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Abstract

In this study, we explore the effects of a change in unskilled labor in China on the direction of innovation in the US by incorporating production offshoring into a North-South model of directed technical change. We find that: absent offshoring and lacking intellectual property rights (IPRs) in China - as in the early 1980s - an increase in unskilled labor in China should lead to skill-biased technical change. If instead offshoring is present and/or IPRs are better enforced (as in more recent times), then a *decrease* in unskilled labor in China should lead to skill-biased technical change. Furthermore, an increase in the per capita stock of capital in China reduces offshoring and also leads to skill-biased technical change. Calibrating the model to China-US data, we find that under a moderate elasticity of substitution between skill-intensive and labor-intensive goods, the decrease in unskilled labor and the increase in capital in China can explain about one-third of the recent increase in the skill premium in China through skill-biased technical change in the US.

JEL classification: O14, O33, J31, F16
Keywords: economic growth, skill-biased technical change, offshoring.

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1 Introduction

After decades of economic development, China is now experiencing a rapid decrease in the share of unskilled labor. According to the Barro-Lee dataset on education attainment, the share of population (over the age of 25) in China without tertiary education decreased from 97.1% in 1995 to 94.0% in 2010. If we consider individuals with the completion of secondary education as moderately skilled workers, then the decrease in unskilled labor in China would be even more dramatic. The share of population (over the age of 25) in China without completion of secondary education decreased from 76.3% in 1995 to 53.6% in 2010, which even implies a decrease in the *number* of unskilled workers in China since 1995.

In this study, we explore the effects of a decrease in the supply of unskilled labor in the South (e.g., China) on the direction of innovation in the North (e.g., the US) by incorporating production offshoring into a North-South model of directed technical change. We find that a decrease in Southern unskilled labor leads to a reduction in the offshoring of labor-intensive goods from the North to the South, which in turn triggers skilled-biased technical change in the North. A recent article in *The Economist* documents a decreasing trend in production offshoring from the US to China;[1] for example, "[t]he Boston Consulting Group reckons that in areas such as transport, computers, fabricated metals and machinery, 10-30% of the goods that America now imports from China could be made at home by 2020". The article also argues that this decreasing trend is due to changes in the manufacturing process in developed economies such as the digitization of manufacturing;[2] as a result of which, "companies now want to be closer to their customers so that they can respond more quickly to changes in demand. And some products are so sophisticated that it helps to have the people who design them and the people who make them in the same place." In other words, this new manufacturing process is relatively skill-intensive. As a result of skilled-biased technical change, the skill premium has been increasing in both countries. Acemoglu and Autor (2011) document that the relative wage between workers with college education and workers with high school education in the US increased from 1.80 in 1995 to 1.97 in 2008. Ge and Yang (2013) document that the relative wage between workers with college education and workers with high school education in China increased from 1.21 in 1992 to 1.52 in 2007.

In a North-South model of directed technical change, we find that if the equilibrium features offshoring, then a decrease in unskilled labor in the South would lead to skill-biased technical change in the North. In contrast, if the equilibrium does not feature offshoring, then a decrease in Southern unskilled labor would lead to unskill-biased technical change. Intuitively, when offshoring is absent in equilibrium, a reduction in the supply of unskilled labor in the South causes through international trade a price effect that raises the world price of goods produced with unskilled labor and improves incentives for innovation in labor-intensive goods. In contrast, when offshoring is present in equilibrium, some Southern workers are hired to work with Northern intermediate inputs that are protected by strong patent protection in the North. In this case, a reduction in the supply of unskilled labor in the South

[1] The Economist, "The Third Industrial Revolution", April 21, 2012.

[2] An important technology under the digitization of manufacturing is 3D printing, "which creates a solid object by building up successive layers of material. The digital design can be tweaked with a few mouseclicks. The 3D printer can run unattended, and can make many things which are too complex for a traditional factory to handle."

causes also a market size effect that decreases the value of labor-intensive inventions and improves incentives for innovation in skill-intensive goods. This finding highlights the different implications of offshoring and conventional trade on the direction of technological progress.

The above theoretical result has the following implications. When China first opened up its economy for international trade in the early 1980's, there was essentially no offshoring in the Chinese economy. Together with a low level of patent protection in China at that time,[3] the opening of the Chinese economy implied a massive increase in the supply of unskilled labor in the world causing predominantly a price effect that improved incentives for innovation directed to the relatively scarce factor, i.e., skilled labors, and this contributed to the skill-biased technical change in developed economies. After the mid 1990's, the amount of offshoring to China has started to increase rapidly. Together with an increased level of patent protection in China,[4] the decrease in unskilled labor in China has been causing also a market size effect that improves incentives for innovation directed to the now more abundant factor, i.e., skilled labors, and this also contributes to skill-biased technical change in developed economies.

Another stylized fact of economic development in China is that capital investment as a share of gross domestic product (GDP) is about 40% and substantially higher than many developed economies. So long as the depreciation rates of capital are not substantially different across countries, China is accumulating capital at a much faster rate than developed countries. From our theoretical analysis, we find that an increase in the stock of capital in the South relative to the North reduces offshoring. Intuitively, a larger stock of capital in China increases the wage rates of Chinese workers rendering offshoring to China less attractive. This decrease in offshoring is like a decrease in the supply of unskilled labor to Northern firms triggering a market size effect. Therefore, a larger stock of capital in the South also leads to skill-biased technical change in the North. In other words, rapid capital accumulation and a decrease in unskilled labor in China could both contribute to skill-biased technical change in the US.

We calibrate the model to China-US data to provide a quantitative analysis. Due to skill-biased technical change, either a decrease in unskilled labor or an increase in capital in the South would raise the skill premium in both countries. The magnitude of the changes depends on the elasticity of substitution between skill-intensive and labor-intensive goods. We consider as our benchmark a value of two for the elasticity of substitution between skill-intensive and labor-intensive goods. In this case, the decrease in unskilled labor and the increase in capital in China explain about one-third of the recent increase in the skill premium in China through skill-biased technical change in the US.

This paper relates to studies on directed technical change, such as Acemoglu (1998, 2002, 2003), Acemoglu and Zilibotti (2001) and Gancia and Bonfiglioli (2008). These influential studies built on the literature of R&D-driven economic growth to analyze the direction of innovation.[5] Acemoglu (1998, 2002) analyzes skill-biased technical change and the rising skill premium in the US, whereas Acemoglu (2003), Acemoglu and Zilibotti (2001) and

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[3]For example, the Ginarte-Park index of patent rights in China was 1.33 in 1985; see Park (2008). The Ginarte-Park index is on a scale of 0 to 5, and a larger number implies stronger patent rights.

[4]The Ginarte-Park index of patent rights in China was 4.08 in 2005; see Park (2008).

[5]See Romer (1990), Segerstrom *et al.* (1990), Grossman and Helpman (1991a) and Aghion and Howitt (1992) for seminal studies in this literature and Gancia and Zilibotti (2005) for a survey.

Gancia and Bonfiglioli (2008) analyze the implications of trade on skill-biased technical change and productivity differences across countries. However, the abovementioned studies do not consider offshoring. This paper also relates to studies on offshoring; see Grossman and Rossi-Hansberg (2008) for a recent contribution and their discussion of earlier studies. The present paper complements these two branches of literature by providing an analysis of the effects of offshoring on the direction of technological progress.

Acemoglu *et al.* (2012) also analyze the effects of offshoring on skill-biased technical change. In addition to some differences in modelling details, our study differs from their interesting analysis by exploring a different set of research questions. Acemoglu *et al.* (2012) explore the effects of an offshoring-cost parameter and a patent-policy parameter on skill-biased technical change, whereas we analyze the effects of a decrease in unskilled labor and an increase in capital on skill-biased technical change through offshoring and patent protection. Therefore, we believe that our study provides a useful complementary analysis to Acemoglu *et al.* (2012) on this unchartered area of offshoring and directed technological progress.

The rest of this study is organized as follows. Section 2 presents the model. Section 3 analyzes the effects of labor supply and capital stock in the South on the direction of innovation in the North. The final section concludes.

2 A North-South model of directed technical change

In this section, we consider a North-South version of the model of directed technical change based on Acemoglu (2002). The innovation process is in the form of variety expansion. When an R&D entrepreneur invents a new variety, her patents generate monopolistic profits in the Northern market and possibly also in the Southern market depending on the level of patent protection in the South. For simplicity, we assume that both countries have access to the same set of varieties of goods.[6] Final goods are produced using skill-intensive and labor-intensive goods, which are freely traded across countries, but labors and capital as well as the intermediate inputs that capital produces are immobile across countries. As is common in the literature, we model offshoring as "shadow migration" of workers through which the output of offshored workers in the South is combined with intermediate inputs in the North. As for the cost of offshoring, we follow Grossman and Rossi-Hansberg (2008) to assume that offshoring involves a variable cost.[7]

2.1 Households

In the North, there is a representative household with the following lifetime utility function:

$$U = \int_0^\infty e^{-\rho t} \ln C_t^n dt, \tag{1}$$

[6]See for example Grossman and Helpman (1991b), Helpman (1993) and Lai (1998) for an alternative branch of North-South models that focus on the gradual transfer of technologies from the North to the South.

