to the developing countries. The increase in FDI flows also has the added advantage of bringing cutting-edge technologies to the developing countries. However, those who are against such strengthening doubt whether FDI activities or innovation intensity will increase with the strengthening of IPR protection. They further argue that the shift of production to the developing countries will reduce the demand for unskilled workers and enlarge the wage inequality in the developed countries.

Most studies in the theoretical literature examining the effects of stronger IPR protection tend to assume that imitation is costless and model the strengthening of IPR protection as an exogenous reduction in imitation intensity. Based on a model where innovation involves the development of new varieties, Lai (1998) demonstrates that strengthening IPR protection in developing countries will raise both the innovation rate and FDI flows. However, Glass and Wu (2007) find that if innovation involves upgrading the quality of products, then the effects of such strengthening depend on the targets of imitation. If innovation targets all types of products, stronger IPR protection will raise both innovation intensity and FDI flows, but if innovation targets only imitated products, stronger IPR protection will cause reverse effects on the innovation rate and FDI flows. These studies indicate that the nature of the innovation process (innovation involving variety enlargement or quality improvement) and the targets of innovation are important determinants to the effects of IPR protection.

Although assuming that imitation intensity is costless can simplify the analysis, empirical studies find that imitation is in fact a costly process. Levin et al. (1987) report that “patents raise imitation costs by about forty percentage points for both major and typical new drugs, but about thirty percentage points for major new chemical products, and by twenty-five percentage points for typical chemical products.” Therefore, introducing imitation costs into the economic analysis of IPR protection endogenizes rivals' imitation decisions and may generate different results. By modeling the strengthening of IPR protection as an increase in the cost of imitation, Glass and Saggi (2002) show that such strengthening is accompanied by a reduction in the innovation rate due to labor wastage and imitation tax effects.[1]

Although the change in wage inequality in developed countries is one of the major concerns regarding the effects of IPR protection and FDI, very few theoretical studies focus on this concern due to the complexity of the model caused by the setting of the heterogeneous agents in the developed countries.[2] An examination of the effects of outsourcing and IPR protection on wage inequality is found in Sayek and Sener (2006) and Benz (2012),[3] but the fraction of skilled (unskilled) population is not endogenized and is assumed to be constant in both studies. As a result, their analyses focus on the demand-side effect as firms adjust labor demand in response to changes in outsourcing costs or Southern IPR protection and ignore the fact that these changes will also affect labor supplies of skilled and unskilled workers.[4]

In this paper we revisit the issue of the effects of stronger IPR protection in developing countries. In particular, we consider a North-South general-equilibrium model with costly imitation and heterogeneous Northerners.[5] This quality-ladder model features innovative R&D in the North (a developed country) and imitative R&D in the South (a developing country). Innovation improves the quality of goods and Northern innovative firms hire skilled Northern workers to engage in R&D activity. The skill choice of Northerners is endogenized - that is, Northerners can choose to become skilled workers and work in the R&D sector or remain unskilled and work in the production sector.

Northern production firms could choose either to carry out the entire production of the goods in the North or allow the goods to be produced through FDI in the South. Multinational firms produce products in the South through the use of state-of-the-art technologies in order to take advantage of the lower Southern wage rate, but they face the risk of imitation by Southern firms. Southern firms can invest in imitation and strengthening IPR protection in the South will raise the

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1 See Gallini (1992) and Pepall and Richards (1994) for studies that allow for non-trivial imitation.

2 Recently, studies of Chu (2010) and Cozzi and Galli (2013) examine the effects of patent protection on income/wage inequality for a closed economy. Based on a quality-ladder model, Chu (2010) finds that strengthening patent protection will raise income inequality. Based on a structure of a two-stage cumulative innovation, Cozzi and Galli (2013) show that tightening patent protection in basic research has ambiguous effect on wage inequality.

3 Lai (1995) and Chen (2013) also adopt the setting of heterogeneity of workers to examine the effects of the labor supply on the global distribution of income and the impact of IPR protection on FDI and outsourcing decisions.

4 Based on a model with the existence of heterogeneous workers in both the developed and developing countries, the effect of the strengthening of IPR protection on innovation and FDI is also examined by Parello (2008). However, the results of his study do not provide any clear direction of the effects of the strengthening of IPR protection on either innovation or FDI due to the complexity of the model.

5 The North-South product-cycle model is originally introduced by Vernon (1966) and subsequently developed by Segerstrom, Anant and Dinopoulos (1990) and Grossman and Helpman (1991a, 1991b).

cost of imitation. Once Southern firms succeed in imitation, they will be able to use the state-of-the-art technologies to produce the highest quality products. Traditionally, stronger IPR protection is modeled as an exogenous *reduction* in the imitation rate. However, with the endogeneity of imitation intensity, stronger IPR protection may *increase* or *decrease* the imitation rate.

Two scenarios of innovation are considered herein. In the first scenario, Northern innovation targets all types of products. Stronger IPR protection in the South will lead to an increase in the incentives of Northern firms to shift production to the South, causing a reduction in the demand for Northern unskilled labor. However, the increases in FDI flows and the labor cost of imitation raise the demand for Southern labor, thereby restoring the rewards of Northern production. This will cause a decrease in the extent of FDI and an increase in the demand for Northern unskilled labor. We find that there will be an overall increase in the fraction of Northern unskilled labor and a decrease in Northern wage inequality, thereby reducing the innovation rate and raising the imitation rate. As for the pattern of production, the extent of Northern production will increase while the extent of FDI will decrease if strengthening IPR protection in the South reduces adjusted global expenditure.

In the second scenario, only those products imitated by Southern firms will be targeted by Northern innovation.[6] The stronger IPR protection affects Northern wage inequality through three channels. First, it raises the demand for Northern skilled labor due to an increase in the incentive of innovation, causing an increase in Northern wage inequality. Second, since innovation targets only imitated goods, the reduction in imitation risk means that there are fewer products imitated by Southern firms, and this will reduce the demand for Northern skilled labor, thereby decreasing Northern wage inequality. Third, the increase in the demand for Southern labor due to increases in the extent of FDI and the requirement of Southern labor for imitation will restore the rewards of Northern production, thereby generating increases in the extent of Northern production and the demand for Northern unskilled labor and a reduction in Northern wage inequality. We find that there will be an overall increase in the proportion of unskilled workers in the North, along with corresponding decreases in Northern wage inequality, the extent of FDI and the innovation rate.

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6 Glass and Wu (2007) also adopt the same innovation setting, where innovators are separated into leaders and followers, with those firms developing the most recent quality improvement being the leaders. If followers are as efficient as leaders, then innovation will target all types of products. If followers are less efficient than leaders, then innovation will be undertaken only by leaders and leaders will not undertake further innovation until Southern firms have imitated their most recent innovation. Acemoglu and Akcigit (2012) study to what extent should the IPR of innovators be protected based on a model where followers can copy the technology of the leader. With quantitative investigation of the implications of different types of IPR protection on the equilibrium growth rate and welfare, they find that full patent protection is not optimal.

Moreover, the strengthening of Southern IPR protection will raise the imitation rate, but its effect on the pattern of production is ambiguous.

Stronger IPR protection in the South which raises the incentives for innovation and the motivation to shift production from the North to the South will cause different effects on the demand of skilled and unskilled labor in the North. Moreover, the endogeneity of imitation risk allows for the re-allocation of Southern labor between the production sector and imitation sector in response to the strengthening of IPR protection. Therefore, when considering the effects of the strengthening of IPR protection, the character of Northern labor (homogeneous v.s. heterogeneous Northern workers) and the nature of the imitation process (exogenous v.s. endogenous imitation risk) matter. Our finding that stronger Southern IPR protection will raise the imitation rate while reducing the innovation rate and the extent of FDI also provides one possible explanation why this policy may not generate the desired effects as expected by the North and the South.

The remainder of this paper is organized as follows. The next section develops a model where innovation targets all products and then examines the effects of the strengthening of IPR protection under a balanced-growth-path (BGP) equilibrium. Section 3 develops and studies a model where innovation targets only imitated goods. The final section concludes.

2. THE MODEL

We develop a North-South quality-ladder model with skills accumulation based on Dinopoulos and Segerstrom (1999) and Parello (2008). There exist a developed Northern country (*N*) and a developing Southern country (*S*). Each economy ($i = \{N, S\}$) is comprised of $L_i(t)$ households at time *t*. In both countries, each individual has a lifespan of *T* periods. Given the birth rate, θ, and the death rate, δ, in both countries, the population dynamics imply that $\theta L_i(t) = \delta L_i(t+T)$. The growth rate of the population, g, is equal to $(\theta - \delta)$, and this indicates that $L_i(t+T) = L_i(t)e^{gT}$.[7]

2.1. Consumers

The lifetime utility of the representative household in country i is:

$$U_i(0) = \int_0^{\infty} L_i(0)e^{-(\rho-g)t} \log u_i(t)\, dt, \qquad L_i(0) > 0, \qquad \rho > g, \tag{1}$$

where ρ denotes the subjective discount factor, and $\log u_i(t)$ is the instantaneous utility faced by a representative household.

Consumers living in either countries care about both the quantity and quality of goods and can choose from a continuum of products $z \in [0,1]$ available at different quality levels (j). Each quality

[7] Note that the population dynamics indicate that $\theta = ge^{gT}/(e^{gT} - 1)$ and $\delta = g/(e^{gT} - 1)$.

level 'j' is better than quality level '$j-1$' by λ times, where the size of the quality increment λ is assumed to be constant and greater than 1. All products begin at time $t = 0$ with a quality level $j = 0$ and a base quality $\lambda^0 = 1$. This indicates that each product of quality level j provides quality λ^j. The instantaneous utility faced by a representative household in country i is:

$$log\, u_i(t) = \int_0^1 log\left[\sum_j \lambda^j q_{ij}(z,t)\right] dz, \tag{2}$$

where $q_{ij}(z,t)$ is the household consumption in country i for quality level j of product z at time t.

Let $W_i(t)$, $A_i(t)$, and $E_i(t)$ respectively represent the sum of the discount wage income of the household from country i, the value of assets that the household holds at time t, and the total expenditure. The aggregate intertemporal budget constraint is:

$$W_i(t) + A_i(t) = \int_t^\infty L_i(0)[E_i(t) + g_G]e^{g\tau}e^{-[R(\tau)-R(t)]}d\tau, \tag{3}$$

where $g_G \geq 0$ is a lump-sum tax in every period. The cumulative interest rate, up to time t, is given by $R(t) = \int_0^t r(\tau)d\tau$, where $r(\tau)$ is the instantaneous interest rate at time τ. The total expenditure for all products with different quality levels under price $p_{ij}(z,t)$ is:

$$E_i(t) = \int_0^1 \left[\sum_j p_{ij}(z,t)q_{ij}(z,t)\right] dz. \tag{4}$$

The optimization problem can be solved by three steps. First, the expenditure for each product across available quality levels at each instant is allocated in a such way that consumers choose the quality that gives the lowest adjusted price, $\frac{p_{j(z,t)}}{\lambda^j}$. This implies that consumers are willing to pay λ for a single quality level improvement in a product.

