Innovation and Intellectual Property Rights in a Product-cycle Model of Skills Accumulation

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ABSTRACT

This paper examines the effects of stronger intellectual property rights (IPR) protection in the South on innovation, skills choice, wage inequality and pattern of production based on a North-South general-equilibrium model with foreign direct investment (FDI) and skills accumulation. Two types of innovation are considered, innovation targeting all products and innovation targeting only imitated products. The results reveal that for both types of innovation, there will be increases in the rate of innovation and wage inequality in the North and a decrease in the proportion of Northern unskilled labor if imitation intensity is sufficiently low. As regards the pattern of production, the extent of FDI will increase while the extents of Northern production and Southern production will decrease.

Keywords: FDI; IPR; R&D; Skill; Wage inequality.

JEL Classification: F12; F23; O31.

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1. INTRODUCTION

With dissatisfaction of inadequate protection of intellectual property rights (IPR) within many of the developing countries, the US, along with certain European countries, began to place considerable effort throughout the 1980s into the improvement of IPR protection in many of these developing countries. Their efforts ultimately led to the approval of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) for the Uruguay Round.

Since then, there has been considerable debate on the pros and cons of the strengthening IPR protection for both developed and developing countries. Those supporting the strengthening IPR protection argue that not only developed countries, but also developing countries can benefit from this agreement. Such strengthening of IPR protection can be beneficial to the developed countries by reducing imitation risk and encouraging innovation, while also reducing production cost. Given that it is now very common for international production to be achieved through efforts such as foreign direct investment (FDI), developing countries can benefit from stronger IPR protection by attracting firms to shift their production bases from the developed countries to the developing countries. Furthermore, the increase in the flows of FDI has the added advantage of bringing cutting-edge technologies to the developing countries. There are, however, arguments against stronger IPR protection, since it is doubtful whether it can actually increase either FDI activities or innovation intensity; those opposing such strengthening further argue that any shift in production to the developing countries will further exacerbate wage inequality in the developed countries.

These phenomena have led to interest among economists in the effects of stronger IPR protection when international production is available to firms. Based on a model where innovation happens in developed countries and imitation occurs in developing countries, the early study of Helpman (1993) examines the effects of IPR protection
when firms can undertake production in developing countries through FDI. However, given the assumption of an exogenous innovation rate, the impact of the strengthening of IPR protection on innovation is not analyzed in the study. The Helpman (1993) model subsequently undergoes various modifications in several studies where examinations are undertaken of the effects of IPR protection on innovation and FDI flows. Based on the assumption that innovation involves the development of new varieties, Lai (1998) demonstrates that stronger IPR protection is equally beneficial to developed and developing countries since it raises both the innovation rate and FDI flows. But the reversed effects of stronger IPR protection on the rate of innovation and the flows of FDI are found by Glass and Saggi (2002) and Glass and Wu (2007) who assume that innovation involves upgrading the quality of products. By modeling the strengthening of IPR protection as an increase in the cost of imitation, Glass and Saggi (2002) find that such strengthening is accompanied by a reduction in the rate of innovation due to labor wastage and imitation tax effects. By modeling the strengthening of IPR protection as an exogenous reduction in imitation intensity, Glass and Wu (2007) find that if innovation targets only imitated products, stronger IPR protection will reduce both innovation intensity and FDI flows. These studies indicate that when considering the effects of IPR protection, the nature of the innovation process (innovation involving variety enlargement or quality improvement) is clearly of importance, whereas the endogeneity of imitation intensity does not appear to be so.

Despite numerous empirical studies having examined the ways in which international production affects wage inequality in the developed countries, there are apparently very few theoretical studies on this issue, essentially because of the complexity of the model (caused by the setting of the heterogeneous agents in the model). The Helpman (1993) model is also used to study the impact of the strengthening IPR protection on outsourcing activities. Refer to Yang and Maskus (2001) and Glass (2004) for discussions on the strengthening of IPR protection and its impact on outsourcing decisions.
developed countries). There is no doubt that when setting out to examine the consequences of the strengthening of IPR protection, it is necessary to provide a framework with heterogeneous agents which can be used to analyze the wage inequality response. Therefore, in this study, the effects of IPR protection are revisited using a model with heterogeneous workers in developed countries.

With the recognition that global production would affect country’s wage inequality between skilled and unskilled workers, Sayek and Sener (2006) and Benz (2012) examine the effects of outsourcing and IPR protection on wage inequality based on a model with unskilled and skilled workers. However, the fraction of skilled (unskilled) population is assumed to be exogenous in both studies and outsourcing activities and IPR protection will not affect workers’ choices of being skilled or unskilled workers. Therefore, their analysis focuses on the demand-side effect as firms adjust to changes in outsourcing costs or Southern IPR protection by changing their labor demand and ignores the fact that these changes will also affect incentives of skills choice and labor supplies of skilled and unskilled workers.

In this study, we develop a dynamic North-South product-cycle general-equilibrium model, within which innovation occurs in the North (a developed country) and 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 (a developing country). Innovation improves the quality of goods and stronger IPR protection will cause an exogenous decrease in the imitation intensity. Northerners can

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2 The effect of the strengthening IPR protection on innovation and FDI is also studied by Parello (2008); however, since it is based on a complicated model where heterogeneous workers are present in both the developed and developing countries, the results of that study do not provide any clear direction of the effects of the strengthening of IPR protection on either innovation or FDI.

3 The heterogeneity of workers is also assumed by Lai (1995) and Chen (2013). Lai (1995) examines the effects of the labor supply on the global distribution of income while Chen (2013) studies how IPR protection affects FDI and outsourcing decisions.

4 The North-South product-cycle model is originally introduced by Vernon (1966) and subsequently extended by Segerstrom, Anant and Dinopoulos (1990) and Grossman and Helpman (1991a, 1991b).
choose to become skilled workers and work in the R&D sector or remain unskilled and work in the production sector. The heterogeneity among Northerners allows us to examine changes in Northern wage inequality when IPR protection is strengthened.

Two scenarios of innovation are considered, with the first of these scenarios involving innovation in the North targeting all types of products. Under this innovation setting, stronger IPR protection in the South will reduce the imitation risk and raise incentives for FDI, thereby motivating Northern firms to shift their production from the North to the South through FDI and reducing the demand for Northern unskilled workers. This will bring about an increase in the Northern wage inequality and a reduction in the proportion of unskilled labor in the North. The rate of innovation will increase because more skilled Northern workers become available for employment in the R&D sector. As regards the pattern of production, if imitation intensity is sufficiently low, the strengthening of IPR protection will raise the global expenditure and there will be an increase in the extent of FDI, along with corresponding reductions in the extents of Northern production in and Southern production.

Under the second scenario, only those products imitated by Southern firms will be targeted by innovation.\(^5\) Stronger IPR protection in the South affects the demand for skilled labor in the North in two ways. First, it raises the incentives for innovation and increases the demand for skilled labor in the North; and second, the reduced imitation intensity induces the product cycle to go around more slowly, such that fewer products are be imitated by Southern firms. Since innovation targets only imitated goods, this implies that there will be a reduction in the demand for skilled labor in the

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\(^5\) See Glass and Wu (2007) for a discussion on 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 less efficient than leaders, innovation costs will be higher for followers and such innovation will be undertaken only by leaders. They further assume that leaders will not undertake further innovation until Southern firms have imitated their most recent innovation; however, if followers are as efficient as leaders, innovation will target all types of products.
North. We find that there will be an overall increase in the proportion of Northern skilled workers, leading to an increase in the wage inequality in the North. The increase in the proportion of skilled workers in the North leads to a rise in the rate of innovation while the increase in Northern wage inequality motivates Northern firms to shift their production to the South. If imitation intensity is sufficiently low and the strengthening of Southern IPR protection raises the global expenditure, there will be an increase in the extent of FDI.

