International Scholarly Research Network
ISRN Economics
Volume 2012, Article ID 702974, 8 pages
doi:10.5402/2012/702974

Research Article

Outsourcing Innovation in Product Cycles

Hsiao-Lei Chu

Department of Economics, National Tsing Hua University, 101 Section 2, Kuang-Fu Road, Hsinchu 30013, Taiwan

Correspondence should be addressed to Hsiao-Lei Chu, hlchu@mx.nthu.edu.tw

Received 4 June 2012; Accepted 22 August 2012

Academic Editors: T. Kuosmanen, A. Watts, and J. Zarnikau

In this quality-ladder product-cycles model, a southern firm can undertake innovation by collaborating with a northern firm through R&D outsourcing. Generally, I find that the initial steady-state scale of R&D outsourcing and the fraction of innovative tasks undertaken by southern labor through R&D outsourcing critically affect the results of comparative statics. Particularly, the friendly policy to promote R&D outsourcing may be beneficial for both of the North and the South only if the scale of R&D outsourcing is small.

1. Introduction

The Vernon-type product-cycles model generally consists of two countries, North and South. The North is distinguished from the South by its superior ability of innovation and higher wage rate. In addition, a production process in the model generally consists of two stages, R&D and manufacturing. Given the key character that the latest innovation through R&D replaces outdated products, various patterns of production process have been discussed in this Vernon-type product-cycles framework. Particularly, outsourcing part of the production process, which is consistent with the observation of global fragmentation in production and trading semifinished products [1, 2], has been investigated. (In addition, FDI (e.g., [3–5]) and licensing (e.g., [6]) have also been discussed in the product-cycles framework.) Glass and Saggi [7] divide the manufacturing stage into an advanced stage and a basic stage, where the basic stage can be outsourced to the South. Their framework is extended by Glass [8] with imitation, and by Sayek and Sener [9] with heterogenous labor. Sener and Zhao [10] push out the outsourcing frontier further outward by considering that the North is able to outsource domestically developed innovation directly to the South without manufacturing the innovation at home in advance. Although they all recognize the importance of international outsourcing to product cycles, no R&D outsourcing is discussed. (Lai et al. [11] model outsourcing innovation in a principal-agent framework. They mainly focus on optimal contracting. Innovation in the South actually has been discussed in product-cycles models by Chui et al. [12] and Chu [13]; however, neither of the two articles considers outsourcing.)

If the South is also capable of undertaking innovation, it might stimulate the North to outsource at least a part of R&D stage to the South because of the lower wage rate in the South. In fact, some reports do point out that international outsourcing of innovation is rising. For example, Technology Forecasters Inc. reports that USA companies have increased outsourcing innovation overseas from less than US $30 billion in 2000 to over US $60 billion in 2004 [14]; BusinessWeek (March 21, 2005) tells that "Today, the likes of Dell, Motorola and Philips are buying complete designs of some digital devices from Asian developers, tweaking them to their own specifications, and slapping on their own brand names.…About 30% of digital cameras are produced by ODMs, 65% of MP3 players, and roughly 70% of personal digital assistants." Based on a survey of over 300 executives worldwide, Economist Intelligence Unit [15] concludes that the proportion of respondents with at least some of their R&D function overseas is 65% in 2007 and the percentage is expected to be higher over time. These observations of outsourcing innovation are consistent with the upward trends of granted patents in the developing countries (which may be classified as southern countries in the product-cycles framework) such as China, India, South Korea, and Taiwan as showed in Appendix A. (A report from Markets, Patents & Alliances, LLC [16], shows that particularly in the computer and telecommunication industries, many Taiwanese ODM firms, like Hon Hai Precision Industry (also known as Foxconn Electronics) and Taiwan Semiconductor Manufacturing Corporation (TSMC), experience a huge growth in patent activities since 1995.These ODMs design and assemble products for companies with brand names. Multinational corporations also offshore R&D. For example, Nortel Networks and GECIS in India, HP in Taiwan have hired local scientists to work on R&D.)

Motivated by the rising of international outsourcing of innovation, this paper incorporates southern innovation into a product-cycles framework. Specifically, it is assumed that a southern firm can undertake innovation by collaborating with a northern firm through R&D outsourcing. I intend to investigate how the steady-state relative wage, the aggregate rate of innovation, and the measure of northern firms which outsource R&D (dubbed the scale of R&D outsourcing hereafter) are determined in this model. Particularly, I investigate the impacts of R&D subsidies, of an improvement on southern R&D ability and of the sizes of regional labor force on the steady-state equilibrium. In this model I leave imitation out of the picture, which can be justified by a sufficiently high cost of a violation of the intellectual property right faced by a country once it integrates into the global trade system.

