

Intellectual Property Rights and Skills Accumulation: A North-South Model of FDI and Outsourcing

Hung- Ju Chen*

ABSTRACT

This study investigates the effects of stronger intellectual property rights (IPR) protection in the South on innovation, skills choice, wage inequality and patterns of production based on a North-South general-equilibrium model with foreign direct investment (FDI) and international outsourcing. We find that stronger IPR protection in the South raises the extent of outsourcing and reduces the extent of FDI. This raises the proportion of Southerners being unskilled and mitigates wage inequality in the South. In the North, stronger Southern IPR protection raises the proportion of Northerners being skilled and wage inequality. The increased welfare due to the lower average price of goods may be offset by damage caused by lower average income. The effects of international specialization, R&D cost and Northern population are also examined.

Keywords: FDI; Outsourcing; Quality ladder; Skill; Wage inequality.

JEL Classification: F12; F23; O31.

* Department of Economics, National Taiwan University, 21 Hsu-Chow Road, Taipei 100, Taiwan; Tel: 886-2-23582284; Fax: 886-2-23582284; e-mail: hjc@ntu.edu.tw. The author would like to thank Yi-Li Chien, Jang-Ting Guo, Chia-Hui Lu, Chi-Yuan Tsai, Ping Wang, participants at the 2011 CEANA Annual Meeting in Denver, the 2010 Taipei International Conference on Growth, Trade and Dynamics and the 2010 SAET conference and seminar audiences at National Tsing-Hua University and National Chengchi University (Department of Public Finance) for helpful discussions and comments. The financial support provided by the Program for Globalization Studies at the Institute for Advanced Studies in Humanities at the National Taiwan University (grant number: 99R018) is gratefully acknowledged. The usual disclaimer applies.

1. INTRODUCTION

It is quite obvious that foreign direct investment (FDI) and international outsourcing are now very common on a global scale. When considering the production of part of their goods abroad as a means of saving costs, firms can produce goods abroad either through multinationals or by licensing foreign firms to produce them on their behalf. Over the years, these phenomena have led to economists devoting considerable interest in the causes and effects of international specialization.¹

In this paper, we examine the effects of global production on innovation, wage inequality and patterns of production based on a North-South product-cycle general-equilibrium model, within which final-good producers are based in the North, but the firms can choose either to carry out the entire production of the goods in the North or to allow the goods to be produced in the South (a foreign country) through FDI or international outsourcing. The North-South product-cycle model was originally introduced by Vernon (1966) and subsequently extended by Segerstrom et al. (1990), Grossman and Helpman (1991a, 1991b) and Aghion and Howitt (1992), with the literature relating to this model essentially following two major lines of research. The first research line focuses on the examination of the impact of FDI on imitation activity in developing countries (Helpman, 1993; Lai, 2001; Glass and Saggi, 2002); the second research line investigates the effects of increased international outsourcing of production on innovation, wages and patterns of production (Glass and Saggi, 2001).² Thus, in prior studies where the product-cycle model is adopted, there has clearly been a tendency to study FDI and international outsourcing activities as

¹ Grossman and Helpman (2003) investigate the trade-off between FDI and outsourcing based on the assumption that final-good producers can manufacture the goods by themselves or through specific investment governed by imperfect contracts. Antras and Helpman (2004) go on to develop a model within which firms can choose between engaging in FDI or domestic/international outsourcing based on a model with heterogeneous firms.

² One of the earlier theoretical studies of the effects of outsourcing is provided by Feenstra and Hanson (1996a) who assume that the final goods are produced from a continuum of intermediate goods using different proportions of skilled and unskilled workers.

separate issues, thereby ignoring the fact that firms can choose to undertake their production in foreign countries based on both FDI and outsourcing.

In this study, we allow firms to choose between FDI and outsourcing when carrying out production in the South. There are two major differences between FDI and outsourcing strategies. First, conducting FDI activity incurs higher governance costs (Williamson, 1985; Grossman and Helpman, 2003).³ A Northern firm needs to recruit Southern skilled workers to manage or monitor its production process in the South. Second, Lai et al. (2009) argue that the major disadvantage of outsourcing is the possibility of the leakage of production secrets due to the incompleteness of contracts. Without properly managing or monitoring its production process in the South and given that outsourcing is plagued with contractual difficulties in the absence of perfect contracting, outsourcing is subject to the risk of imitation.⁴ However, the risk of imitation will be reduced if intellectual property rights (IPR) protection in the South is strengthened.⁵

The other feature which distinguishes this paper from the extant literature is that we allow for the heterogeneity among the agents by endogenizing skills choice. All Northerners are assumed to be skilled and work in the R&D sector or production sector, whereas Southerners can choose to either remain unskilled or become skilled. Unskilled Southerners work in the production sector while skilled Southerners work in the FDI sector. The heterogeneity of Southerners allows us to study the effects of strengthening IPR protection and global production on wage inequality in the South

³ Tomiura (2007) finds that firms involving in FDI activity are more productive than foreign outsourcers based on the firm-level data of 118,300 firms across all manufacturing industries in Japan. Although FDI requires higher fixed entry costs, it brings in higher gross profits for firms.

⁴ The 2003 survey of the Shared Services and Business Process Outsourcing Association (SBPOA) reports that 33% of respondents agree that a lack of control and loss of internal knowledge are the main concerns when making an outsourcing decision.

⁵ Previous literature examining the effects of stronger Southern IPR protection also tends to separate FDI and outsourcing activities. The impact of strengthening IPR protection on FDI decision is studied by Lai (1998), Glass and Saggi (2002), Glass and Wu (2007) and Parello (2008) while its effect on outsourcing decision is examined by Yang and Maskus (2001) and Glass (2004).

and the international wage dispersion of skilled workers.⁶

We find that stronger Southern IPR protection increases the extents of outsourcing and Southern production while reducing the extents of FDI and Northern production.⁷ Our result outlining the reduced extent of FDI caused by stronger Southern IPR protection is different from Lai (1998) and Glass and Wu (2007) who show that stronger IPR protection will increase the extent of FDI. In addition, the result of the lower extent of Northern production is also different from Glass and Saggi (2002) and Parello (2008) who demonstrate that stronger Southern IPR protection will raise the extent of Northern production. This is because by assuming that firms only engage in Northern production and FDI (outsourcing) strategy, previous studies are not able to detect the behavior that firms will switch between FDI and outsourcing strategies when there is an increased Southern IPR protection.

We also examine the effects of international specialization, the cost of R&D and Northern population. We find that increasing incentives for outsourcing (such as the lower labor intensity for outsourcing) will increase the extent of outsourcing and the demand for unskilled Southerners, thereby reducing the proportion of Southerners becoming skilled and the extent of FDI. Similar effects will be caused by a reduction in the cost of R&D. On the other hand, increasing incentives for FDI (such as the lower labor intensity for FDI) will cause reversed effects on the proportion of Southerners being skilled and the extents of FDI and outsourcing.

In order to address the issue about the effects on the Northern wage inequality, we then consider an economy with heterogeneous Northerners. Our results show that those changes inducing greater demand for Southern unskilled workers (such as

⁶ The heterogeneity of workers is also assumed by Lai (1995) in an examination of the effects of the labor supply on the global distribution of income.

⁷ We also find that stronger Southern IPR protection will raise the R&D difficulty and this result is different from Parello (2008) who finds that strengthening IPR protection will reduce the R&D difficulty due to lower R&D employment.

stronger Southern IPR protection) will raise wage inequality in the North and reduce wage inequality in the South, along with an increase in the international wage dispersion of skilled workers. On the other hand, changes inducing a reduction in cost of FDI, which increases the extent of FDI and the demand for Southern skilled workers, will cause reversed effects on the Northern and Southern wage inequalities, ultimately lowering the international wage dispersion of skilled workers.⁸

By assuming that R&D difficulty grows with the innovation intensity, welfare is affected by the average price level and expenditure. Since strengthening Southern IPR protection raises Southern production, it reduces the average price which is beneficial to the welfare of consumers worldwide. However, it would also hurt welfare by reducing Northern (Southern) average wage rate and expenditure. Therefore, the impact of strengthening Southern IPR protection on the welfare is not clear, depending which effect dominates.

