From China with love: Effects of the Chinese economy on skill-biased technical change in the US

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Abstract

In this study, we analyze the effects of labor shortage 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 if offshoring is present (absent) in equilibrium, then a decrease (an increase) in unskilled labor in the South would lead to skill-biased technical change in the North. This finding highlights the different implications of offshoring and conventional trade on innovation. Furthermore, we find that an increase in the Southern stock of capital reduces offshoring and also leads to skill-biased technical change. Therefore, rapid capital accumulation and labor shortage in China could lead to a rising skill premium in the US. Calibrating the model to China-US data, we find that a 1% decrease in unskilled labor (1% increase in capital) in China leads to a 0.8% (0.6%) increase in the skill premium in the US under a moderate elasticity of substitution between skill-intensive and labor-intensive goods.

JEL classification: O14, O33, J31, F16
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1 Introduction

After three decades of economic development, China is now facing a shortage of workers, especially among coastal cities. "According to a director of the Chinese Academy of Social Sciences, China's coastal cities are short an estimated 10 million workers."[1] As a result of this shortage of workers in China, wages have been rising rapidly. For example, it is not uncommon for manufacturing plants in China to experience rising wages of 20% per year.[2] Given this rapidly rising wages, China is becoming a less attractive place for the offshoring of manufacturing activities. A recent article of *The Economist* documents a reversing trend of production offshoring from developed economies to China;[3] 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 reversing trend is due to changes in the manufacturing process in developed economies such as the digitization of manufacturing;[4] 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.

In this study, we analyze the effects of labor shortage in China on the direction of innovation in the US by incorporating production offshoring into a North-South model of directed technical change based on Acemoglu (1998, 2002, 2003), Acemoglu and Zilibotti (2001) and Acemoglu *et al.* (2012). 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 improves incentives of innovation for labor-intensive goods. On the other hand, when offshoring is present in equilibrium, a reduction in the supply of unskilled labor in the South causes also a market size effect that improves incentives of innovation for skill-intensive goods. This finding highlights the different implications of offshoring and conventional trade on the direction of technological progress.

The above theoretical result is consistent with the following stylized facts. When China first opened up its economy for international trade in the 1980's, there was essentially no offshoring to the economy. Together with a low level of patent protection in China at that time,[5] the opening of the Chinese economy implies a massive increase in the supply of unskilled labor in the world causing predominantly a price effect that improves incentives of

[1] Forbes, "In Coastal China, A Labor Shortage", December 20, 2011.

[2] The Economist, "The End of Cheap China", March 10, 2012.

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

[4] 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."

[5] 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.

innovation directed to the relatively scarce factor, i.e., skilled labors.[6] After the mid 1990's, the amount of offshoring to China started to increase rapidly. Together with an increased level of patent protection in China,[7] the recent shortage of unskilled labor in China causes mainly a market size effect that improves incentives of innovation directed to the now relatively abundant factor, i.e., skilled labors.[8]

Another stylized fact of the Chinese economy 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 would reduce offshoring. Intuitively, a larger stock of capital in China increases the wage rates of Chinese workers rendering offshoring to China less attractive. As a result, a larger stock of capital in the South also leads to skill-biased technical change in the North. Therefore, both the stylized facts of rapid capital accumulation and labor shortage in China could 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 stock in the South would raise the skill premium in the North. The magnitude of the changes depends on the elasticity of substitution between skill-intensive and labor-intensive goods. We find that a 1% decrease in the supply of unskilled labor in China leads to a 0.8% (3.7%) increase in the skill premium in the US when the elasticity of substitution is 2.2 (2.4). Furthermore, a 1% increase in the capital stock in China leads to a 0.6% (2.0%) increase in the skill premium in the US when the elasticity of substitution is 2.2 (2.4).

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.[9] Acemoglu (1998, 2002) analyzes skill-biased technical change and the rising skill premium in the US, whereas Acemoglu (2003), Acemoglu and Zilibotti (2001) and 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 on the effects of offshoring on the direction of technological progress.

A recent study by Acemoglu *et al.* (2012) also analyzes the effects of offshoring on skill-biased technical change. In addition to some differences in modelling details, our study differs from their interesting analysis in a number of important dimensions. First, Acemoglu *et al.* (2012) analyze the effects of an offshoring-cost parameter on skill-biased technical change,

[6] From 1980 to 1995, the share of population in China with at least completion of secondary education was on average 13.7%; see the Barro-Lee dataset on educational attainment.

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

[8] From 2000 to 2010, the share of population in China with at least completion of secondary education was on average 39.5%; see the Barro-Lee dataset.