Second, consumers allocate expenditures across products at each instant. Note that expenditure across all products will be the same since the elasticity of substitution between any two products is constant at unity. This leads to a global demand function for product z of quality j at time t equal to $q_j(z,t) = E(t)/p_j(z,t)$, where $E(t) = E_N(t)L_N(t) + E_S(t)L_S(t)$ represents global expenditure.

Finally, consumers allocate lifetime wealth across time by maximizing lifetime utility subject to the intertemporal budget constraint. This gives the optimal expenditure path for the representative agent in each country:

$$\frac{\dot{E}_i(t)}{E_i(t)} = r(t) - \rho\,. \tag{5}$$

In the following analysis, we focus on the balanced-growth-path (BGP) equilibrium where $r(t) = \rho$ holds.

2.2. Accumulation of skills

All Southerners are unskilled workers and spend all of their time at work to earn the wage rate w_S, which is normalized to 1. Agents in the North can choose to remain unskilled and earn the wage rate w_N^L, or choose to spend the time period (D_N) in school for skill training (human capital accumulation). After completing the education, skilled Northerners will receive the skilled wage rate w_N^H per unit of effective labor.

The accumulation of skills depends on public spending in education and time spent in schools. Public educational spending is financed by tax revenue and the government runs a balanced budget. We assume that each Northerner needs to pay a lump-sum tax of $g_G > 0$ in every period.[8] This implies that the total Northern public educational spending in period t is $G_N = g_G L_N$. We use ϕ_N to denote the proportion of the unskilled population in the North, and it is endogenously determined. The remaining $(1-\phi_N)L_N(t)$ individuals either attend schools for skill training or work as skilled workers. All skilled Northerners can benefit from public educational spending.[9] The subsidy received by each Northern skilled worker is $g_N = \frac{G_N}{(1-\phi_N)L_N}$.[10]

Each Northerner chooses to receive education if the income of being a skilled worker is greater or equal to the income of being an unskilled worker; that is:

$$\int_t^{t+T} e^{-[R(\tau)-R(t)]}\, w_N^L d\tau \leq \int_{t+D_N}^{t+T} e^{\,-[R(\tau)-R(t)]} w_N^H h_N(D_N) {g_N}^{\gamma} d\tau, \tag{6}$$

where $\gamma \in (0,1)$ denotes the elasticity of accumulation of skills with respect to the public educational investment. The function $h_N(D_N)$ with $h_N'(D_N) > 0$ and $h_N''(D_N) < 0$ represents the skill production function of the amount of time spent in schools. Therefore, $h_N(D_N){g_N}^{\gamma}$ represents one efficiency unit of skilled labor.[11]

In the equilibrium with the co-existence of skilled and unskilled workers in the North, equation (6) holds with equality. The optimal time spent in schools $(\overline{D}_N)$ is determined by the following equation:

$$\rho h_N(\overline{D}_N) = \left(1 - e^{-\rho(T-\overline{D}_N)}\right) h_N'(\overline{D}_N). \tag{7}$$

Substituting the solution of $\overline{D}_N$ in (7) into (6), wage inequality (measured by the wage of skilled workers divided by the wage of unskilled workers) in the North can be expressed as:

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8 Note that $g_G = 0$ in the South since Southerners do no accumulate skills.

9 Public educational spending provides on-the-job training for those Northern workers who have completed education in order to prevent their human capital from depreciation.

10 Note that $g_N = G_N/[(1-\phi_N)L_N] = g_G/(1-\phi_N)$.

11 See Glomm and Ravikumar (1992), Kaganovich and Zilcha (1999) and Chen (2005, 2006) for the literature of accumulation of human capital.

$$\frac{w_N^H}{w_N^L} = w_N = \frac{\sigma_N(\bar{D}_N)(1-\phi_N)^\gamma}{h_N(\bar{D}_N)g_G{}^\gamma}\,, \tag{8}$$

where $\sigma_N(\bar{D}_N) = \frac{1-e^{-\rho T}}{e^{-\rho \bar{D}_N}-e^{-\rho T}} > 1$. In this paper, we assume that $w_N > 1$.

The supply of Northern unskilled labor (L_N^L) is:

$$L_N^L = \phi_N L_N\,.$$

In the subpopulation of Northerners who choose to become skilled, the working agents are those born between period $(t-T)$ and $(t-\bar{D}_N)$:

$$\int_{t-T}^{t-\bar{D}_N} \theta\,(1-\phi_N)L_N(\tau)d\tau = (1-\phi_N)B_N(\bar{D}_N)L_N(t),$$

where $B_N(\bar{D}_N) = \left(e^{g(T-\bar{D}_N)}-1\right)/(e^{gT}-1) < 1$. The supply of effective Northern skilled labor (L_N^H) is then:

$$L_N^H = (1-\phi_N)B_N(\bar{D}_N)h_N(\bar{D}_N)g_N{}^\gamma L_N = \psi_N(\phi_N)L_N\,, \tag{9}$$

where $\psi_N(\phi_N) = B_N(\bar{D}_N)h_N(\bar{D}_N)g_G{}^\gamma(1-\phi_N)^{1-\gamma}$.

2.3. Producers

Innovation occurs only in the North and all existing products are the targets of innovation. We assume that R&D difficulty ($X(t)$) is positively correlated with the size of the Northern population; that is, $X(t) = \kappa L_N$ with $\kappa > 0$.[12] This assumption takes into account the concept that introducing new products to replace old ones is more difficult in a larger market.

Northern firms engaging in R&D activity hire skilled Northern workers and produce cutting-edge quality products through innovation. A Northern firm in industry z engaged in innovation intensity $\iota_R(z,t)$ will achieve one level of quality improvement in the final product with a probability $\iota_R(z,t)dt$ for a time interval dt. In order to achieve this, $a_R\iota_R(z,t)X(t)dt$ units of labor will be required at a total cost of $w_N^H a_R\iota_R(z,t)X(t)dt$.

After succeeding in innovating a higher-level quality product, a Northern firm can undertake its production in the North by hiring unskilled Northern workers or carry out its production in the South, lowering its costs through FDI by hiring Southern workers to carry out this production.[13] Let v_N denote the expected discounted value of a Northern firm that has discovered a new product. To generate a finite rate of innovation, expected gains from innovation cannot exceed the costs, with equality being achieved when innovation occurs with positive intensity; that is:

$$v_N \le w_N^H a_R X,\ \iota_R > 0 \Leftrightarrow v_N = w_N^H a_R X\,. \tag{10}$$

Northern firms can optimally choose the intensity of FDI. To simplify the model, we assume

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12 This is referred to as the *permanent effects on growth* approach in Dinopoulos and Segerstrom (1999).

13 Equation (32) indicates that $w_N^L > w_S = 1$.

that FDI is costless.[14] Let v_F and ι_F respectively represent capital gains from undertaking production in the South through FDI and FDI intensity. All Northern firms will choose to shift their productions to the South through FDI if $v_F > v_N$, while FDI intensity will be zero if $v_F < v_N$. Therefore, a Northern firm will feel indifferent between producing in the North or in the South, and FDI will occur with positive intensity:

$$v_F = v_{N.} \tag{11}$$

Although Northern firms undertaking production in the South through FDI can save costs of production, they face the risk of imitation, which is denoted by ι_S. A Southern firm engaged in imitation intensity $\iota_S(z,t)$ for a time interval dt requires $a_S(1+\mu)\iota_S(z,t)X(t)dt$ units of labor. With the cost of $w_S a_S(1+\mu)\iota_S(z,t)X(t)dt$, the Southern firm can successfully imitate the final product with a probability of $\iota_S(z,t)dt$. Strengthening IPR protection in the South increases the cost of imitation and causes an exogenous increase in μ. Let v_S be the expected gains of imitation, and then we have:

$$v_S \leq w_S a_S(1+\mu)X,\ \iota_S > 0 \iff v_S = w_S a_S(1+\mu)X\ . \tag{12}$$

We assume that that one unit of labor will be needed to produce one unit of the final product, regardless of the location of production. Old technologies that designs have been improved are available internationally; therefore, Southern firms are able to produce final goods by using old technologies. Following Howitt (1999), we assume that once a Northern firm has exited the market, it will not reenter the market because maintaining unused production and R&D facilities is costly.[15] Then Northern firms which produce through the use of state-of-the-art technologies will charge the price equal to the size of the improvement in quality times the marginal cost of closest rivals since they possess a one quality level lead over the closest rivals; that is, $p = \lambda$ (and make a sale $q = E/\lambda$). When successful at adapting its technology for Southern production, multinationals can earn a higher profit through by charging the price $p = \lambda$ and hiring Southerners for production. Multinationals face higher production costs relative to Southern firms and the unit labor requirement for multinational equals ξ which is greater than one.[16]

When successful at imitating the technology of multinationals, a Southern firm is able to capture the entire industry market by setting a price that is slightly lower than ξ. As maintaining unused production and R&D facilities are costly, the Northern rival which has exited the market will

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[14] Glass and Wu (2007) also adopt the same simplified setting of FDI.

[15] Previous studies tend to assume that either it is free to reenter the market for both Northern and Southern firms (Glass and Saggi, 2002) or it is costly to reenter the market for both Northern and Southern firms (Parello, 2008). Since comparing with Southern firms (imitators), it is more costly for Northern firms (innovators) to maintain unused production and R&D facilities once they have exited the market, we then follow Howitt (1999) and assume that it is costly for innovators to reenter the market.

[16] The same setting of production cost for multinationals is also adopted by Glass and Saggi (2002) and Parello (2008).

not reenter, then the Southern firm will raise its price to λ. This price is the Nash equilibrium price since the Southern firm has no incentive to deviate from it and the presence of positive costs for unused production and R&D facilities ensures that the former Northern rival will not reenter the market. In equilibrium, only the highest quality level available will sell.

Since the cost of firms completing one unit of final production in the North is w_N^L, the instantaneous profits for Northern production are:

$$\pi_N = \frac{E}{\lambda}(\lambda - w_N^L). \tag{13}$$

The instantaneous profits for FDI are therefore:

$$\pi_F = \frac{E}{\lambda}(\lambda - \xi). \tag{14}$$

Since the marginal cost for a Southern firms is the Southern wage rate, the instantaneous profits for a Southern firm which is successful at imitating the technology of multinationals are the same as multinationals:

$$\pi_S = \frac{E}{\lambda}(\lambda - 1). \tag{15}$$

The no-arbitrage condition that determines v_N is:

$$r(t) = \frac{\dot{v}_N(t) + \pi_N(t) - \iota_R v_N(t)}{v_N(t)}. \tag{16}$$

Equation (16) equates the real interest rate to the asset return per unit of asset for Northern production. The asset return includes (i) any potential capital gain $\dot{v}_N(t)$; (ii) profits of successful R&D; and (iii) the expected capital loss $-\iota_R v_N(t)$ from creative destruction.

The no-arbitrage condition that determines v_F is:

$$r(t) = \frac{\dot{v}_F(t) + \pi_F(t) - (\iota_R + \iota_S) v_F(t)}{v_F(t)}. \tag{17}$$

Equation (17) equates the real interest rate to the asset return per unit of asset for FDI. The asset return is the sum of (i) any potential capital gain $\dot{v}_F(t)$; (ii) profits of a successful imitation; (iii) the expected capital loss $-\iota_R v_F(t)$ from creative destruction; and (iv) the expected capital loss $-\iota_S v_F(t)$ from imitation.