[7]See Acemoglu *et al.* (2012) for an interesting formulation of offshoring that involves a fixed cost.

where C_t^n denotes consumption in the North at time t, and $\rho > 0$ is the subjective discount rate. The household maximizes utility subject to the following asset-accumulation equation:[8]

$$\dot{A}_t^n = r_t A_t^n + w_{h,t}^n H^n + w_{l,t}^n L^n + q_t^n K^n - C_t^n. \tag{2}$$

A_t^n is the amount of financial assets in the form of patents owned by the household, and r_t is the rate of return.[9] H^n and L^n are respectively the inelastic supply of high-skilled and low-skilled labors. $w_{h,t}^n$ and $w_{l,t}^n$ are respectively the wage rates of high-skilled and low-skilled labors. K^n is the inelastic supply of capital,[10] and q_t^n is the rental price of capital. From standard dynamic optimization, the familiar Euler equation is[11]

$$\frac{\dot{C}_t^n}{C_t^n} = r_t - \rho. \tag{3}$$

As for the South, there are analogous conditions. Finally, we assume that the North is more skill-abundant than the South (i.e., $H^n/L^n > H^s/L^s$) and that the North is also more capital-abundant than the South (i.e., $K^n/L^n > K^s/L^s$).[12]

2.2 Final goods

The production of final goods is perfectly competitive; therefore, it does not matter where production takes place. Final goods are produced with the following CES aggregator:

$$Y_t = \left[\gamma\left(Y_{l,t}^n + Y_{l,t}^s\right)^{(\varepsilon-1)/\varepsilon} + (1-\gamma)\left(Y_{h,t}^n + Y_{h,t}^s\right)^{(\varepsilon-1)/\varepsilon}\right]^{\varepsilon/(\varepsilon-1)}, \tag{4}$$

where $Y_{l,t}^n$ and $Y_{l,t}^s$ are respectively labor-intensive goods produced in the North and in the South, and $Y_{h,t}^n$ and $Y_{h,t}^s$ are respectively skill-intensive goods produced in the North and in the South. $\varepsilon > 1$ is the elasticity of substitution between the two types of goods,[13] and γ determines their relative importance. $\{Y_{l,t}^n, Y_{l,t}^s, Y_{h,t}^n, Y_{h,t}^s\}$ are freely traded across countries subject to international prices $\{P_{l,t}, P_{h,t}\}$. The standard price index of final goods is

$$1 = \left[\gamma^{\varepsilon}\left(P_{l,t}\right)^{1-\varepsilon} + (1-\gamma)^{\varepsilon}\left(P_{h,t}\right)^{1-\varepsilon}\right]^{1/(1-\varepsilon)}, \tag{5}$$

where we have set the price of final goods (numeraire) to one. The resource constraint on final goods is

$$Y_t = R_t + C_t^n + C_t^s, \tag{6}$$

where R_t is the global amount of final goods devoted to R&D.

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[8] We also impose the usual no-Ponzi game condition that requires the household's lifetime budget constraint to be satisfied.

[9] r_t is not indexed by a superscript because we assume that there is a global financial market, and our derivations are robust to any distribution of financial assets across the two countries. One special case is that all financial assets are owned by the Northern household.

[10] We differ from Acemoglu (2002) by assuming that intermediate goods are produced using capital instead of final goods. This modification allows us to analyze the effects of changes in the supply of capital. For simplicity, we focus on an inelastic supply of capital; see the conclusion for a discussion of this assumption.

[11] Also, the transversality condition requires $r_t > \dot{A}_t^n/A_t^n$, which holds on the balanced growth path given the log utility function and $\rho > 0$.

[12] See for example, Bai *et al.* (2006) for a discussion on the relatively low capital-labor ratio in China.

[13] See Acemoglu (2003) for a discussion of evidence for $\varepsilon > 1$.

2.3 Labor-intensive goods

In the South, the production function of labor-intensive goods is

$$Y_{l,t}^{s}=\frac{(l_t^s)^{\beta}}{1-\beta}\left(\int_0^{N_{l,t}}[x_{l,t}^{s}(i)]^{1-\beta}di\right)(N_{l,t})^{1-\beta}, \tag{7}$$

where $\beta\in((\varepsilon-2)/(\varepsilon-1),1)$ determines the elasticity of substitution between intermediate inputs. l_t^s is the amount of Southern unskilled labor employed in the production of $Y_{l,t}^{s}$. In addition to using labor, the production of $Y_{l,t}^{s}$ requires differentiated intermediate inputs $x_{l,t}^{s}(i)$ for $i\in[0,N_{l,t}]$, where $N_{l,t}$ is the number of differentiated inputs for labor-intensive goods that have been invented as of time t. The term $(N_{l,t})^{1-\beta}$ captures an externality effect of $N_{l,t}$ on the production of $Y_{l,t}^{s}$ in order to ensure a balanced growth path along which $N_{l,t}$ and $Y_{l,t}^{s}$ grow at the same rate.[14]

In the North, the production function of labor-intensive goods is given by

$$Y_{l,t}^{n}=\frac{(l_t^n+\delta o_t^s)^{\beta}}{1-\beta}\left(\int_0^{N_{l,t}}[x_{l,t}^{n}(i)]^{1-\beta}di\right)(N_{l,t})^{1-\beta}, \tag{8}$$

where o_t^s is the amount of Southern unskilled labor employed by Northern firms to produce $Y_{l,t}^{n}$ capturing the offshoring of production. Following Grossman and Rossi-Hansberg (2008), we use a parameter $\delta\in(0,1)$ to capture the variable cost of offshoring. A higher cost of offshoring is reflected by a smaller value of δ. If $\delta=0$, then offshoring of labor-intensive goods would be absent,[15] and the model is left with conventional trade in $\{Y_{l,t}^{n},Y_{l,t}^{s},Y_{h,t}^{n},Y_{h,t}^{s}\}$. We refer to a larger δ as a higher degree of offshoring. As a result of offshoring, the resource constraint for Southern unskilled labor is $l_t^s+o_t^s=L^s$, whereas the resource constraint for Northern unskilled labor is $l_t^n=L^n$.

2.4 Skill-intensive goods

In the South, the production function of skill-intensive goods is given by

$$Y_{h,t}^{s}=\frac{(h_t^s)^{\beta}}{1-\beta}\left(\int_0^{N_{h,t}}[x_{h,t}^{s}(j)]^{1-\beta}dj\right)(N_{h,t})^{1-\beta}. \tag{9}$$

h_t^s is the amount of Southern skilled labor employed in the production of $Y_{h,t}^{s}$. In addition to using labor, the production of $Y_{h,t}^{s}$ requires differentiated intermediate inputs $x_{h,t}^{n}(j)$ for $j\in[0,N_{h,t}]$, where $N_{h,t}$ is the number of differentiated inputs for skill-intensive goods that have been invented as of time t. The term $(N_{h,t})^{1-\beta}$ captures an externality effect of $N_{h,t}$ on the production of $Y_{h,t}^{s}$ in order to ensure a balanced growth path along which $N_{h,t}$ and $Y_{h,t}^{s}$ grow at the same rate.

In the North, the production function of labor-intensive goods is given by

$$Y_{h,t}^{n}=\frac{(h_t^n)^{\beta}}{1-\beta}\left(\int_0^{N_{h,t}}[x_{h,t}^{n}(j)]^{1-\beta}dj\right)(N_{h,t})^{1-\beta}, \tag{10}$$

[14] In Acemoglu (2002), this externality is not needed because $x_{l,t}^{n}(i)$ is produced from final goods, whereas $x_{l,t}^{n}(i)$ is produced from a fixed supply of capital in the present study.

[15] In fact, we find that if δ is below a threshold value, then offshoring would be absent in equilibrium.

where we have ruled out offshoring of skill-intensive goods.[16] Due to the absence of offshoring for skill-intensive goods, the resource constraint for Southern skilled labor is $h_t^s = H^s$, whereas the resource constraint for Northern skilled labor is $h_t^n = H^n$.

2.5 Intermediate inputs

For notational convenience, we suppress the index $i \in [0, N_{l,t}]$ for the intermediate inputs of labor-intensive goods and the index $j \in [0, N_{h,t}]$ for the intermediate inputs of skill-intensive goods. In the North, the production function of each differentiated intermediate input is

$$x_{z,t}^n = k_{z,t}^n, \tag{11}$$

where $z \in \{h, l\}$. In other words, one unit of capital produces one unit of intermediate input. Given the capital-rental price q_t^n in the North, the monopolistic producer of each differentiated intermediate input charges a profit-maximizing markup η^n over q_t^n such that

$$p_{z,t}^n = \eta^n q_t^n, \tag{12}$$

where $z \in \{h, l\}$ and $\eta^n = 1/(1-\beta) > 1$. Therefore, the amount of profit captured by each intermediate input in the North is

$$\pi_{z,t}^n = (1 - 1/\eta^n) p_{z,t}^n x_{z,t}^n = \beta p_{z,t}^n x_{z,t}^n, \tag{13}$$

where $z \in \{h, l\}$. Due to symmetry, the resource constraint on capital in the North is $N_{l,t} x_{l,t}^n + N_{h,t} x_{h,t}^n = K_{l,t}^n + K_{h,t}^n = K^n$.

In the South, the production function of each differentiated intermediate input is

$$x_{z,t}^s = k_{z,t}^s, \tag{14}$$

where $z \in \{h, l\}$. Given the capital-rental price q_t^s in the South, the monopolistic producer of each differentiated intermediate input charges a markup η^s over q_t^s such that

$$p_{z,t}^s = \eta^s q_t^s, \tag{15}$$

where $z \in \{h, l\}$. Here we follow Goh and Olivier (2002) to model incomplete patent protection that constrains the markup in the South;[17] specifically, we assume that $\eta^s = 1/(1-\phi) \leq \eta^n$ where $\phi \in [0, \beta]$. Intuitively, the presence of potential imitation due to incomplete patent protection forces the monopolistic producers to lower their markup in the South. If $\phi = \beta$, then patent protection is complete in the South. If $\phi = 0$, then patent protection is zero in the South. The amount of profit captured by each intermediate input in the South is

$$\pi_{z,t}^s = (1 - 1/\eta^s) p_{z,t}^s x_{z,t}^s = \phi p_{z,t}^s x_{z,t}^s, \tag{16}$$

where $z \in \{h, l\}$. The resource constraint on capital in the South is $N_{l,t} x_{l,t}^s + N_{h,t} x_{h,t}^s = K_{l,t}^s + K_{h,t}^s = K^s$.

[16] We have found that if and only if a knife-edge condition holds such that the costs of offshoring for labor-intensive and skill-intensive goods are the same (i.e., $\delta_h = \delta_l = \delta > 0$), then the model would feature offshoring in both sectors. Given that our focus is on the offshoring of labor-intensive goods, we consider the case of $0 \leq \delta_h < \delta_l = \delta$ under which the equilibrium features zero offshoring of skill-intensive goods and is identical to the case of $\delta_h = 0$.

[17] See also Li (2001), Chu (2011) and Iwaisako and Futagami (2013).