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

whereas we analyze the effects of labor shortage and capital accumulation on skill-biased technical change through offshoring. Second, we calibrate our model to China-US data and find that in the recent episode of trade in China, the degree of offshoring is sufficiently high such that a decrease in unskilled labor supply in China would lead to skill-biased technical change and a rising skill premium in the US. 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 Southern labor supply and capital stock on the direction of Northern innovation. The final section concludes.

2 A North-South model of directed technical change

In this section, we consider a North-South 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. Final goods are produced using skill-intensive and labor-intensive goods, which are freely traded across countries, but capital and labors are immobile across countries. To consider production offshoring, we follow Grossman and Rossi-Hansberg (2008) to assume that offshoring involves a variable cost.

2.1 Households

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

$$U = \int_{0}^{\infty} e^{-\rho t} \ln C_t^n dt, \tag{1}$$

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.

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

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.[10] 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,[11] and q_t^n is the rental price of capital. From

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

[11] We differ from Acemoglu (2002) by assuming that intermediate goods are produced using capital instead of final goods. For simplicity, we consider an inelastic supply of capital, which also allows us to analyze the comparative statics of the capital stock.

standard dynamic optimization, the familiar Euler equation is

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

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 for 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.

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 $\beta > (\varepsilon-2)/(\varepsilon-1)$ 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 $x_{l,t}^n(i)$ 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

[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 $\varepsilon > 1$.

of $N_{l,t}$ on the production of $Y^s_{l,t}$ in order to ensure a balanced growth path along which $N_{l,t}$ and $Y^s_{l,t}$ grow at the same rate; see also Acemoglu *et al.* (2012).[14]

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

$$Y^n_{l,t} = \frac{(l^n_t + \delta \mathbf{l}^s_t)^\beta}{1-\beta} \left(\int_0^{N_{l,t}} [x^n_{l,t}(i)]^{1-\beta} di \right) (N_{l,t})^{1-\beta}, \tag{8}$$

where $\mathbf{l}^s_t$ is the amount of Southern unskilled labor employed by Northern firms to produce $Y^n_{l,t}$ 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 $\{Y^n_{l,t}, Y^s_{l,t}, Y^n_{h,t}, Y^s_{h,t}\}$. 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 $l^s_t + \mathbf{l}^s_t = L^s$, whereas the resource constraint for Northern unskilled labor is $l^n_t = L^n$.

2.4 Skill-intensive goods

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

$$Y^s_{h,t} = \frac{(h^s_t)^\beta}{1-\beta} \left(\int_0^{N_{h,t}} [x^s_{h,t}(j)]^{1-\beta} dj \right) (N_{h,t})^{1-\beta}. \tag{9}$$

h^s_t is the amount of Southern skilled labor employed in the production of $Y^s_{h,t}$. In addition to using labor, the production of $Y^s_{h,t}$ requires differentiated intermediate inputs $x^n_{h,t}(j)$ 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 $Y^s_{h,t}$ in order to ensure a balanced growth path along which $N_{h,t}$ and $Y^s_{h,t}$ grow at the same rate.

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

$$Y^n_{h,t} = \frac{(h^n_t)^\beta}{1-\beta} \left(\int_0^{N_{h,t}} [x^n_{h,t}(j)]^{1-\beta} dj \right) (N_{h,t})^{1-\beta}, \tag{10}$$

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 $h^s_t = H^s$, whereas the resource constraint for Northern skilled labor is $h^n_t = H^n$.

[14] In Acemoglu (2002), this externality is not needed because $x^n_{l,t}(i)$ is produced from final goods, whereas $x^n_{l,t}(i)$ 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.

[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 $\delta_h = 0$.

2.5 Intermediate inputs for labor-intensive goods

In the North, the production function of differentiated intermediate input i for labor-intensive goods is

$$x^n_{l,t}(i) = k^n_{l,t}(i) \tag{11}$$

for $i \in [0, N_{l,t}]$. In other words, one unit of capital produces one unit of intermediate input. Given the capital-rental price q^n_t in the North, the monopolistic producer of differentiated intermediate input i charges a profit-maximizing markup η^n over q^n_t such that

$$p^n_{l,t}(i) = p^n_{l,t} = \eta^n q^n_t, \tag{12}$$

where $\eta^n = 1/(1-\beta) > 1$. Therefore, the amount of profit captured by intermediate input i in the North is

$$\pi^n_{l,t}(i) = (1 - 1/\eta^n)p^n_{l,t}(i)x^n_{l,t}(i) = \beta p^n_{l,t}x^n_{l,t} \tag{13}$$

for $i \in [0, N_{l,t}]$.