The no-arbitrage condition that determines v_S is:

$$r(t) = \frac{\dot{v}_S(t) + \pi_S(t) - \iota_R v_S(t)}{v_S(t)}. \tag{18}$$

Equation (18) equates the real interest rate to the asset return per unit of asset for Southern production. The asset return is the sum of (i) any potential capital gain $\dot{v}_S(t)$; (i) profits of a successful imitation; and (iii) the expected capital loss $-\iota_R v_S(t)$ from creative destruction.

2.4. Factor markets and the BGP equilibrium

We focus our analysis on the BGP equilibrium. Equations (10)-(12) together imply that along the BGP equilibrium:

$$\frac{\dot{v}_N(t)}{v_N(t)} = \frac{\dot{v}_F(t)}{v_F(t)} = \frac{\dot{v}_S(t)}{v_S(t)} = \frac{\dot{X}(t)}{X(t)} = \frac{\dot{L}_N(t)}{L_N(t)} = g. \tag{19}$$

Substituting (19) into (16)-(18) and using the condition that $r(t) = \rho$, we can derive v_N, v_F and v_S as:

$$v_N = \frac{\pi_N}{\rho - g + \iota_R}, \tag{20}$$

$$v_F = \frac{\pi_F}{\rho - g + \iota_R + \iota_S}, \tag{21}$$

$$v_S = \frac{\pi_S}{\rho - g + \iota_R}. \tag{22}$$

Let n_N, n_F, and n_S respectively denote the proportion of products produced completely in the North (the extent of Northern production), the proportion of the goods for which production is carried out through FDI (the extent of FDI) and the proportion of products produced completely in the South (the extent of Southern production). The sum of these product measures should be one:

$$n_N + n_F + n_S = 1. \tag{23}$$

Along the BGP equilibrium, the flows into FDI activities and Southern production equal the flows out of them:

$$\iota_F n_N = (\iota_R + \iota_S) n_F, \tag{24}$$

$$\iota_S n_F = \iota_R n_S. \tag{25}$$

Skilled Northern labor is used for the R&D sector, while unskilled Northern labor is used for the production sector. The labor-market clearing conditions for skilled and unskilled labor in the North are respectively:

$$a_R \iota_R X = \psi_N(\phi_N) L_N, \tag{26}$$

$$n_N \frac{E}{\lambda} = \phi_N L_N. \tag{27}$$

The labor-market clearing condition for the South indicates that:

$$(n_F + n_S)\frac{E}{\lambda} + a_S(1+\mu)\iota_S n_F X = L_S. \tag{28}$$

We define two stationary variables as the adjusted level of R&D difficulty, $x = X/L_N = \kappa$, and the adjusted global expenditure, $\hat{E} = E/L_N$. Substituting (10)-(15) into (20)-(22), we obtain:

$$\hat{E}\left(1 - \frac{w_N^L}{\lambda}\right) = (\rho - g + \iota_R) w_N^H a_R \kappa, \tag{29}$$

$$\hat{E}\left(1-\frac{\xi}{\lambda}\right)=(\rho-g+\iota_R+\iota_S)w_N^H a_R \kappa. \tag{30}$$

$$\hat{E}\left(1-\frac{1}{\lambda}\right)=(\rho-g+\iota_R)w_S a_S(1+\mu)\kappa. \tag{31}$$

Note that w_S equals one. Then the economy is described by (7), (8) and (23)-(31) with eleven variables $\{w_N^H, w_N^L, \overline{D}_N, \phi_N, \hat{E}, n_N, n_F, n_S, \iota_R, \iota_S, \iota_F\}$. Using (29) and (30), we derive the wage rates as:

$$w_N^L=\frac{\xi(\rho-g+\iota_R)+\lambda\iota_S}{\rho-g+\iota_R+\iota_S}, \tag{32}$$

$$w_N^H=\frac{\hat{E}(\lambda-\xi)}{\lambda a_R\kappa(\rho-g+\iota_R+\iota_S)}. \tag{33}$$

From (31), we can express $\hat{E}$ as a function of ι_R:

$$\hat{E}(\iota_R)=\frac{\lambda a_S(1+\mu)\kappa(\rho-g+\iota_R)}{\lambda-1}. \tag{34}$$

Combining (32) and (33) and using (34) to substitute $\hat{E}$ in (33), we derive ι_S as:

$$\iota_S=\frac{\rho-g+\iota_R}{\lambda}\left[\frac{(\lambda-\xi)a_S(1+\mu)}{(\lambda-1)a_R w_N}-\xi\right]. \tag{35}$$

Substituting w_N in (35) by using (8), we now express ι_S as a function of ϕ_N and ι_R:

$$\iota_S(\phi_N,\iota_R)=\frac{\rho-g+\iota_R}{\lambda}\left[\frac{(\lambda-\xi)a_S(1+\mu)h_N(\overline{D}_N)g_G{}^{\gamma}}{(\lambda-1)a_R\sigma_N(\overline{D}_N)(1-\phi_N)^{\gamma}}-\xi\right]. \tag{36}$$

Using (34) to substitute $\hat{E}$ in (27), we derive $n_N=n_N(\phi_N,\iota_R)=\frac{\lambda\phi_N}{\hat{E}(\iota_R)}$. Combining (23), (25), and (36), we obtain $n_F=n_F(\phi_N,\iota_R)=\frac{\iota_R[1-n_N(\phi_N,\iota_R)]}{\iota_S(\phi_N,\iota_R)+\iota_R}$ and $n_S=n_S(\phi_N,\iota_R)=1-n_N(\phi_N,\iota_R)-n_F(\phi_N,\iota_R)$. From (24), we derive $\iota_F=\iota_F(\phi_N,\iota_R)=\frac{(\iota_R+\iota_S)n_F(\phi_N,\iota_R)}{n_N(\phi_N,\iota_R)}$. Finally, using (26) and (28), the equilibrium can be reduced to the following two equations in ϕ_N and ι_R:

$$\iota_R=\frac{\psi_N(\phi_N)}{a_R\kappa}, \tag{37}$$

$$[n_F(\phi_N,\iota_R)+n_S(\phi_N,\iota_R)]\frac{\hat{E}(\iota_R)}{\lambda}+a_S(1+\mu)\iota_S(\phi_N,\iota_R)n_F(\phi_N,\iota_R)\kappa=\frac{L_S}{L_N}. \tag{38}$$

Because $\frac{d\psi_N}{d\phi_N}<0$, equation (37) implies a negative relationship between ϕ_N and ι_R. In Appendix A, we show that if a_S is sufficiently small, then (38) will imply a positive relationship between ϕ_N and ι_R. Equations (37) and (38) are respectively represented by the *NN* locus and *SS* locus in Figure 1, and these are two equations that implicitly solve for the equilibrium values of $\{\phi_N,\iota_R\}$. Once one derives the solution of $\{\phi_N,\iota_R\}$, the remaining endogenous variables can be solved accordingly.[17]

<Figure 1 is inserted about here>

2.5. Effects of IPR protection

We are now ready to examine the effects of stronger Southern IPR protection. To facilitate our analysis, we assume that a_S is sufficiently small in this section. Strengthening IPR protection lowers imitation risk, thereby motivating Northern firms to shift their production to the South. Equation (21) indicates that a lower ι_S *ceteris paribus* raises v_F, increasing the motivation of FDI, reducing the demand for Northern unskilled labor and causing an increase in Northern wage inequality. However, stronger IPR protection raises the requirement of Southern labor for imitation activity. Together with an increase in the motivation of FDI, the demand for Southern labor will increase and this will restore rewards of Northern production and motivate firms to carry out production in the North. The increase in the extent of Northern production will raise the demand for Northern unskilled labor. We find that there will be an overall increase in the proportion of Northern unskilled labor, thereby reducing the innovation rate. Equation (8) indicates that a decrease in the proportion of Northern skilled labor will cause a reduction in Northern wage inequality.

As illustrated in Figure 1, a higher μ shifts the *SS* locus downward while leaving the *NN* locus unaffected, leading to a lower innovation rate and a higher fraction of Northern unskilled workers. The following proposition summarizes these findings.

Proposition 1. When Northern innovation targets all products, strengthening IPR protection in the South leads to (a) a reduction in Northern wage inequality; (b) an increase in the proportion of Northern unskilled workers; and (c) a decrease in the innovation rate.[18]

Equation (35) indicates that the strengthening of IPR protection in the South will affect imitation intensity through three channels of ι_R, μ and w_N. First, the lower innovation rate caused by stronger IPR protection will reduce imitation intensity. Second, the higher imitation cost (an increase in μ) raises the expected gains of imitation under the no-arbitrage condition that determines v_S as indicated by (31) and causes an increase in adjusted global expenditure (equation (34)), inducing an increase in imitation intensity. Third, the decrease in Northern wage inequality decreases the cost of Northern production, lowering the incentives of Southern firms to allocate Southern labor in the production sector and increasing the incentives to allocate Southern labor in the imitation sector. This will raise imitation intensity. In Appendix B, we show that if a_R is

[17] See Appendix A for more details.
[18] Appendix B presents the proofs of Propositions 1 and 2.

sufficiently large, then strengthening Southern IPR protection will result in an increase in imitation intensity. Equation (32) indicates that both the decrease in innovation intensity and the increase in imitation intensity will raise the wage rate of Northern unskilled workers. Because the wage rate of Southern (unskilled) workers is normalized to one, this means that the international wage dispersion of unskilled labor (which is measured by the ratio of the wage rate of unskilled Northerners to the wage rate of unskilled Southerners) will increase. Therefore, we have the following proposition.

Proposition 2. When Northern innovation targets all products, then strengthening IPR protection in the South will raise imitation intensity and the international wage dispersion of unskilled labor if a_R is sufficiently large.

The no-arbitrage condition that determines v_S (equation (31)) indicates that there are two opposite effects caused by the strengthening of IPR protection on adjusted global expenditure as demonstrated by (34). A higher μ caused by the strengthening of IPR protection raises adjusted global expenditure while a lower innovation intensity reduces it. Therefore, adjusted global expenditure may increase or decrease, depending on which effect dominates. From the market-clearing condition of unskilled labor in the North shown in (27), the extent of Northern production is determined by adjusted global expenditure and the fraction of Northern unskilled labor. Hence, the change of the extent of Northern production is ambiguous.