Section 2 develops the model and determines the balanced-growth-path (BGP) equilibrium. Section 3 examines how strengthening IPR protection, international specialization, cost of R&D and Northern population affect innovation, skills choice, wages, patterns of production and welfare. An economy with heterogeneous Northerners is considered in Section 4. The final section concludes.

2. THE MODEL

We begin with a description of a product-cycle model with endogenous innovation and skills (human capital) accumulation in the spirit of Romer (1990), Grossman and Helpman (1991a, 1991b) and Dinopoulos and Segerstrom (1999). In our model, there exist a developed Northern country (N) and a developing Southern country (S). Within each country, $i = \{N, S\}$, the economy is comprised of $L_i(t)$ households at time t .

⁸ The empirical study of Aitken et al. (1996) finds that FDI activity and Southern relative wages are positively correlated.

Given the birth rate, θ , and the death rate, δ , in both countries, the growth rate of the population, g , is equal to $(\theta - \delta)$. Assuming that the lifespan of each individual is T , the population dynamics imply that $\theta L_i(t) = \delta L_i(t + T)$ and $L_i(t + T) = L_i(t)e^{gT}$.⁹ This indicates that the number of births at time t equals the number of deaths at time $t+T$. Thus, we can express $\theta = \frac{ge^{gT}}{e^{gT}-1}$ and $\delta = \frac{g}{e^{gT}-1}$.

2.1. Consumers

Consumers can choose from a continuum of products $z \in [0, 1]$ available at different quality levels (j). The quality increment between a quality ' j ' product and a quality ' $j-1$ ' product is constant and equal to $\lambda > 1$. Thus, each product of quality j provides quality λ^j . All products begin at time $t=1$ with the quality level $j=0$ and the base quality $\lambda^0 = 1$.

The representative household in country i is faced with a lifetime utility of:

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

where ρ denotes the subjective discount factor. The instantaneous utility is:

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

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

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

$$E_i(t) = \int_0^1 [\sum_j p_{ij}(z, t) q_{ij}(z, t)] dz. \quad (3)$$

The representative household will maximize the lifetime utility subject to the following aggregate intertemporal budget constraint:

⁹ This implicitly assumes that for $t < T$, $L_i(t)$ includes those who have lived for less than T periods. For example, when $t = 0$, $\psi L_i(0)$ consumers are born and $\delta L_i(0)$ consumers die immediately after the economy starts.

$$W_i(t) + A_i(t) = \int_t^\infty L_i(0)[E_i(t) + g_G]e^{g\tau}e^{-[R(\tau)-R(t)]}d\tau, \quad (4)$$

where $W_i(t)$ denotes the sum of discount wage income of those households from country i , $A_i(t)$ represents the value of assets that the household holds at time t and $g_G \geq 0$ 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 instantaneous interest rate at time τ .

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. Based on the generalized Cobb-Douglas utility specification in Eq. (2), consumers will choose the quality which gives the lowest adjusted price, $\frac{p_j(z,t)}{\lambda^j}$. That is, consumers are willing to pay λ for a single quality level improvement in a product.

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

In the final step, consumers allocate lifetime wealth across time by maximizing Eq. (1) subject to the intertemporal budget constraint in Eq. (4). This yields the optimal expenditure path for the representative agent in each country:

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

In order to ensure the existence of the balanced-growth-path equilibrium, we focus on a steady state where $r(t) = \rho$ holds.

2.2. Skills accumulation

All Northerners are skilled workers who spend all of their time at work to earn the wage rate w_N^H . Agents in the South can choose to remain unskilled and earn the wage rate, w_S^L , which is normalized to 1, or choose the time period (D_S) spent in schools for skills training; on completion of their education, they will receive the skilled wage rate w_S^H per unit of effective labor.

It is widely accepted within the literature on human capital that important determinants of the accumulation of human capital include public investments in education and time spent in schools. We therefore consider human capital formation as being dependent on these two important determinants. Public educational investment is supported by the tax revenue and we assume that government runs a balanced budget.¹⁰ The total Southern public educational investment in period t is $G_S(t) = g_G L_S(t)$. Let ϕ_S denote the proportion of the unskilled population in the South. The remaining $(1 - \phi_S)L_S(t)$ individuals either attend schools for skill training or work as skilled workers. All skilled Southerners are eligible for public subsidy. Thus, the subsidy received by each Southern skilled worker is $g_S = \frac{G_S(t)}{(1 - \phi_S)L_S(t)}$.¹¹

The income of an unskilled worker equals the unskilled wage rate multiplied by one unit of unskilled labor while the income of a skilled worker equals the skilled wage rate multiplied by one efficiency unit of skilled labor. Thus, individuals choose to receive education if:

$$\int_t^{t+T} e^{-[R(\tau)-R(t)]} w_S^L d\tau \leq \int_{t+D_S}^{t+T} e^{-[R(\tau)-R(t)]} w_S^H h_S(D_S) g_S^\gamma d\tau, \quad (6)$$

where $\gamma \in (0,1)$ is the elasticity of skills accumulation with respect to the public educational investment. The skills production function of the amount of time spent in

¹⁰ Since Northerners are all skilled workers, we first assume that Northern government does not levy tax. This assumption will be relaxed in Section 4.

¹¹ Since human capital depreciates over time, for those Southerners who have started working, the public educational subsidy provides on-the-job training for them in order to keep the level of their human capital unchanged.

schools is represented by $h_S(D_S) = A_S D_S^{\beta_S}$, where $A_S > 0$ is the productivity of skills production and $\beta_S \in (0,1)$ is the elasticity of human capital accumulation with respect to the time spent in schools. Therefore, $h_S(D_S)g_S^\gamma$ represents one efficiency unit of skilled labor.¹²

In an equilibrium where skilled and unskilled workers coexist in the South, Eq. (6) holds with equality. The optimal time spent in schools (\bar{D}_S) is determined by the following equation:

$$\rho h_S(\bar{D}_S) = (1 - e^{-\rho(T-\bar{D}_S)})h'_S(\bar{D}_S). \quad (7)$$

Eq. (7) indicates that \bar{D}_S is dependent on the skill production function $h_S(\bar{D}_S)$.

From Eqs. (6) and (7), wage inequality (measured by the wage of skilled workers divided by the wage of unskilled workers) in the South can be expressed as:

$$\frac{w_S^H}{w_S^L} = w_S^H = \frac{\sigma_S(\bar{D}_S)(1 - \phi_S)^\gamma}{h_S(\bar{D}_S)g_S^\gamma}, \quad (8)$$

where $\sigma_S(\bar{D}_S) = \frac{1 - e^{-\rho T}}{e^{-\rho \bar{D}_S} - e^{-\rho T}} > 1$.

The supply of unskilled labor (L_S^L) is:

$$L_S^L(t) = \phi_S L_S(t). \quad (9)$$

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

$$\int_{t-T}^{t-\bar{D}_S} \theta (1 - \phi_S) L_S(\tau) d\tau = (1 - \phi_S) B_S(\bar{D}_S) L_S(t),$$

where $B_S(\bar{D}_S) = (e^{g(T-\bar{D}_S)} - 1)/(e^{gT} - 1) < 1$. Then the supply of effective skilled Southern labor (L_S^H) is:

$$L_S^H(t) = \psi_S L_S(t), \quad (10)$$

where $\psi_S = (1 - \phi_S) B_S(\bar{D}_S) h_S(\bar{D}_S) g_S^\gamma = B_S(\bar{D}_S) h_S(\bar{D}_S) g_S^\gamma (1 - \phi_S)^{1-\gamma}$.

2.3. Producers

¹² The Cobb-Douglas formation of the human capital accumulation function has been widely used in the literature; see, for example, Glomm and Ravikumar (1992) and Chen (2005, 2006).