2.6 R&D

There is a continuum of entrepreneurs investing in R&D, and the invention of a new variety of skill-intensive or labor-intensive inputs requires μ units of final goods. If μ is the same across the two countries, then the location of R&D is indeterminate, and our derivations are robust to any geographical distribution of R&D. If μ is smaller in the North than in the South, then innovation takes place only in the North as in, for example, Acemoglu and Zilibotti (2001) and Gancia and Bonfiglioli (2008).[18] When an entrepreneur invents a new variety, she obtains patents in both the North and the South.[19] The innovation process is

$$\dot{N}_{z,t} = R_{z,t}/\mu, \tag{17}$$

where $z \in \{h, l\}$. Suppose we denote $V_{z,t}$ as the value of an invention. Free entry ensures that

$$(V_{z,t} - \mu)\dot{N}_{z,t} = 0, \tag{18}$$

where $z \in \{h, l\}$. The familiar Bellman equation is

$$r_t = \frac{\pi^n_{z,t} + \pi^s_{z,t} + \dot{V}_{z,t}}{V_{z,t}}, \tag{19}$$

where $z \in \{h, l\}$. Intuitively, the Bellman equation equates the interest rate to the asset return per unit of asset, where the asset return is the sum of monopolistic profits $\pi^n_{z,t} + \pi^s_{z,t}$ and any potential capital gain $\dot{V}_{z,t}$.

2.7 Decentralized equilibrium

The equilibrium is a time path of prices $\{r_t, w^n_{l,t}, w^s_{l,t}, w^n_{h,t}, w^s_{h,t}, q^n_t, q^s_t, P_{l,t}, P_{h,t}, p^n_{l,t}(i), p^s_{l,t}(i), p^n_{h,t}(j), p^s_{h,t}(j)\}$ and a time path of allocations $\{R_{l,t}, R_{h,t}, C^n_t, C^s_t, Y_t, Y^n_{l,t}, Y^s_{l,t}, Y^n_{h,t}, Y^s_{h,t}, x^n_{l,t}(i), x^s_{l,t}(i), x^n_{h,t}(j), x^s_{h,t}(j), l^n_t, l^s_t, o^s_t, h^n_t, h^s_t\}$. Also, at each instance of time, the followings hold:

- Households maximize utility taking $\{r_t, w^n_{l,t}, w^n_{h,t}, q^n_t, w^s_{l,t}, w^s_{h,t}, q^s_t\}$ as given;
- Competitive final-goods firms produce $\{Y_t\}$ to maximize profit taking prices $\{P_{l,t}, P_{h,t}\}$ as given;
- Competitive labor-intensive goods firms in the two countries produce $\{Y^n_{l,t}, Y^s_{l,t}\}$ to maximize profit taking the international price $\{P_{l,t}\}$ as given;
- Competitive skill-intensive goods firms in the two countries produce $\{Y^n_{h,t}, Y^s_{h,t}\}$ to maximize profit taking the international price $\{P_{h,t}\}$ as given;
- Monopolistic intermediate-goods firms in the labor-intensive sector produce $\{x^n_{l,t}(i), x^s_{l,t}(i)\}$ and choose $\{p^n_{l,t}(i), p^s_{l,t}(i)\}$ to maximize profit taking prices $\{q^n_t, q^s_t\}$ as given;

[18] See Acemoglu and Zilibotti (2001) for a discussion of evidence that 90% of global R&D is performed in OECD countries and 35% in the US.

[19] It is useful to note that given the global financial market, a patent that is based on a variety invented in the North is not necessarily owned by the Northern household.

- Monopolistic intermediate-goods firms in the skill-intensive sector produce $\{x^n_{h,t}(j), x^s_{h,t}(j)\}$ and choose $\{p^n_{h,t}(j), p^s_{h,t}(j)\}$ to maximize profit taking prices $\{q^n_t, q^s_t\}$ as given;
- R&D firms choose $\{R_{l,t}, R_{h,t}\}$ to maximize profit taking $\{V_{l,t}, V_{h,t}\}$ as given;
- The market-clearing condition for unskilled labor in the two countries holds such that $l^n_t = L^n$ and $l^s_t + o^s_t = L^s$;
- The market-clearing condition for skilled labor in the two countries holds such that $h^n_t = H^n$ and $h^s_t = H^s$;
- The market-clearing condition for capital in the two countries holds such that $N_{l,t}x^n_{l,t} + N_{h,t}x^n_{h,t} = K^n$ and $N_{l,t}x^s_{l,t} + N_{h,t}x^s_{h,t} = K^s$;
- The market-clearing condition for final goods holds such that $Y_t = R_{l,t} + R_{h,t} + C^n_t + C^s_t$.

2.8 Balanced growth equilibrium and offshoring

In this subsection, we discuss the balanced growth equilibrium of the model. The model features a unique steady-state value of $N_{h,t}/N_{l,t}$. If the initial value of $N_{h,t}/N_{l,t}$ is above (below) this steady-state value, then the equilibrium initially features R&D in labor-intensive (skill-intensive) goods only until the economy reaches the balanced growth path along which $N_{h,t}$ and $N_{l,t}$ grow at the same rate g, which is constant and positive. On the balanced growth path, the equilibrium features a positive amount of offshoring $o^s > 0$ if and only if δ is sufficiently large. We summarize these results in Proposition 1.

Proposition 1 *The dynamics of $N_{h,t}/N_{l,t}$ is characterized by global stability such that the economy converges to a unique and stable balanced growth path along which $N_{h,t}$ and $N_{l,t}$ grow at the same rate g, which is constant and positive. If and only if $\delta > [(K^s/L^s)/(K^n/L^n)]^{1-\beta}$, then the equilibrium would feature a positive amount of offshoring (i.e., $o^s > 0$).*

Proof. See Appendix A. ■

The threshold value of δ above which the equilibrium features offshoring is given by $[(K^s/L^s)/(K^n/L^n)]^{1-\beta} < 1$. Intuitively, in the presence of offshoring, the wage rate of unskilled labor in the South must be a fraction δ of that in the North. However, if the capita-labor ratio in the South is sufficiently high relative to the North, then it would be impossible for the South to have such a low relative wage in equilibrium. To better understand this result, we use the following conditions. For the rest of the analysis, we focus on the balanced growth path and omit the time subscript for convenience. From (7) and (8), one can derive the following conditional demand functions for l^s and l^n:

$$w^s_l = \frac{\beta P_l N_l}{1-\beta}\left(\frac{K^s_l}{l^s}\right)^{1-\beta}, \tag{20}$$

$$w_l^n = \frac{\beta P_l N_l}{1-\beta}\left(\frac{K_l^n}{l^n + \delta o^s}\right)^{1-\beta}, \tag{21}$$

where we have applied symmetry on $x_l^s(i) = x_l^s = K_l^s/N_l$ and $x_l^n(i) = x_l^n = K_l^n/N_l$. Given that the equality $w_l^s = \delta w_l^n$ must hold when offshoring is present (i.e., $o^s > 0$), we have[20]

$$\left(\frac{K_l^s}{L^s - o^s}\right)^{1-\beta} = \delta\left(\frac{K_l^n}{L^n + \delta o^s}\right)^{1-\beta} \Leftrightarrow o^s = \frac{\delta^{1/(1-\beta)}K_l^n L^s - K_l^s L^n}{\delta^{1/(1-\beta)}K_l^n + \delta K_l^s}, \tag{22}$$

where we have used $l^s + o^s = L^s$ and $l^n = L^n$. As shown in Proposition 1, the equilibrium features offshoring if and only if δ is sufficiently large. Equation (22) highlights the intuition of this result as follows: the productivity δ of offshored workers must be sufficiently high in order for Northern firms to find them worth hiring at the Southern market wage w_l^s. Holding K_l^n and K_l^s constant, an increase in L^s or a decrease in L^n reduces the relative wage w_l^s/w_l^n for a given o^s and hence raises the amount of offshoring o^s in equilibrium. In contrast, an increase in K_l^s or a decrease in K_l^n in the labor-intensive sector raises the relative wage w_l^s/w_l^n for a given o^s and reduces the amount of offshoring o^s in equilibrium.

3 How the South affects innovation in the North

In this section, we analyze the effects of a reduction in the supply of Southern unskilled labor L^s and an increase in Southern capital K^s on the direction of Northern innovation. In Section 3.1, we provide a qualitative analysis. In Section 3.2, we calibrate the model to provide a quantitative analysis.

3.1 Qualitative analysis

We sketch out the results in the main text and relegate the detailed derivations to Appendix A. First, we explore the effects of offshoring o^s on the relative value of skill-intensive and labor-intensive inventions. From (8) and (10), one can derive the following conditional demand functions for $x_l^n(i)$ and $x_h^n(j)$:

$$x_l^n(i) = \left[\frac{P_l(N_l)^{1-\beta}}{p_l^n(i)}\right]^{1/\beta}(l^n + \delta o^s), \tag{23}$$

$$x_h^n(j) = \left[\frac{P_h(N_h)^{1-\beta}}{p_h^n(j)}\right]^{1/\beta} h^n. \tag{24}$$

The steady-state version of (19) simplifies to

$$\frac{V_h}{V_l} = \frac{\pi_h^n + \pi_h^s}{\pi_l^n + \pi_l^s} = \frac{\beta p_h^n x_h^n + \phi p_h^s x_h^s}{\beta p_l^n x_l^n + \phi p_l^s x_l^s}, \tag{25}$$

[20] Recall that K_l^n and K_l^s are endogenous variables that are determined by parameters including K^n and K^s. In Appendix A, we provide the equilibrium conditions that implicitly determine the unique equilibrium value of o^s as a function of parameters.

where $p_h^n = p_l^n = \eta^n q^n = p^n$ and $p_h^s = p_l^s = \eta^s q^s = p^s$. Substituting (23) and (24) into (25) yields

$$\frac{V_h}{V_l} = \left(\frac{N_h}{N_l}\right)^{(1-\beta)/\beta} \underbrace{\left(\frac{P_h}{P_l}\right)^{1/\beta}}_{\text{price effect}} \underbrace{\frac{\beta H^n + \delta\phi H^s}{\beta L^n + \delta\phi L^s + \delta(\beta-\phi)o^s}}_{\text{market size effect}}, \tag{26}$$

where we have also used $p^n = \delta^{\beta/(1-\beta)} p^s$. From (26), we obtain the following intuition. Holding constant the market size effect, a decrease in the supply of Southern unskilled labor L^s leads to a negative price effect by decreasing P_h/P_l. As a result, V_h/V_l decreases causing innovation to be directed towards labor-intensive goods, and this gives rise to unskill-biased technical change (i.e., N_h/N_l decreases). However, the decrease in the supply of Southern unskilled labor L^s also leads to a positive market size effect by decreasing offshoring o^s and the term $\delta\phi L^s + \delta(\beta-\phi)o^s$ in the denominator of the market size effect. As a result, V_h/V_l increases causing innovation to be directed towards skill-intensive goods, and this gives rise to skill-biased technical change (i.e., N_h/N_l increases).