Combining (23) and (25) yields :

$$n_F = \frac{\iota_R(1 - n_N)}{\iota_S + \iota_R}.$$

With the ambiguous change in the extent of Northern production, we are not able to determine the change in the extent of FDI. However, if strengthening IPR protection in the South reduces adjusted global expenditure, then the extent of Northern production will increase and decrease the extent of FDI, leaving the change of the extent of Southern production undetermined.[19]

3. INNOVATION TARGETS ONLY IMITATED PRODUCTS

In Section 2 all products are the targets of Northern innovation. One may wonder if the results are sensitive to the setting of Northern innovation. Will the results remain robust if North innovation targets only those products imitated and produced by Southern firms? In order to answer this question, we modify some of the equations relating to innovation. Since innovation in the North does not target the products of other Northern firms, the expected capital loss from creative

[19] See Appendix B for more details.

destruction does not affect the asset return of firms that carry out production in the North and the no-arbitrage condition that determines v_N becomes:

$$r(t) = \frac{\dot{v}_N(t) + \pi_N(t)}{v_N(t)}. \tag{39}$$

The expected capital loss from creative destruction does not affect the asset return of multinationals and the no-arbitrage condition that determines v_F becomes:

$$r(t) = \frac{\dot{v}_F(t) + \pi_F(t) - \iota_S v_F(t)}{v_F(t)}. \tag{40}$$

Therefore, the reward for successful innovation by a Northern firm and the reward for multinationals become higher:

$$v_N = \frac{\pi_N}{\rho - g}. \tag{41}$$

$$v_F = \frac{\pi_F}{\rho - g + \iota_S}. \tag{42}$$

At the BGP equilibrium, FDI inflows equal FDI outflows, with this condition becoming:

$$\iota_F n_N = \iota_S n_F, \tag{43}$$

Because only imitated products produced by Southern firms are the targets of Northern innovation, the labor-market clearing condition for the Northern skilled labor becomes:

$$a_R \iota_R n_S X = \psi_N L_N, \tag{44}$$

It should be noted that all other equations remain unchanged.[20]

3.1. The BGP equilibrium

Substituting (10) and (13) into (41) as well as (11) and (14) into (42) yields:

$$\hat{E}\left(1 - \frac{w_N^L}{\lambda}\right) = (\rho - g) w_N^H a_R \kappa, \tag{45}$$

$$\hat{E}\left(1 - \frac{\xi}{\lambda}\right) = (\rho - g + \iota_S) w_N^H a_R \kappa. \tag{46}$$

The economy is described by (7), (8), (22), (23), (25), (27), (28), (43)-(46) with eleven variables $\{ w_N^H, w_N^L, \overline{D}_N, \phi_N, \hat{E}, n_N, n_F, n_S, \iota_R, \iota_S, \iota_F \}$. Since (31) remains the same, we get the same function of $\hat{E}(\iota_R)$ as presented by (34).

From (45) and (46), we can derive the wage rates of Northern unskilled and skilled labor as:

$$w_N^L = \frac{\xi(\rho - g) + \lambda \iota_S}{\rho - g + \iota_S}, \tag{47}$$

[20] Equations (7), (8), (22), (23), (25), (27), (28) remain unchanged.

$$w_N^H = \frac{\hat{E}(\lambda - \xi)}{\lambda a_R \kappa(\rho - g + \iota_S)}. \tag{48}$$

Using (34) to substitute $\hat{E}$ in (48) and combining (47) and (48), we can derive ι_S as:

$$\iota_S = \frac{1}{\lambda}\left[\frac{(\lambda - \xi)a_S(1+\mu)(\rho - g + \iota_R)}{(\lambda - 1)a_R w_N} - \xi(\rho - g)\right]. \tag{49}$$

Substituting (8) into (49), we now express ι_S as a function of ϕ_N and ι_R:

$$\iota_S(\phi_N, \iota_R) = \frac{1}{\lambda}\left[\frac{(\lambda - \xi)a_S(1+\mu)(\rho - g + \iota_R)h_N(\bar{D}_N)g_G{}^{\gamma}}{(\lambda - 1)a_R\sigma_N(\bar{D}_N)(1 - \phi_N)^{\gamma}} - \xi(\rho - g)\right]. \tag{50}$$

Combining (27) and (34), we derive $n_N = n_N(\phi_N, \iota_R) = \frac{\lambda\phi_N}{\hat{E}(\iota_R)}$. From (44), we obtain $n_S = n_S(\phi_N, \iota_R) = \frac{\psi_N(\phi_N)}{a_R\kappa\iota_R}$. Combining (25), (44), and (50), we derive $n_F = n_F(\phi_N, \iota_R) = \frac{\psi_N(\phi_N)}{a_R\kappa\iota_S(\phi_N,\iota_R)}$. From (43), we then calculate $\iota_F = \iota_F(\phi_N, \iota_R) = \frac{\iota_S n_F(\phi_N,\iota_R)}{n_N(\phi_N,\iota_R)}$. Equation (23) then becomes:

$$n_N(\phi_N, \iota_R) + n_F(\phi_N, \iota_R) + n_S(\phi_N, \iota_R) = 1, \tag{51}$$

Using (25), we now rewrite (28) as:

$$[n_F(\phi_N, \iota_R) + n_S(\phi_N, \iota_R)]\frac{\hat{E}(\iota_R)}{\lambda} + a_S(1+\mu)\iota_R n_S(\phi_N, \iota_R)\kappa = \frac{L_S}{L_N}. \tag{52}$$

The equilibrium can thus be reduced to the two equations of (51) and (52) in ϕ_N and ι_R. Appendix C shows that (52) exhibits a negative relationship between ϕ_N and ι_R. Furthermore, if μ is sufficiently large, then (51) will imply a negative relationship between ϕ_N and ι_R. Equations (51) and (52) are respectively represented by the *NI* locus and *SI* locus in Figure 2 and are two equations that implicitly solve for the equilibrium values of $\{\phi_N, \iota_R\}$. The other endogenous variables are solved accordingly once we get the solution of $\{\phi_N, \iota_R\}$.

<Figure 2 is inserted about here>

3.2. Effects of IPR protection

We are now ready to examine the effects of strengthening IPR protection in the South when innovation targets only imitated products. In the following analysis in this section, we assume that μ is sufficiently large. As indicated in Figure 2, strengthening IPR protection will cause a downward shift in the *NI* locus and an upward shift in the *SI* locus, resulting in a lower rate of innovation and a higher proportion of unskilled workers in the North.

Strengthening IPR protection lowers imitation risk, thereby motivating Northern firms to shift their production to the South. Equation (42) indicates that a decrease in ι_S *ceteris paribus* raises v_F, strengthening the motivation of FDI, reducing the demand of Northern unskilled labor and increasing the Northern wage inequality. However, the reduction in the imitation risk means that there are fewer products imitated by Southern firms. Since innovation targets only imitated goods, this implies that there will be a decrease in the demand for skilled labor in the North, causing Northern wage inequality to decrease. With more Northern firms shifting their production to the South and an increase in the requirement of Southern labor for imitation, the demand for Southern labor will increase. The restoration of the rewards of Northern production will raise the demand for Northern unskilled labor and reduce Northern wage inequality. Our results indicate that if μ is sufficiently large, there will be an overall increase in the proportion of unskilled workers in the North, along with corresponding decreases in Northern wage inequality. The innovation rate will decrease due to a lower proportion of Northern skilled labor available for the R&D sector.

Proposition 3. When Northern innovation targets only products imitated by Southern firms, then strengthening Southern IPR protection will cause (a) a reduction in Northern wage inequality; (b) an increase in the proportion of Northern unskilled workers; and (c) a decrease in the innovation rate.[21]

Equation (49) illustrates that stronger Southern IPR protection affects imitation intensity through three channels of ι_R, μ and w_N. First, the lower innovation intensity induced by stronger IPR protection will reduce imitation intensity. Second, the higher imitation cost (an increase in μ) raises the expected gain of Southern production under the no-arbitrage condition that determines v_S, inducing an increase in imitation intensity. Third, the decrease in Northern wage inequality restores the reward of Northern production and more Southern labor is available for the imitation sector, causing imitation intensity to increase. Appendix D shows that if μ and γ are sufficiently large, then imitation intensity will increase with the strengthening of IPR protection.

Because innovation targets only imitated goods, the profits of Northern production and FDI are not affected by innovation intensity. Combining (45) and (46) yields:

$$\frac{\lambda - w_N^L}{\lambda - 1} = \frac{\rho - g}{\rho - g + \iota_S}. \qquad (53)$$

Equation (53) indicates that there is a negative relationship between w_N^L and ι_S. Therefore, the wage rate of Northern unskilled workers will decrease with the increase in imitation intensity. Because innovation targets only imitated products and imitation only targets products produced through FDI (see (25) and (44)), the labor-market equilibrium condition for the Northern skilled labor can be rewritten as:

$$a_R \kappa \iota_S n_F = \psi_N.$$

This indicates that with the increase in ι_S and the decrease in ψ_N, the extent of FDI will increase. The following proposition summarizes these results.

[21] Appendix D provides the proofs of Propositions 3 and 4.

Proposition 4. When Northern innovation targets only products imitated by Southern firms, then strengthening IPR protection in the South will raise imitation intensity and international wage dispersion of unskilled workers while reducing the extent of FDI if μ and γ are sufficiently large.

As indicated by (34), the higher imitation cost due to stronger IPR protection will raise adjusted global expenditure while the lower innovation intensity will reduce it. Therefore, the change in adjusted global expenditure is ambiguous. From the market-clearing condition of unskilled labor in the North shown in (27), adjusted global expenditure will affect the extent of Northern production. Hence, the effect of stronger IPR protection on the extent of Northern production is also ambiguous. Furthermore, the change of the extent Southern production is also undetermined as indicated by (23). However, if stronger Southern IPR protection reduces adjusted global expenditure, then the extent of Northern production will increase while the change of the extent of Southern production is still undetermined.[22]

Our findings indicate that the strengthening of IPR protection in the South will lead to decreases in both the rate of innovation and FDI activities, regardless of the targets for such innovation. The results on the changes in innovation intensity and FDI under the first scenario where innovation targets all products are quite different from those found by Glass and Wu (2007). There are two major differences between this paper and Glass and Wu (2007): the character of Northern labor and the nature of imitation process. Under the assumptions of homogeneous Northern workers and exogenous imitation risk, Glass and Wu (2007) show that if innovation targets all products, the strengthening of IPR protection in the South will cause a reduction in the labor wage rate in the North, thereby restoring the rewards of Northern production. The consequences of this will be an increase in the rate of innovation. Because the increase in employment in the innovation sector crowds out Northern labor used for production, the extent of Northern production will decrease, causing a corresponding increase in the extent of FDI.

In this paper, the assumption of the heterogeneity among Northern labor allows firms to reallocate Northern labor between the innovation sector and production sector in response to the strengthening of Southern IPR protection. Moreover, we endogenize imitation intensity by assuming that imitation requires Southern labor. With a costly setting of imitation, stronger IPR protection will cause a reallocation of Southern labor between the production sector and imitation sector; as a result, the rate of imitation may increase or decrease. Our results reveal that regardless of the targets of innovation, stronger IPR protection will raise the demand for Southern labor and lower the wage inequality in the North. Comparing the results in these two scenarios, we find that in the second

22 See Appendix D for more details.

scenario where innovation targets only imitated goods, there will be one more force to reduce the demand for Northern skilled labor and Northern wage inequality since stronger IPR protection directly implies that there are fewer products imitated by Southern firms, causing fewer products targeted by innovation. The restoration of the rewards of Northern production will reduce the proportion of Northern skilled labor, resulting in decreases in innovation intensity and the extent of FDI and an increase in imitation intensity. Therefore, this paper highlights the significant roles of heterogeneity among Northern labor and the endogeneity of imitation intensity when analyzing the effects of IPR protection.