In the South, the production function of differentiated intermediate input i for labor-intensive goods is

$$x^s_{l,t}(i) = k^s_{l,t}(i) \tag{14}$$

for $i \in [0, N_{l,t}]$. Given the capital-rental price q^s_t in the South, the monopolistic producer of differentiated intermediate input i charges a markup η^s over q^s_t such that

$$p^s_{l,t}(i) = \eta^s q^s_t. \tag{15}$$

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 $\phi = \beta$ ($\phi = 0$), then patent protection is complete (zero) in the South. The amount of profit captured by intermediate input i in the South is

$$\pi^s_{l,t}(i) = (1 - 1/\eta^s)p^s_{l,t}(i)x^s_{l,t}(i) = \phi p^s_{l,t}x^s_{l,t}. \tag{16}$$

2.6 Intermediate inputs for skill-intensive goods

In the North, the production function of differentiated intermediate input j for skill-intensive goods is

$$x^n_{h,t}(j) = k^n_{h,t}(j) \tag{17}$$

for $j \in [0, N_{h,t}]$. Given the capital-rental price q^n_t in the North, the monopolistic producer of differentiated intermediate input j charges a profit-maximizing markup η^n over q^n_t such that

$$p^n_{h,t}(j) = p^n_{h,t} = \eta^n q^n_t, \tag{18}$$

[17] See also Li (2001), Chu (2011) and Iwaisako and Futagami (2012).

where $\eta^n = 1/(1-\beta) > 1$. Therefore, the amount of profit captured by intermediate input j in the North is

$$\pi^n_{h,t}(j) = (1 - 1/\eta^n)p^n_{h,t}(j)x^n_{h,t}(j) = \beta p^n_{h,t}x^n_{h,t}. \tag{19}$$

Due to symmetry, the resource constraint for capital in the North is $N_{l,t}x^n_{l,t} + N_{h,t}x^n_{h,t} = K^n_{l,t} + K^n_{h,t} = K^n$.

In the South, the production function of differentiated intermediate input j for skill-intensive goods is

$$x^s_{h,t}(j) = k^s_{h,t}(j) \tag{20}$$

for $j \in [0, N_{h,t}]$. Given the capital-rental price q^s_t in the South, the monopolistic producer of differentiated intermediate input j charges a constrained markup η^s over q^s_t such that

$$p^s_{h,t}(j) = p^s_{h,t} = \eta^s q^s_t, \tag{21}$$

where $\eta^s = 1/(1-\phi) \leq \eta^n$. Therefore, the amount of profit captured by intermediate input j in the South is

$$\pi^s_{h,t}(j) = (1 - 1/\eta^s)p^s_{h,t}(j)x^s_{h,t}(j) = \phi p^s_{h,t}x^s_{h,t}. \tag{22}$$

The resource constraint for capital in the South is $N_{l,t}x^s_{l,t} + N_{h,t}x^s_{h,t} = K^s_{l,t} + K^s_{h,t} = K^s$.

2.7 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

$$\dot{N}_{z,t} = R_{z,t}/\mu \tag{23}$$

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

$$(V_{z,t} - \mu)\dot{N}_{z,t} = 0 \tag{24}$$

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

$$r_t = \frac{\pi^n_{z,t} + \pi^s_{z,t} + \dot{V}_{z,t}}{V_{z,t}} \tag{25}$$

for $z \in \{h, l\}$. 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 $\dot{V}_{z,t}$.

[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, patents that are based on a variety invented in the North (South) are not necessarily solely owned by Northern (Southern) households.

2.8 Decentralized equilibrium

The equilibrium is a time path of prices $\{r_t, w_{l,t}^n, w_{l,t}^s, w_{h,t}^n, w_{h,t}^s, q_t^n, q_t^s, P_{l,t}, P_{h,t}, p_{l,t}^n(i), p_{l,t}^s(i), p_{h,t}^n(j), p_{h,t}^s(j)\}$ and a time path of allocations $\{R_{l,t}, R_{h,t}, C_t^n, C_t^s, Y_t, Y_{l,t}^n, Y_{l,t}^s, Y_{h,t}^n, Y_{h,t}^s, x_{l,t}^n(i), x_{l,t}^s(i), x_{h,t}^n(j), x_{h,t}^s(j), l_t^n, l_t^s, \mathbf{l}_t^s, h_t^n, h_t^s\}$. Also, at each instance of time, the followings hold:

- Households maximize utility taking $\{r_t, w_{l,t}^n, w_{h,t}^n, q_t^n, w_{l,t}^s, w_{h,t}^s, q_t^s\}$ 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 $\{Y_{l,t}^n, Y_{l,t}^s\}$ to maximize profit taking the international price $\{P_{l,t}\}$ as given;
- Competitive skill-intensive goods firms in the two countries produce $\{Y_{h,t}^n, Y_{h,t}^s\}$ to maximize profit taking the international price $\{P_{h,t}\}$ as given;
- Monopolistic intermediate-goods firms in the labor-intensive sector produce $\{x_{l,t}^n(i), x_{l,t}^s(i)\}$ and choose $\{p_{l,t}^n(i), p_{l,t}^s(i)\}$ to maximize profit taking prices $\{q_t^n, q_t^s\}$ as given;
- Monopolistic intermediate-goods firms in the skill-intensive sector produce $\{x_{h,t}^n(j), x_{h,t}^s(j)\}$ and choose $\{p_{h,t}^n(j), p_{h,t}^s(j)\}$ to maximize profit taking prices $\{q_t^n, q_t^s\}$ as given;
- R&D firms choose $\{R_{l,t}, R_{h,t}\}$ to maximize profit taking $\{V_{h,t}, V_{l,t}\}$ as given;
- The market-clearing condition for unskilled labor in the two countries holds such that $l_t^n = L^n$ and $l_t^s + \mathbf{l}_t^s = L^s$;
- The market-clearing condition for skilled labor in the two countries holds such that $h_t^n = H^n$ and $h_t^s = H^s$;
- The market-clearing condition for capital in the two countries holds such that $N_{l,t}x_{l,t}^n + N_{h,t}x_{h,t}^n = K^n$ and $N_{l,t}x_{l,t}^s + N_{h,t}x_{h,t}^s = K^s$;
- The market-clearing condition for final goods holds such that $Y_t = R_{l,t} + R_{h,t} + C_t^n + C_t^s$.

2.9 Balanced growth equilibrium

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. On the balanced growth path, the equilibrium features a positive amount of offshoring 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. 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., $\mathbf{l}^s > 0$).*

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.

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 stock K^s on the direction of Northern innovation. In Section 3.1, we analyze a special case of zero patent protection in the South (i.e., $\phi = 0$). In Section 3.2, we analyze another special case of complete patent protection in the South (i.e., $\phi = \beta$). In Section 3.3, we analyze the general case of incomplete patent protection in the South (i.e., $0 < \phi < \beta$).

3.1 Zero patent protection in the South

Here we sketch out the results in the main text and relegate the detailed derivations to Appendix A. We focus on the balanced growth path and omit the time subscript for convenience. From (8) and (10), one can derive the following conditional demand functions for $x_l^n(i)$ and $x_h^n(j)$.

$$x_l^n(i) = \left[\frac{P_l(N_l)^{1-\beta}}{p_l^n(i)}\right]^{1/\beta} (l^n + \delta \mathbf{l}^s), \tag{26}$$

$$x_h^n(j) = \left[\frac{P_h(N_h)^{1-\beta}}{p_h^n(j)}\right]^{1/\beta} h^n. \tag{27}$$

Under the special case of zero patent protection (i.e., $\phi = 0$) in the South, the steady-state version of (25) simplifies to

$$\frac{V_h}{V_l} = \frac{\pi_h^n}{\pi_l^n} = \frac{p_h^n}{p_l^n}\frac{x_h^n}{x_l^n}, \tag{28}$$

where $p_h^n = p_l^n = \eta^n q^n$. Substituting (26) and (27) into (28) yields

$$\frac{V_h}{V_l} = \left(\frac{N_h}{N_l}\right)^{(1-\beta)/\beta} \underbrace{\left(\frac{P_h}{P_l}\right)^{1/\beta}}_{\text{price effect}} \underbrace{\frac{H^n}{L^n + \delta \mathbf{l}^s}}_{\text{market size effect}}. \tag{29}$$

This expression is similar to the one in Acemoglu (2002) except for the terms $\delta \mathbf{l}^s$ and $(N_h/N_l)^{(1-\beta)/\beta}$, which captures the externality effect. A decrease in Southern unskilled labor L^s reduces the offshoring $\mathbf{l}^s$ of labor-intensive goods. Therefore, we obtain the following intuition from (29). When offshoring is absent (i.e., $\mathbf{l}^s = 0$), a reduction in the supply of Southern unskilled labor L^s leads to only 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. However, when offshoring is present (i.e., $\mathbf{l}^s > 0$), a reduction in the supply of Southern unskilled labor L^s leads to also a positive market size effect by increasing $H^n/(L^n + \delta \mathbf{l}^s)$; as a result, V_h/V_l increases causing innovation to be directed towards skill-intensive goods. We summarize these results in Proposition 2.

Proposition 2 *If the equilibrium features a positive amount of offshoring, then a reduction in the supply of Southern unskilled labor L^s would lead to skill-biased technical change (i.e., N_h/N_l increases). If the equilibrium does not feature offshoring, then an increase in the supply of Southern unskilled labor L^s would lead to skill-biased technical change.*

Proof. See Appendix A. ■

This result is consistent with the following stylized facts. First, the opening of the Chinese economy for international trade in the 1980's implies a massive increase in the supply of unskilled labor and causes skilled-biased technical change because there was very little offshoring to China at that time. Second, the substantial amount of offshoring to China in the present implies that the recent shortage of unskilled labor in China would also lead to skill-biased technical change.