To better understand the effects of offshoring o^s on N_h/N_l, we derive the following equilibrium condition in Appendix A:[21]

$$\frac{N_h}{N_l} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}} \underbrace{\left(\frac{H^n + \delta H^s}{L^n + \delta L^s}\right)^{-\frac{1}{1-(1-\beta)(\varepsilon-1)}}}_{\text{price effect}} \underbrace{\left(\frac{\beta H^n + \delta\phi H^s}{\beta L^n + \delta\phi L^s + \delta(\beta-\phi)o^s}\right)^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}}}_{\text{market size effect}}, \tag{27}$$

where $\varepsilon > 1$ and $1-(1-\beta)(\varepsilon-1) > 0$ because $\beta > (\varepsilon-2)/(\varepsilon-1)$. Equation (27) confirms the previous claim that a decrease in L^s causes a negative effect on N_h/N_l via the price effect. Furthermore, (27) shows $\varepsilon > 1$ implies that the exponent associated with the market size effect is greater than the exponent associated with the price effect. As a result, the market size effect dominates the price effect such that a decrease in L^s leads to an increase in N_h/N_l as we will show in Appendix A. This is true regardless of the level of Southern patent protection $\phi \in [0, \beta]$. In the special case of complete Southern patent protection (i.e., $\phi = \beta$), (27) nicely simplifies to

$$\frac{N_h}{N_l} = \left[\left(\frac{1-\gamma}{\gamma}\right)^{\varepsilon} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s}\right)^{\beta(\varepsilon-1)}\right]^{\frac{1}{1-(1-\beta)(\varepsilon-1)}}, \tag{27a}$$

which clearly shows that a decrease in L^s leads to an increase in N_h/N_l if and only if $\varepsilon > 1$.

What happens when offshoring is absent in the equilibrium? In this case, the result depends on the level of patent protection in the South. In the case of zero Southern patent protection (i.e., $\phi = 0$), changes in L^s do not cause any market size effect. As a result, a decrease in L^s leads to unskill-biased technical change (i.e., N_h/N_l decreases) via the price effect. In the case of complete Southern patent protection (i.e., $\phi = \beta$), changes in L^s also cause the market size effect, which dominates the price effect given $\varepsilon > 1$. In this case, a decrease in L^s leads to skill-biased technical change (i.e., N_h/N_l increases) despite the absence of offshoring. We summarize all the above results in Proposition 2.

[21] See (A12).

Proposition 2 *If the equilibrium features offshoring, then a decrease in the supply of Southern unskilled labor would lead to skill-biased technical change. If the equilibrium does not feature offshoring, then the effects would depend on the level of patent protection in the South as follows: (a) under zero Southern patent protection, a decrease in the supply of Southern unskilled labor leads to unskill-biased technical change; and (b) under complete Southern patent protection, a decrease in the supply of Southern unskilled labor leads to skill-biased technical change.*

Proof. See Appendix A. ■

The intuition for Proposition 2 can be explained as follows. In the absence of offshoring, any change in the supply of unskilled labor in the South causes only a price effect on the value of inventions. As in Acemoglu (2003), a decrease in L^s raises the world price of goods produced with unskilled labor thereby leading to innovation biased in favor of the unskilled. In this case, the market size effect is absent due to zero patent protection or more generally, weak patent protection in the South, so that production in the South generates a negligible amount of monopolistic profit. In the presence of offshoring, some Southern workers are hired to work with Northern intermediate inputs that are protected by complete patent protection in the North. As a result, a decrease in the supply of Southern unskilled labor causes through offshoring a negative market size effect on the value of labor-intensive inventions leading to innovation biased in favor of the skilled. This result is also consistent with the finding in Acemoglu (2003) under complete Southern patent protection *without* offshoring. In other words, Southern patent protection and offshoring serve as two substitutable channels through which the supply of unskilled labor in the South causes a market size effect on the value of inventions in the North.

The results in Proposition 2 have the following implications. First, the opening of the Chinese economy for international trade in the 1980's implied a massive *increase* in the supply of unskilled labor and caused skilled-biased technical change because patent protection in China was very weak and there was very little offshoring to China at that time. Second, stronger patent protection in China and the substantial amount of offshoring to China in the present imply that it would now be a *decrease* in the supply of unskilled labor in China that leads to skill-biased technical change.

As for the effect of increasing capital in China, a larger K^s leads to an increase in K_l^s. As a result, w_l^s increases holding other variables constant. Given that the condition $w_l^s = \delta w_l^n$ must hold in the presence of offshoring, an increase in K_l^s reduces o^s as shown in (22). Intuitively, a larger K_l^s increases the wage rate of Southern unskilled labor rendering offshoring less attractive. As shown in (26) and (27), this reduction in o^s generally triggers a market size effect unless the level of patent protection in the South is complete (i.e., $\phi = \beta$). Therefore, as long as the level of Southern patent protection is incomplete (i.e., $\phi < \beta$), a larger capital stock in the South leads to skill-biased technical change (i.e., N_h/N_l increases). In the special case of complete Southern patent protection (i.e., $\phi = \beta$), (27) shows that N_h/N_l is independent of K^s. Intuitively, although a larger K^s reduces offshoring o^s, any decrease in o^s is offset by an equal increase in unskilled labor l^s devoted to production in the South. Because of complete Southern patent protection, the market size effect of unskilled labor depends on L^s regardless of its distribution in o^s and l^s. Therefore, despite its effect on offshoring o^s, a larger Southern capital stock K^s no longer leads to skill-biased technical change under complete patent protection. We summarize these results in Proposition 3.

Proposition 3 *If the equilibrium features offshoring, then an increase in Southern capital stock would have the following effects: (a) it leads to skill-biased technical change under incomplete (and zero) Southern patent protection; and (b) it has no effect on the direction of innovation under complete Southern patent protection.*

Proof. See Appendix A. ■

What happens when offshoring is absent in the equilibrium? In the absence of offshoring, increasing K^s has a positive effect on N_h/N_l (i.e., skill-biased technical change) under zero patent protection in the South, and this effect operates through the price effect. The intuition can be explained as follows. Suppose there is a zero supply of high-skill labor H^s in the South. Then, a larger capital stock K^s expands only the production of labor-intensive goods Y_l^s, which leads to a positive price effect by increasing P_h/P_l and consequently skill-biased technical change. Under complete patent protection in the South, increasing K^s has a negative effect on N_h/N_l (i.e., unskill-biased technical change). This effect operates through the market size effect under which the increased supply of labor-intensive goods Y_l^s raises the value of labor-intensive inventions relative to skill-intensive inventions. A similar intuition also applies to the more general case of $H^s/L^s < H^n/L^n$, which we have assumed throughout the analysis. We summarize these results in the following proposition.

Proposition 4 *If the equilibrium does not feature offshoring, then the effects of Southern capital stock would depend on the level of patent protection in the South as follows: (a) under zero Southern patent protection, an increase in Southern capital stock leads to skill-biased technical change; and (b) under complete Southern patent protection, an increase in Southern capital stock leads to unskill-biased technical change.*

Proof. See Appendix A. ■

In the rest of this section, we explore the effects of L^s and K^s on the skill premium in the presence of offshoring. In Appendix B, we derive

$$\frac{w_h^n}{w_l^n} = \frac{w_h^s}{w_l^s} = \left[\left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon/(\varepsilon-1)} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s} \right)^{-1/(\varepsilon-1)} \left(\frac{H^n + \frac{\phi}{\beta}\delta H^s}{L^n + \frac{\phi}{\beta}\delta L^s + \delta o^s(\beta-\phi)/\beta} \right) \right]^{\zeta}, \quad (28)$$

where $\zeta \equiv (\varepsilon - 1)/[1-(1-\beta)(\varepsilon-1)] > 0$ because $\varepsilon > 1$ and $\beta > (\varepsilon-2)/(\varepsilon-1)$. Suppose we consider the special case of complete Southern patent protection (i.e., $\phi = \beta$). Then, (28) simplifies to

$$\frac{w_h^n}{w_l^n} = \frac{w_h^s}{w_l^s} = \left[\left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon/(\varepsilon-1)} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s} \right)^{(\varepsilon-2)/(\varepsilon-1)} \right]^{\zeta}. \quad (28a)$$

In the case of complete Southern patent protection, a decrease in L^s raises the skill premium w_h^n/w_l^n if and only if ε is greater than a threshold value of two, under which the market size effect is sufficiently strong to induce a positive relationship between relative supply H^s/L^s and relative wage w_h^s/w_l^s. In the case of incomplete Southern patent protection (i.e., $\phi < \beta$), our numerical results indicate that this threshold value of ε can be slightly below two. Another interesting implication from (28a) is that under complete Southern patent protection, w_h^n/w_l^n is independent of K^s. In other words, an increase in K^s raises the skill premium if and only if $\phi < \beta$, under which K^s increases w_h^n/w_l^n by decreasing offshoring o^s as shown in (28).

3.2 Quantitative analysis

In the previous section, we show that whenever offshoring is present, a decrease in unskilled labor and an increase in capital in the South leads to skill-biased technical change. However, we are also interested in quantitative implications. Therefore, in this section, we calibrate the model for the general case of incomplete Southern patent protection in order to provide an illustrative numerical investigation on the effects of changes in unskilled labor and capital in China on the skill premium in both countries. The model features the following set of parameters $\{\varepsilon, \delta, \gamma, \rho, \beta, \phi, L^s, H^s, L^n, H^n, K^s, K^n\}$.[22] We either consider standard values of these parameters or calibrate them using empirical moments in China and the US.