4. CONCLUSION

In this paper we examine the effects of strengthening IPR protection in the South on innovation, imitation, Northern wage inequality, and the pattern of production based on a dynamic North-South general-equilibrium model with skill choice. Two scenarios of innovation settings are considered: innovation targets all products or innovation targets only imitated products. We find under both scenarios that strengthening IPR protection in the South will raise the fraction of Northern unskilled labor and reduce wage inequality in the North. Innovation intensity will decrease while imitation intensity will increase. When innovation targets all products, the effect of stronger IPR protection on the pattern of production is ambiguous. If global expenditure increases with the strengthening of IPR protection, then the extent of Northern production will increase while the extent of FDI will decrease. When innovation targets only imitated products, the extent of FDI will decrease with the strengthening of IPR protection. The extent of Northern production will increase if global expenditure increases. Our results reveal that stronger Southern IPR protection may not bring the desired effects on the innovation rate and the extent of FDI if imitation is costly.

Our paper can be extended and applied by several ways to study different issues and we now point out two directions. First, in addition to products produced through FDI, Southern firms can also imitate products produced in the North. Second, Southerners are assumed to be homogeneous in order to simplify our analysis herein. By assuming that Southern workers, like their Northern counterparts, can have a choice of skills, our model can be extended to study the effects of strengthening IPR protection in the South, not only on Northern wage inequality and the skill choice of Northerners, but also on Southern wage inequality and the skill choice of Southerners.

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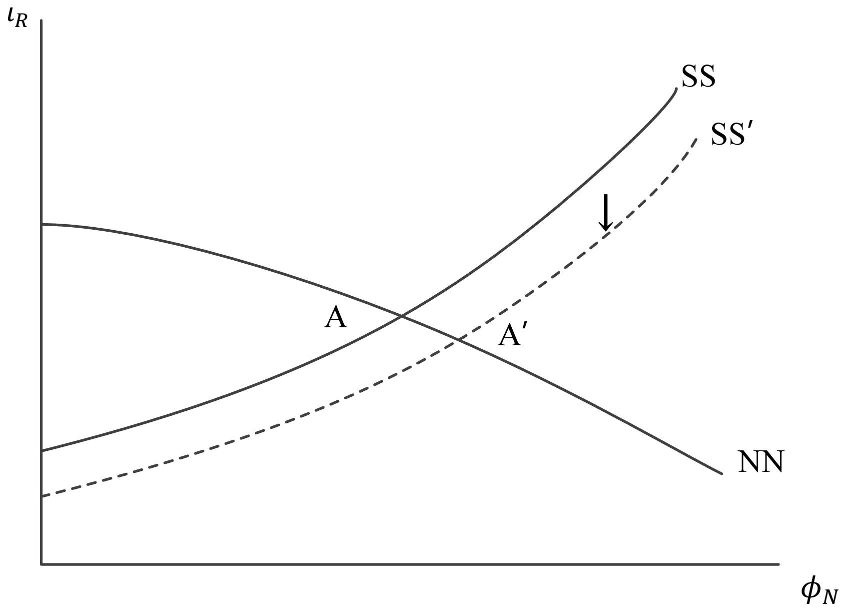

Figure 1. The BGP equilibrium when innovation targets all products

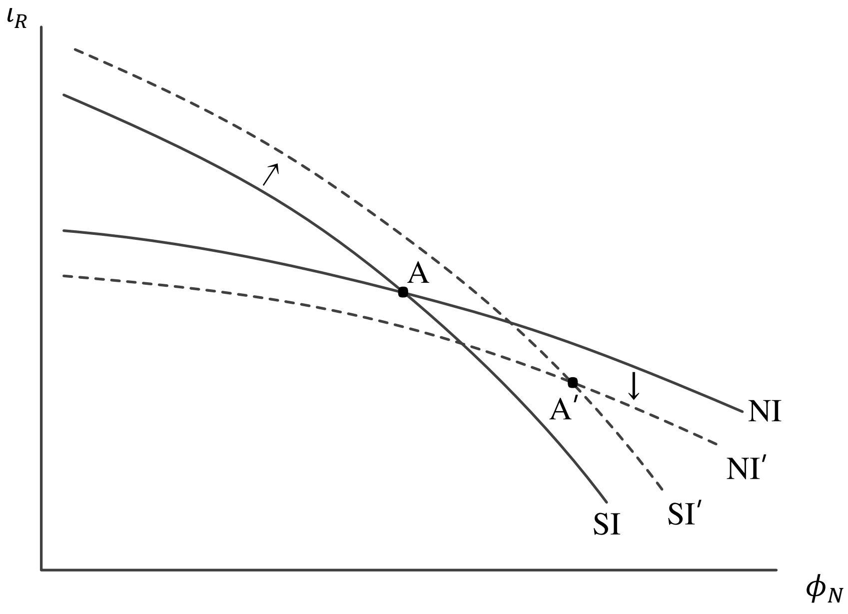

Figure 2. The BGP equilibrium when innovation targets only imitated products

APPENDIX A

The BGP equilibrium when innovation targets all products

First note that $x = \kappa$, and $\overline{D}_N$ and w_N are respectively determined by (7) and (8). Using (29) and (30), we derive the wage rates as:

$$w_N^L = \frac{\xi(\rho - g + \iota_R) + \lambda\iota_S}{\rho - g + \iota_R + \iota_S}, \tag{A1}$$

$$w_N^H = \frac{\hat{E}(\lambda - \xi)}{\lambda a_R \kappa(\rho - g + \iota_R + \iota_S)}. \tag{A2}$$

From (31), we can express $\hat{E}$ as a function of ι_R:

$$\hat{E}(\iota_R) = \frac{\lambda a_S(1+\mu)\kappa(\rho - g + \iota_R)}{\lambda - 1}. \tag{A3}$$

Equation (A3) indicates that $\frac{\partial \hat{E}}{\partial \iota_R} = \frac{\hat{E}}{\rho - g + \iota_R} > 0$ and $\frac{\partial \hat{E}}{\partial \mu} = \frac{\hat{E}}{1+\mu} > 0$.

Substituting (8) into (35), we express ι_S as a function of ϕ_N and ι_R:

$$\iota_S(\phi_N, \iota_R) = \frac{\rho - g + \iota_R}{\lambda}\left[\frac{(\lambda - \xi)a_S(1+\mu)h_N(\overline{D}_N)g_G{}^{\gamma}}{(\lambda - 1)a_R\sigma_N(\overline{D}_N)(1-\phi_N)^{\gamma}} - \xi\right]. \tag{A4}$$

Equation (A4) indicates that $\frac{\partial \iota_S}{\partial \phi_N} = \frac{\gamma}{1-\phi_N}\left(\iota_S + \frac{\xi(\rho - g + \iota_R)}{\lambda}\right) > 0$, $\frac{\partial \iota_S}{\partial \iota_R} = \frac{\iota_S}{\rho - g + \iota_R} > 0$ and $\frac{\partial \iota_S}{\partial \mu} = \frac{1}{1+\mu}\left(\iota_S + \frac{\xi(\rho - g + \iota_R)}{\lambda}\right) > 0$.

Combining (27) and (A3), we have:

$$n_N = \frac{\lambda\phi_N}{\hat{E}(\iota_R)} = n_N(\phi_N, \iota_R). \tag{A5}$$

Equations (A5) and (A3) indicate that $\frac{\partial n_N}{\partial \phi_N} = \frac{\lambda}{\hat{E}} > 0$, $\frac{\partial n_N}{\partial \iota_R} = -\frac{n_N}{\rho - g + \iota_R} < 0$ and $\frac{\partial n_N}{\partial \mu} = -\frac{n_N}{1+\mu} < 0$.

Combining (23), (25) and (A4) yields:

$$n_F = \frac{\iota_R[1 - n_N(\phi_N, \iota_R)]}{\iota_S(\phi_N, \iota_R) + \iota_R} = n_F(\phi_N, \iota_R). \tag{A6}$$

Equation (A6) indicates that $\frac{\partial n_F}{\partial \phi_N} = \frac{-\iota_R(\iota_S + \iota_R)\left(\frac{\partial n_N}{\partial \phi_N}\right) - \iota_R(1-n_N)\left(\frac{\partial \iota_S}{\partial \phi_N}\right)}{(\iota_S + \iota_R)^2} < 0$ and $\frac{\partial n_F}{\partial \iota_R} = \frac{-\iota_R(\iota_S + \iota_R)\left(\frac{\partial n_N}{\partial \iota_R}\right) + \iota_S(1-n_N)\left(\frac{\rho - g}{\rho - g + \iota_R}\right)}{(\iota_S + \iota_R)^2} > 0$. From (23), (A5), and (A6), we have $n_S = 1 - n_N(\phi_N, \iota_R) - n_F(\phi_N, \iota_R) = n_S(\phi_N, \iota_R)$.

Equation (24), (A5) and (A6) indicate that:

$$\iota_F = \frac{(\iota_R + \iota_S)n_F(\phi_N, \iota_R)}{n_N(\phi_N, \iota_R)} = \iota_F(\phi_N, \iota_R). \tag{A7}$$

Equation (26) implies that:

$$\iota_R = \frac{\psi_N(\phi_N)}{a_R\kappa}. \tag{A8}$$

Equation (A8) indicates that ι_R and ϕ_N are negatively correlated since $\psi_N'(\phi_N) = \frac{d\psi_N}{d\phi_N} = -\frac{(1-\gamma)\psi_N}{1-\phi_N} < 0$.

Using (23) and (A3)-(A6), we rewrite (28) as:

$$[1 - n_N(\phi_N, \iota_R)]\frac{\hat{E}(\iota_R)}{\lambda} + a_S(1+\mu)\kappa\iota_S(\phi_N, \iota_R)n_F(\phi_N, \iota_R) = \frac{L_S}{L_N}. \tag{A9}$$

Using (27), we rewrite (A9) as:

$$\frac{\hat{E}(\iota_R)}{\lambda} - \phi_N + a_S(1+\mu)\kappa\iota_S(\phi_N, \iota_R)n_F(\phi_N, \iota_R) = \frac{L_S}{L_N}. \tag{A10}$$

Define $g(\phi_N, \iota_R) = \frac{\hat{E}(\iota_R)}{\lambda} - \phi_N + a_S(1+\mu)\kappa\iota_S(\phi_N, \iota_R)n_F(\phi_N, \iota_R)$. Taking the partial derivatives of $g(\phi_N, \iota_R)$ with respect to ι_R yields:

$$\frac{\partial g}{\partial \iota_R} = \frac{1}{\lambda}\left(\frac{\partial \hat{E}}{\partial \iota_R}\right) + a_S(1+\mu)\kappa\left[\iota_S\left(\frac{\partial n_F}{\partial \iota_R}\right) + n_F\left(\frac{\partial \iota_S}{\partial \iota_R}\right)\right] > 0.$$

Taking the partial derivatives of $g(\phi_N, \iota_R)$ with respect to ϕ_N yields:

$$\frac{\partial g}{\partial \phi_N} = -1 + a_S(1+\mu)\kappa\left[\iota_S\left(\frac{\partial n_F}{\partial \phi_N}\right) + n_F\left(\frac{\partial \iota_S}{\partial \phi_N}\right)\right].$$

Using the fact that $\frac{\partial n_F}{\partial \phi_N} = \frac{-\iota_R(\iota_S+\iota_R)\left(\frac{\partial n_N}{\partial \phi_N}\right) - \iota_R(1-n_N)\left(\frac{\partial \iota_S}{\partial \phi_N}\right)}{(\iota_S+\iota_R)^2}$, we can derive:

$$\frac{\partial g}{\partial \phi_N} = -1 + a_S(1+\mu)\kappa\frac{\iota_R}{\iota_S + \iota_R}\left[-\iota_S\left(\frac{\partial n_N}{\partial \phi_N}\right) + n_F\left(\frac{\partial \iota_S}{\partial \phi_N}\right)\right].$$