Our findings indicate that the strengthening of IPR protection in the South will lead to increases in both the rate of innovation and FDI activities, regardless of the targets for such innovation. Although our results on the changes in innovation intensity and FDI under the first scenario are consistent with those reported in Glass and Wu (2007), our results under the second scenario are quite the reverse. The study of Glass and Wu (2007) demonstrates that when determining the effects of the strengthening of IPR protection under the assumption of homogeneous Northern workers, the nature of the innovation process must be taken into consideration. They show that if innovation targets only imitated 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 extent of Northern production and a corresponding reduction in the extent of FDI. Because the increase in the extent of Northern production crowds out Northern labor used for innovation, the innovation intensity will decrease.

However, we show that if Northern workers are heterogeneous, although the decrease in the wage rate for Northern unskilled workers will reduce global expenditure, the increase in the proportion of Northern skilled workers will raise the aggregate income of Northern workers, thereby leading to an increase in global expenditure. If imitation intensity is sufficiently low, the proportion of Northern
skilled workers will be high enough such that the overall global expenditure will increase. In response to the reduction in the proportion of Northern unskilled labor used for production, there will be a reduction in the extent of Northern production and a corresponding increase in the extent of FDI. Since more Northern labor has been freed up from the production sector, innovation intensity will increase. Our findings therefore demonstrate that in addition to allowing us to analyze changes in wage inequality, the heterogeneity among agents also plays an important role in determining the effects of IPR protection.

The remainder of this paper is organized as follows. In the next section, we develop a model within which innovation is targeted at all products, and then examine the effects of the strengthening of IPR protection on innovation, skills choices, wages and the pattern of production under balanced-growth-path (BGP) equilibrium. We subsequently go on in Section 3 to consider a model where innovation targets only imitated goods. The final section concludes.

2. THE MODEL

We develop a product-cycle model with skills (human capital) accumulation in the spirit of Dinopoulos and Segerstrom (1999). We assume that there exist a developed Northern country \( \mathbb{N} \) and a developing Southern country \( \mathbb{S} \). Each economy \( \mathbb{i} \in \{\mathbb{N}, \mathbb{S}\} \) is composed of \( L_i(t) \) households at time \( t \). In both countries, each individual faces the birth rate of \( \theta \) and the death rate of \( \delta \) and has the lifespan of \( T \) periods. Therefore, the growth rate of the population, \( g \), is equal to \( (\theta - \delta) \) and the population dynamics imply that \( \theta L_i(t) = \delta L_i(t + T) \) and \( L_i(t + T) = L_i(t)e^{gT} \).

2.1. Skills accumulation

\[ \text{Note that the population dynamics indicates that } \theta = g e^{gT}/(e^{gT} - 1) \text{ and } \delta = g/(e^{gT} - 1). \]
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 schools for skill training (human capital accumulation). They will receive the skilled wage rate $w_N^H$ per unit of effective labor when they complete their education.

Skills accumulation is assumed to depend on public investments in education and time spent in schools. Public educational investment is financed by the tax revenue and government runs a balanced budget. We assume that each Northerner needs to pay a lump-sum tax of $g_g \geq 0$ in every period. This implies that the total Northern public educational investment in period $t$ is $G_N = g_g L_N$. All skilled Northerners can benefit from public educational investments. The proportion of the unskilled population in the North is denoted by $\phi_N$ and is endogenously determined. The remaining $(1 - \phi_N)L_N(t)$ individuals either attend schools for skill training or work as skilled workers. The subsidy received by each Northern skilled worker is $g_N = \frac{G_N}{(1 - \phi_N)L_N}$.

Besides public investments, schooling time is another important determinant to the skills accumulation. Let the function $h_N(D_N)$ with $h_N'(D_N) > 0$ and $h_N''(D_N) < 0$ represent the skill production function of the amount of time spent in schools. 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:

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

where $\gamma \in (0,1)$ denotes the elasticity of skills accumulation with respect to the public educational investment. Therefore, $h_N(D_N) g_N^\gamma$ represents one efficiency unit.

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Footnote 7: For those Northerners who have completed education and started working, the public educational spending provides on-the-job training for them in order to avoid their human capital from depreciation.
of skilled labor.\textsuperscript{8} Then the left-hand side of Eq. (1) represents the income of an unskilled Northerner while the right-hand side of Eq. (1) represents the income of a skilled Northerner.

In the equilibrium with the co-existence of skilled and unskilled workers in the North, Eq. (1) holds with equality. The optimal time spent in schools ($\bar{D}_N$) is determined by the following equation:\textsuperscript{9}

$$\rho h_N(\bar{D}_N) = (1 - e^{-\rho(T-\bar{D}_N)})h_N(\bar{D}_N).$$

(2)

From Eqs. (1) and (2), wage inequality (measured by the wage of skilled workers divided by the wage of unskilled workers) in the North can be expressed as:

$$\frac{w_{N}^{H}}{w_{N}^{L}} = w_N = \frac{\sigma_N(\bar{D}_N)(1 - \phi_N)^y}{h_N(\bar{D}_N)g^y},$$

(3)

where $\sigma_N(\bar{D}_N) = \frac{1-e^{-\rho t}}{e^{-\rho \bar{D}_N}-e^{-\rho T}} > 1$.

The supply of 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 $B_N(\bar{D}_N) = (e^{\theta(T-\bar{D}_N)} - 1)/(e^{\theta T} - 1) < 1$ . Then the supply of effective skilled Northern labor ($L_N^H$) is:

$$L_N^H = \psi_N(\phi_N)L_N,$$

(4)

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

\textbf{2.2. Consumers}

\textsuperscript{8} See Glomm and Ravikumar (1992), Kaganovich and Zilcha (1999) and Chen (2005, 2006) for the literature of human capital accumulation.

\textsuperscript{9} We focus our analysis on the balanced-growth-path (BGP) equilibrium where $r(t) = \rho$ holds. See Section 2.2 for more details about the BGP equilibrium.
Consumers live in either countries can choose from a continuum of products \( z \in [0,1] \) available at different quality levels \( j \). Each quality level \( j \) is \( \lambda \)-times better than quality level \( j-1 \). The size of the quality increment \( \lambda \) is assumed to be constant and greater than 1. Thus, each product of quality \( j \) provides quality \( \lambda^j \). All products begin at time \( t = 1 \) with the quality level \( j=0 \) and the base quality \( \lambda^0 = 1 \).

Consumers care about both the quantity and quality of goods. The instantaneous utility faced by a representative household in country \( i \) is:

\[
\log u_i(t) = \int_0^1 \log \left[ \sum_j \lambda^j q_{ij}(z,t) \right] dz , \tag{5}
\]

where \( q_{ij}(z,t) \) is the household consumption in country \( i \) for quality level \( j \) of product \( z \) at time \( t \). The lifetime utility of the representative agent is:

\[
U_i(0) = \int_0^\infty L_i(0) e^{-(\rho - g)t} \log u_i(t) \, dt; \quad L_i(0) > 0; \quad \rho > g , \tag{6}
\]

where \( \rho \) denotes the subjective discount factor.

The total expenditure for all products with different quality levels under price \( p_{ij}(z,t) \) is:

\[
E_i(t) = \int_0^1 \left[ \sum_j p_{ij}(z,t) q_{ij}(z,t) \right] dz . \tag{7}
\]

Let \( W_i(t) \) and \( A_i(t) \) respectively denote the sum of discount wage income of those households from country \( i \) and the value of assets that the household holds at time \( t \). The aggregate intertemporal budget constraint is:

\[
W_i(t) + A_i(t) = \int_t^\infty L_i(0) \left[ E_i(t) + g_G e^{\theta_T} e^{-[R(t) - R(t)]} \right] d\tau , \tag{8}
\]

where \( R(t) = \int_0^t r(\tau) d\tau \) represents the cumulative interest rate up to time \( t \) and \( r(\tau) \) is instantaneous interest rate at time \( \tau \). Note that \( g_G > 0 \) in the North and \( g_G = 0 \) in the South.