For the discount rate ρ, we follow Acemoglu and Akcigit (2012) to set ρ to a standard value of 0.05. For the labor-share parameter β, we set β to the lower value of 0.4 in China,[23] which also implies a more realistic markup $\eta^n = 1/(1-\beta) = 1.67$. According to the Ginarte-Park index of patent rights, the level of patent protection in China from 1995 to 2005 is on average 63.5% of that in the US, so we set $\eta^s - 1 = 0.635(\eta^n - 1)$, which implies $\phi \equiv 1 - 1/\eta^s = 0.30$ in China. We normalize Southern unskilled labor L^s to unity and compute Southern skilled labor H^s using data on the share of population in China with at least some tertiary education (i.e., $H^s/(H^s + L^s)$, which is 2.9% in 1995 according to the Barro-Lee dataset on education attainment). Similarly, we compute Northern unskilled labor L^n and skilled labor H^n using data on the share of population in the US with at least some tertiary education (i.e., $H^n/(H^n + L^n)$, which is 46.5% in 1995 according to the Barro-Lee dataset) and the relative population size between China and the US (i.e., $(H^s+L^s)/(H^n+L^n)$, which is 4.57 in 1995 according to the Penn World Table). We normalize Northern capital K^n to unity and compute Southern capital K^s using data on the relative GDP between China and the US (i.e., $(P_hY_h^s + P_lY_l^s)/(P_hY_h^n + P_lY_l^n)$, which is 0.35 in 1995 according to the Penn World Table). For the remaining parameters $\{\varepsilon, \delta, \gamma\}$, we consider a range of values for the substitution elasticity $\varepsilon \in \{2.0, 2.1, 2.2\}$.[24] For each value of ε, we calibrate the values of $\{\delta, \gamma\}$ using the following moments. For the offshoring parameter δ, we calibrate δ using the value of exports in China as a share of GDP, which is 20.5% in 1995.[25] Finally, we

[22]It can be shown that the calibration and simulation of the interested variables are independent of μ.

[23]See for example Luo and Zhang (2010) for data on labor share in China.

[24]Acemoglu and Zilibotti (2001) consider $\varepsilon = 2$ whereas Gancia and Zilibotti (2009) consider a case in which $\varepsilon > 2$. Therefore, we consider a small range of values for $\varepsilon \geq 2$.

[25]Data source: China Statistical Yearbook.

calibrate the relative share γ of labor-intensive goods using the college premium in China (i.e., w_h^s/w_l^s, which is 1.21 in 1992).[26] Table 1 reports the calibrated parameter values.[27]

Table 1: Calibrated parameters under different values of ε			
ε: substitution elasticity	2.0	2.1	2.2
δ: offshoring parameter	0.15	0.15	0.15
γ: relative share of labor-intensive goods	0.50	0.49	0.48
ρ: discount rate	0.05	0.05	0.05
β: Northern patent protection	0.4	0.4	0.4
ϕ: Southern patent protection	0.3	0.3	0.3
L^s: Southern unskilled labor	1	1	1
H^s: Southern skilled labor	0.03	0.03	0.03
L^n: Northern unskilled labor	0.12	0.12	0.12
H^n: Northern skilled labor	0.10	0.10	0.10
K^s: Southern capital	0.10	0.10	0.10
K^n: Northern capital	1	1	1

We consider the following policy experiment. We decrease the supply of unskilled labor and increase capital in China and examine their effects on N_h/N_l and w_h^s/w_l^s.[28] From 1995 to 2005, the share of population without any tertiary education in China decreases by about 2%.[29] The relative GDP between China and the US increases from 0.35 in 1995 to 0.49 in 2005. We use this change in relative GDP to calibrate the change in K^s, which increases by about 40%. During this period, the relative wage w_h^s/w_l^s between workers with college education and workers with high school education in China increases by about 25%.[30] We examine how large a fraction of this increase in the skill premium can be attributed to the changes in L^s and K^s. Table 2 reports the results for different values of ε.[31] Due to skill-biased technical change, the decrease in L^s and the increase in K^s in China raise the skill premium in both countries. The magnitude of the changes is sensitive to the value of ε (i.e., the elasticity of substitution between skill-intensive and labor-intensive goods) as is well known in the literature. Suppose we consider a moderate value of $\varepsilon = 2$ as our benchmark. Then, we find that the decrease in L^s and the increase in K^s in China would lead to a 8.5% increase in w_h^s/w_l^s, which explains about one-third of the observed increase in the skill premium in China. If we consider a larger value of $\varepsilon = 2.2$, then the decrease in L^s and the increase in K^s in China would raise w_h^s/w_l^s by as much as 17.8%. Quantitatively, the increase in capital is responsible for the vast majority of these effects given that the change in L^s has been small relative to the change in K^s.

[26] See Ge and Yang (2013).

[27] We provide the equilibrium expressions for calibration in Appendix B.

[28] In our model, the skill premiums in the North and the South are the same; i.e., $w_h^n/w_l^n = w_h^s/w_l^s$.

[29] The decrease in the share of population without completion of secondary education in China is more dramatic. Therefore, considering tertiary education (rather than the completion of secondary education) as the cutoff for skilled versus unskilled makes our results more conservative.

[30] See Ge and Yang (2013).

[31] The results in Table 2 are expressed as percent changes in N_h/N_l and w_h^n/w_l^n.

Table 2: Simulated effects of L^s and K^s			
ε	2.0	2.1	2.2
$\Delta N_h/N_l$	13.4%	17.2%	23.5%
$\Delta w_h^n/w_l^n$	8.5%	12.0%	17.8%

As for the effects of a further decrease in L^s or a further increase in K^s, we compute the elasticities of N_h/N_l and w_h^s/w_l^s with respect to L^s and K^s at the new values of L^s and K^s. Table 3 reports the results. Suppose we consider a moderate value of $\varepsilon = 2$. Then, we find that a 1% decrease in unskilled labor L^s in China would lead to a 0.1% increase in w_h^s/w_l^s, whereas a 1% increase in capital K^s in China would lead to a 0.3% increase in w_h^s/w_l^s. If we consider a larger value of $\varepsilon = 2.2$, then a 1% decrease in unskilled labor in China would raise w_h^s/w_l^s by as much as 0.6%, whereas a 1% increase in capital would raise w_h^s/w_l^s by 0.5%.

Table 3a: 1% decrease in L^s			
ε	2.0	2.1	2.2
$\Delta N_h/N_l$	0.7%	0.9%	1.3%
$\Delta w_h^n/w_l^n$	0.1%	0.3%	0.6%
Table 3b: 1% increase in K^s			
ε	2.0	2.1	2.2
$\Delta N_h/N_l$	0.4%	0.5%	0.7%
$\Delta w_h^n/w_l^n$	0.3%	0.4%	0.5%

4 Conclusion

In this study, we have analyzed how economic development in China could affect skill-biased technical change in the US. In our analysis, we have assumed that the supply of unskilled labor and the capital stock are exogenous. In reality, they are all endogenous variables. In the case of China, their changes are mainly driven by economic development. As the economy develops, the supply of unskilled labor decreases and the stock of physical capital increases. As a result, the smaller supply of unskilled labor and the larger supply of physical capital reinforce each other in triggering skill-biased technical change through offshoring. Furthermore, if the reduction in the supply of unskilled labor also increases the skill premium in both the US and China as in our simulation results, then there would be more incentives for skill acquisition in both countries further decreasing the supply of unskilled labor and triggering skill-biased technical change. Therefore, we conjecture that our results are robust to the endogenous accumulation of physical and human capital. However, allowing for these additional features would complicate our analysis significantly, so that we leave these interesting extensions to future research.

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Appendix A

In this appendix, we provide proofs of the propositions. Before we proceed to the proofs, it would be helpful to first present the following preliminary derivations. The prices of intermediate inputs do not depend on $z \in \{l, h\}$, so that $p^n_{l,t} = p^n_{h,t} = \eta^n q^n_t = p^n_t$ and $p^s_{l,t} = p^s_{h,t} = \eta^s q^s_t = p^s_t$. The conditional demand functions for labors are

$$w^s_{l,t} = \frac{\beta P_{l,t}}{1-\beta}(l^s_t)^{\beta-1}\left(x^s_{l,t}\right)^{1-\beta}(N_{l,t})^{2-\beta}, \quad \text{(A1-a)}$$

$$w^n_{l,t} = \frac{\beta P_{l,t}}{1-\beta}(l^n_t+\delta o^s_t)^{\beta-1}\left(x^n_{l,t}\right)^{1-\beta}(N_{l,t})^{2-\beta}, \quad \text{(A1-b)}$$

$$w^s_{h,t} = \frac{\beta P_{h,t}}{1-\beta}(h^s_t)^{\beta-1}\left(x^s_{h,t}\right)^{1-\beta}(N_{h,t})^{2-\beta}, \quad \text{(A1-c)}$$

$$w^n_{h,t} = \frac{\beta P_{h,t}}{1-\beta}(h^n_t)^{\beta-1}\left(x^n_{h,t}\right)^{1-\beta}(N_{h,t})^{2-\beta}. \quad \text{(A1-d)}$$

The conditional demand functions for intermediate inputs are

$$x^s_{l,t} = (P_{l,t})^{\frac{1}{\beta}}(p^s_t)^{-\frac{1}{\beta}}(l^s_t)(N_{l,t})^{\frac{1-\beta}{\beta}}, \quad \text{(A1-e)}$$

$$x^n_{l,t} = (P_{l,t})^{\frac{1}{\beta}}(p^n_t)^{-\frac{1}{\beta}}(l^n_t+\delta o^s_t)(N_{l,t})^{\frac{1-\beta}{\beta}}, \quad \text{(A1-f)}$$

$$x^s_{h,t} = (P_{h,t})^{\frac{1}{\beta}}(p^s_t)^{-\frac{1}{\beta}}(h^s_t)(N_{h,t})^{\frac{1-\beta}{\beta}}, \quad \text{(A1-g)}$$

$$x^n_{h,t} = (P_{h,t})^{\frac{1}{\beta}}(p^n_t)^{-\frac{1}{\beta}}(h^n_t)(N_{h,t})^{\frac{1-\beta}{\beta}}. \quad \text{(A1-h)}$$