Since $\frac{\partial n_N}{\partial \phi_N} > 0$, we have:

$$\frac{\partial g}{\partial \phi_N} < -1 + a_S(1+\mu)\kappa\frac{\iota_R}{\iota_S + \iota_R}n_F\left(\frac{\partial \iota_S}{\partial \phi_N}\right).$$

Moreover, the conditions that $\frac{\iota_R}{\iota_S+\iota_R} < 1$ and $n_F < 1$ imply that:

$$\frac{\partial g}{\partial \phi_N} < -1 + a_S(1+\mu)\kappa\left(\frac{\partial \iota_S}{\partial \phi_N}\right).$$

Since $\frac{\partial \iota_S}{\partial \phi_N} = \frac{\gamma}{1-\phi_N}\left[\iota_S + \frac{\xi(\rho-g+\iota_R)}{\lambda}\right] < \frac{\gamma}{1-\phi_N}\left(1 + \frac{\xi(\rho-g+1)}{\lambda}\right)$, we have:

$$\frac{\partial g}{\partial \phi_N} < -1 + a_S(1+\mu)\kappa\frac{\gamma}{1-\phi_N}\left(1 + \frac{\xi(\rho-g+1)}{\lambda}\right). \tag{A11}$$

From (27), we get $n_N = \frac{\lambda\phi_N}{\hat{E}} < 1$. This indicates that $\phi_N < \frac{\hat{E}}{\lambda}$. Therefore, using (A3), we can derive $\frac{1}{1-\phi_N} < \frac{\lambda}{\lambda-\hat{E}} = \frac{\lambda-1}{\lambda-1-(\rho-g+\iota_R)a_S(1+\mu)\kappa} < \frac{\lambda-1}{\lambda-1-(\rho-g+1)a_S(1+\mu)\kappa}$. We can rewrite (A11) as:

$$\frac{\partial g}{\partial \phi_N} < -1 + \frac{a_S(1+\mu)\kappa\gamma[\lambda+\xi(\rho-g+1)]}{\lambda}\frac{\lambda-1}{\lambda-1-(\rho-g+1)a_S(1+\mu)\kappa}.$$

We then have $\frac{\partial g}{\partial \phi_N} < 0$ if

$$\frac{a_S(1+\mu)\kappa\gamma[\lambda+\xi(\rho-g+1)]}{\lambda}\frac{\lambda-1}{\lambda-1-(\rho-g+1)a_S(1+\mu)\kappa} < 1.$$

That is,

$$a_S < \frac{\lambda(\lambda-1)}{(1+\mu)\kappa\{\gamma(\lambda-1)[\lambda+\xi(\rho-g+1)]+\lambda(\rho-g+1)\}}. \tag{P1}$$

Then (A10) will exhibit a positive relationship between ι_R and ϕ_N if a_S is sufficiently small such that (P1) holds. Equations (A8) and (A10) are used to solve for $\{\phi_N, \iota_R\}$. Once one derives the solution of $\{\phi_N, \iota_R\}$, the remaining endogenous variables can be solved accordingly.

APPENDIX B

Proof of Propositions 1 and 2

Totally differentiating (A8) and (A10) with respect to ϕ_N, ι_R and μ yields:

$$\begin{bmatrix} \psi_N'(\phi_N) & -a_R\kappa \\ \frac{\partial g}{\partial \phi_N} & \frac{\partial g}{\partial \iota_R} \end{bmatrix} \begin{bmatrix} d\phi_N \\ d\iota_R \end{bmatrix} = \begin{bmatrix} 0 \\ b_1 \end{bmatrix} d\mu,$$

where $b_1 = -\frac{1}{\lambda}\left(\frac{\partial \hat{E}}{\partial \mu}\right) - a_S\kappa\left\{\iota_S n_F + \frac{(1+\mu)\iota_R}{(\iota_R+\iota_S)^2}\left[(1-n_N)\iota_R\left(\frac{\partial \iota_S}{\partial \mu}\right) - (\iota_R+\iota_S)\iota_S\left(\frac{\partial n_N}{\partial \mu}\right)\right]\right\} < 0.$

Let $B_1 = \begin{bmatrix} \psi_N'(\phi_N) & -a_R\kappa \\ \frac{\partial g}{\partial \phi_N} & \frac{\partial g}{\partial \iota_R} \end{bmatrix}$. Note that $\frac{\partial g}{\partial \iota_R} > 0$. Furthermore, $\frac{\partial g}{\partial \phi_N} < 0$ if a_S is sufficiently small. Then t he determinant of B_1 is $|B_1| = -\psi_N'(\phi_N)\left(\frac{\partial g}{\partial \iota_R}\right) - a_R\kappa\left(\frac{\partial g}{\partial \phi_N}\right) < 0$.

Then the effects of the strengthening of IPR protection on ϕ_N and ι_R are:

$$\phi_N'(\mu) = \frac{d\phi_N}{d\mu} = \frac{a_R\kappa b_1}{|B_1|} > 0, \tag{B1}$$

$$\iota_R'(\mu) = \frac{d\iota_R}{d\mu} = \frac{\psi_N'(\phi_N)b_1}{|B_1|} < 0. \tag{B2}$$

Equations (B1) and (B2) indicate that an increase of μ will raise ϕ_N and reduce ι_R.

We are now ready to examine the effects of μ on other key variables. From (A4), we can calculate:

$$\iota_S'(\mu) = \frac{d\iota_S}{d\mu}$$

$$= \frac{\iota_S \iota_R'(\mu)}{\rho - g + \iota_R} + \frac{(\rho - g + \iota_R)(\lambda - \xi) a_S h_N(\bar{D}_N) g_G{}^{\gamma}[1 - \phi_N + \gamma(1+\mu)\phi_N'(\mu)]}{\lambda(\lambda - 1) a_R \sigma_N(\bar{D}_N)(1 - \phi_N)^{1+\gamma}}.$$

Using (A3), we now rewrite $\iota_S'(\mu)$ as:

$$\iota_S'(\mu) = \frac{(\lambda - \xi)\hat{E}}{\lambda^2 a_R \kappa w_N}\left[\frac{\gamma \phi_N'(\mu)}{1 - \phi_N} + \frac{\iota_R'(\mu)}{\rho - g + \iota_R} + \frac{1}{1 + \mu}\right] - \frac{\xi \iota_R'(\mu)}{\lambda}. \quad \text{(B3)}$$

Using (B1) and (B2) to substitute $\phi_N'(\mu)$ and $\iota_R'(\mu)$ in (B3) yields:

$$\iota_S'(\mu) = \frac{(\lambda - \xi)\hat{E}}{\lambda^2 a_R \kappa w_N}\left[\frac{(\rho - g + \iota_R)\gamma \phi_N'(\mu) + (1 - \phi_N)\iota_R'(\mu)}{(1 - \phi_N)(\rho - g + \iota_R)} + \frac{1}{1 + \mu}\right] - \frac{\xi \iota_R'(\mu)}{\lambda}$$

$$= \frac{(\lambda - \xi)\hat{E}}{\lambda^2 a_R \kappa w_N}\left[b_1 \frac{(\rho - g + \iota_R)\gamma a_R \kappa - (1 - \gamma)\psi_N}{(1 - \phi_N)(\rho - g + \iota_R)|B_1|} + \frac{1}{1 + \mu}\right] - \frac{\xi \iota_R'(\mu)}{\lambda}. \quad \text{(B4)}$$

Since $b_1 < 0$, $|B_1| < 0$ and $\iota_R'(\mu) < 0$, (B4) indicates that $\iota_S'(\mu) > 0$ if the following inequality holds:

$$(1 - \gamma)\psi_N < (\rho - g + \iota_R)\gamma a_R \kappa. \quad \text{(B5)}$$

Because $(1 - \gamma)\psi_N < (1 - \gamma)B_N(\bar{D}_N)h_N(\bar{D}_N)g_G{}^{\gamma}$ and $(\rho - g + \iota_R)\gamma a_R \kappa > (\rho - g)\gamma a_R \kappa$, then the inequality of (B5) will hold if:

$$(1 - \gamma)B_N(\bar{D}_N)h_N(\bar{D}_N)g_G{}^{\gamma} < (\rho - g)\gamma a_R \kappa.$$

That is,

$$a_R > \frac{(1 - \gamma)B_N(\bar{D}_N)h_N(\bar{D}_N)g_G{}^{\gamma}}{(\rho - g)\gamma \kappa}. \quad \text{(P2)}$$

Therefore, $\iota_S'(\mu) > 0$ if the condition (P2) holds; that is, if a_R is sufficiently large.

Equations (8) and (A1) indicate that:

$$w_N'(\mu) = \frac{dw_N}{d\mu} = -\frac{\gamma w_N}{1 - \phi_N}\phi_N'(\mu) < 0,$$

$$w_N^L{}'(\mu) = \frac{dw_N^L}{d\mu} = -\frac{(\lambda - \xi)[(\rho - g + \iota_R)\iota_S'(\mu) - \iota_S \iota_R'(\mu)]}{(\rho - g + \iota_R + \iota_S)^2} > 0.$$

Then an increase in μ will reduce Northern wage inequality and raise the wage rate for unskilled Northern workers.

From (A3), we derive:

$$\hat{E}'(\mu) = \frac{d\hat{E}}{d\mu} = \hat{E}\left[\frac{1}{1 + \mu} + \frac{\iota_R'(\mu)}{\rho - g + \iota_R}\right]. \quad \text{(B6)}$$

Since $\iota_R'(\mu) < 0$, equation (B6) implies that an increase in μ may increase or decrease $\hat{E}$, depending on its effect on ι_R.

From (A5), (A6), and (25), we can derive:

$$n_N'(\mu) = \frac{dn_N}{d\mu} = \frac{\lambda[\phi_N'(\mu)\hat{E} - \phi_N \hat{E}'(\mu)]}{\hat{E}^2},$$

$$n_F'(\mu) = \frac{dn_F}{d\mu} = \frac{-(\iota_R + \iota_S)\iota_R\, n_N'(\mu) + (1 - n_N)[\iota_S \iota_R'(\mu) - \iota_S'(\mu)\iota_R]}{(\iota_R + \iota_S)^2},$$

$$n_S'(\mu) = -[n_N'(\mu) + n_F'(\mu)].$$

The above two equations indicate that if $\hat{E}'(\mu) < 0$, then we have $n_N'(\mu) > 0$ and $n_F'(\mu) < 0$, but the sign of $n_S'(\mu)$ is still undetermined.