Innovation occurs only in the North. Northern firms engage in R&D activity and produce cutting-edge quality products through innovation. A Northern firm in industry z which is engaged in innovation intensity $\iota_R(z, t)$, for a time interval, dt , will achieve one level of quality improvement in the final product, with probability $\iota_R(z, t)dt$. 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 $w_N^H a_R \iota_R(z, t)X(t)dt$, where $X(t)$ denotes R&D difficulty. Based on the *temporary effects on growth* approach, as proposed by Segerstrom (1998), we assume that R&D difficulty grows in line with innovation intensity. That is, $\frac{\dot{X}(t)}{X(t)} = \xi \iota_R(t)$ with $0 < \xi < 1$, wherein this assumption takes into account the concept whereby innovations can be discovered more easily will be achieved earlier in time.

After succeeding in innovating a higher-level quality product, a Northern firm can undertake its production in the North or carry out its production in the South, lowering its costs through FDI or outsourcing by hiring unskilled Southern workers to carry out this production. Let v_N denote the expected discounted value of a Northern firm that has discovered a new product. In order to avoid the infinite intensity of innovation, a Northern firm will select its research intensity such that the expected gains from innovation do not exceed the costs, with equality being achieved when innovation occurs with positive intensity:

$$v_N \leq w_N^H a_R X, \iota_R > 0 \Leftrightarrow v_N = w_N^H a_R X. \quad (11)$$

To undertake its production in the South through FDI, a Northern firm needs to hire skilled Southern workers to manage its production process in the South. Engaging in FDI intensity $\iota_F(z, t)$ for a time interval, dt , will require $a_F \iota_F(z, t)X(t)dt$ units of labor at a cost of $w_S^H a_F \iota_F(z, t)X(t)dt$, with a probability of success of $\iota_F(z, t)dt$. Let $(v_F - v_N)$ represent capital gains from undertaking production in the South through FDI. A Northern firm will choose its FDI intensity such that the expected

gains from FDI do not exceed the costs, with equality being achieved when FDI occurs with positive intensity:

$$v_F - v_N \leq w_S^H a_F X, \iota_F > 0 \Leftrightarrow v_F - v_N = w_S^H a_F X. \quad (12)$$

Alternatively, Northern firms can choose to license Southern firms to carry out their production processes on a contractual basis. To undertake its production in the South through outsourcing, Northern firms need to hire some Northern workers to carry out the paperwork involved in setting up the contracts.¹³ Engaging in outsourcing intensity $\iota_O(z, t)$ for a time interval, dt , will require $a_O \iota_O(z, t) X(t) dt$ units of labor at a cost of $w_N^H a_O \iota_O(z, t) X(t) dt$, with a probability of success of $\iota_O(z, t) dt$.¹⁴

$$v_O - v_N \leq w_N^H a_O X, \iota_O > 0 \Leftrightarrow v_O - v_N = w_N^H a_O X. \quad (13)$$

Eqs. (11) to (13) together imply that along the BGP equilibrium:

$$\frac{\dot{X}(t)}{X(t)} = \frac{\dot{v}_N(t)}{v_N(t)} = \frac{\dot{v}_F(t)}{v_F(t)} = \frac{\dot{v}_O(t)}{v_O(t)} = \xi \iota_R(t). \quad (14)$$

Assume old technologies which designs have been improved are available internationally. Thus, Southern firms are able to produce final goods by using old technologies. Firms are assumed to confront a Bertrand competition. Since Northern firms which produce through the use of state-of-the-art technologies possess a one quality level lead over the closest rivals, they will charge the price $p = \lambda$ (and make a sale $q = E/\lambda$) to just prevent their closest rivals from earning positive profits. The cost of firms completing their final production in the North is w_N^H . The instantaneous profits for them are:¹⁵

$$\pi_N = E \left(1 - \frac{w_N^H}{\lambda} \right). \quad (15)$$

¹³ Outsourcing is assumed to require Northern labor in Glass and Saggi (2001) while FDI is assumed to require Southern labor in Glass and Saggi (2002) and Parello (2008).

¹⁴ It should be noted that our model setting induces that $w_N^H a_O X < w_S^H a_F X$, which implies that the paperwork costs involved in outsourcing are less than the management costs involved in FDI.

¹⁵ In order to guarantee a positive profit of π_N , we need $1 < w_N^H < \lambda$. As we will see later, this condition will be guaranteed by Eq. (31).

Firms undertaking production in the South (either through FDI or outsourcing) can save costs by hiring unskilled Southern workers to produce goods, leading to marginal costs of $w_S^L = 1$. The instantaneous profits are therefore:

$$\pi = E \left(1 - \frac{1}{\lambda} \right). \quad (16)$$

The reward for successful innovation by a Northern firm is:

$$v_N = \frac{\pi_N}{\rho + (1 - \xi)\iota_R}. \quad (17)$$

The reward for a firm successfully carrying out its production in the South through FDI is:

$$v_F = \frac{\pi}{\rho + (1 - \xi)\iota_R}. \quad (18)$$

If a Northern firm chooses to outsource in the South, it faces the risk of imitation which is denoted by ε .¹⁶ Thus, the reward for a firm successfully undertaking its production in the South through outsourcing is:

$$v_O = \frac{\pi}{\rho + (1 - \xi)\iota_R + \varepsilon}. \quad (19)$$

2.4. The BGP equilibrium and factor markets

As noted earlier, the focus of our analysis is on the BGP equilibrium, along which the growth rate in R&D difficulty is equal to the population growth rate. This allows us to derive the long-run innovation rate, which is expressed as:

$$\iota_R = \frac{g}{\xi}. \quad (20)$$

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, let n_F and n_O respectively represent the

¹⁶ In order to simplify our analysis, we assume that only outsourcing is subject to an imitation risk. We can also assume that there is an imitation risk for a Northern firm which chooses to carry out its production in the South through FDI. However, assuming that FDI faces with a lower risk of imitation will generate the same results qualitatively.

proportions of the goods for which production is carried out through FDI (the extent of FDI) and outsourcing (the extent of outsourcing). The sum of these product measures should be one:

$$n_N + n_F + n_O + n_S = 1. \quad (21)$$

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

$$\iota_F n_N = \iota_R n_F, \quad (22)$$

$$\iota_O n_N = (\iota_R + \varepsilon) n_O, \quad (23)$$

$$\varepsilon n_O = \iota_R n_S. \quad (24)$$

We define two stationery variables as the adjusted level of R&D difficulty, $x = X/L_S$, and the adjusted global expenditure, $\hat{E} = E/L_S$. Since Northern labor can be used for R&D, outsourcing and production, the labor-market clearing condition for the North is:

$$a_R \iota_R x + a_O \iota_O x n_N + n_N \frac{\hat{E}}{\lambda} = \frac{L_N}{L_S}. \quad (25)$$

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

$$a_F \iota_F x n_N = \psi_S, \quad (26)$$

$$(n_F + n_O + \lambda n_S) \frac{\hat{E}}{\lambda} = \phi_S. \quad (27)$$

Substituting Eqs. (11)-(13), (15) and (16) into Eqs. (17)-(19), we obtain:

$$\hat{E} \left(1 - \frac{w_N^H}{\lambda} \right) = [\rho + (1 - \xi) \iota_R] w_N^H a_R x, \quad (28)$$

$$\frac{\hat{E}}{\lambda} (w_N^H - 1) = [\rho + (1 - \xi) \iota_R] w_S^H a_F x, \quad (29)$$

$$\frac{\hat{E}}{\lambda} (w_N^H - 1) = \mu w_N^H x, \quad (30)$$

where $\mu = [\rho + (1 - \zeta) \iota_R] a_O + \varepsilon (a_O + a_R)$.