The optimization problem can be solved by three steps. In the first step, consumers allocate expenditure at each point for each product across available quality
levels in a way such that consumers choose the quality which gives the lowest adjusted price, $\frac{p_j(z,t)}{\lambda_j}$. That is, consumers are willing to pay $\lambda$ for a single quality level improvement in a product.

In the second step, consumers allocate expenditures across products at each point in time. Since the elasticity of substitution between any two products is constant at unity, expenditure across all products will be the same. Let $E(t) = E_N(t)L_N(t) + E_S(t)L_S(t)$ represent the global expenditure at time $t$, the global demand function for product $z$ of quality $j$ is $q_j(z,t) = E(t)/p_j(z,t)$. In the equilibrium, only the highest quality level available will sell.

In the final step, 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:

$$\frac{\dot{E}_i(t)}{E_i(t)} = r(t) - \rho.$$  \hfill (9)

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

### 2.3. Producers

Innovation occurs only in the North and all existing products are the targets of innovation. Northern firms engage in R&D activity hires skilled Northern workers and produce cutting-edge quality products through innovation. A Northern firm in industry $z$ engaged in innovation intensity $t_R(z,t)$ will achieve one level of quality improvement in the final product with probability $t_R(z,t)dt$ for a time interval $dt$. In order to achieve this, $a_{iR}(z,t)X(t)dt$ units of labor will be required at a total cost of $w_H^H a_{iR}(z,t)X(t)dt$, where $X(t)$ denotes R&D difficulty. Based on the *semi-endogenous growth* approach, as proposed by Dinopoulos and Segerstrom (1999),
we assume that R&D difficulty is positively correlated with the size of Northern population.\(^{10}\) That is, \(X(t) = \kappa L_N\) with \(\kappa > 0\). This assumption takes into account the concept that introducing new products to replace old ones is more difficult to in a larger market.

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.\(^{11}\) Let \(\nu_N\) denote the expected discounted value of a Northern firm that has discovered a new product. To generate finite rate of innovation, expected gains from innovation cannot exceed the costs, with equality being achieved when innovation occurs with positive intensity:

\[
\nu_N \leq w_N^f a_R X, \quad \tau_r > 0 \iff \nu_N = w_N^f a_R X. \tag{10}
\]

Northern firms can optimally choose the intensity of the production in the South. To simplify the model, we assume that FDI is costless.\(^{12}\) Let \(\nu_F\) and \(\tau_F\) 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 \(\nu_F > \nu_N\) while the FDI intensity will be zero if \(\nu_F < \nu_N\). Therefore, a Northern firm will feel indifferent between producing in the North or in the South and FDI will occur with positive intensity:

\[
\nu_F = \nu_N. \tag{11}
\]

Eqs. (10) to (11) together imply that along the BGP equilibrium:

\[
\frac{\dot{\nu}_N(t)}{\nu_N(t)} = \frac{\dot{\nu}_F(t)}{\nu_F(t)} = \frac{\dot{X}(t)}{X(t)} = \frac{\dot{L}_N(t)}{L_N(t)} = g. \tag{12}
\]

We assume that firms face a Bertrand competition and old technologies which

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\(^{10}\) This is referred as the permanent effects on growth approach in Segerstrom (1998).

\(^{11}\) Eq. (25) indicates that \(w_N^f > w_S = 1\).

\(^{12}\) The same setting of FID is also adopted by Glass and Wu (2007).
designs have been improved are available internationally. Therefore, Southern firms are able to produce final goods by using old technologies. Then Northern firms which produce through the use of state-of-the-art technologies will charge the price \( p = \lambda \) (and make a sale \( q = E/\lambda \)) to just prevent their closest rivals from earning positive profits since they possess a one quality level lead over the closest rivals.

We assume that one unit of labor will be needed for one unit of the final product if a Northern (Southern) firm undertakes production in the North (South). Since the cost of firms completing one unit of final production in the North is \( w_N \), the instantaneous profits for them are:

\[
\pi_N = \frac{E}{\lambda} (\lambda - w_N).
\]  

(13)

Firms undertaking production in the South through FDI can save costs of production by hiring Southern workers to produce goods. The instantaneous profits for FDI are therefore:

\[
\pi_F = \frac{E}{\lambda} (\lambda - 1).
\]  

(14)

The reward for successful innovation by a Northern firm is:

\[
v_N = \frac{\pi_N}{\rho - g + t_R}.
\]  

(15)

If a Northern firm chooses to undertake production in the South through FDI, it faces the exogenous risk of imitation which is denoted by \( t_S \). Thus, the reward for a firm successfully undertaking its production in the South through FDI is:

\[
v_F = \frac{\pi_F}{\rho - g + t_R + t_S}.
\]  

(16)

The strengthening IPR protection in the South reduces imitation risk and causes an exogenous decrease in \( t_S \).

2.4. Factor markets and the BGP equilibrium

We focus our analysis on the BGP equilibrium. Two stationary variables are defined as
the adjusted level of R&D difficulty, \( x = X/L_N = \kappa \), and the adjusted global expenditure, \( \hat{E} = E/L_N \). Let \( n_N \) and \( n_S \), respectively, denote the proportions of products produced completely in the North (the extent of Northern production) and in the South (the extent of Southern production). Similarly, we use \( n_F \) to represent the proportion of the goods for which production is carried out through FDI (the extent of FDI). The sum of these product measures should be one:

\[
 n_N + n_F + n_S = 1. \tag{17}
\]

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

\[
 t_F n_N = (\iota_R + \iota_S) n_F, \tag{18}
\]

\[
 \iota_S n_F = \iota_R n_S. \tag{19}
\]

Skilled Northern labor is used for R&D while unskilled Northern labor is used for production. The labor-market clearing conditions for skilled and unskilled Northern labor are:

\[
 a_R \iota_R X = \psi_N(\phi_N) L_N, \tag{20}
\]

\[
 n_N \frac{E}{\lambda} = \phi_N L_N. \tag{21}
\]

We assume that once the product is imitated, the Southern firms are able to carry out the entire production and charge a price equal to the cost of production; that is, they earn zero profits. The labor-market clearing condition for the South indicates that:

\[
 (n_F + \lambda n_S) \frac{E}{\lambda} = L_S. \tag{22}
\]

Substituting Eqs. (10)-(11), (13) and (14) into Eqs. (15)-(16), we obtain:

\[
 \hat{E} \left( 1 - \frac{w_N^H}{\lambda} \right) = (\rho - g + \iota_R) w_N^H a_R \kappa, \tag{23}
\]

\[
 \hat{E} \left( 1 - \frac{1}{\lambda} \right) = (\rho - g + \iota_R + \iota_S) w_N^H a_R \kappa. \tag{24}
\]

The economy is described by Eqs. (2), (3) and (17)-(24) with ten variables.
\{ w^H_N, w^L_N, \bar{D}_N, \phi_N, \bar{E}, n_N, n_F, n_S, t_R, t_F \}. Using Eqs. (23) and (24), we can derive the wage rates as:

\[
w^H_N = \frac{\rho - g + \lambda \bar{l}_S}{\rho - g + t_R + \bar{l}_S}, \tag{25}\]

\[
w^L_N = \frac{\bar{E}(\lambda - 1)}{\lambda a_R \kappa (\rho - g + t_R + \bar{l}_S)}. \tag{26}\]

Substituting the wage rates in Eqs. (25) and (26) into Eq. (3), then $\bar{E}$ can be expressed as a function of $\phi_N$ and $i_R$:

\[
\bar{E}(\phi_N, i_R) = \frac{\lambda a_R \kappa (\rho - g + t_R + \lambda \bar{l}_S) \sigma_N(\bar{D}_N)(1 - \phi_N)^\gamma}{(\lambda - 1) h_N(\bar{D}_N) g_G \gamma}. \tag{27}\]