When offshoring takes place in equilibrium (i.e., $o^s_t > 0$), the marginal productivity of domestic unskilled labor must be proportional to the marginal productivity of foreign unskilled labor subject to the offshoring cost δ; therefore, we have $\delta w^n_{l,t} = w^s_{l,t}$. Using this condition along with the above first-order conditions, we obtain

$$\frac{p^n_t}{p^s_t} = \delta^{\frac{\beta}{1-\beta}}. \quad \text{(A2)}$$

Because the final-goods sector is perfectly competitive, profit maximization implies

$$\frac{P_{h,t}}{P_{l,t}} = \frac{1-\gamma}{\gamma}\left(\frac{Y^n_{h,t}+Y^s_{h,t}}{Y^n_{l,t}+Y^s_{l,t}}\right)^{-\frac{1}{\varepsilon}}. \quad \text{(A3)}$$

The production functions (7)-(10) can be re-expressed as

$$Y^s_{l,t} = \frac{l^s_t}{1-\beta}(P_{l,t})^{\frac{1-\beta}{\beta}}(N_{l,t})^{\frac{1}{\beta}}(p^s_t)^{-\frac{1-\beta}{\beta}}, \quad \text{(A4-a)}$$

$$Y^n_{l,t} = \frac{l^n_t+\delta o^s_t}{1-\beta}(P_{l,t})^{\frac{1-\beta}{\beta}}(N_{l,t})^{\frac{1}{\beta}}(p^n_t)^{-\frac{1-\beta}{\beta}}, \quad \text{(A4-b)}$$

$$Y^s_{h,t} = \frac{h^s_t}{1-\beta}(P_{h,t})^{\frac{1-\beta}{\beta}}(N_{h,t})^{\frac{1}{\beta}}(p^s_t)^{-\frac{1-\beta}{\beta}}, \quad \text{(A4-c)}$$

$$Y^n_{h,t} = \frac{h^n_t}{1-\beta}(P_{h,t})^{\frac{1-\beta}{\beta}}(N_{h,t})^{\frac{1}{\beta}}(p^n_t)^{-\frac{1-\beta}{\beta}}. \quad \text{(A4-d)}$$

Taking into account (A4) together with the labor-market-clearing conditions, (A2) and (A3) imply

$$\frac{P_{h,t}}{P_{l,t}} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\beta\varepsilon}{1+\beta(\varepsilon-1)}} \left(\frac{N_{h,t}}{N_{l,t}}\right)^{-\frac{1}{1+\beta(\varepsilon-1)}} \left(\frac{H^n+\delta H^s}{L^n+\delta L^s}\right)^{-\frac{\beta}{1+\beta(\varepsilon-1)}}, \tag{A5}$$

which serves as the first condition that we will use to solve for the steady-state equilibrium values of $\{N_{h,t}/N_{l,t}, P_{h,t}/P_{l,t}, o_t^s\}$. The other two conditions can be derived as follows.

The R&D conditions imply that $V_{z,t} = \mu$ and thus $\dot{V}_{z,t} = 0$ when $\dot{N}_{z,t} > 0$ for $z \in \{l, h\}$. Using (19), we obtain

$$r_t = \frac{\pi_{z,t}^n + \pi_{z,t}^s}{\mu}. \tag{A6}$$

The equilibrium bias is $V_{h,t}/V_{l,t} = (\pi_{h,t}^n + \pi_{h,t}^s)/(\pi_{l,t}^n + \pi_{l,t}^s) = 1$. Also using (13), (16), (A1) and (A2), we derive

$$\frac{P_{h,t}}{P_{l,t}} = \left(\frac{N_{h,t}}{N_{l,t}}\right)^{-(1-\beta)} \left(\frac{\frac{\phi}{\beta}\delta H^s + H^n}{\frac{\phi}{\beta}\delta(L^s - o_t^s) + L^n + \delta o_t^s}\right)^{-\beta}. \tag{A7}$$

Finally, the capital-market conditions give rise to[32]

$$\frac{P_{h,t}}{P_{l,t}} = \left(\frac{N_{h,t}}{N_{l,t}}\right)^{-1} \left(\frac{\left(\delta^{1/(1-\beta)}\frac{K^n}{K^s} + \delta\right) o_t^s + L^n - \delta^{1/(1-\beta)} L^s \frac{K^n}{K^s}}{\delta^{1/(1-\beta)} H^s \frac{K^n}{K^s} - H^n}\right)^{\beta}, \tag{A8}$$

noting (A1) and (A2). The steady-state equilibrium values of $\{N_{h,t}/N_{l,t}, P_{h,t}/P_{l,t}, o_t^s\}$ are determined by (A5), (A7) and (A8) along with the resource constraint $o_t^s \in [0, L^s]$.

Proof of Proposition 1 . Using (A7), one can show that if the following inequality holds,

$$\frac{P_{h,t}}{P_{l,t}} > \left(\frac{N_{h,t}}{N_{l,t}}\right)^{-(1-\beta)} \left(\frac{\frac{\phi}{\beta}\delta H^s + H^n}{\frac{\phi}{\beta}\delta(L^s - o^s) + L^n + \delta o^s}\right)^{-\beta}, \tag{A9}$$

then $V_{h,t} = \left(\pi_{h,t}^n + \pi_{h,t}^s\right)/r_t = \mu$ and $V_{l,t} < \mu$, which imply that $\dot{N}_{h,t} > 0$ and $\dot{N}_{l,t} = 0$. Combined with (A5), this inequality can be rewritten as

$$\frac{N_{h,t}}{N_{l,t}} < \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{H^n+\delta H^s}{L^n+\delta L^s}\right)^{-\frac{1}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{\frac{\phi}{\beta}\delta H^s + H^n}{\frac{\phi}{\beta}\delta(L^s-o^s)+L^n+\delta o^s}\right)^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}}, \tag{A10}$$

where $o^s \in [0, L^s]$ is given by its steady-state equilibrium value. Thus, following Acemoglu and Zilibotti (2001), we have shown that there is only one type of innovation off the steady

[32] To derive (A8), we use

$$\frac{K^s}{K^n} = \frac{x_{h,t}^s N_{h,t} + x_{l,t}^s N_{l,t}}{x_{h,t}^n N_{h,t} + x_{l,t}^n N_{l,t}} = \frac{N_{l,t}\ (P_{l,t})^{\frac{1}{\beta}} (p_t^s)^{-\frac{1}{\beta}} (l_t^s)(N_{l,t})^{\frac{1-\beta}{\beta}} + N_{h,t}\ (P_{h,t})^{\frac{1}{\beta}} (p_t^s)^{-\frac{1}{\beta}} (H^s)(N_{h,t})^{\frac{1-\beta}{\beta}}}{N_{l,t}\ (P_{l,t})^{\frac{1}{\beta}} (p_t^n)^{-\frac{1}{\beta}} (L^n + \delta \mathbf{l}_t^s)(N_{l,t})^{\frac{1-\beta}{\beta}} + N_{h,t}\ (P_{h,t})^{\frac{1}{\beta}} (p_t^n)^{-\frac{1}{\beta}} (H^n)(N_{h,t})^{\frac{1-\beta}{\beta}}}.$$

state, and the economy monotonically reaches the balanced growth path in finite time. On the balanced growth path, $N_{h,t}$ and $N_{l,t}$ grow at the same rate g. The same proof can be applied to an economy starting from $N_{h,t}/N_{l,t}$ larger than the right-hand side of (A10).

Next we show that the steady-state equilibrium growth rate $g = \dot{N}_{h,t}/N_{h,t} = \dot{N}_{l,t}/N_{l,t} = \dot{C}_t^n/C_t^n = \dot{C}_t^s/C_t^s$ is constant and positive. By the Euler equation (3), the steady-state growth rate is given by $g = r - \rho$. From (A6),

$$r = \frac{\pi_z^n + \pi_z^s}{\mu} = \frac{\beta p_z^n x_z^n + \phi p_z^s x_z^s}{\mu},$$

where the second equality uses (13) and (16). Substituting (A1-e) and (A1-f) into this,

$$r = \left(\frac{P_l N_l}{p^s}\right)^{\frac{1-\beta}{\beta}} (P_l) \frac{\frac{\beta}{\delta}(L^n + \delta o^s) + \phi(L^s - o^s)}{\mu},$$

which uses $p^n = p^s \delta^{\beta/(1-\beta)}$ from (A2) and the resource constraints $l^s = L^s - o^s$ and $l^n = L^n$. By substituting (A8) for $P_l N_l$, (B1-a) for P_l, and (B2) for p^s, the steady-state interest rate becomes[33]

$$r = \frac{\beta}{\delta\mu} \frac{\left(\delta^{1/(1-\beta)} H^s K^n - H^n K^s\right)^{1-\beta} \left[L^n + \frac{\phi}{\beta}\delta L^s + \left(1 - \frac{\phi}{\beta}\right)\delta o^s\right]}{\left[H^s L^n - H^n L^s + (H^n + \delta H^s) o^s\right]^{1-\beta}} \left[\gamma^\varepsilon + (1-\gamma)^\varepsilon \left(\frac{P_h}{P_l}\right)^{1-\varepsilon}\right]^{\frac{1}{\varepsilon - 1}}, \tag{A11}$$

where P_h/P_l and o^s are constant and unique in the steady-state equilibrium as we will show below. Therefore, the steady-state equilibrium growth rate $g = r - \rho$ must also be constant. Furthermore, we can ensure that $g > 0$ by assuming a sufficiently small ρ or μ.

In the rest of this proof, we consider the existence and uniqueness of the equilibrium. Using (A5), (A7) and (A8), we derive the following two conditions that can be used to solve for the steady-state equilibrium values of $\{N_h/N_l, o^s\}$.

$$\begin{aligned} \frac{N_h}{N_l} &= \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s}\right)^{-\frac{1}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{\frac{\phi}{\beta}\delta H^s + H^n}{\frac{\phi}{\beta}\delta(L^s - o^s) + L^n + \delta o^s}\right)^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}} \\ &\equiv F(o^s), \end{aligned} \tag{A12}$$

$$\begin{aligned} \frac{N_h}{N_l} &= \left(\frac{\gamma}{1-\gamma}\right)^{\frac{\varepsilon}{\varepsilon-1}} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s}\right)^{\frac{1}{\varepsilon-1}} \left(\frac{\left(\delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} + \delta\right) o^s + L^n - \delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} L^s}{\delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} H^s - H^n}\right)^{\frac{1+\beta(\varepsilon-1)}{(\varepsilon-1)}} \\ &\equiv G(o^s). \end{aligned} \tag{A13}$$

$F(o^s)$ is (weakly) decreasing in o^s because $\phi \leq \beta$. As for $G(o^s)$, it depends on the value of δ; specifically, there are three parameter spaces to consider: (a) $\delta > [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, (b)

[33] In an unpublished appendix (see Appendix C), we show that the interest rate r is always positive.