APPENDIX C

The BGP equilibrium when innovation targets only imitated products

First note that $x = \kappa$, and $\bar{D}_N$ and w_N are respectively determined by (7) and (8). Using (45) and (46), we derive the wage rates as:

$$w_N^L = \frac{\xi(\rho - g) + \lambda\iota_S}{\rho - g + \iota_S}, \tag{C1}$$

$$w_N^H = \frac{\hat{E}(\lambda - \xi)}{\lambda a_R \kappa(\rho - g + \iota_S)}. \tag{C2}$$

From (31), we can express $\hat{E}$ as a function of i_R:

$$\hat{E}(\iota_R) = \frac{\lambda a_S(1 + \mu)\kappa(\rho - g + \iota_R)}{\lambda - 1}. \tag{C3}$$

Equation (C3) indicates that $\frac{\partial \hat{E}}{\partial \iota_R} = \frac{\hat{E}}{\rho - g + \iota_R} > 0$ and $\frac{\partial \hat{E}}{\partial \mu} = \frac{\hat{E}}{1+\mu} > 0$.

Substituting (8) into (49), we can express ι_S as a function of ϕ_N and ι_R:

$$\iota_S(\phi_N, \iota_R) = \frac{1}{\lambda}\left[\frac{(\lambda - \xi)a_S(1 + \mu)(\rho - g + \iota_R)h_N(\bar{D}_N)g_G{}^\gamma}{(\lambda - 1)a_R\sigma_N(\bar{D}_N)(1 - \phi_N)^\gamma} - \xi(\rho - g)\right]. \tag{C4}$$

Equation (C4) indicates that $\frac{\partial \iota_S}{\partial \phi_N} = \frac{\gamma}{1-\phi_N}\left(\iota_S + \frac{\xi(\rho-g)}{\lambda}\right) > 0$, $\frac{\partial \iota_S}{\partial \iota_R} = \frac{1}{\rho-g+\iota_R}\left(\iota_S + \frac{\xi(\rho-g)}{\lambda}\right) > 0$ and $\frac{\partial \iota_S}{\partial \mu} = \frac{1}{1+\mu}\left(\iota_S + \frac{\xi(\rho-g)}{\lambda}\right) > 0$.

Substituting (C3) into (21) yields:

$$n_N = \frac{\lambda\phi_N}{\hat{E}(\iota_R)} = n_N(\phi_N, \iota_R). \tag{C5}$$

Equations (C5) and (C3) indicate that $\frac{\partial n_N}{\partial \phi_N} = \frac{\lambda}{\hat{E}} = \frac{n_N}{\phi_N} > 0$, $\frac{\partial n_N}{\partial \iota_R} = -\frac{n_N}{\rho-g+\iota_R} < 0$ and $\frac{\partial n_N}{\partial \mu} = -\frac{n_N}{1+\mu} < 0$.

From (44), we obtain:

$$n_S = \frac{\psi_N(\phi_N)}{a_R \kappa \iota_R} = n_S(\phi_N, \iota_R). \tag{C6}$$

Equation (C6) indicates that $\frac{\partial n_S}{\partial \phi_N} = \frac{n_S \psi'_N(\phi_N)}{\psi_N} < 0$, $\frac{\partial n_S}{\partial \iota_R} = -\frac{n_S}{\iota_R} < 0$.

Combining (25), (44), and (C4) yields:

$$n_F = \frac{\psi_N(\phi_N)}{a_R \kappa \iota_S(\phi_N, \iota_R)} = n_F(\phi_N, \iota_R), \tag{C7}$$

where $\frac{\partial n_F}{\partial \phi_N} = n_F\left[\frac{\psi'_N(\phi_N)}{\psi_N} - \frac{1}{\iota_S}\left(\frac{\partial \iota_S}{\partial \phi_N}\right)\right] < 0$, $\frac{\partial n_F}{\partial \iota_R} = -\frac{n_F}{\iota_S}\left(\frac{\partial \iota_S}{\partial \iota_R}\right) < 0$ and $\frac{\partial n_F}{\partial \mu} = -\frac{n_F}{\iota_S}\left(\frac{\partial \iota_S}{\partial \mu}\right) < 0$.

Equation (43) indicates that:

$$\iota_F = \frac{\iota_S n_F(\phi_N, \iota_R)}{n_N(\phi_N, \iota_R)} = \iota_F(\phi_N, \iota_R). \tag{C8}$$

Using (23) and (28), the equilibrium is reduced to the following two equations in ϕ_N and ι_R:

$$n_N(\phi_N, \iota_R) + n_F(\phi_N, \iota_R) + n_S(\phi_N, \iota_R) = 1, \tag{C9}$$

$$[n_F(\phi_N, \iota_R) + n_S(\phi_N, \iota_R)]\frac{\hat{E}(\iota_R)}{\lambda} + a_S(1+\mu)\iota_S(\phi_N, \iota_R) n_F(\phi_N, \iota_R)\kappa = \frac{L_S}{L_N}. \tag{C10}$$

We define $h(\phi_N, \iota_R) = n_N(\phi_N, \iota_R) + n_F(\phi_N, \iota_R) + n_S(\phi_N, \iota_R)$. Then we can calculate:

$$\frac{\partial h}{\partial \iota_R} = \frac{\partial n_N}{\partial \iota_R} + \frac{\partial n_F}{\partial \iota_R} + \frac{\partial n_S}{\partial \iota_R} < 0.$$

$$\begin{aligned}
\frac{\partial h}{\partial \phi_N} &= \frac{n_N}{\phi_N} + n_F\left[\frac{\psi'_N(\phi_N)}{\psi_N} - \frac{1}{\iota_S}\left(\frac{\partial \iota_S}{\partial \phi_N}\right)\right] + \frac{n_S \psi'_N(\phi_N)}{\psi_N} \\
&= \frac{n_N}{\phi_N} - n_F \frac{1}{\iota_S}\left(\frac{\partial \iota_S}{\partial \phi_N}\right) + \frac{\psi'_N(\phi_N)}{\psi_N}(n_F + n_S) \\
&= \frac{n_N}{\phi_N} - n_F \frac{1}{\iota_S}\frac{\gamma}{1-\phi_N}\left(\iota_S + \frac{\xi(\rho - g)}{\lambda}\right) + \frac{1-\gamma}{1-\phi_N}(1 - n_N) \\
&= \frac{n_N}{\phi_N} - n_F \frac{\gamma}{1-\phi_N}\left(1 + \frac{\xi(\rho - g)}{\lambda \iota_S}\right) + \frac{1-\gamma}{1-\phi_N}(1 - n_N) \\
&= \frac{n_N(1-\gamma\phi_N) - (1-\gamma)\phi_N}{\phi_N(1-\phi_N)} - n_F \frac{\gamma}{1-\phi_N}\left(1 + \frac{\xi(\rho - g)}{\lambda \iota_S}\right)
\end{aligned}$$

Equation (27) indicates that $\frac{n_N}{\phi_N} = \frac{\lambda}{\hat{E}}$. Then we have:

$$\frac{\partial h}{\partial \phi_N} = \frac{1}{1-\phi_N}\left[(1-\gamma\phi_N)\frac{\lambda}{\hat{E}} - (1-\gamma) - \gamma n_F\left(1 + \frac{\xi(\rho - g)}{\lambda \iota_S}\right)\right]. \tag{C11}$$

Since $(1-\gamma\phi_N)\frac{\lambda}{\hat{E}} < \frac{\lambda}{\hat{E}}$, then (11) indicates that $\frac{\partial h}{\partial \phi_N} < 0$ if $\frac{\lambda}{\hat{E}} < 1 - \gamma$. Note that $\frac{\lambda}{\hat{E}} =$

$\frac{\lambda-1}{a_S(1+\mu)\kappa(\rho-g+\iota_R)} < \frac{\lambda-1}{a_S(1+\mu)\kappa(\rho-g)}$. Then $\frac{\partial h}{\partial \phi_N} < 0$ if μ is sufficiently large such that the following condition holds:

$$\frac{\lambda-1}{a_S(1+\mu)\kappa(\rho-g)} < 1-\gamma. \tag{P3}$$

If (P3) holds, we will obtain $\frac{\partial h}{\partial \phi_N} < 0$. Then (C9) implies that there is a negative relationship between ϕ_N and ι_R since:

$$\frac{d\iota_R}{d\phi_N} = -\frac{\left(\frac{\partial h}{\partial \phi_N}\right)}{\left(\frac{\partial h}{\partial \iota_R}\right)} < 0.$$

Using (25), we can rewrite (C10) as:

$$[n_F(\phi_N,\iota_R) + n_S(\phi_N,\iota_R)]\frac{\hat{E}(\iota_R)}{\lambda} + a_S(1+\mu)\iota_R n_S(\phi_N,\iota_R)\kappa = \frac{L_S}{L_N}. \tag{C12}$$

Taking the total derivatives of (C12) with respect to ϕ_N and ι_R, we obtain:

$$\frac{d\iota_R}{d\phi_N} = \frac{\left(\frac{\partial n_F}{\partial \phi_N} + \frac{\partial n_S}{\partial \phi_N}\right)\frac{\hat{E}}{\lambda} + a_S(1+\mu)\iota_R\kappa\left(\frac{\partial n_S}{\partial \phi_N}\right)}{\frac{\hat{E}(\rho-g)}{\lambda(\rho-g+\iota_R)}\left(\frac{\xi n_O}{\lambda\iota_S} + \frac{n_S}{\iota_R}\right)} < 0.$$

Equation (C12) indicates that there is a negative relationship between ϕ_N and ι_R. Equations (C9) and (C12) are the two equations that implicitly solve for the equilibrium values of $\{\phi_N, \iota_R\}$. After solving the solution of $\{\phi_N, \iota_R\}$, we can solve other endogenous variables accordingly.

APPENDIX D

Proof of Propositions 3 and 4

In the following analysis, we assume that condition (P3) holds. Totally differentiating (C9) and (C11) with respect to ϕ_N, ι_R and μ yields:

$$\begin{bmatrix} b_2 & b_3 \\ b_4 & b_5 \end{bmatrix}\begin{bmatrix} d\phi_N \\ d\iota_R \end{bmatrix} = -\begin{bmatrix} b_6 \\ b_7 \end{bmatrix} d\mu,$$

where $b_2 = \frac{\partial h}{\partial \phi_N} < 0$, $b_3 = \frac{\partial h}{\partial \iota_R} < 0$, $b_4 = \left(\frac{\partial n_F}{\partial \phi_N} + \frac{\partial n_S}{\partial \phi_N}\right)\frac{\hat{E}}{\lambda} + a_S(1+\mu)\iota_R\kappa\left(\frac{\partial n_S}{\partial \phi_N}\right) < 0$, $b_5 = -\frac{\hat{E}(\rho-g)}{\lambda(\rho-g+\iota_R)}\left(\frac{\xi n_O}{\lambda\iota_S} + \frac{n_S}{\iota_R}\right) < 0$, $b_6 = \frac{\partial n_N}{\partial \mu} + \frac{\partial n_F}{\partial \mu} < 0$ and $b_7 = \frac{n_F+n_S}{\lambda}\left(\frac{\partial \hat{E}}{\partial \mu}\right) + \frac{\hat{E}}{\lambda}\left(\frac{\partial n_F}{\partial \mu}\right) + a_S\iota_R n_S\kappa$.