Combining Eqs. (21) and (27), we can derive $n_N = n_N(\phi_N, i_R)$. From Eqs. (17), (19), we can obtain $n_F = n_F(\phi_N, t_R)$ and $n_S = n_S(\phi_N, t_R)$. Then we can derive $t_F = t_F(\phi_N, t_R)$ from Eq. (18). Using Eqs. (20) and (22), the equilibrium can be reduced to the following two equations in $\phi_N$ and $i_R$:

\[
t_R = \frac{\psi_N(\phi_N)}{a_R \kappa}, \tag{28}\]

\[
[n_F(\phi_N, i_R) + \lambda n_S(\phi_N, i_R)] \frac{\bar{E}(\phi_N, i_R)}{\lambda} = \frac{L_S}{L_N}. \tag{29}\]

Eq. (28) indicates that $\phi_N$ and $t_R$ are negatively correlated. In Appendix A, we show that if $\lambda$ is sufficiently small such that $(\lambda - 1)(\rho - g + \lambda) < 1$, Eq. (29) will imply a positive relationship between $\phi_N$ and $t_R$.\footnote{The value of $\lambda$ is calibrated to 1.05 in Acemoglu and Akcigit (2012). This number is consistent with empirical findings of Bloom, Schankerman and Van Reenen (2005).} Therefore, there will exist a unique BGP equilibrium in the model where Northern innovation targets all products if $\lambda$ is sufficiently small.\footnote{See Appendix A for more details of the BGP equilibrium.} Eqs. (28) and (29) are respectively represented by the $SS$ and $PP$ locus in Figure 1. Once one derives the solution of $\{\phi_N, t_R\}$, the remaining endogenous variables can be solved accordingly.

\[<\text{Figure 1 is inserted about here}>\]
2.5. Effects of IPR protection

During the course of economic development, the Southern country places effort into improving its economic environment in order to attract Northern firms to carry out their production in the South. To study the effects of the strengthening IPR protection, we assume that \((\lambda - 1)(\rho - g + \lambda) < 1\) and there exists a unique equilibrium in the following analysis in this section.

The strengthening of IPR protection in the South will lower the imitation risk and raise the incentives for innovation, leading to increases in both the demand for skilled labor in the North and Northern wage inequality. As illustrated in Figure 1, a lower \(t_s\) shifts \(PP\) locus upward while leaving \(SS\) locus unaffected and results in a higher rate of innovation and a lower fraction of Northern unskilled workers. The following proposition summarizes these findings.

**Proposition 1.** When Northern innovation targets all products, the strengthening of IPR protection in the South will cause: (a) an increase in the rate of innovation; (b) a reduction in the proportion of Northern unskilled workers; and (c) the widening of wage inequality in the North.\(^{15}\)

The strengthening IPR protection in the South affects the adjusted global expenditure through two channels. First, as shown in Appendix B, a reduction in \(t_s\) lowers the wage rate of unskilled Northern labor, which will in turn reduce the aggregate income of Northern workers, and there will be a consequent reduction in the adjusted global expenditure. Second, with an increase in the proportion of Northern skilled workers, there will be a corresponding increase in the aggregate income of Northern workers, thereby leading to a rise in the adjusted global expenditure. The adjusted global expenditure may either increase or decrease, depending on which

\(^{15}\) The proofs of Propositions 1 and 2 are provided in Appendix B.
effect dominates. If imitation intensity is sufficiently low, there will be an increase in the adjusted global expenditure due to the high proportion of Northern skilled workers. With a decrease in the fraction of Northern unskilled labor, there will be an overall reduction in the extent of Northern production as indicated by the market-clearing condition of unskilled labor in the North shown in Eq. (21).

Besides, the reduced imitation intensity of FDI will motivate Northern firms to shift the production to the South, thereby leading to an increase in the extent of FDI. Note that while a higher extent of FDI will raise the extent of Southern production, a lower imitation intensity will reduce the extent of Southern production. We find that there will be an overall reduction in the extent of Southern production. We summarize the results on globalization production decisions as follows.

**Proposition 2.** When Northern innovation targets all products, the strengthening IPR protection in the South will raise the extent of FDI while reducing the extents of Northern production and Southern production, provided that there is a sufficiently low imitation intensity.

3. **INNOVATION TARGETS ONLY IMITATED PRODUCTS**

The model presented in Section 2 assumes that innovation in the North targets all products; however, it remains to be seen whether the results will be unchanged if innovation in the North targets only those products imitated and produced by firms in the South. In order to tackle this issue, we modify some of the equations relating to innovation. Since innovation in the North does not target the products of other Northern firms, the reward for successful innovation by a Northern firm becomes higher:

\[
\nu_N = \frac{\pi_N}{\rho - g}.
\]  

(30)
Similarly, the reward for the firm undertaking its production in the South through FDI also becomes higher:

$$v_F = \frac{\pi_F}{\rho - g + \lambda_S}. \quad (31)$$

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

$$\tau_F n_N = \tau_S n_F, \quad (32)$$

Because Northern innovation targets only imitated products produced by Southern firms, the labor-market clearing condition for the skilled labor in the North which is used for innovation becomes:

$$a_R \tau_R n_S X = \psi_N L_N, \quad (33)$$

It should be noted that all other equations remain unchanged.

3.1. The BGP equilibrium

The wage rates of Northern unskilled and skilled labor are:

$$w_N^u = \frac{\rho - g + \lambda_S}{\rho - g + \lambda_S}, \quad (34)$$

$$w_N^s = \frac{\hat{E}(\lambda - 1)}{\lambda a_R \kappa (\rho - g + \lambda_S)} \quad (35)$$

Substituting the wage rates in Eqs. (34) and (35) into Eq. (3), then $\hat{E}$ can be solely expressed as a function of $\phi_N$:

$$\hat{E}(\phi_N) = \frac{\lambda a_R \kappa (\rho - g + \lambda_S) \sigma_N (\bar{D}_N)(1 - \phi_N)^\gamma}{(\lambda - 1) h_N (\bar{D}_N) g_c \gamma}. \quad (36)$$

Substituting Eq. (36) into Eq. (21), we can drive $n_N = n_N(\phi_N)$. Combining Eqs. (19) and (33), we can obtain $n_F = n_F(\phi_N)$. Then Eq. (17) indicates that $n_S = 1 - n_N(\phi_N) - n_O(\phi_N) = n_S(\phi_N)$. Using Eqs. (32) and (33), we can derive $\tau_F = \tau_F(\phi_N)$ and $\tau_R = \tau_R(\phi_N)$. Combining Eqs. (17) and (22), the equilibrium can be reduced to the following equations in $\phi_N$:
\[
\{ \lambda [1 - n_N(\phi_N)] - (\lambda - 1) n_F(\phi_N) \} \frac{\dot{E}(\phi_N)}{\lambda} = \frac{L_S}{L_N}, \tag{37}
\]

We define \( f(\phi_N) = \{ \lambda [1 - n_N(\phi_N)] - (\lambda - 1) n_F(\phi_N) \} \frac{\dot{E}(\phi_N)}{\lambda} - \frac{L_S}{L_N} \). The locus of \( f(\phi_N) \) is illustrated in Figure 2. In Appendix C, we show that \( f(\phi_N) \) is a monotonically decreasing function in \( \phi_N \) if \( \lambda (1 - \gamma) < 1 \). Therefore, if \( \lambda \) is sufficiently small, there will exist a unique BGP equilibrium in the model where Northern innovation targets only imitated product. The intersection of \( f(\phi_N) \) and the x-axis gives the unique equilibrium value of \( \phi_N \). After solving the solution of \( \phi_N \), other endogenous variables can be solved accordingly.