From (7) and (8), one can derive the following conditional demand functions for l^s and l^n.

$$w_l^s = \frac{\beta P_l N_l}{1-\beta} \left(\frac{K_l^s}{l^s} \right)^{1-\beta}, \tag{30}$$

$$w_l^n = \frac{\beta P_l N_l}{1-\beta} \left(\frac{K_l^n}{l^n + \delta \mathbf{l}^s} \right)^{1-\beta}, \tag{31}$$

where we have imposed symmetry on $x_l^s(i) = x_l^s = K_l^s/N_l$ and $x_l^n(i) = x_l^n = K_l^n/N_l$. 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 equality $w_l^s = \delta w_l^n$ must hold when offshoring is present (i.e., $\mathbf{l}^s > 0$), we have

$$\left(\frac{K_l^s}{L^s - \mathbf{l}^s} \right)^{1-\beta} = \delta \left(\frac{K_l^n}{L^n + \delta \mathbf{l}^s} \right)^{1-\beta}, \tag{32}$$

where we have used $l^s + \mathbf{l}^s = L^s$ and $l^n = L^n$. Therefore, an increase in K_l^s reduces $\mathbf{l}^s$; intuitively, a larger K_l^s increases the wage rate of Southern unskilled labor rendering offshoring less attractive. This reduction in $\mathbf{l}^s$ triggers a market size effect as shown in (29). As a result, a larger capital stock in the South leads to skill-biased technical change in the North. We summarize this result in Proposition 3.

Proposition 3 *When the equilibrium features offshoring, an increase in Southern capital stock K^s leads to skill-biased technical change (i.e., N_h/N_l increases). When the equilibrium does not feature offshoring, an increase in Southern capital stock K^s also leads to skill-biased technical change.*

Proof. See Appendix A. ■

Although the comparative statics of N_h/N_l with respect to K^s are the same regardless of whether or not the equilibrium features offshoring, the intuition behind the two scenarios is quite different. In the absence of offshoring, the effect of K^s on N_h/N_l operates through the price effect. 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. 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.

3.2 Complete patent protection in the South

In this subsection, we consider complete patent protection in the South (i.e., $\phi = \beta$). In this case, the steady-state ratio of N_h/N_l can be expressed as[20]

$$\frac{N_h}{N_l} = \left[\left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s} \right)^{\beta(\varepsilon-1)} \right]^{\frac{1}{1-(1-\beta)(\varepsilon-1)}}, \tag{33}$$

where $\varepsilon > 1$ and $1 - (1-\beta)(\varepsilon - 1) > 0$ because $\beta > (\varepsilon - 2)/(\varepsilon - 1)$. Equation (33) shows that a decrease in L^s leads to an increase in N_h/N_l as before; however, N_h/N_l is independent of K^s under complete Southern patent protection. Intuitively, although a larger K^s reduces offshoring $\mathbf{l}^s$, any decrease in $\mathbf{l}^s$ 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 $\mathbf{l}^s$ and l^s. Therefore, despite its effect on offshoring $\mathbf{l}^s$, 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 4.

Proposition 4 *Under complete patent protection in the South, a decrease in the supply of Southern unskilled labor L^s leads to skill-biased technical change (i.e., N_h/N_l increases). However, changes in Southern capital stock K^s have no effect on N_h/N_l.*

Proof. See (33). ■

[20] Equation (33) can be derived by setting $\phi = \beta$ in (A11) of Appendix A.

3.3 Incomplete patent protection in the South

In this subsection, we calibrate the model for the general case of incomplete Southern patent protection in order to provide a quantitative analysis on the effects of changes in unskilled labor and capital in China on the direction of innovation in the US. The model features the following set of parameters $\{\varepsilon, \delta, \gamma, \rho, \beta, \phi, L^s, H^s, L^n, H^n, K^s, K^n\}$.[21] We either consider standard values of these parameters or calibrate them using empirical moments in China and the US.