Similar to Glass and Saggi [7] and Sener and Zhao [10], this paper also finds that an R&D friendly policy in the South raises southern relative wage; however, its impacts on the aggregate rate of innovation and on the scale of outsourcing (though the paper refers to R&D outsourcing and their articles refer to manufacturing outsourcing) are uncertain in this paper. Glass and Saggi [7] consider manufacturing outsourcing and find that subsidies to adapting technologies for southern production lead to more international outsourcing and the subsidies also raise the aggregate rate of innovation and the southern relative wage. Sener and Zhao [10] emphasize the phenomenon of simultaneous innovation and outsourcing by northern firms. They show that if the South subsidizes on northern firms which directly transfer technologies to the South or if the South subsidizes on local manufacturing, all of the aggregate rate of innovation, the scale of outsourcing, and the southern relative wage should rise.

In this paper, the South controls two variables, s_s and s_n, for R&D friendly policies. s_s denotes the rate of R&D subsidy on the southern firms and s_n denotes the rate of R&D subsidy on the northern firms that outsource R&D to the South. An increase in s_s or an increase in s_n raises southern relative wage and the size of this effect depends on the fraction of innovative tasks undertaken by the southern labor employed in R&D outsourcing. An improvement on southern R&D ability, an increase in southern labor force, a higher s_s and a higher s_n generate the same qualitative effect on the scale of R&D outsourcing and on the aggregate rate of innovation. The qualitative effect can be positive or negative, and it will be positive if the initial steady-state scale of R&D outsourcing is not too large (will define "too large" later). If the development of R&D outsourcing raises the southern relative wage but reduces the aggregate rate of innovation then R&D outsourcing casts shadow on the welfare of the North and might even reduce the welfare of the South, which is in contrast with the conclusion of Glass and Saggi [7]. They argue that international (manufacturing) outsourcing can potentially create gains sufficient to offset the decline in the northern wage because the rate of innovation is raised by outsourcing. In addition, in this paper a larger northern labor force might reduce the aggregate rate of innovation; however, it always speeds up the global rate of innovation in the literature because the northern labor is the sole input for innovation. Generally, I find that the initial steady-state scale of R&D outsourcing and the fraction of innovative tasks undertaken by the southern labor through R&D outsourcing are two variables which critically affect the results of comparative statics. These two variables can emerge because of taking international R&D outsourcing into consideration.

In the rest of the paper, Section 2 sets up the model, Section 3 derives the steady-state equilibrium and comparative statics, and Section 4 concludes the paper.

2. The Model

The world consists of two countries: North and South denoted by N and S, respectively. Agents worldwide consume goods indexed by ω, $\omega \in [0,1]$. The quality of good ω can be improved by innovation and one improvement raises the quality by λ times. Let $q_j(\omega) = \lambda^j$, $\lambda > 1$, $q_j(\omega)$ is the quality of good ω that experiences j times of improvement on quality. Labor is the only input in production and the wage rate in the North, w_n, is strictly greater than the wage rate in the South, w_s. For any good ω, firms which possess the technologies to produce various qualities of good ω compete with each other, leading to only one firm that offers the lowest quality-adjusted price in the industry ω. Only northern firms are capable of inventing new quality independently and any southern firm can undertake innovation only if it collaborates with a northern firm through R&D outsourcing.

2.1. Types of Firms and Technology. The production process in a northern industry ω includes an R&D stage to innovate the state-of-the-art quality of good ω and a manufacturing stage to produce good ω featuring this top quality. A northern firm becomes the incumbent firm of an industry ω once its new invention is launched in the market. At the same time, the technology utilized by the precedent of this incumbent firm, that is, the technology for the second-to-the-top quality, becomes common knowledge to all firms in the world. Each northern firm has the option to outsource the manufacturing stage and/or the R&D stage to the South. An incumbent northern firm is type-jr (r indicates northern innovation) if its precedent outsources the manufacturing stage only and is type-jo (o indicates outsourcing innovation) if its precedent outsources both of the R&D and the manufacturing stages, where $j = r$ if this incumbent northern firm undertakes the R&D stage at home and outsources the manufacturing stage to the South and $j = o$ if it outsources both of the R&D and manufacturing stages. A southern firm that undertakes innovative activity in the R&D stage is called type-s. Define $J_n \equiv \{jk, j = r, o \text{ and } k = r, o\}$.