Let $B_2 = \begin{bmatrix} b_2 & b_3 \\ b_4 & b_5 \end{bmatrix}$. With a few steps of calculation, we can derive the determinant of B_2, $|B_2| = b_2 b_5 - b_3 b_4$, as follows:

$$|B_2| = b_4\left(\frac{\partial n_N}{\partial \iota_R}\right) - b_5\left(\frac{\partial n_N}{\partial \phi_N}\right) + a_S(1+\mu)\iota_R\kappa\left(\frac{\partial n_S}{\partial \phi_N}\right)\left(\frac{\partial n_F}{\partial \iota_R} + \frac{\partial n_S}{\partial \iota_R}\right)$$

$$- \frac{n_F + n_S}{\lambda}\left(\frac{\partial \hat{E}}{\partial \iota_R}\right)\left(\frac{\partial n_F}{\partial \phi_N} + \frac{\partial n_S}{\partial \phi_N}\right) > 0.$$

With a few steps of calculation, we derive:

$$b_7 = \frac{\hat{E}}{\lambda(1+\mu)}\left[n_S - \frac{\xi n_F(\rho - g)}{\lambda \iota_S}\right] + a_S \iota_R n_S \kappa.$$

From (25), we obtain that $n_F = \frac{\iota_R n_S}{\iota_S}$. Then we can rewrite b_7 as:

$$b_7 = \frac{\hat{E} n_S}{\lambda(1+\mu)}\left[1 - \frac{\xi \iota_R(\rho - g)}{\lambda {\iota_S}^2}\right] + a_S \iota_R n_S \kappa. \tag{D1}$$

Equation (D1) indicates that $b_7 > 0$ if:

$$\frac{\xi \iota_R(\rho - g)}{\lambda {\iota_S}^2} < \frac{\xi(\rho - g)}{\lambda {\iota_S}^2} < 1. \tag{D2}$$

From (C4), we have:

$$\iota_S = \frac{1}{\lambda}\left[\frac{(\lambda - \xi)a_S(1+\mu)(\rho - g + \iota_R)h_N(\overline{D}_N){g_G}^\gamma}{(\lambda - 1)a_R\sigma_N(\overline{D}_N)(1-\phi_N)^\gamma} - \xi(\rho - g)\right]$$

$$> \frac{(\rho - g)}{\lambda}\left[\frac{(\lambda - \xi)a_S(1+\mu)h_N(\overline{D}_N){g_G}^\gamma}{(\lambda - 1)a_R\sigma_N(\overline{D}_N)} - \xi\right]$$

Then the inequality of (D2) will hold if:

$${\iota_S}^2 > \left\{\frac{(\rho - g)}{\lambda}\left[\frac{(\lambda - \xi)a_S(1+\mu)h_N(\overline{D}_N){g_G}^\gamma}{(\lambda - 1)a_R\sigma_N(\overline{D}_N)} - \xi\right]\right\}^2 > \frac{\xi(\rho - g)}{\lambda}.$$

Then $b_7 > 0$ if μ is sufficiently large such that the following condition holds:

$$\left[\frac{(\lambda - \xi)a_S(1+\mu)h_N(\overline{D}_N){g_G}^\gamma}{(\lambda - 1)a_R\sigma_N(\overline{D}_N)} - \xi\right]^2 > \frac{\xi\lambda}{\rho - g}. \tag{P4}$$

In the following analysis, we assume that μ is sufficiently large such that the condition (P4) holds. The effects of the strengthening of IPR protection on ϕ_N and ι_R are:

$$\phi_N'(\mu) = \frac{d\phi_N}{d\mu} = \frac{b_5 b_6 - b_3 b_7}{|B_2|} > 0, \tag{D3}$$

$$\iota_R'(\mu) = \frac{d\iota_R}{d\mu} = \frac{b_2 b_7 - b_4 b_6}{|B_2|} < 0. \tag{D4}$$

Therefore, an increase of μ will raise ϕ_N while reducing ι_R.

We are now ready to examine the effects of μ on other key variables. From (C4), we can calculate:

$$\iota_S'(\mu) = \frac{d\iota_S}{d\mu} = \frac{(\lambda - \xi)\hat{E}}{\lambda^2 a_R \kappa w_N}\left[\frac{\gamma\phi_N'(\mu)}{1-\phi_N} + \frac{\iota_R'(\mu)}{\rho - g + \iota_R} + \frac{1}{1+\mu}\right]. \tag{D5}$$

Using (D3) and (D4) to substitute $\phi_N'(\mu)$ and $\iota_R'(\mu)$ in (D5), we can get:

$$\iota_S'(\mu) = \frac{(\lambda-\xi)\hat{E}}{\lambda^2 a_R \kappa w_N}\left[\frac{(\rho-g+\iota_R)\gamma\phi_N'(\mu)+(1-\phi_N)\iota_R'(\mu)}{(1-\phi_N)(\rho-g+\iota_R)}+\frac{1}{1+\mu}\right]$$

$$= \frac{(\lambda-\xi)\hat{E}}{\lambda^2 a_R \kappa w_N}\left[\frac{b_6\varepsilon_1+b_7\varepsilon_2}{(1-\phi_N)(\rho-g+\iota_R)|B_2|}+\frac{1}{1+\mu}\right], \quad \text{(D6)}$$

where $\varepsilon_1 = -\gamma(\rho-g+\iota_R)b_3+(1-\phi_N)b_2$ and $\varepsilon_2 = \gamma(\rho-g+\iota_R)b_5-(1-\phi_N)b_4$. With a few steps of calculation, we can derive:

$$\varepsilon_1 = -(1-\gamma)+\frac{\gamma(\rho-g+\iota_R)\psi_N}{a_R\kappa\iota_R^2}+\frac{\lambda}{\hat{E}}$$

$$= -(1-\gamma)+\frac{\gamma(\rho-g+\iota_R)B_N(\bar{D}_N)h_N(\bar{D}_N){g_G}^{\gamma}(1-\phi_N)^{1-\gamma}}{a_R\kappa}.$$

Thus, $\varepsilon_1 > 0$ if γ is sufficiently large such that the following condition holds:

$$(1-\phi_N)^{1-\gamma} > \frac{(1-\gamma)a_R\kappa}{\gamma(\rho-g+\iota_R)B_N(\bar{D}_N)h_N(\bar{D}_N){g_G}^{\gamma}}. \quad \text{(D7)}$$

Since $\iota_S < 1$,we can use (C4) to derive:

$$1-\phi_N > \left\{\frac{(\lambda-\xi)a_S(1+\mu)(\rho-g+\iota_R)h_N(\bar{D}_N){g_G}^{\gamma}}{(\lambda-1)a_R\sigma_N(\bar{D}_N)[\lambda+\xi(\rho-g)]}\right\}^{\frac{1}{\gamma}}. \quad \text{(D8)}$$

Then condition (D7) will hold if

$$\left\{\frac{(\lambda-\xi)a_S(1+\mu)(\rho-g+\iota_R)h_N(\bar{D}_N){g_G}^{\gamma}}{(\lambda-1)a_R\sigma_N(\bar{D}_N)[\lambda+\xi(\rho-g)]}\right\}^{\frac{1-\gamma}{\gamma}} > \frac{(1-\gamma)a_R\kappa}{\gamma(\rho-g+\iota_R)B_N(\bar{D}_N)h_N(\bar{D}_N){g_G}^{\gamma}}.$$

Since $\iota_R > 0$, then the above inequality will holds if:

$$\left\{\frac{(\lambda-\xi)a_S(1+\mu)(\rho-g)h_N(\bar{D}_N){g_G}^{\gamma}}{(\lambda-1)a_R\sigma_N(\bar{D}_N)[\lambda+\xi(\rho-g)]}\right\}^{\frac{1-\gamma}{\gamma}} > \frac{(1-\gamma)a_R\kappa}{\gamma(\rho-g)B_N(\bar{D}_N)h_N(\bar{D}_N){g_G}^{\gamma}}.$$

This inequality can be re-written as:

$$\left\{\frac{(\lambda-\xi)a_S(1+\mu)}{(\lambda-1)a_R\sigma_N(\bar{D}_N)[\lambda+\xi(\rho-g)]}\right\}^{\frac{1-\gamma}{\gamma}} > \frac{(1-\gamma)a_R\kappa}{\gamma g_G B_N(\bar{D}_N)[h_N(\bar{D}_N)(\rho-g)]^{\frac{1}{\gamma}}}. \quad \text{(P5)}$$

Then $\varepsilon_1 > 0$ if μ is sufficiently large such that condition (P5) holds.

With a few steps of calculation, we can derive:

$$\varepsilon_2 = \frac{\hat{E}n_S}{\lambda\iota_S}\left[\iota_R+(1-\gamma)\iota_S\frac{\rho-g+\lambda\iota_R}{\rho-g+\iota_R}-\gamma(\rho-g)\right]$$

$$< \frac{\hat{E}n_S}{\lambda\iota_S}\left[\iota_R+(1-\gamma)\frac{\rho-g+\lambda\iota_R}{\rho-g+\iota_R}-\gamma(\rho-g)\right]$$

Thus, $\varepsilon_2 < 0$ if ι_R is sufficiently large such that the following condition holds:

$$\iota_R + (1-\gamma)\frac{\rho - g + \lambda\iota_R}{\rho - g + \iota_R} < \gamma(\rho - g). \tag{P6}$$

Condition (P6) will hold if ι_R is sufficiently small and γ is sufficiently large. Since $\iota_R'(\mu) < 0$, then the condition (P6) will hold if μ and γ are sufficiently large. Because $|B_2| > 0$, $b_6 > 0$ and $b_7 < 0$, then (D5) indicates that $\iota_S'(\mu) > 0$ if μ and γ are sufficiently large such that conditions (P5) and (P6) hold.

Equations (A1) and (8) indicate that:

$$w_N'(\mu) = \frac{dw_N}{d\mu} = -\frac{\gamma w_N}{1-\phi_N}\phi_N'(\mu) < 0,$$

$$w_N^{L\,\prime}(\mu) = \frac{dw_N^L}{d\mu} = \frac{(\lambda - \xi)(\rho - g)\iota_S'(\mu)}{(\rho - g + \iota_S)^2} > 0.$$

From (C7), we obtain:

$$n_F'(\mu) = \frac{dn_F}{d\mu} = \frac{\iota_S\psi_N'(\mu) - \psi_N\iota_S'(\mu)}{a_R\kappa{\iota_S}^2} < 0.$$

Then an increase in μ will raise w_N^L and reduce w_N and n_F.

From (C3), we derive:

$$\hat{E}'(\mu) = \frac{d\hat{E}}{d\mu} = \hat{E}\left[\frac{1}{1+\mu} + \frac{\iota_R'(\mu)}{\rho - g + \iota_R}\right].$$

Then an increase in μ may increase or decrease $\hat{E}$, depending on its effect on ι_R.

Equations (C5) and (C6) imply that:

$$n_N'(\mu) = \frac{dn_N}{d\mu} = \frac{\lambda[\phi_N'(\mu)\hat{E} - \phi_N\hat{E}'(\mu)]}{\hat{E}^2}, \tag{D9}$$

$$n_S'(\mu) = \frac{dn_S}{d\mu} = \frac{\iota_R\psi_N'(\mu) - \psi_N\iota_R'(\mu)}{a_R\kappa\iota_R^2}.$$

The above two equations indicates that the effects of an increase in μ on n_N and n_S are ambiguous. Equation (D9) indicates that if $\hat{E}'(\mu) < 0$, then we have $n_N'(\mu) > 0$. But the sign of $n_S'(\mu)$ is still undetermined.