The economy is described by Eqs. (7), (8) and (20)-(30) with thirteen variables $\{w_N^H, w_S^H, \bar{D}_S, \phi_S, x, \hat{E}, n_N, n_F, n_O, n_S, \iota_R, \iota_F, \iota_O\}$. Using Eqs. (28)-(30), we can derive the wage rates as:

$$w_N^H = \frac{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R}{\mu + [\rho + (1 - \xi)\iota_R]a_R} > 1, \quad (31)$$

$$w_S^H = \frac{\mu}{[\rho + (1 - \xi)\iota_R]a_F} w_N^H. \quad (32)$$

Eq. (32) implies that the international wage dispersion of skilled workers is:

$$w^H = \frac{w_N^H}{w_S^H} = \frac{[\rho + (1 - \xi)\iota_R]a_F}{\mu}. \quad (33)$$

Combining Eqs. (21)-(30), the equilibrium can be reduced to the following two equations in x and n_S :

$$n_S = \frac{1 - \frac{\psi_S}{a_F x \iota_R} + \frac{(\lambda - 1) \left(a_R x \iota_R - \frac{L_N}{L_S} \right)}{x \{ \lambda \mu + [\rho + (1 - \xi)\iota_R] a_R \}}}{\frac{\varepsilon + i_R}{\varepsilon} - \frac{a_O x \iota_R (\iota_R + \varepsilon) (\lambda - 1)}{\varepsilon x \{ \lambda \mu + [\rho + (1 - \xi)\iota_R] a_R \}}}, \quad (34)$$

$$n_S = \frac{\varepsilon}{x(\lambda\varepsilon + i_R)} \left\{ \frac{\phi_S(\lambda - 1)}{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R} - \frac{\psi_S}{a_F \iota_R} \right\}. \quad (35)$$

Eqs. (34) and (35) are respectively represented by the NL and SL locus in Figure 1. As shown in Appendix A, there exists a unique BGP equilibrium. Once one derives the solution of $\{x, n_S\}$, the remaining endogenous variables can be solved accordingly.

<Figure 1 is inserted about here>

3. IPR PROTECTION, FDI AND OUTSOURCING

In order to attract Northern firms to carry out their production in the South, the South can make efforts to improve its economic environment. Strengthening IPR protection is one way to attract Northern firms to conduct outsourcing activities. Besides, such improvements in the economic environment can be also represented by reductions in the labor intensity for outsourcing and the labor intensity for FDI.

We first examine the effects of stronger IPR protection which lowers the imitation risk (ε). Due to the complexity of the model, the theoretical analysis of the effects on the patterns of trade may not be able to provide clear results; thus, we resort to a numerical analysis and calibrate the parameter values used in the model. For the benchmark model, the per capita real GDP growth rate is set at $g = 2\%$. The discount factor $\rho = 0.06$ is chosen to generate a 6% real interest rate. Following Glass and Saggi (2001), we set the one-stage quality improvement at $\lambda = 2$, and the labor intensities for R&D and outsourcing at $a_R = 2$ and $a_O = 1$. The labor intensity for FDI is set at $a_F = 1.8$ to make the extent of Northern production (n_N) roughly equal to 50%.¹⁷ The parameter of the growth rate in R&D difficulty (ξ) is assigned to 0.99 and the risk of imitation (ε) is set to 0.01 in order to generate enough international wage dispersion of skilled workers and wage inequality in the South. We normalize the initial Northern population to 1 and set the ratio of the Northern population to Southern population (L_N/L_S) to 1, but will allow this ratio to vary to examine its impact.

The skills accumulation depends on the quantity of education (D_S) and the quality of education (g_G). Following Dinopoulos and Segerstrom (1999), we assume that each agent has a working life of 40 years which is normalized to one in the model ($T = 1$), and an “unskilled” high-school graduate becomes skilled worker by spending 4 years in college. Thus, we calibrate $\beta_S = 0.1$ to match the value that skilled workers spend about 10% of working life on skills training and 90% of working life on work. The parameter A_S is set to 1.08 so that less than 5% of Southern workers are skilled workers. Compared to the quantity of education, the quality of education has a much smaller effect on earnings (Card and Krueger, 1996; Krueger and Lindahl, 2001), so

¹⁷ We follow Glass and Saggi (2001) to match the extent of Northern production at 50%. Note that under our parameterization, footnote 14 indicates that $w_S^H/w_N^H > a_O/a_F = 0.56$ which is consistent with the empirical literature on wage inequality (Juhn et al., 1992).

we set $\gamma = 0.02$. Public investment in education (g_G) is set at 1.1 which is 36% of adjusted global expenditure.

Based on our parameterization of the benchmark model, 1.36% of Southern workers will spend 8.87% of their time on education in order to become skilled workers. The wage rate in the North is 1.43 while the wage rate for skilled workers in the South is 1.19. Thus, the international wage dispersion of skilled workers is 1.20. The resultant adjusted global expenditure is 3.03 and adjusted R&D difficulty is 5.03. The respective extents of Northern production, FDI, outsourcing and Southern production are 49.56%, 6.27%, 29.55% and 14.63%. The benchmark values are presented in Table 1, which summarizes the effects of various events on the key macroeconomic variables in our model; these events are described in the following sub-sections.

<Table 1 is inserted about here>

A reduction in ε by 1% raises the extent of outsourcing because outsourcing becomes more attractive to firms. There will be a reduction in the extent of FDI as a result of an increase in the demand for Southern unskilled production workers. A lower imitation risk will reduce the extent of Southern production while a higher extent of outsourcing will raise the extent of Southern production. Our numerical results indicate that overall, the extent of Southern production will increase. As illustrated in Figure 1, a lower ε shifts both NL and SL locus upward and results in a higher extent of Southern production. The extent of Northern production will decrease while the adjusted level of R&D difficulty will increase. Consequently, there will also be a reduction (increase) in FDI (outsourcing) intensity to restore the steady-state condition. We summarize the results on globalization production decisions as follows.

Effects of Strengthening IPR Protection on Production. Along the balanced-growth path, strengthening IPR protection in the South is in favor of outsourcing over FDI. It

raises the extents of outsourcing and Southern production while reducing the extents of FDI and Northern production.

As a result of a decrease for the demand of Southern skilled workers, wage inequality in the South will be reduced, leading to a rise in the international wage dispersion of skilled workers. The lower wage rate for Southern skilled workers will lead to a lower proportion of the population in the South becoming skilled. These results are summarized in Proposition 1.¹⁸

Proposition 1. An increase in IPR protection in the South (or a reduction in the labor intensity for outsourcing) reduces the Northern and Southern wage rates for skilled workers, raises the North-South wage gap among skilled workers and increases the proportion of Southern unskilled workers.

One may wonder how strengthening IPR protection in the South affects the long-run welfare of consumers. To answer this question, we examine the steady-state lifetime utility. Since consumers pay the price of 1 for imitated goods and λ for other production, the average price equals:

$$\bar{p} = (n_N + n_F + n_O)\lambda + n_S = \lambda - (\lambda - 1)n_S.$$

Because the expected number of innovations arriving in period t is $\iota_R t$, the instantaneous utility (Eq. (2)) is:

$$\log u_i(t) = \log E_i - \log \bar{p} + \iota_R t \log \lambda.$$

Then the lifetime utility (Eq. (1)) can be written as:

$$U_i(0) = \frac{L_i(0)}{\rho - g} \left\{ \log E_i - \log[\lambda - (\lambda - 1)n_S] + \frac{\iota_R}{\rho - g} \log \lambda \right\}.$$

¹⁸ Because it is quite easy to prove Propositions 1 and 2 by taking the derivatives of Eqs. (31)-(33) and (A4) with respect to ε , a_O and a_F , we do not provide the proofs in the paper; they are, however, available upon request.

Note that Eq. (20) indicates that t_R is not affected by changes in IPR protection. Therefore, welfare increases with expenditure and decreases with the average price.