\<Figure 2 is inserted about here>\n
### 3.2. Effects of IPR protection

Based on the preceding discussion, we are now ready to examine the effects of the strengthening of IPR protection in the South when innovation targets only imitated products. In the following analysis in this section, we assume that \( \lambda (1 - \gamma) < 1 \), whilst placing the focus on the unique equilibrium.

As indicated in Figure 2, the strengthening of IPR protection will cause a downward shift in the \( f(\phi_N) \) locus, resulting in a lower proportion of unskilled workers in the North. First, stronger IPR protection reduces imitation risk and raises the incentives of innovation and increases the demand of Northern skilled labor. Second, the reduced imitation rate means there are fewer products imitated by Southern firms. Since innovation targets only imitated goods, this implies that there will be a reduction in the demand for skilled labor in the North. Our results indicate that overall, there will be an increase (reduction) in the proportion of skilled (unskilled) workers in the North, along with a corresponding increase in Northern wage inequality.

16 See Appendix C for more details about the BGP equilibrium.
Although the strengthening of IPR protection in the South reduces adjusted global expenditure due to the reduction in the wage rate for unskilled labor in the North, an increase in the proportion of skilled workers in the North will lead to a rise in adjusted global expenditure. If imitation intensity is sufficiently low, there will be an increase in adjusted global expenditure. Then the reduction in the proportion of unskilled labor in the North will result in a reduction in the extent of Northern production in order to restore the labor-market equilibrium of unskilled labor in the North shown in Eq. (21). This will cause the extent of FDI to increase. With more labor available for R&D, innovation intensity will rise. To restore the labor-market equilibrium for the South shown in Eq. (22), the extent of Southern production will decrease. The following proposition summarizes these results.  

**Proposition 3.** When Northern innovation targets only products imitated by Southern firms, the strengthening Southern IPR protection will reduce the proportion of Northern unskilled workers and raise Northern wage inequality. If imitation risk is sufficiently low, the rate of innovation and the extent of FDI will increase while the extents of Northern production and Southern production will decrease.

Glass and Wu (2007) find that when considering the impact of Southern IPR protection on the rate of innovation and pattern of production, the efficiency of Northern innovation followers matters. If Northern innovation followers are efficient and innovation targets all products, the strengthening IPR protection in the South will have the same effects on the rate of innovation and pattern of production as stated in Propositions 1 and 2. However, if Northern innovation followers are inefficient and innovation targets only imitated products, strengthening Southern IPR protection will

---

17 The proof of Proposition 3 is given in Appendix D.
cause the reverse effects on the rate of innovation and pattern of production, as stated in Proposition 3.

Our model is similar to the model adopted by Glass and Wu (2007), with the important exception of the nature of Northern workers; that is, we consider Northern workers to be heterogeneous, whereas Glass and Wu (2007) assume Northern workers to be homogeneous. If Northern workers are homogeneous, then the strengthening IPR protection in the South will provide motivation for Northern firms to shift their production to the South, thereby reducing the wage rate of Northern workers, with a resultant reduction in global expenditure. The decrease in the Northern wage restores the reward of Northern production and the extent of Northern production will increase, causing the extent of FDI to decrease. With reductions in both global expenditure and the extent of FDI, the extent of Southern production will increase to restore the equilibrium of the Southern labor market. Because the increase in the extent of Northern production crowds out Northern labor used for innovation, the innovation intensity will decrease.

However, if Northerners are heterogeneous, then global expenditure will not necessarily be reduced as a result of the strengthening of Southern IPR protection. Although the shift of the production to the South will lower the wage rate of unskilled Northerners, causing the aggregate Northern income and the global expenditure to decrease, the increase in the fraction of skilled Northerners will lead to an increase in the aggregate income of Northern workers, and a resultant increase in global expenditure. If the global expenditure increases with the strengthening of Southern IPR protection, a reduction in the proportion of Northern labor for use in production will cause reductions in the extents of Northern and Southern production and a corresponding increase in the extent of FDI. With more Northern labor freed up from the production sector, the innovation intensity will rise. Therefore, we show that under
the assumption of heterogeneous Northerners, if stronger Southern IPR protection raises the adjusted global expenditure, the innovation intensity and the extent of FDI will increase while the fraction of Northern unskilled labor and the extents of Northern and Southern production will decrease, regardless of targets of innovation.

4. CONCLUSION

This paper develops a North-South general-equilibrium model with skills accumulation to examine effects of the strengthening IPR protection in the South on innovation, skills accumulation, Northern wage inequality, and pattern of production. Two scenarios of innovation settings are considered: innovation targets all products or innovation targets only imitated products. We find that under both scenarios, the strengthening IPR protection in the South will reduce the fraction of Northern unskilled labor and increase R&D intensity and wage inequality in the North. If imitation risk is sufficiently low, the extent of FDI will increase while the extent of Northern production will decrease, along with a corresponding reduction in the extent of Southern production.

A few notes are worth discussing. First, since the imitation risk is exogenous, the strengthening of IPR protection in the South is therefore represented by an exogenous reduction in imitation risk; however, Southern firms can increase the imitation intensity by devoting additional labor input to the imitation sector. Therefore, it would be interesting to examine an economy where the imitation risk is endogenized. Second, in order to simplify our analysis, we assume that Southern labor is homogeneous and that Southern workers do not make decisions on skills choice. By assuming that Southern workers, like their Northern counterparts, can choose to become skilled or unskilled workers, our model can be extended to study the effects of the strengthening
of IPR protection in the South, along with the effects of trade policies not only on Northern wage inequality, but also on Southern wage inequality.
REFERENCES


Figure 1. The BGP equilibrium when innovation targets all products

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

Existence of the BGP equilibrium when innovation targets all products

First note that \( x = \kappa \) and \( \bar{D}_N \) and \( w_N \) are determined by Eqs. (2) and (3). Using Eqs. (23) and (24), we can derive the wage rates as:

\[
\begin{align*}
  w^l_N &= \frac{\rho - g + \iota_R + \lambda t_s}{\rho - g + \iota_R + t_s}, \\
  w^h_N &= \frac{\bar{E}(\lambda - 1)}{\lambda a_R \kappa (\rho - g + \iota_R + t_s)}.
\end{align*}
\]

Substituting the wage rates in Eqs. (A1) and (A2) into Eq. (3) yields the following function of the adjusted global expenditure:

\[
\bar{E}(\phi_N, \iota_R) = \frac{\lambda a_R \kappa (\rho - g + \iota_R + \lambda t_s) \sigma_N (\bar{D}_N)(1 - \phi_N)^\gamma}{(\lambda - 1) h_N (\bar{D}_N) g_{c, \gamma}}.
\]

From Eq. (21), we have:

\[
n_N = \frac{\lambda \phi_N}{\bar{E}(\phi_N, \iota_R)} = n_N(\phi_N, \iota_R).
\]

Combining Eqs. (17) and (19) gives us:

\[
n_F = \frac{\iota_R [1 - n_N(\phi_N, \iota_R)]}{i_s + \iota_R} = n_F(\phi_N, \iota_R).
\]

From Eq. (17), we can derive \( n_S = 1 - n_N(\phi_N, \iota_R) - n_F(\phi_N, \iota_R) = n_S(\phi_N, \iota_R) \).

Eq. (18) indicates that:

\[
\iota_F = \frac{(\iota_R + t_s) n_F(\phi_N, \iota_R)}{n_N(\phi_N, \iota_R)} = \iota_F(\phi_N, \iota_R).
\]

Eq. (20) implies that:

\[
\iota_R = \frac{\psi_N(\phi_N)}{a_R \kappa}.
\]

Eq. (A7) indicates that \( \iota_R \) and \( \phi_N \) are negatively correlated since \( \psi_N'(\phi_N) = \frac{\partial \psi_N}{\partial \phi_N} = \frac{(1 - \gamma) \psi_N}{1 - \phi_N} < 0 \).