$[(L^n/L^s)(K^s/K^n)]^{1-\beta} < \delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$,[34] and (c) $\delta \leq [(L^n/L^s)(K^s/K^n)]^{1-\beta}$. Recall that $[(H^n/H^s)(K^s/K^n)]^{1-\beta} > [(L^n/L^s)(K^s/K^n)]^{1-\beta}$ because $H^n/L^n > H^s/L^s$.

Case (a): If $\delta > [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, then $G(o^s)$ is strictly increasing in o^s guaranteeing the uniqueness of the equilibrium (if it exists). To establish its existence, we need to ensure that $F(o^s)$ and $G(o^s)$ cross within $o^s \in [0, L^s]$. First, $F(0) > G(0)$ because $F(0) > 0$ and $G(0) < 0$ as a result of $L^n - \delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} L^s < 0$. Second, $F(L^s) < G(L^s)$ would also hold if and only if γ is sufficiently large.

Case (b): If $[(L^n/L^s)(K^s/K^n)]^{1-\beta} < \delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, then $G(o^s)$ would be decreasing in o^s. Furthermore, $G(o^s)$ would be positive if and only if $o^s < \left(\frac{\delta^{1/1-\beta} K^n/K^s - L^n/L^s}{\delta^{1/1-\beta} K^n/K^s + \delta}\right) L^s$. As $o^s \to \left(\frac{\delta^{1/1-\beta} K^n/K^s - L^n/L^s}{\delta^{1/1-\beta} K^n/K^s + \delta}\right) L^s$, $G(o^s) = 0 < F(o^s)$. Finally, $G(0) > F(0)$ would also hold if and only if γ is sufficiently large; in this case, it can be shown that $G(o^s)$ crosses $F(o^s)$ exactly once from above.[35]

Case (c): If $\delta \leq [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, then $\delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$ implying that $\delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} H^s - H^n < 0$ in $G(o^s)$. In this case, $G(o^s)$ must be nonpositive for $o^s \in [0, L^s]$ because $L^n - \delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} L^s \geq 0$; therefore, an offshoring equilibrium does not exist. ■

Proof of Propositions 2, 3 and 4. By eliminating o^s from (A12) and (A13), we derive the following condition that implicitly determines N_h/N_l.

$$\left(\frac{H^n}{H^s} + \frac{\delta\phi}{\beta}\right)\left(\frac{N_h}{N_l}\right)^{-\frac{1-(1-\beta)(\varepsilon-1)}{1+\beta(\varepsilon-1)}} = \delta(1 - \tfrac{\phi}{\beta}) \frac{\delta^{\frac{1}{1-\beta}} K^n/K^s - H^n/H^s}{\delta^{\frac{1}{1-\beta}} K^n/K^s + \delta} \left(\frac{N_h}{N_l}\right)^{\frac{\varepsilon-1}{1+\beta(\varepsilon-1)}} + \left(\frac{L^n+\delta L^s}{H^s}\right)^{\frac{\beta(\varepsilon-1)}{1+\beta(\varepsilon-1)}} \frac{\delta^{\frac{1}{1-\beta}} K^n/K^s + \delta(\phi/\beta)}{\delta^{\frac{1}{1-\beta}} K^n/K^s + \delta} \left(\frac{\gamma}{1-\gamma}\right)^{\frac{\varepsilon}{1+\beta(\varepsilon-1)}} \left(\frac{H^n}{H^s} + \delta\right)^{\frac{1}{1+\beta(\varepsilon-1)}}, \tag{A14}$$

Once again, we need to consider the two parameter spaces under which offshoring exists: (a) $\delta > [(H^n/H^s)(K^s/K^n)]^{1-\beta}$ and (b) $[(L^n/L^s)(K^s/K^n)]^{1-\beta} < \delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$.

Case (a): If $\delta > [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, then the right-hand side of (A14) is increasing in N_h/N_l, whereas the left-hand side of (A14) is always decreasing in N_h/N_l. In this case, a decrease in L^s shifts down the right-hand side and gives rise to a larger equilibrium value of N_h/N_l. An increase in K^s shifts down the right-hand side (because $\phi < \beta$), which gives rise to a larger equilibrium value of N_h/N_l.

Case (b): If $[(L^n/L^s)(K^s/K^n)]^{1-\beta} < \delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, then the right-hand side of (A14) is also decreasing in N_h/N_l and crosses the left-hand side exactly once from below in the feasible space.[36] In this case, a decrease in L^s shifts down the right-hand side and also gives rise to a larger equilibrium value of N_h/N_l. An increase in K^s shifts down the right-hand side, which gives rise to a larger equilibrium value of N_h/N_l. When $\phi = \beta$, (A14) does not depend on K^s. We summarize these results in the following Lemma.

[34] It can be shown that if $\delta = [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, then $o^s = \left(\frac{\delta^{1/1-\beta} K^n/K^s - L^n/L^s}{\delta^{1/1-\beta} K^n/K^s + \delta}\right) L^s$ instead of being determined by (A13).

[35] On the other hand, if $G(0) < F(0)$, then the model may feature multiple equilibria, which we rule out by imposing a sufficiently large γ to ensure that $G(0) > F(0)$ holds.

[36] In fact, after it crosses the left-hand side from below, the right-hand side crosses the left-hand side once again from above. However, it can be shown from (A12) and (A13) that the second intersection (with a higher value of N_h/N_l) is infeasible because it implies $o^s < 0$.

Lemma 1: *If $\delta > [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, then a decrease in L^s or an increase in K^s would lead to an increase in N_h/N_l for $\phi \in [0, \beta)$. When $\phi = \beta$, an increase in K^s has no effect on N_h/N_l, whereas a decrease in L^s still leads to an increase in N_h/N_l.*

No-offshoring equilibrium: Now we consider the case of $\delta \leq [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, under which offshoring does not take place in equilibrium (i.e., $o^s = 0$). In this case, we derive three equilibrium conditions,

$$\frac{P_h}{P_l} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\beta\varepsilon}{1+\beta(\varepsilon-1)}} \left(\frac{N_h}{N_l}\right)^{-\frac{1}{1+\beta(\varepsilon-1)}} \left[\frac{(p^s)^{-(1-\beta)/\beta} H^s + (p^n)^{-(1-\beta)/\beta} H^n}{(p^s)^{-(1-\beta)/\beta} L^s + (p^n)^{-(1-\beta)/\beta} L^n}\right]^{-\frac{\beta}{1+\beta(\varepsilon-1)}}, \tag{A15}$$

$$\frac{P_h}{P_l} = \left(\frac{N_h}{N_l}\right)^{-(1-\beta)} \left[\frac{(\phi/\beta)(p^s)^{-(1-\beta)/\beta} H^s + (p^n)^{-(1-\beta)/\beta} H^n}{(\phi/\beta)(p^s)^{-(1-\beta)/\beta} L^s + (p^n)^{-(1-\beta)/\beta} L^n}\right]^{-\beta}, \tag{A16}$$

and

$$\left(\frac{p^n}{p^s}\right)^{1/\beta} = \frac{K^s}{K^n}\left[\frac{L^n + (P_h/P_l)^{1/\beta}(N_h/N_l)^{1/\beta} H^n}{L^s + (P_h/P_l)^{1/\beta}(N_h/N_l)^{1/\beta} H^s}\right], \tag{A17}$$

which correspond to (A5), (A7) and (A8), respectively.

Zero patent protection in the South: Suppose $\phi = 0$. Substituting (A16) and (A17) into (A15), we obtain

$$\frac{N_h}{N_l} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{H^n}{L^n}\right)^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}} \left[\frac{L^s\left(\frac{K^s}{K^n}\left(1+\frac{N_h}{N_l}\right)\right)^{1-\beta} + L^n\left(\frac{L^s}{L^n}+\frac{H^s}{H^n}\frac{N_h}{N_l}\right)^{1-\beta}}{H^s\left(\frac{K^s}{K^n}\left(1+\frac{N_h}{N_l}\right)\right)^{1-\beta} + H^n\left(\frac{L^s}{L^n}+\frac{H^s}{H^n}\frac{N_h}{N_l}\right)^{1-\beta}}\right]^{\frac{1}{1-(1-\beta)(\varepsilon-1)}}. \tag{A18}$$

Because $H^n/L^n > H^s/L^s$, the right-hand side is monotonically increasing and concave in N_h/N_l, which ensures the unique existence of a steady-state equilibrium. One can show that the right-hand side is increasing in L^s and K^s, so we can prove the following lemma by means of a usual graphical analysis.