Under our parameterization, a 1% decrease in ε raises the extent of Southern production and reduces the average price by 0.14%. The Northern expenditure decreases by 0.16% due to the lower Northern wage rate.¹⁹ Since both the wage rate for Southern skilled workers and the fraction of Southern skilled workers become lower, the average Southern wage rate will decrease, leading to a 0.16% reduction in the Southern expenditure. While the lower average price will raise the welfare for the representative Northerner (Southerner), the lower Northern (Southern) expenditure will reduce it. The numerical results indicate that overall, the welfare for the representative Northerner (Southerner) will decrease by 0.070% and 4.63%, respectively.²⁰

3.1. Labor intensities for outsourcing and FDI

A reduction in the labor intensity for outsourcing (a_o) will cause the same effects on wage inequality, international wage dispersion of skilled workers and skill choice for Southerners as strengthening IPR protection (see Proposition 1). Table 1 also reveals that it also causes similar effects on the extents of FDI, outsourcing and Southern production, the adjusted level of R&D difficulty as well as FDI and outsourcing intensities. However, the extent of Northern production will increase.

A decrease in a_F by 1% increases the incentives for FDI, which raises the extent of FDI. Both the extents of outsourcing and Southern production will decrease because Northern firms will switch from outsourcing strategy to FDI. Overall, the extent of

¹⁹ When conducting a numerical analysis of welfare, we assume that the initial asset holdings for the representative Northerner and Southerner are the same.

²⁰ Our results of welfare are different from Glass (2004) who shows that a reduction in imitation risk will raise both the Northern and Southern welfare. The main reason is that in her study, a reduction in imitation will also raise innovation which is beneficial to the welfare. However, in our paper, innovation is independent of an imitation rate.

Northern production will decrease. The demand for Southern skilled workers becomes higher, which in turn, leads to an increase in wage inequality in the South. This increase in the Southern wage inequality lowers the international wage dispersion of skilled workers. Our findings on wage rates are summarized as follows:

Proposition 2. A fall in the labor intensity for FDI raises the Southern wage rate for skilled workers, reduces the North-South wage gap among skilled workers, and increases the proportion of Southern skilled workers. However, it does not affect the Northern wage rate.

3.2. Labor intensity for R&D

We go on to examine the effects of a reduction in the labor intensity for R&D (a_R). A decrease in a_R increases the incentives for R&D activity and raises the adjusted level of R&D difficulty. The lower labor intensity for R&D raises the extent of Northern production since more Northern labor is available for Northern production. The increase in the demand for Northern labor leads to a rise in the Northern wage rate.

There will be a resultant increase in the demand for unskilled Southerners, which lowers wage inequality in the South and increases the international wage dispersion of skilled workers. This will lead to a reduction in the extents of FDI and Northern production and an increase in the extent of outsourcing. Overall, the extent of Northern production will increase.

3.3. Labor supply

Finally, we investigate the impact of a decrease in the Northern population (L_N). Because Northern labor supply does not directly affect the incentives for innovations, FDI and outsourcing, the wage rates in both the North and the South are unaffected. Thus, there is also no change in the international wage dispersion of skilled workers.

With no change in the incentives for skills accumulation, the proportion of skilled Southerners remains the same. Nevertheless, a reduction in the Northern labor supply implies that less labor can be devoted to innovation and production in the North. This will lead to a reduction in the adjusted level of R&D difficulty, a smaller extent of Northern production and a greater extent of FDI.

Although a lower Northern labor supply will shift production from the North to the South, which will, in turn, raise the extent of outsourcing, it also has the effect of reducing the extent of outsourcing because outsourcing requires Northern labor. The former will dominate the latter, such that there will be an increase in the extent of outsourcing. We summarize the results in the following proposition.²¹

Proposition 3. A reduction in the Northern labor supply will result in a corresponding reduction in the adjusted level of R&D difficulty, along with a reduction in the extent of Northern production and increases in the extents of FDI, outsourcing and Southern production. Both the FDI and outsourcing intensities will increase. However, wage rates in the North and the South and the proportion of Southern workers being skilled will be unaffected.

4. HETEROGENEOUS NORTHERNERS

There has been considerable debate on the pros and cons of international production for the North. Those advocating such international production argue that it can reduce the costs of production, while its opponents argue that it leads to an increase in the Northern wage inequality. Despite numerous empirical studies in this field, very few theoretical studies have set out to explain the linkage between the two issues.²² In order to address this, we extend our basic model to allow for heterogeneity among

²¹ The proof of Proposition 3 is provided in the Appendix B.

²² The empirical examination of the effects of outsourcing on wage inequality can be found in Feenstra and Hanson (1996b).

Northerners.

Like Southerners, Northerners can choose to remain unskilled and earn the wage rate w_N^L or to spend a time period D_N in school for skills training and receive the skilled wage rate w_N^H on completion of their skills education. Let ϕ_N represent the proportion of population remaining unskilled in the North. Each Northerner needs to pay $g_G > 0$ for tax in every period and we assume that Northern government runs a balanced budget. The total Northern public investment in education is $G_N(t) = g_G L_N(t)$, which implies that such investment amounts to $g_N = \frac{G_N(t)}{(1-\phi_N)L_N(t)}$ for each

skilled Northerner. Northerners will choose to receive skills training if:

$$\int_t^{t+T} e^{-[R(\tau)-R(t)]} w_N^L d\tau \leq \int_{t+D_N}^{t+T} e^{-[R(\tau)-R(t)]} w_N^H h_N(D_N) g_N^\gamma d\tau, \quad (36)$$

where the function $h_N(D_N) = A_N D_N^{\beta_N}$ with $A_N > 0$ and $\beta_N \in (0,1)$.

The optimal time spent in schools (\bar{D}_N) is chosen by:

$$\rho h_N(\bar{D}_N) = (1 - e^{-\rho(T-\bar{D}_N)}) h'_N(\bar{D}_N). \quad (37)$$

Wage inequality in the North is therefore:

$$w_N = \frac{w_N^H}{w_N^L} = \frac{\sigma_N(\bar{D}_N)(1 - \phi_N)^\gamma}{h_N(\bar{D}_N) g_G^\gamma}, \quad (38)$$

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

We define $B_N(\bar{D}_N) = (e^{g(T-\bar{D}_N)} - 1)/(e^{gT} - 1)$. The supply of unskilled labor (L_N^L) is therefore:

$$L_N^L(t) = \phi_N L_N(t),$$

and the supply of effective skilled labor (L_N^H) is:

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

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

Northern unskilled workers are employed in manufacturing of new products, whereas Northern skilled workers are engaged in R&D investment and outsourcing activities. Thus, Eq. (17) becomes:

$$\pi_N = E \left(1 - \frac{w_N^L}{\lambda} \right). \quad (39)$$

Note that the instantaneous profit for firms carrying out FDI or outsourcing (Eq. (16)) remains the same.

It should be noted that Eqs. (11)-(13) and (17)-(21) remain unchanged, as do the steady-state conditions in Eqs. (22) to (24) and the labor market clearing conditions for the South in Eqs. (26) to (27). The labor market clearing conditions for the skilled and unskilled Northern labor are:

$$a_R t_R x + a_O t_O x n_N = \psi_N \frac{L_N}{L_S}. \quad (40)$$

$$n_N \frac{\hat{E}}{\lambda} = \phi_N \frac{L_N}{L_S}. \quad (41)$$

The setting for the South remains the same. As compared with the benchmark model in Section 2, we have three new variables $\{w_N^L, \bar{D}_N, \phi_N\}$ and three more equations (Eqs. (37), (38) and one more equation for the Northern labor market).