Substituting Eq. (17) into Eq. (22), we have:

\[
\{(1 - \lambda) n_F(\phi_N, \iota_R) + \lambda [1 - n_N(\phi_N, \iota_R)]\} \bar{E}(\phi_N, \iota_R) = \frac{\bar{E}(\phi_N, \iota_R)}{\lambda} = \frac{L_S}{L_N}.
\]

Substituting Eqs. (A4) and (A5) into Eq. (A8), we have:
\[
\frac{i_R + \lambda i_S}{\lambda(i_R + i_S)} [\hat{E}(\phi_N, i_R) - \lambda \phi_N] = \frac{L_S}{L_N}.
\]

(A9)

The relationship of \( \phi_N \) and \( \lambda \) indicated by Eq. (A9) is:

\[
\frac{dt_R}{d\phi_N} = \frac{(i_R + \lambda i_S)(\hat{E}_N - \lambda \phi_N)}{\Omega},
\]

(A10)

where \( \hat{E}_N = \frac{\partial \hat{E}(\phi_N, i_R)}{\partial \phi_N} = -\frac{\gamma \hat{E}}{1-\phi_N} < 0 \) and \( \Omega = \frac{i_s(\lambda - 1)(\hat{E} - \lambda \phi_N)}{\lambda} - \frac{(i_R + \lambda i_S)\hat{E}}{\rho - g + \lambda i_S} \). Note that \( \Omega < 0 \) if

\[
i_s(\lambda - 1)(\rho - g + i_R + \lambda i_S) - (i_R + i_S)(i_R + \lambda i_S) < (\lambda - 1)(\rho - g + \lambda) - 1 < 0; \text{ that is, } (\lambda - 1)(\rho - g + \lambda) < 1. \]

If \( \Omega < 0 \), Eq. (A10) implies that \( i_R \) and \( \phi_N \) will be positively correlated.

Eqs. (A9) and (A10) are used to solve for \( \{\phi_N, i_R\} \). If \((\lambda - 1)(\rho - g + \lambda) < 1\), then there will exist a unique solution. Graphically, \( i_R \) and \( \phi_N \) are determined by the intersection of SS and PP curvature in Figure 1. Once one derives the solution of \( \{\phi_N, i_R\} \), the remaining endogenous variables can be solved accordingly. Thus, we have completely solved the model and showed that there exists a unique solution.

**APPENDIX B**

**Proof of Propositions 1 and 2**

From Eq. (A3), the partial derivatives of \( \hat{E} \) with respect to \( \phi_N, i_R \) and \( i_S \) are

\[
\frac{\partial \hat{E}}{\partial \phi_N} = -\frac{\gamma \hat{E}}{1-\phi_N} < 0, \quad \frac{\partial \hat{E}}{\partial i_R} = \frac{\hat{E}}{\rho - g + i_R + \lambda i_S} > 0 \quad \text{and} \quad \frac{\partial \hat{E}}{\partial i_S} = \frac{\lambda \hat{E}}{\rho - g + i_R + \lambda i_S} > 0.
\]

Totally differentiating Eqs. (A7) and (A9) with respect to \( i_R, \phi_N \) and \( i_S \) yields:

\[
\left[ -\psi_N'(\phi_N) \quad a_R \right] \begin{bmatrix} \frac{d\phi_N}{d i_R} \\ \frac{d\phi_N}{d i_S} \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} \begin{bmatrix} d i_R \\ d i_S \end{bmatrix},
\]

where

\[
b_1 = \frac{(i_R + \lambda i_S)}{\lambda(i_R + i_S)} \left( \frac{\partial \hat{E}}{\partial \phi_N} - \lambda \right) < 0, \quad b_2 = \frac{-\Omega}{\lambda(i_R + i_S)} > 0 \quad \text{and} \quad b_3 = \frac{i_R + \lambda i_S}{\lambda(i_R + i_S)} \left( \frac{\partial \hat{E}}{\partial i_S} \right) + \frac{(\lambda - 1)i_R \hat{E}}{\lambda(i_R + i_S)^2} > 0.
\]

The determinant of \( B_1 \) is positive since \( |B| = -\psi_N'(\phi_N)b_2 - a_R \lambda b_1 > 0 \). Then the effects of the strengthening IPR protection on \( \phi_N \) and \( i_R \) are:
\[
\phi_N'(i_S) = \frac{d\phi_N}{di_S} = -\frac{a_R \kappa b_3}{|B_1|} > 0, \quad \text{(B1)}
\]
\[
\tau'_R(i_S) = \frac{d\tau_R}{di_S} = -\frac{\psi_N'(\phi_N)b_3}{|B_1|} < 0. \quad \text{(B2)}
\]

Therefore, a decrease of \(i_S\) will lower \(\phi_N\) and raise \(\tau_R\).

We are now ready to examine the effects of \(i_S\) on other key variables. Eqs. (A1) and (3) indicate that:
\[
\begin{align*}
\omega_N'(i_S) &= \frac{d\omega_N}{di_S} = -\frac{(\lambda - 1)[\rho - g + \tau_R - \tau'_R(i_S)]}{(\rho - g + \tau_R + i_S)^2} > 0, \\
\omega_N'(i_S) &= \frac{d\omega_N}{di_S} = -\frac{\gamma \omega_N - \phi_N'(i_S)}{1 - \phi_N} < 0.
\end{align*}
\]

Then a decrease in \(\tau_S\) will lower the wage rate for unskilled Northern workers and raise the Northern wage inequality.

From Eq. (A3), we can derive that:
\[
\hat{E}^'(i_S) = \frac{d\hat{E}}{di_S} = \hat{E} \left[ \frac{\lambda + \tau'_R(i_S)}{\rho - g + \tau_R + \lambda \tau_S} - \frac{\gamma \phi_N'(i_S)}{1 - \phi_N} \right]. \quad \text{(B3)}
\]

Eq. (B3) indicates that \(\hat{E}^'(i_S)\) can be positive or negative, depending on the value of \(\tau'_R(i_S)\) and \(\phi_N'(i_S)\). Substituting Eqs. (B1) and (B2) for \(\tau'_R(i_S)\) and \(\phi_N'(i_S)\) in Eq. (B3) gives us:
\[
\hat{E}^'(i_S) = \frac{\hat{E}(\theta_1 + \theta_2 + \theta_3 + \theta_4 + \theta_5 + \theta_6)}{|B|(\rho - g + \tau_R + \lambda \tau_S)(1 - \phi_N)},
\]

Where
\[
\begin{align*}
\theta_1 &= \psi_N'(\phi_N)b_3(1 - \phi_N) < 0, \\
\theta_2 &= -\frac{\lambda(1 - \gamma)(\lambda - 1)i_S \psi_N \phi_N}{(\tau_R + i_S)^2} < 0, \\
\theta_3 &= \frac{(1 - \gamma)(\lambda - 1)i_S \psi_N \hat{E}}{(\tau_R + i_S)^2} > 0, \\
\theta_4 &= -\frac{(1 - \gamma)\psi_N(i_R + \lambda i_S)\hat{E}}{(\tau_R + i_S)(\rho - g + \tau_R + \lambda i_S)} < 0, \\
\theta_5 &= \frac{a_R \kappa \lambda(i_R + \lambda i_S)(1 - \phi_N)}{\tau_R + i_S} > 0, \\
\theta_6 &= -\frac{\gamma a_R \kappa \rho - g + \tau_R + \lambda i_S(\lambda - 1)i_R \hat{E}}{\lambda(\tau_R + i_S)^2} < 0.
\end{align*}
\]
Note that:

$$
\theta_4 + \theta_5 < \frac{a_R \kappa \lambda (i_R + \lambda i_S)}{i_R + i_S} \left[ -\frac{(1 - \gamma) B_N (\overline{D}_N) \sigma_N (\overline{D}_N) (1 - \phi_N)}{(\lambda - 1)} + 1 \right]. \tag{B4}
$$

Eq. (B4) indicates that $\theta_4 + \theta_5 < 0$ if $(1 - \phi_N)$ is sufficiently high. Because $\phi_N' (i_S) > 0$, this implies that $\theta_4 + \theta_5 < 0$ if $i_S$ is sufficiently low.