Lemma 2: *If $\delta \leq [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, then there would be no outsourcing in equilibrium (i.e., $o^s = 0$). In this case, if $\phi = 0$, then an increase in K^s would lead to an increase in N_h/N_l whereas a decrease in L^s would lead to a decrease in N_h/N_l.*

Complete patent protection in the South: Suppose $\phi = \beta$. Using (A15)–(A17), we obtain

$$\left(\frac{N_h}{N_l}\right)^{\frac{\varepsilon-2}{\beta(\varepsilon-1)}} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{\beta(\varepsilon-1)}} \frac{L^s\left(\frac{H^n - L^n\left(\frac{\gamma}{1-\gamma}\right)^{\frac{\varepsilon}{\beta(\varepsilon-1)}}(N_h/N_l)^{\frac{1-(1-\beta)(\varepsilon-1)}{\beta(\varepsilon-1)}}}{L^s\left(\frac{\gamma}{1-\gamma}\right)^{\frac{\varepsilon}{\beta(\varepsilon-1)}}(N_h/N_l)^{\frac{1-(1-\beta)(\varepsilon-1)}{\beta(\varepsilon-1)}} - H^s}\right)^{\frac{1}{1-\beta}} - L^n\frac{K^s}{K^n}}{H^n\frac{K^s}{K^n} - H^s\left(\frac{H^n - L^n\left(\frac{\gamma}{1-\gamma}\right)^{\frac{\varepsilon}{\beta(\varepsilon-1)}}(N_h/N_l)^{\frac{1-(1-\beta)(\varepsilon-1)}{\beta(\varepsilon-1)}}}{L^s\left(\frac{\gamma}{1-\gamma}\right)^{\frac{\varepsilon}{\beta(\varepsilon-1)}}(N_h/N_l)^{\frac{1-(1-\beta)(\varepsilon-1)}{\beta(\varepsilon-1)}} - H^s}\right)^{\frac{1}{1-\beta}}}. \tag{A19}$$

The right-hand side is decreasing in $N_{h,t}/N_{l,t}$, and it can be shown to be decreasing in L^s and K^s. When $\varepsilon \geq 2$, where the left-hand side is increasing in $N_{h,t}/N_{l,t}$, (A19) uniquely determines $N_{h,t}/N_{l,t}$, which is decreasing in L^s and K^s. When $\varepsilon < 2$, the left-hand side of (A19) is also decreasing, which gives rise to a potential possibility of multiple solutions.

However, if we focus on a unique equilibrium case by some sufficient conditions,[37] it is easy to verify that $N_{h,t}/N_{l,t}$ is also decreasing in L^s and K^s by means of a graphical analysis.

Lemma 3: *If $\delta < [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, then there would be no outsourcing in equilibrium (i.e., $o^s = 0$). In this case, if $\phi = \beta$, then an increase in K^s would lead to a decrease in N_h/N_l where as a decrease in L^s would lead to an increase in N_h/N_l.*

Finally, note that Lemmata 1, 2 and 3 prove Propositions 2, 3 and 4. ■

[37] One can show that these conditions include a sufficiently large β and sufficiently small H^n/H^s, L^s/L^n and K^n/K^s.

Appendix B

In this appendix, we provide the equilibrium expressions for calibrating the model: (a) offshoring as a share of GDP $w_l^s o^s/(P_l Y_l^s + P_h Y_h^s)$, (b) the relative GDP $(P_l Y_l^s + P_h Y_h^s)/(P_h Y_h^n + P_l Y_l^n)$, and (c) the skill premium $w_h^n/w_l^n = w_h^s/w_l^s$. Note that (5) implies

$$P_l = \left[\gamma^\varepsilon + (1-\gamma)^\varepsilon \left(\frac{P_h}{P_l}\right)^{1-\varepsilon}\right]^{\frac{1}{\varepsilon-1}}, \tag{B1-a}$$

$$P_h = \left[\gamma^\varepsilon \left(\frac{P_h}{P_l}\right)^{-(1-\varepsilon)} + (1-\gamma)^\varepsilon\right]^{\frac{1}{\varepsilon-1}}. \tag{B1-b}$$

Then, using the capital-market condition for s and (A1), we obtain

$$p^s = (K^s)^{-\beta}\left[(P_l N_l)^{1/\beta} l^s + (P_h N_h)^{1/\beta} H^s\right]^\beta. \tag{B2}$$

As for $P_l Y_l^n + P_h Y_h^n$, we use (A4) to obtain

$$P_h Y_h^n + P_l Y_l^n = \frac{\delta^{\frac{\beta}{1-\beta}} K^n P_l N_l}{1-\beta}\left[\frac{H^s L^n - H^n L^s + (H^n + \delta H^s)\, o^s}{\delta^{\frac{1}{1-\beta}} K^n H^s - K^s H^n}\right]^\beta, \tag{B3}$$

noting (A2) and (A8). Using (A1), we obtain

$$w_l^s = \frac{\beta P_l N_l}{1-\beta}\left(\frac{P_l N_l}{p^s}\right)^{\frac{1-\beta}{\beta}}. \tag{B4}$$

Using (A4), (A8) and (B2), we obtain

$$P_l Y_l^s + P_h Y_h^s = \frac{K^s P_l N_l}{1-\beta}\left[\frac{H^s L^n - H^n L^s + (H^n + \delta H^s)\, o^s}{\delta^{\frac{1}{1-\beta}} K^n H^s - K^s H^n}\right]^\beta. \tag{B5}$$

Using (B2), (B4) and (B5), we obtain

$$\frac{w_l^s o^s}{P_l Y_l^s + P_h Y_h^s} = \frac{\beta\left(\delta^{\frac{1}{1-\beta}} K^n H^s - K^s H^n\right) o^s}{K^s\left[H^s L^n - H^n L^s + (H^n + \delta H^s)\, o^s\right]}. \tag{B6}$$

Using (B3) and (B5), we obtain

$$\frac{P_l Y_l^s + P_h Y_h^s}{P_h Y_h^n + P_l Y_l^n} = \frac{K^s}{\delta^{\frac{\beta}{1-\beta}} K^n}. \tag{B7}$$

Finally, using (A1), we obtain

$$\frac{w_h^n}{w_l^n} = \frac{w_h^s}{w_l^s} = \left(\frac{P_h}{P_l}\frac{N_h}{N_l}\right)^{\frac{1}{\beta}}. \tag{B8}$$

By (A5) and (A7),

$$\left(\frac{P_h}{P_l}\frac{N_h}{N_l}\right)^{\frac{1}{\beta}} = \left[\left(\frac{1-\gamma}{\gamma}\right)^{\varepsilon/(\varepsilon-1)}\left(\frac{H^n+\delta H^s}{L^n+\delta L^s}\right)^{-1/(\varepsilon-1)}\left(\frac{H^n + \frac{\phi}{\beta}\delta H^s}{L^n + \frac{\phi}{\beta}\delta L^s + \delta o^s(\beta-\phi)/\beta}\right)\right]^{\frac{\varepsilon-1}{1-(1-\beta)(\varepsilon-1)}}. \tag{B9}$$

Then, (B8) and (B9) imply (28).

Appendix C (not for publication)

In this appendix, we will prove that the interest rate r is positive in all three cases.

Case (a): $\delta > [(H^n/H^s)(K^s/K^n)]^{1-\beta}$. In order for the right-hand side of (A13) to be positive, o^s has a lower bound such that

$$o^s > \frac{\delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} L^s - L^n}{\delta^{\frac{1}{1-\beta}} \frac{K^n}{K^s} + \delta} \equiv \tilde{o}. \tag{C1}$$

Given $\delta > [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, the numerator in the right-hand side of (A11) is positive. Thus, from (A11), $r > 0$ holds if and only if the denominator is also positive, i.e.,

$$o^s > \frac{H^n L^s - H^s L^n}{H^n + \delta H^s}. \tag{C2}$$

This always holds because the right-hand side of (C2) is less than $\tilde{o}$ (i.e., the lower bound of o^s) so long as $\delta > [(H^n/H^s)(K^s/K^n)]^{1-\beta}$.

Case (b): $[(L^n/L^s)(K^s/K^n)]^{1-\beta} < \delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$. In order for the right-hand side of (A13) to be positive, o^s has an upper bound such as $o^s < \tilde{o}$.[38] Given $\delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, the numerator in the right-hand side of (A11) is negative. Thus, from (A11), $r > 0$ holds if and only if the denominator is also negative, i.e.,

$$o^s < \frac{H^n L^s - H^s L^n}{H^n + \delta H^s}. \tag{C3}$$

This always holds because the right-hand side of (C3) is greater than the upper bound $\tilde{o}$ so long as $\delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$.

Case (c): $\delta < [(L^n/L^s)(K^s/K^n)]^{1-\beta}$. By substituting $o^s = 0$ into (A11), $r > 0$ holds, noting $H^n K^s - \delta^{1/(1-\beta)} H^s K^n > 0$ and $H^n L^s - H^s L^n > 0$.

[38] The threshold $\tilde{o}$ becomes an upper bound in case (b), whereas it is a lower bound in case (a).

Appendix D (not for publication)

We will consider how the wage premium is determined in the *no-offshoring* case (i.e., $o^s = 0$). By eliminating P_h/P_l, (A15) and (A16) imply

$$\frac{N_h}{N_l} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}} \left[\frac{H^n+(\phi/\beta)H^s(p^n/p^s)^{(1-\beta)/\beta}}{L^n+(\phi/\beta)L^s(p^n/p^s)^{(1-\beta)/\beta}}\right]^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}} \left[\frac{H^n+H^s(p^n/p^s)^{(1-\beta)/\beta}}{L^n+L^s(p^n/p^s)^{(1-\beta)/\beta}}\right]^{-\frac{1}{1-(1-\beta)(\varepsilon-1)}}. \tag{D1}$$

Equations (A16) and (A17) imply[39]

$$\frac{N_h}{N_l} = \left[\frac{H^n+(\phi/\beta)H^s(p^n/p^s)^{(1-\beta)/\beta}}{L^n+(\phi/\beta)L^s(p^n/p^s)^{(1-\beta)/\beta}}\right]\left[\frac{L^s(K^n/K^s)(p^n/p^s)^{1/\beta}-L^n}{H^n-H^s(K^n/K^s)(p^n/p^s)^{1/\beta}}\right]. \tag{D2}$$

The equation system consisting of (D1) and (D2) determine N_h/N_l and p^n/p^s in equilibrium. Finally, one can show from (A1) and (A17) that the skill premia satisfy

$$\frac{w_h^n}{w_l^n} = \frac{w_h^s}{w_l^s} = \left(\frac{P_h}{P_l}\frac{N_h}{N_l}\right)^{1/\beta} = \frac{L^s(K^n/K^s)(p^n/p^s)^{1/\beta}-L^n}{H^n-H^s(K^n/K^s)(p^n/p^s)^{1/\beta}}. \tag{D3}$$

[39] Note that (A17) can be rewritten as

$$\left(\frac{P_h}{P_l}\frac{N_h}{N_l}\right)^{1/\beta} = \frac{L^s(K^n/K^s)\,(p^n/p^s)^{1/\beta}-L^n}{H^n-H^s(K^n/K^s)\,(p^n/p^s)^{1/\beta}}.$$