As shown in Appendix C, in equilibrium, the extent of FDI (n_F) can be expressed in terms of n_S , the proportion of Southern population being unskilled (ϕ_S) can be expressed as a function of ϕ_N while the adjusted expenditure (\hat{E}) can be expressed in terms of ϕ_N and n_S . Then the market clearing conditions for Northern and Southern unskilled workers become can be expressed by n_S and ϕ_N :

$$n_S = \frac{\varepsilon}{\varepsilon + a_R} \left[1 - n_F(n_S) - \frac{\lambda \phi_N L_N}{\hat{E}(\phi_N, n_S) L_S} \right]. \quad (42)$$

$$n_S = \frac{\varepsilon}{\lambda \varepsilon + a_R} \left[\frac{\lambda \phi_S(\phi_N)}{\hat{E}(\phi_N, n_S)} - n_F(n_S) \right]. \quad (43)$$

Figure 2 illustrates the equilibrium where Eq. (42) is represented by the NN locus and Eq. (43) is represented by SS locus.²³ Since stronger IPR protection will shift both the NN and SS locus upward, the extent of Southern production increases while the change of the fraction of unskilled Northerners is not clear. To conduct numerical analysis, we set $\beta_N = 0.12$ which is higher than β_S so that Northerners will spend a longer period in schools than Southerners.²⁴ We assign $A_N = 1.32$ and $A_S = 1$, so that about 24.81% of Northerners and 1.38% of Southerners are skilled workers.²⁵ This will also generate the result that wage inequality is lower in the North than in the South. The remaining parameters are set at the same values as those in the benchmark model. The equilibrium values of the key variables are presented in Table 2.

<Figure 2 is inserted about here>

Table 2 shows that stronger IPR protection policy raises the extents of outsourcing and Southern production while reducing the extents of FDI and Northern production. Both the fraction of unskilled Northerners and the wage rate for unskilled Northerners will decrease due to the shift of production from the North to the South. The higher supply of skilled Northerners will reduce the wage rate for skilled Northerners. Overall, wage inequality will be higher in the North. On the other hand, an increase in the fraction of unskilled Southerners will reduce wage inequality in the South. The international wage dispersion for skilled workers will increase. Regarding welfare, a 1% decrease in ε reduces the average price by 0.14%. Due to the lower average Northern and Southern wage rates, the Northern and Southern expenditures will respectively decrease by 0.15% and 0.16%. Consequently, the Northern welfare

²³ See Appendix C for the details about deriving the BGP equilibrium and Appendix D for the calculations of the slopes of NN and SS locus.

²⁴ This parameter setting produces $\bar{D}_N = 10.46\%$, which is higher than $\bar{D}_S = 8.87\%$.

²⁵ The parameterization used by Dinopoulos and Segerstrom (1999) guarantees that the proportion of the labor force becomes skilled is less than 25% in both developed and developing countries.

will decrease by 0.046% while the Southern welfare will decrease by 1.52%.

<Table 2 is inserted about here>

Table 2 also indicates that a reduction in a_0 will cause similar effects on wage inequalities for the North and the South and the international wage dispersion for skilled workers as those caused by stronger IPR protection. However, a reduction in the labor intensity for FDI will generate the reversed effects on the wage inequalities for the North and the South and the international wage dispersion for skilled workers. This is because it increases the demand for Southern skilled workers while reducing the demand for Northern skilled workers.

A decrease in the labor intensity for R&D raises the demand for both skilled and unskilled workers in the North. Both the Northern wage rates for skilled and unskilled workers will increase, leaving wage inequality in the North to decrease. This reduction in the Northern wage inequality motivates firms to engage in outsourcing, with the effect of reducing the extent of FDI. The demand for Southern skilled workers is therefore reduced, which lowers the wage rate for Southern skilled workers. Therefore, the international wage dispersion for skilled workers will increase.

If there is a decrease in Northern population, there will be a corresponding increase in wage inequality in the North, since it raises the wage rate for skilled Northerners, while leaving the wage rate for unskilled Northerners unchanged. With lower labor resources devoted to production in the North, there will be an increase in the extent of FDI, which thereby raises the demand for skilled workers in the South. Wage inequality in the South will increase, leaving the international wage dispersion of skilled workers unchanged.

A comparison between Tables 1 and 2 reveals that the effects on adjusted R&D difficulty and patterns of production arising from increasing globalization, R&D cost and the

Northern population, are all similar to those in the benchmark model, with one exception: a decrease in the level of Northern population reduces the proportion of Southern unskilled workers in the presence of heterogeneous Northern workers.²⁶

5. CONCLUSION

In this paper, we develop a North-South general-equilibrium model to investigate the effects of strengthening IPR protection on innovation, skills choice, wage inequality, patterns of production and welfare. Our results illustrate that strengthening IPR protection in the South will raise the extents of outsourcing and Southern production, along with corresponding reductions in the extents of FDI and Northern production. The Northern wage inequality will increase since firms will shift their production from the North to the South. The Southern wage inequality will decrease as a result of the increase in the demand for Southern unskilled production workers. The increased welfare due to the lower average price may be offset by damage caused by lower average income. We also examine the effects of increasing globalization, R&D cost and the Northern population.

We conclude this study with the suggestion that our model can be extended and applied to a variety of issues, and by pointing out two specific directions which would appear to be ripe for future study. First, in addition to products produced through outsourcing, Southern firms can also imitate products produced through FDI or products completely produced in the North. Second, the outsourcing contracts could also be endogenized. By designing elaborate contracts, Northern firms could avoid the loss of profits caused by contract default.

²⁶ We also perform a sensitivity analysis to check the robustness of our results in Tables 1 and 2. In particular, we allow λ , ξ , γ and g_G to decrease or increase from their benchmark values by 5%. The results indicate that the effects of stronger IPR protection in the South on the production choice of FDI and outsourcing, wage inequalities and fraction of Southerners (Northerners) being skilled remain the same qualitatively. Although we do not provide the results in the paper, they are available upon request.

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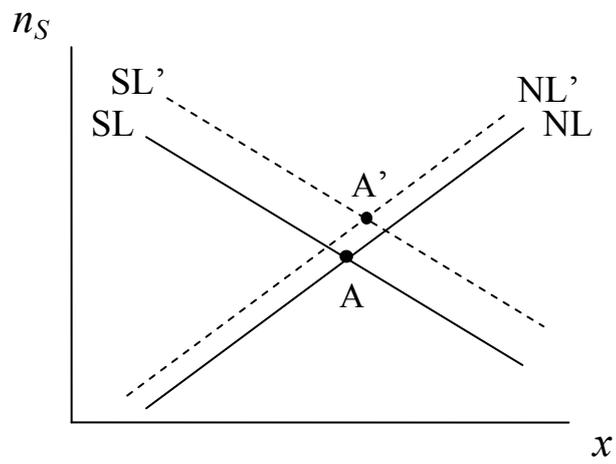


Figure 1. Adjusted R&D difficulty and Southern production

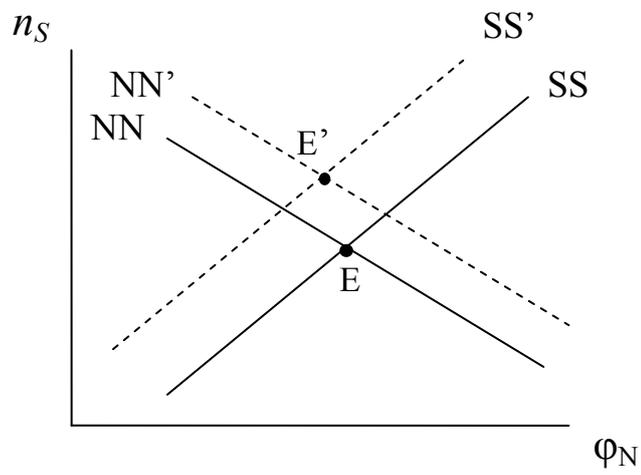


Figure 2. Northern skilled labor and Southern production

Table 1 Numerical results

Variables	Equilibrium Values	Measures of Exogenous Shifts				
		ε down 1%	a_O down 1%	a_F down 1%	a_R down 1%	L_N down 1%
Panel A: Effects on Wage Rates						
w_N^H	1.4283	-0.0571	-0.1339	0.0000	0.1343	0.0000
w_S^H	1.1889	-0.3895	-0.9111	1.0101	-0.0877	0.0000
w^H	1.2013	0.3337	0.7844	-1.0000	0.2222	0.0000
Panel B: Other Effects						
ϕ_S	0.9864	0.2450	0.5074	-0.9022	0.0593	0.0000
x	5.0399	0.0407	0.0279	0.7165	0.5233	-0.5815
n_N	0.4956	-0.0029	0.1997	-0.4314	0.0770	-0.5952
n_F	0.0627	-17.4389	-36.1584	64.1117	-4.7070	0.5849
n_O	0.2955	2.8178	4.9059	-8.6118	0.5814	0.5849
n_S	0.1463	1.7897	4.9059	-8.6118	0.5814	0.5849
l_F	0.0026	-17.4365	-36.2857	64.8227	-4.7830	1.1872
l_O	0.0180	2.4804	4.6967	-8.2159	0.5040	1.1872

Note: All figures refer to the percentage changes in the key variables from their benchmark values (presented in column 2) as a result of each exogenous shift.