Besides, we can also derive that:

$$
\theta_3 + \theta_6 = \frac{(\lambda - 1) \psi_N \overline{E}}{\lambda (i_R + i_S)^2} [\lambda (1 - 2 \gamma) i_S - \gamma (\rho - g + i_R)]. \tag{B5}
$$

Eq. (B5) indicates that if $\gamma \geq \frac{1}{2}$, then $\theta_3 + \theta_6 < 0$. Because the empirical estimate by Card and Krueger (1992) shows that income elasticity for education expenditure is 0.2, it is more reasonable to assume that $\gamma < \frac{1}{2}$. If $\gamma < \frac{1}{2}$, then $\theta_3 + \theta_6 < 0$ if if $i_S$ is sufficiently small since $t'_R (i_S) < 0$. If $\overline{E}' (i_S) < 0$, a decrease in $i_S$ will cause an increase in $\overline{E}$.

Under the condition that $\overline{E}' (i_S) < 0$, the extents of Northern and Southern production will decrease while the extent of FDI will increase as $i_S$ decreases since Eqs. (A4), (A5) and (22) imply that:

$$
n'_N (i_S) = \frac{dn_N}{di_S} = \frac{\lambda [\phi_N' (i_S) \overline{E} - \phi_N \overline{E}' (i_S)]}{\overline{E}^2} > 0,
$$

$$
n'_F (i_S) = \frac{dn_F}{di_S} = \frac{i_S (1 - n_N) t'_R (i_S) - (i_R + i_S) i_R n'_N (i_S)}{(i_R + i_S)^2} < 0,
$$

$$
n'_S (i_S) = \frac{dn_S}{di_S} = -\frac{1}{\overline{E}^2} \left[ \frac{n'_F (i_S) \overline{E}}{\lambda} + \overline{E}' (i_S) \left( \frac{L_S}{L_N} - \frac{n_F}{\lambda} \right) \right] > 0.
$$

**APPENDIX C**

*Existence of the BGP equilibrium when innovation targets only imitated products*

First note that $x = \kappa$ and $\overline{D}_N$ and $w_N$ are determined by Eqs. (2) and (3). The wage rates of Northern unskilled and skilled labor are:

$$
w_N^L = \frac{\rho - g + \lambda i_S}{\rho - g + i_S}, \tag{C1}
$$

$$
w_N^S = \frac{\lambda i_S}{\rho - g + i_S}.
$$
\[ w_N^H = \frac{\hat{E}(\lambda - 1)}{\lambda a_R k(\rho - g + \psi)}. \] (C2)

Substituting the wage rates in Eqs. (34) and (35) into Eq. (3), then \( \hat{E} \) can be expressed as a function of \( \phi_N \):

\[ \hat{E}(\phi_N) = \frac{\lambda a_R k(\rho - g + \lambda s)\sigma_N(\bar{D}_N)(1 - \phi_N)\gamma}{(\lambda - 1)h_N(\bar{D}_N)g_G^\gamma}. \] (C3)

Substituting Eq. (C3) into Eq. (21), we can drive:

\[ n_N = \frac{\lambda \phi_N}{E(\phi_N)} = n_N(\phi_N). \] (C4)

Combining Eqs. (19) and (33), we can obtain:

\[ n_F = \frac{\psi_N(\phi_N)}{a_R k s} = n_F(\phi_N). \]  

(C5)

From Eq. (17), we can obtain that \( n_S = 1 - n_N(\phi_N) - n_F(\phi_N) = n_S(\phi_N) \). Using Eqs. (32) and (33), we can derive:

\[ \tau_F = \frac{\tau s n_F(\phi_N)}{n_N(\phi_N)} = \tau_F(\phi_N), \]  

(C6)

\[ \tau_R = -\frac{\psi_N(\phi_N)}{a_R k n_S(\phi_N)} = \tau_R(\phi_N). \]  

(C7)

Combining Eqs. (17), (22) and (C3)-(C5), the equilibrium can be reduced to the following equation in \( \phi_N \):

\[ \{ \lambda[1 - n_N(\phi_N)] - (\lambda - 1)n_F(\phi_N) \} \frac{\hat{E}(\phi_N)}{\lambda} = \frac{L_S}{L_N}. \]  

(C8)

Define \( f(\phi_N) = \{ \lambda[1 - n_N(\phi_N)] - (\lambda - 1)n_F(\phi_N) \} \frac{\hat{E}(\phi_N)}{\lambda} - \frac{L_S}{L_N} \). Then Eq. (C8) can be represented by:

\[ f(\phi_N) = 0. \]  

(C9)

Note that:

\[ f'(\phi_N) = \frac{df}{d\phi_N} = \hat{E} n_F[\lambda(1 - \gamma) - 1] - \frac{\lambda}{(\lambda - 1)\phi_N} + n_s \frac{\partial \hat{E}}{\partial \phi_N}. \]  

(C9)

Since Eqs. (C3) and (C4) imply that \( \frac{\partial \hat{E}}{\partial \phi_N} = \frac{\gamma \hat{E}}{1 - \phi_N} < 0 \) and \( \frac{\partial n_N}{\partial \phi_N} = \frac{L_S}{L_N} \lambda^{\frac{\phi_N}{\lambda}} \frac{\partial \hat{E}}{\partial \phi_N} < 0 \), then Eq. (C9) indicates that \( f'(\phi_N) < 0 \) if \( \lambda(1 - \gamma) < 1 \).
Therefore, if \( \lambda \) is sufficiently small, \( f(\phi_N) \) will be a monotonic function in \( \phi_N \) and there will be a unique intersection of \( f(\phi_N) \) and the x-axis exists. Once one derives the solution of \( \phi_N \), the remaining endogenous variables can be solved accordingly. Thus, we have completely solved the model and showed that there exists a unique solution.

**APPENDIX D**

*Proof of Proposition 3*

From Eq. (C3), the partial derivatives of \( \hat{E} \) with respect to \( \phi_N \) and \( i_S \) are

\[
\frac{\partial \hat{E}}{\partial \phi_N} = -\frac{\gamma \hat{E}}{1-\phi_N} < 0 \quad \text{and} \quad \frac{\partial \hat{E}}{\partial i_S} = \frac{\lambda \hat{E}}{\rho - g + \lambda i_S} > 0.
\]

Besides, Eqs. (C4) and (C5) imply that the partial derivatives of \( n_N \) and \( n_F \) with respect to \( i_S \) are

\[
\frac{\partial n_N}{\partial i_S} = -\frac{\lambda \phi_N n_S}{E^2} < 0 \quad \text{and} \quad \frac{\partial n_F}{\partial i_S} = -\frac{\psi_N}{r \kappa i_S^2} < 0.
\]

To study the impact of \( i_S \) on the equilibrium, we need to know how the locus of the function \( f \) responds to the change of \( i_S \) while keeping other things unchanged; that is, we differentiate the function \( f \) with respect to \( i_S \) and obtain:

\[
\frac{df}{di_S} = \frac{1}{\lambda} \left\{ (n_F + \lambda n_S) \frac{\partial \hat{E}}{\partial i_S} - \hat{E} \left[ \lambda \frac{\partial n_N}{\partial i_S} + (\lambda - 1) \frac{\partial n_F}{\partial i_S} \right] \right\} > 0. \tag{D1}
\]

Eq. (D1) implies that a decrease in \( i_S \) will shift the locus of \( f(\phi_N) \) downward as shown in Figure 2 and result in a lower value of \( \phi_N \); that is, \( \phi_N(i_S) = \frac{d\phi_N}{di_S} > 0 \).