For the discount rate, we set ρ to a standard value of 0.03. For the parameter on labor share, we set β to the lower value of 0.4 in China because it 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 $\phi = 0.30$. We normalize L^s to unity and compute 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 on average 4.6% from 1995 to 2010 according to the Barro-Lee dataset on education attainment). Similarly, we compute L^n and 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 on average 51% from 1995 to 2010 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 on average 4.44 from 1995 to 2009 according to the Penn World Table). We normalize K^n to unity and compute K^s using data on the relative GDP between China and the US (i.e., $(P_h Y_h^s + P_l Y_l^s)/(P_h Y_h^n + P_l Y_l^n)$, which is on average 0.47 from 1995 to 2009 according to the Penn World Table).[22] For the remaining parameters $\{\varepsilon, \delta, \gamma\}$, we consider a standard range of values of $\varepsilon \in \{2.0, 2.1, 2.2, 2.3, 2.4\}$. For each value of ε, we calibrate the values of $\{\delta, \gamma\}$ using the following moments. For the offshoring parameter, we calibrate δ using the value of processing trade surplus in China as a share of GDP (i.e., $w_l^s \mathbf{l}^s/(P_h Y_h^s + P_l Y_l^s)$, which is on average 4.7% from 1995 to 2008).[23] Finally, we calibrate the value of γ using the college premium in the US (i.e., w_h^n/w_l^n, which is on average about 1.7 from 1995 to recent time). Table 1 reports the calibrated parameter values.[24]

Table 1: Calibrated parameter values

ε	δ	γ	ρ	β	ϕ	L^s	H^s	L^n	H^n	K^s	K^n
2.0	0.16	0.49	0.03	0.4	0.3	1	0.05	0.12	0.12	0.14	1
2.1	0.16	0.49	0.03	0.4	0.3	1	0.05	0.12	0.12	0.14	1
2.2	0.16	0.48	0.03	0.4	0.3	1	0.05	0.12	0.12	0.14	1
2.3	0.16	0.48	0.03	0.4	0.3	1	0.05	0.12	0.12	0.14	1
2.4	0.16	0.48	0.03	0.4	0.3	1	0.05	0.12	0.12	0.14	1

We consider two policy experiments. First, we reduce the supply of unskilled labor in the South and examine its effect on N_h/N_l and w_h^n/w_l^n.[25] Second, we increase the capital stock

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

[22] There are two versions of data on China in the Penn World Table, and we compute our values using both versions and taking an average of the two values.

[23] Data on the value of processing trade surplus in China is obtained from Xing (2011). Data on China's GDP is obtained from United Nations: National Account Main Aggregates Database.

[24] We provide the equilibrium expressions for calibration in an unpublished appendix (see Appendix B).

[25] It is useful to note that $w_h^n/w_l^n = w_h^s/w_l^s$ in this model.

in the South and examine its effect on N_h/N_l and w_h^n/w_l^n. Table 2 reports the results.[26] Due to skill-biased technical change, either a decrease in L^s or an increase in K^s would raise the skill premium in the North. 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 $\varepsilon = 2.2$ as our benchmark. Then, we find that a 1% decrease in the supply of unskilled labor L^s in China would lead to a 0.8% increase in the skill premium in the US, whereas a 1% increase in the capital stock K^s in China could lead to a 0.6% increase in the skill premium in the US. If we consider a larger value of $\varepsilon = 2.4$, then a 1% decrease in unskilled labor (1% increase in capital) in China would raise the skill premium in the US by as much as 3.7% (2.0%).

Table 2a: 1% decrease in L^s

ε	2.0	2.1	2.2	2.3	2.4
$\Delta N_h/N_l$	0.7%	1.0%	1.4%	1.5%	4.6%
$\Delta w_h^n/w_l^n$	0.1%	0.3%	0.8%	2.3%	3.7%

Table 2b: 1% increase in K^s

ε	2.0	2.1	2.2	2.3	2.4
$\Delta N_h/N_l$	0.5%	0.6%	0.8%	1.2%	2.3%
$\Delta w_h^n/w_l^n$	0.3%	0.4%	0.6%	1.0%	2.0%

To have a better understanding of the effects of L^s and K^s on the skill premium w_h^n/w_l^n, we derive[27]

$$\frac{w_h^n}{w_l^n} = \left[\left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon/(\varepsilon-1)} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s} \right)^{-1/(\varepsilon-1)} \left(\frac{H^n + \frac{\phi}{\beta}\delta H^s}{L^n + \frac{\phi}{\beta}\delta L^s + \delta \mathbf{l}^s (\beta - \phi)/\beta} \right) \right]^{\zeta}, \tag{34}$$

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, (34) simplifies to

$$\frac{w_h^n}{w_l^n} = \left[\left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon/(\varepsilon-1)} \left(\frac{H^n + \delta H^s}{L^n + \delta L^s} \right)^{(\varepsilon-2)/(\varepsilon-1)} \right]^{\zeta}. \tag{35}$$

Under 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 2. Under incomplete Southern patent protection (i.e., $\phi < \beta$), our numerical results indicate that this threshold value of ε can be slightly below 2. Another interesting implication from (35) 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 affects w_h^n/w_l^n through offshoring $\mathbf{l}^s$.