Table 2 Heterogeneous Northerners

Variables	Equilibrium Values	Measures of Exogenous Shifts				
		ε down 1%	a_O down 1%	a_F down 1%	a_R down 1%	L_N down 1%
Panel A: Effects on Wage Rates						
w_N^H	1.5429	-0.0474	-0.1194	-0.0169	0.1305	0.0104
w_N^L	1.4283	-0.0571	-0.1339	0.0000	0.1343	0.0000
w_N	1.0802	0.0097	0.0144	-0.0169	-0.0038	0.0104
w_S^H	1.2843	-0.3798	-0.8968	0.9930	-0.0915	0.0104
w^H	1.2013	0.3337	0.7844	-1.0000	0.2222	0.0000
Panel B: Other Effects						
ϕ_N	0.7519	-0.1603	-0.2391	0.2780	0.0632	-0.1722
ϕ_S	0.9862	0.2417	0.5059	-0.8914	0.0624	-0.0073
x	4.6676	0.0337	0.0151	0.7244	0.5246	-0.5860
n_N	0.4958	-0.0042	0.1991	-0.4264	0.0785	-0.5983
n_F	0.0632	-17.0400	-35.6969	62.7441	-4.8871	1.1040
n_O	0.2950	2.7884	4.8948	-8.5176	0.6125	0.5143
n_S	0.1460	1.7605	4.8948	-8.5176	0.6125	0.5143
l_F	0.0026	-17.0366	-36.8246	63.4410	-4.9617	1.7125
l_O	0.0180	2.4524	4.6864	-8.1258	0.5336	1.1193

Note: All figures refer to the percentage changes in the key variables from their equilibrium values (presented in column 2) as a result of each exogenous shift.

APPENDIX A

BGP Equilibrium

First note that \bar{D}_S and ι_R are respectively determined by Eqs. (7) and (20). Using Eqs. (28)-(30), we can derive:

$$\hat{E} = \frac{x\lambda\{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R\}}{\lambda - 1}, \quad (\text{A1})$$

$$w_N^H = \frac{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R}{\mu + [\rho + (1 - \xi)\iota_R]a_R} > 1, \quad (\text{A2})$$

$$w_S^H = \frac{\mu}{[\rho + (1 - \xi)\iota_R]a_F} w_N^H. \quad (\text{A3})$$

From Eq. (8), we can compute the proportion of unskilled Southerners:

$$\phi_S = 1 - \left[\frac{h_S(\bar{D}_S)g_G^\gamma w_S^H}{\sigma_S(\bar{D}_S)} \right]^{\frac{1}{\bar{\gamma}}}, \quad (\text{A4})$$

where w_S^H is given by Eq. (A3).

Combining Eqs.(22) and (26) gives us:

$$n_F = \frac{\psi_S}{a_F \iota_R x}. \quad (\text{A5})$$

Then substitution Eqs. (21), (24), (A1) and (A5) into the market clearing condition of Northern labor (Eq. (25)), we can derive

$$n_S = \frac{1 - \frac{\psi_S}{a_F x \iota_R} + \frac{(\lambda - 1) \left(a_R x \iota_R - \frac{L_N}{L_S} \right)}{x \{ \lambda \mu + [\rho + (1 - \xi) \iota_R] a_R \}}}{\frac{\varepsilon + i_R}{\varepsilon} - \frac{a_O x \iota_R (\iota_R + \varepsilon) (\lambda - 1)}{\varepsilon x \{ \lambda \mu + [\rho + (1 - \xi) \iota_R] a_R \}}}. \quad (\text{A6})$$

Substitution Eqs. (24), (A1) and (A5) into the market clearing condition of Southern unskilled labor (Eq. (27)) gives us

$$n_S = \frac{\varepsilon}{x(\lambda\varepsilon + i_R)} \left\{ \frac{\phi_S(\lambda - 1)}{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R} - \frac{\psi_S}{a_F \iota_R} \right\}. \quad (\text{A7})$$

Note that Eq. (46) indicates that n_S and x are positively correlated while Eq. (47) implies that there is a negative relationship between n_S and x .

From Eqs. (A6) and (A7), we can derive the unique solution of x :

$$x = \frac{(\lambda\varepsilon + i_R) \frac{L_N}{L_S} + \frac{\psi_S}{a_F} \theta_1 - \phi_S \theta_2}{(\lambda\varepsilon + i_R) \left\{ a_R \iota_R + \frac{\lambda\mu + [\rho + (1-\xi)\iota_R] a_R}{\lambda - 1} \right\}}, \quad (\text{A8})$$

where $\theta_1 = a_O(\varepsilon + i_R) + \frac{\varepsilon\{\lambda\mu + [\rho + (1-\xi)\iota_R] a_R\}}{i_R}$ and $\theta_2 = \frac{a_O(\varepsilon + i_R)(\lambda - 1)}{\lambda\mu + [\rho + (1-\xi)\iota_R] a_R} - (\varepsilon + i_R)$.

Substituting the solution of x in Eqs. (A7) and (A1), we can get n_S and \hat{E} . Using Eqs. (24), (21), (22) and (23), we can derive $n_O = \iota_R n_S / \varepsilon$, $n_N = 1 - n_O - n_F - n_S$, $\iota_F = \iota_R n_F / n_N$ and $\iota_O = (\iota_R + \varepsilon) n_O / n_N$. Thus, we have completely solved the model and showed that there exists a unique solution.

APPENDIX B

Proof of Proposition 4

Note that Eqs. (20), (A2), (A3) and (A4) indicate that ι_R , w_N^H , w_S^H and ϕ_S do not depend on L_N . This implies that w_N^H is also independent of L_N . Using Eq. (A8) to differentiate x with respect to L_N , we obtain:

$$\frac{\partial x}{\partial L_N} = \frac{(\lambda\varepsilon + i_R)}{L_S(\lambda\varepsilon + i_R) \left\{ a_R \iota_R + \frac{\lambda\mu + [\rho + (1-\xi)\iota_R] a_R}{\lambda - 1} \right\}} > 0. \quad (\text{B1})$$

Eq. (A5) indicates that

$$\frac{\partial n_F}{\partial L_N} = \frac{-\psi_S}{a_F \iota_R x^2} \frac{\partial x}{\partial L_N} < 0. \quad (\text{B2})$$

From Eq. (A7), we can get that

$$\frac{\partial n_S}{\partial L_N} = \frac{-\varepsilon}{x^2(\lambda\varepsilon + i_R)} \left\{ \frac{\phi_S(\lambda - 1)}{\lambda\mu + [\rho + (1-\xi)\iota_R] a_R} - \frac{\psi_S}{a_F \iota_R} \right\} \frac{\partial x}{\partial L_N} < 0. \quad (\text{B3})$$

Then

$$\frac{\partial n_O}{\partial L_N} = \frac{\iota_R}{\varepsilon} \frac{\partial n_S}{\partial L_N} < 0. \quad (\text{B4})$$

Eqs. (B2)-(B4) implies that:

$$\frac{\partial n_N}{\partial L_N} = - \left(\frac{\partial n_F}{\partial L_N} + \frac{\partial n_S}{\partial L_N} + \frac{\partial n_O}{\partial L_N} \right) > 0. \quad (\text{B5})$$

Differentiating ι_F and ι_O with respect to L_N , we have:

$$\frac{\partial \iota_F}{\partial L_N} = \frac{\iota_R}{n_N^2} \left(n_N \frac{\partial n_F}{\partial L_N} - n_F \frac{\partial n_N}{\partial L_N} \right) < 0. \quad (\text{B6})$$

$$\frac{\partial \iota_O}{\partial L_N} = \frac{\iota_R + \varepsilon}{n_N^2} \left(n_N \frac{\partial n_O}{\partial L_N} - n_O \frac{\partial n_N}{\partial L_N} \right) < 0. \quad (\text{B7})$$

Eqs. (B1)-(B7) indicate that a decrease in L_N lowers x and n_N , and raises n_F , n_O , n_S , ι_F and ι_O .