Accordingly, we can obtain

\[
\psi_N'(i_S) = \frac{d\psi_N}{di_S} = -\frac{(1-\gamma)\psi_N}{1-\phi_N} \phi_N'(i_S) < 0.
\]

From Eqs. (17), (C4) and (C5), we can obtain that \( n_S = 1 - n_N - n_F \),

\[
\frac{\partial n_N}{\partial i_S} = n_N \left( \frac{\partial \hat{E}}{\partial i_S} \right) \quad \text{and} \quad \frac{\partial n_F}{\partial i_S} = n_F \left( \frac{\partial \hat{E}}{\partial i_S} \right). \]

Together with the fact that \( \frac{\partial \hat{E}}{\partial i_S} = \frac{\lambda \hat{E}}{\rho - g + \lambda i_S} \), we can rewrite Eq. (D1) as:

\[
\frac{df}{di_S} = \frac{(\lambda - 1)n_F \hat{E}(\rho - g)}{\lambda i_S(\rho - g + \lambda i_S)}. \tag{D2}
\]
From Eqs. (17), (C3) and (C4), we can obtain that 

\[ n_N + n_S = 1 - n_F, \]

\[ \frac{\partial \hat{E}}{\partial \phi_N} = -\frac{\gamma \hat{E}}{1-\phi_N} \] and \[ \frac{\partial n_N}{\partial \phi_N} = \lambda \frac{\partial (\hat{E})}{\partial \phi_N} = n_N \left[ \frac{1}{\phi_N} - \frac{1}{\hat{E}} (\frac{\partial \hat{E}}{\partial \phi_N}) \right]. \]

Together with the result that \[ \frac{\partial \hat{E}}{\partial \phi_N} = -\frac{\gamma \hat{E}}{1-\phi_N}, \] Eq. (C9) can be expressed as:

\[ \frac{df}{d\phi_N} = \frac{\hat{E}}{1-\phi_N} \left[ \frac{n_F(\lambda - 1)}{\lambda} - \gamma \right] - \lambda. \] \hspace{1cm} (D3)

To examine the impact of \( i_S \) on \( \phi_N \), we totally differentiate Eq. (C9) and get the result that:

\[ \left( \frac{df}{d\phi_N} \right) d\phi_N + \left( \frac{df}{di_S} \right) di_S = 0. \] \hspace{1cm} (D4)

Combining Eqs. (D2), (D3) and (D5) gives us the impact of \( i_S \) on \( \phi_N \) that:

\[ \phi'_N(i_S) = \frac{d\phi_N}{di_S} = -\frac{\left( \frac{df}{d\phi_N} \right)}{\left( \frac{df}{di_S} \right)} = \frac{\frac{\hat{E}}{1-\phi_N} \left[ \frac{n_F(\lambda - 1)}{\lambda} - \gamma \right]}{\frac{\hat{E}}{1-\phi_N} \left[ \frac{n_F(\lambda - 1)}{\lambda} - \gamma \right] - \lambda}. \] \hspace{1cm} (D5)

We are now ready to examine the effects of \( i_S \) on other key variables. Eqs. (C1) and (3) indicate that:

\[ w^L_N'(i_S) = \frac{dw^L_N}{di_S} = -\frac{\left( \frac{\hat{E}}{1-\phi_N} \left[ \frac{n_F(\lambda - 1)}{\lambda} - \gamma \right] \right)}{\left( \frac{\hat{E}}{1-\phi_N} \left[ \frac{n_F(\lambda - 1)}{\lambda} - \gamma \right] - \lambda \right)} > 0, \]

\[ w_N'(i_S) = \frac{dw_N}{di_S} = -\frac{\gamma w_N}{1-\phi_N} \phi'_N(i_S) < 0. \]

From Eq. (C5), we can derive:

\[ n_F'(i_S) = \frac{dn_F}{di_S} = \frac{\psi_N'(i_S) i_S - \psi_N}{a_R \kappa t_S^2} < 0. \]

Therefore, a decrease in \( t_S \) will lower the wage rate for unskilled Northern workers and raise the Northern wage inequality. Besides, the extent of FDI will increase.

From Eq. (C3), we can derive that:

\[ \hat{E}'(i_S) = \frac{d\hat{E}}{di_S} = \frac{\lambda a_R \kappa \sigma_N (\tilde{D}_N)(1 - \phi_N)^{-\gamma} \left[ \lambda (1 - \phi_N) - \gamma (\rho - g + \lambda t_S) \phi'_N(i_S) \right]}{\tilde{D}_N g_{g'} \lambda - 1}. \]
Because $\phi_N'(i_S) > 0$, then $\hat{E}'(i_S)$ can be positive or negative. The above equation indicates that $\hat{E}'(i_S) < 0$ if:

$$\lambda(1 - \phi_N) < \gamma(\rho - g + \lambda i_S) \phi_N'(i_S). \quad (D6)$$

Substituting Eq. (D5) for $\phi_N'(i_S)$ in Eq. (D6) yields:

$$\lambda^3(1 - \phi_N) < \hat{E} \{n_F(\lambda - 1)[\gamma(\rho - g) + \lambda] - \lambda^2 \gamma\}. \quad (D7)$$

Note that $(1 - \phi_N) < 1$ and $\hat{E} > \frac{\lambda a_R \kappa(\rho - g)}{\lambda - 1}$ since $w_N = \frac{\sigma_N(B_N)(1 - \phi_N)^{\gamma}}{h_N(B_N)g^{\gamma}} > 1$.

Then the inequality of Eq. (D7) will hold if:

$$\lambda^2 < \frac{a_R \kappa(\rho - g)}{\lambda - 1} \{n_F(\lambda - 1)[\gamma(\rho - g) + \lambda] - \lambda^2 \gamma\}.$$ 

That is,

$$n_F > \frac{\lambda^2[\lambda - 1 + a_R \kappa(\rho - g)\gamma]}{a_R \kappa(\rho - g)(\lambda - 1)[\gamma(\rho - g) + \lambda]]. \quad (D8)$$

From Eq. (C5), we have $n_F = \frac{\psi_N}{a_R \kappa i_S}$. Because $\phi_N'(i_S) > 0$, a low $i_S$ will result in a low $\phi_N$ and a high $\psi_N$, inducing a high $n_F$. Therefore, $\hat{E}'(i_S) < 0$ if $i_S$ is sufficiently small. If $\hat{E}'(i_S) < 0$, a decrease in $i_S$ will raise $\hat{E}$.

Under the condition that $\hat{E}'(i_S) < 0$, the extents of Northern production and Southern production will decrease with a decrease in $i_S$ since Eqs. (C4) and (22) imply:

$$n_N'(i_S) = \frac{dn_N}{di_S} = \frac{\lambda[\phi_N'(i_S)\hat{E} - \phi_N\hat{E}'(i_S)]}{\hat{E}^2} > 0,$$

$$n_S'(i_S) = \frac{dn_S}{di_S} = -\frac{1}{\hat{E}^2} \left[\frac{n_F(i_S)\hat{E}}{\lambda} + \hat{E}'(i_S) \left(\frac{L_S}{L_N} - \frac{n_F}{\lambda}\right)\right] > 0.$$ 

Finally, from Eq. (C7), we can derive:

$$i_R'(i_S) = \frac{di_R}{di_S} = \frac{\psi_N'(i_S)n_S - \psi_N n_S'(i_S)}{a_R \kappa n_S^2} < 0.$$ 

Therefore, the R&D intensity will increase with a decrease in $i_S$. 

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