4 Conclusion

In this study, we have analyzed how the Chinese economy could affect skill-biased technical change in the US. In our analysis, we have assumed that the supply of skilled/unskilled

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

[27] We provide the derivations in an unpublished appendix (see Appendix B).

labors 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 share of skilled labor in the work force and the stock of physical capital increase. 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,[28] then there would be more incentives for skill acquisition in both countries increasing the supply of skilled labor and triggering further skill-biased technical change. Therefore, we believe that our results are robust to the endogenous accumulation of physical and human capital. However, allowing for these additional features would significantly complicate our analysis, so that we leave these interesting extensions to future research.

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

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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

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

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

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

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

The conditional demand functions for intermediate inputs are

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

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

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

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

When offshoring takes place in equilibrium (i.e., $\mathbf{l}^s_t > 0$), 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

$$\frac{p^n_t}{p^s_t} = \delta^{\frac{\beta}{1-\beta}}. \tag{A2}$$

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

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

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

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

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

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

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

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 $\{N_{h,t}/N_{l,t}, P_{h,t}/P_{l,t}, \mathbf{l}_t^s\}$. 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 (25), 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), (19), (22), (A1) and (A2), we derive

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

Finally, the capital-market conditions give rise to[29]

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

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

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

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

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

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

where $\mathbf{l}^s \in [0, L^s]$ 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

[29] 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. 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).

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 $\{N_h/N_l, \mathbf{l}^s\}$.

$$\frac{N_h}{N_l} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{H^n+\delta H^s}{L^n+\delta L^s}\right)^{-\frac{1}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{\frac{\phi}{\beta}\delta H^s + H^n}{\frac{\phi}{\beta}\delta(L^s-\mathbf{l}^s)+L^n+\delta\mathbf{l}^s}\right)^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}} \equiv F(\mathbf{l}^s), \tag{A11}$$

$$\frac{N_h}{N_l} = \left(\frac{\gamma}{1-\gamma}\right)^{\frac{\varepsilon}{\varepsilon-1}} \left(\frac{H^n+\delta H^s}{L^n+\delta L^s}\right)^{\frac{1}{\varepsilon-1}} \left(\frac{\left(\delta^{\frac{1}{1-\beta}}\frac{K^n}{K^s}+\delta\right)\mathbf{l}^s + L^n - \delta^{\frac{1}{1-\beta}}\frac{K^n}{K^s}L^s}{\delta^{\frac{1}{1-\beta}}\frac{K^n}{K^s}H^s - H^n}\right)^{\frac{1+\beta(\varepsilon-1)}{(\varepsilon-1)}} \equiv G(\mathbf{l}^s). \tag{A12}$$

$F(\mathbf{l}^s)$ is (weakly) decreasing in $\mathbf{l}^s$ because $\phi \le \beta$. As for $G(\mathbf{l}^s)$, 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) $[(L^n/L^s)(K^s/K^n)]^{1-\beta} < \delta < [(H^n/H^s)(K^s/K^n)]^{1-\beta}$,[30] and (c) $\delta \le [(L^n/L^s)(K^s/K^n)]^{1-\beta}$. 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 $G(\mathbf{l}^s)$ is strictly increasing in $\mathbf{l}^s$ guaranteeing the uniqueness of the equilibrium (if it exists). To establish its existence, we need to ensure that $F(\mathbf{l}^s)$ and $G(\mathbf{l}^s)$ cross within $\mathbf{l}^s \in [0, L^s]$. 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 $G(\mathbf{l}^s)$ would be decreasing in $\mathbf{l}^s$. Furthermore, $G(\mathbf{l}^s)$ would be positive if and only if $\mathbf{l}^s < \left(\frac{\delta^{1/1-\beta}K^n/K^s - L^n/L^s}{\delta^{1/1-\beta}K^n/K^s+\delta}\right)L^s$. As $\mathbf{l}^s \to \left(\frac{\delta^{1/1-\beta}K^n/K^s - L^n/L^s}{\delta^{1/1-\beta}K^n/K^s+\delta}\right)L^s$, $G(\mathbf{l}^s) = 0 < F(\mathbf{l}^s)$. Finally, $G(0) > F(0)$ would also hold if and only if γ is sufficiently large; in this case, it can be shown that $G(\mathbf{l}^s)$ crosses $F(\mathbf{l}^s)$ exactly once from above.[31]

Case (c): If $\delta \le [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, 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 $G(\mathbf{l}^s)$. In this case, $G(\mathbf{l}^s)$ must be nonpositive for $\mathbf{l}^s \in [0, L^s]$ because $L^n - \delta^{\frac{1}{1-\beta}}\frac{K^n}{K^s}L^s \ge 0$; therefore, an offshoring equilibrium does not exist. ■

Proof of Propositions 2 and 3. In the following proofs, we consider the special case of zero patent protection in the South. Setting $\phi = 0$ in (A11), we obtain

$$F(\mathbf{l}^s) = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{H^n+\delta H^s}{L^n+\delta L^s}\right)^{-\frac{1}{1-(1-\beta)(\varepsilon-1)}} \left(\frac{H^n}{L^n+\delta\mathbf{l}^s}\right)^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}}, \tag{A11-a}$$

[30] It can be shown that if $\delta = [(H^n/H^s)(K^s/K^n)]^{1-\beta}$, then $\mathbf{l}^s = \left(\frac{\delta^{1/1-\beta}K^n/K^s - L^n/L^s}{\delta^{1/1-\beta}K^n/K^s+\delta}\right)L^s$ instead of being determined by (A12).