APPENDIX C

Equilibrium of the Model of Heterogeneous Northerners

First note that \bar{D}_N is determined by Eq. (37). Substituting Eqs. (11)-(13), (16) and (39) into Eqs. (17)-(19), we have:

$$\hat{E} \left(1 - \frac{w_N^L}{\lambda} \right) = [\rho + (1 - \xi)\iota_R] w_N^H a_R x, \quad (\text{C1})$$

$$\frac{\hat{E}}{\lambda} (w_N^L - 1) = [\rho + (1 - \xi)\iota_R] w_S^H a_F x, \quad (\text{C2})$$

$$\frac{\hat{E}}{\lambda} (w_N^L - 1) = \mu w_N^H x. \quad (\text{C3})$$

Note that ι_R is solved by Eq. (20). Using Eqs. (C1)-(C3), we can further derive:

$$w_N^H = \frac{\hat{E}(\lambda - 1)}{x\lambda\{\mu + [\rho + (1 - \xi)\iota_R]a_R\}}, \quad (\text{C4})$$

$$w_N^L = \frac{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R}{\mu + [\rho + (1 - \xi)\iota_R]a_R}, \quad (\text{C5})$$

$$w_S^H = \frac{\mu}{[\rho + (1 - \xi)\iota_R]a_F} w_N^H. \quad (\text{C6})$$

Combining Eqs. (8), (38) and (C6), we can express ϕ_S as a function of ϕ_N :

$$\phi_S(\phi_N) = 1 - \Gamma(1 - \phi_N), \quad (\text{C7})$$

where $\Gamma = \left\{ \frac{\sigma_N(\bar{D}_N)\mu w_N^L h_S(\bar{D}_S)}{\sigma_S(\bar{D}_S)[\rho + (1 - \xi)\iota_R]a_F h_N(\bar{D}_N)} \right\}^{\frac{1}{\gamma}}$.

The steady-state conditions in Eqs. (22) to (24) remain unchanged, as do the labor market clearing conditions for the South in Eqs. (26) to (27). From Eq. (40), we can express x as a function of ϕ_N and n_S :

$$x(\phi_N, n_S) = \frac{\varepsilon \psi_N(\phi_N) L_N}{[\varepsilon a_R + a_O(\varepsilon + \iota_R)n_S]\iota_R L_S}. \quad (\text{C8})$$

Using Eqs. (38), (C5) and (C8), we can express \hat{E} in terms of ϕ_N and n_S :

$$\hat{E}(\phi_N, n_S) = \frac{\sigma_N(\bar{D}_N)x(\phi_N, n_S)\{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R\}(1 - \phi_N)^\gamma}{(\lambda - 1)h_N(\bar{D}_N)g_G^\gamma}. \quad (C9)$$

Eqs. (C4), (C.5) and (C9) imply that the Northern wage inequality can be represented as a function of ϕ_N and n_S :

$$w_N(\phi_N, n_S) = \frac{\hat{E}(\phi_N, n_S)(\lambda - 1)}{x\lambda\{\lambda\mu + [\rho + (1 - \xi)\iota_R]a_R\}}. \quad (C10)$$

Combining Eqs. (22), (26) and (C10) and definitions of ψ_N and ψ_S , we can derive n_F as a function of n_S :

$$n_F(n_S) = \frac{[\varepsilon a_R + a_O(\varepsilon + \iota_R)n_S]\iota_R L_S h_S(\bar{D}_S)B_S(\bar{D}_S)\Gamma^{1-\gamma}}{\varepsilon a_F \iota_R L_N h_N(\bar{D}_N)B_N(\bar{D}_N)}. \quad (C11)$$

Substituting Eqs. (21), (24), (C9) and (C11) into labor market clearing conditions for unskilled Northerners and Southerners (Eqs. (41) and (27)), we have:

$$n_S = \frac{\varepsilon}{\varepsilon + a_R} \left[1 - n_F(n_S) - \frac{\lambda\phi_N L_N}{\hat{E}(\phi_N, n_S)L_S} \right]. \quad (C12)$$

$$n_S = \frac{\varepsilon}{\lambda\varepsilon + a_R} \left[\frac{\lambda\phi_S(\phi_N)}{\hat{E}(\phi_N, n_S)} - n_F(n_S) \right]. \quad (C13)$$

Note that Eq. (C12) shows that ϕ_N and n_S are negatively correlated while Eq. (C13) implies that ϕ_N and n_S are positively correlated. The equilibrium ϕ_N and n_S can be derived by using Eqs. (C12) and (C13). Therefore, substituting the ϕ_N and n_S into Eqs. (C4)-(C10), we can compute w_N^H , w_N^L , w_S^H , w_N , \hat{E} , ϕ_S and x . Using Eqs. (24), (21), (22) and (23), we can derive $n_O = \iota_R n_S / \varepsilon$, $n_N = 1 - n_O - n_F - n_S$, $\iota_F = \iota_R n_F / n_N$ and $\iota_O = (\iota_R + \varepsilon)n_O / n_N$. Thus, we have completely solved the model and showed that there exists a unique solution.

APPENDIX D

Slopes of NN and SS locus

Substituting Eqs. (C7)-(C9), and (C11) and the definition of ψ_N into Eq. (C12), we have:

$$n_S = \frac{\alpha_2(1 - \alpha_1 \varepsilon a_R i_R) - \varepsilon a_R i_R \frac{\phi_N L_N}{(1 - \phi_N) L_S}}{\frac{\phi_N L_N}{(1 - \phi_N) L_S} a_O(\varepsilon + \iota_R) \iota_R + \alpha_2 \left[\alpha_1 a_O(\varepsilon + \iota_R) \iota_R + 1 + \frac{\iota_R}{\varepsilon} \right]}, \quad (D1)$$

where $\alpha_1 = \frac{L_S h_S(\bar{D}_S) B_S(\bar{D}_S) \Gamma^{1-\gamma}}{L_N a_F \varepsilon \iota_R h_N(\bar{D}_N) B_N(\bar{D}_N)}$ and $\alpha_2 = \frac{L_N \varepsilon B_N(\bar{D}_N) \sigma_N(\bar{D}_N) \{\lambda \mu + [\rho + (1-\xi) \iota_R] a_R\}}{L_S(\lambda-1)}$.

Using Eq. (D1), we can obtain $dn_S/d\phi_N < 0$. This implies that n_S and ϕ_N are negatively correlated from the perspective of the market clearing condition for Northern unskilled labor.

Substituting Eqs. (C7)-(C9) and (C11) into Eq. (C13), we have:

$$n_S = \frac{\varepsilon a_R i_R [1 - (1 - \phi_N)(\Gamma + \alpha_1 \alpha_2)]}{(1 - \phi_N) \left\{ \alpha_2 \left[\alpha_1 a_O(\varepsilon + \iota_R) \iota_R + \lambda + \frac{\iota_R}{\varepsilon} \right] + \Gamma a_O(\varepsilon + \iota_R) \iota_R \right\} - a_O(\varepsilon + \iota_R) \iota_R}. \quad (D2)$$

From Eq. (D2), we can obtain $dn_S/d\phi_N > 0$. This implies that n_S and ϕ_N are positively correlated from the perspective of the market clearing condition for Southern unskilled labor.