[31] 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.

and $G(\mathbf{l}^s)$ is the same as in (A12). The unique steady-state equilibrium values of $\{N_h/N_l, \mathbf{l}^s\}$ are implicitly determined by solving these two equations. 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 $G(\mathbf{l}^s)$ is increasing in $\mathbf{l}^s$. In this case, an increase in K^s shifts up $G(\mathbf{l}^s)$ and 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 $G(\mathbf{l}^s)$ is decreasing in $\mathbf{l}^s$ and crossing $F(\mathbf{l}^s)$ exactly once from above given a sufficiently large γ. In this case, an increase in K^s shifts down $G(\mathbf{l}^s)$ and also gives rise to a larger equilibrium value of N_h/N_l. We summarize these results in the following Lemma.

Lemma 1: If $\delta > [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, then an increase in K^s would lead to an increase in N_h/N_l.

Using (A11-a) and (A12), we derive the following condition that implicitly determines N_h/N_l.

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

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 (A13) is increasing in N_h/N_l, whereas the left-hand side of (A13) 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.

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 (A13) is also decreasing in N_h/N_l and crosses the left-hand side exactly once from below. 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. We summarize these results in the following Lemma.

Lemma 2: If $\delta > [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, then a decrease in L^s would lead to an increase in N_h/N_l.

Zero-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., $\mathbf{l}^s = 0$). In this case, we derive three equilibrium conditions,

$$\frac{P_h}{P_l}=\left(\frac{1-\gamma}{\gamma}\right)^{\frac{\beta\varepsilon}{1+\beta(\varepsilon-1)}}\left(\frac{N_h}{N_l}\right)^{-\frac{1}{1+\beta(\varepsilon-1)}}\left(\frac{(H^s)(p^s)^{-(1-\beta)/\beta}+(H^n)(p^n)^{-(1-\beta)/\beta}}{(L^s)(p^s)^{-(1-\beta)/\beta}+(L^n)(p^n)^{-(1-\beta)/\beta}}\right)^{-\frac{\beta}{1+\beta(\varepsilon-1)}}, \tag{A14}$$

$$\frac{P_h}{P_l}=\left(\frac{H^n}{L^n}\right)^{-\beta}\left(\frac{N_h}{N_l}\right)^{-(1-\beta)}, \tag{A15}$$

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

which correspond to (A5), (A7) and (A8), respectively. Substituting (A15) and (A16) into (A14), we obtain

$$\frac{N_h}{N_l}=\left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{1-(1-\beta)(\varepsilon-1)}}\left(\frac{H^n}{L^n}\right)^{\frac{1+\beta(\varepsilon-1)}{1-(1-\beta)(\varepsilon-1)}}\left(\frac{L^s\left(\frac{K^s}{K^n}\left(1+\frac{N_h}{N_l}\right)\right)^{(1-\beta)}+L^n\left(\frac{L^s}{L^n}+\frac{H^s}{H^n}\frac{N_h}{N_l}\right)^{1-\beta}}{H^s\left(\frac{K^s}{K^n}\left(1+\frac{N_h}{N_l}\right)\right)^{(1-\beta)}+H^n\left(\frac{L^s}{L^n}+\frac{H^s}{H^n}\frac{N_h}{N_l}\right)^{1-\beta}}\right)^{\frac{1}{1-(1-\beta)(\varepsilon-1)}}. \tag{A17}$$

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 3: If $\delta \leq [(L^n/L^s)(K^s/K^n)]^{1-\beta}$, then there would be no outsourcing in equilibrium (i.e., $\mathbf{l}^s = 0$); in this case, an increase in L^s or K^s leads to an increase in N_h/N_l.

Finally, note that Lemma 2 and Lemma 3 prove Proposition 2, whereas Lemma 1 and Lemma 3 prove Proposition 3. ■

Appendix B: Not for publication

In this appendix, we provide the equilibrium expressions for calibrating the model: (a) offshoring as a share of GDP $w_l^s \mathbf{l}^s/(P_l Y_l^s + P_h Y_h^s)$, (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. 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

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

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

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

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

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

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

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

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

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

By (A5) and (A7),

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

Then, (B8) and (B9) imply (34).