The success of an R&D activity exhibits a continuous Poisson process. In the R&D stage, for $i = rr, ro$, an innovation with intensity ι_i for a time interval dt requires $a_n \iota_i dt$ units of northern labor at a cost of $w_n a_n \iota_i dt$. On the other hand, for $i = or, oo$, an innovation with intensity ι_i for a time interval dt requires $a_s \iota_i dt$ units of southern labor and $a_o \iota_i dt$ units of northern labor for a time interval dt. A type-s firm incurs an R&D cost of $w_s a_s \iota_i dt$ and receives $p_s \iota_i dt$ from its northern outsourcer which also spends $w_n a_o \iota_i dt$ on northern labor to impose its desired intensity of R&D in collaborating with the southern innovation. Any innovation with intensity ι_i for a time interval dt leads to a success with probability $\iota_i dt$. We assume that $a_n < a_o + a_s$ since the North is superior in innovation and assume that $a_n > a_o$ so that outsourcing is worthwhile in the equilibrium. The ratio of $(a_n - a_o)/a_n$ represents the fraction of R&D undertaken by southern labor. We, therefore, define S-share and N-share in R&D as

$$S\text{-share} \equiv \frac{a_n - a_o}{a_n}, \qquad N\text{-share} \equiv \frac{a_o}{a_n}. \tag{1}$$

In an industry ω, an outsourcing connection between an incumbent northern firm and its southern R&D partner ceases when another northern firm launches a better quality in the market. (In reality, firms change their outsourcing partners flexibly. Of course, a long-term contractual relationship between the trading parties can be considered in a more complex framework.)

North and South have the same manufacturing technology which requires one unit of labor to produce one unit of output. To emphasize that outsourcing the manufacturing stage is relatively less complex and to simplify the analysis, it is assumed that outsourcing the manufacturing stage incurs no outsourcing cost which implies that all manufacturing stages are operated in the South given $w_n > w_s$.

2.2. Preferences. All agents have identical preferences and each consumer maximizes his utility U,

$$U = \int_0^{\infty} e^{-\rho t} \int_0^1 \log\left[\sum_j q_j(\omega) x_{jt}(\omega)\right] d\omega dt, \qquad \omega \in [0,1], \quad q_j(\omega) = \lambda^j,\ \lambda > 1, \tag{2}$$

where ρ is the discount rate; t indexes time; ω indexes goods; $q_j(\omega)$ and $x_{jt}(\omega)$, respectively, are the quality and the consumption of good ω that experiences j times of improvement on quality. Let $E(t)$ denote the expenditure at time t and $E(t) = \int_0^1 [\sum_j p_{jt}(\omega) x_{jt}(\omega)] d\omega$, where $p_{jt}(\omega)$ is the price of good ω with quality λ^j. A consumer allocates an equal expenditure share to every good ω that offers the lowest quality adjusted price $p_{jt}(\omega)/q_j(\omega)$. Let $p_t(\omega)$ represent the price of the top-quality good ω. The indirect utility function U_I is derived as

$$U_I = \int_0^{\infty} e^{-\rho t} \left\{ \log E(t) - \int_0^1 \log\left[\frac{p_t(\omega)}{q_t(\omega)}\right] dj \right\} dt. \tag{3}$$

In the equilibrium, we also have

$$\dot{E}/E = r - \rho, \tag{4}$$

where r is the instantaneous interest rate.

2.3. No-Arbitrage Conditions and Free Entry. Let π_i denote the instantaneous profit of a type-i firm and v_i be the value of a type-i firm, $i \in J_n \cup \{s\}$. For a type-jk firm, $jk \in J_n$, over a time interval dt, its stockholders receive $\pi_{jk}(t)$ as dividend payments and suffer a loss of $v_{jk}(t)$ with probability $(\iota_{oj} + \iota_{rj})dt$. That is, the stockholders of this type-jk firm have a probability of $[1 - (\iota_{oj} + \iota_{rj})dt]$ to capture a capital gain (or loss) of $\dot{v}_{jk}\, dt$. We, therefore, define the no-arbitrage condition to be that the expected rate of return from holding the stock of the type-jk firm equals the risk-free interest rate, that is, $\pi_{jk}(t)dt + [1 - (\iota_{oj} + \iota_{rj})dt]\ \dot{v}_{jk}\, dt - (\iota_{oj} + \iota_{rj}) v_{jk}(t) dt = r(t) v_{jk}(t) dt$. As $dt \to 0$, the no-arbitrage condition can be written as

$$v_{jk} = \frac{\pi_{jk}}{r + \iota_{oj} + \iota_{rj} - \left(\dot{v}_{jk}/v_{jk}\right)}, \tag{5}$$

where

$$\pi_{jk} = \frac{E}{\lambda w_s}(\lambda w_s - w_s), \quad jk \in J_n, \tag{6}$$

λw_s is the unit price, w_s is the marginal cost, and $E/\lambda w_s$ is the amount of products sold. Because the quality of a good increases by λ times through one successful innovation and the competing price is w_s, an incumbent firm charges the limit price of λw_s for its products.

A type-s firm receives p_s from its northern outsourcer as the payment for its R&D service, spends $w_s a_s$ on employment for R&D, receives a subsidy of $s_s w_s a_s$ (recall that s_s denotes the rate of R&D subsidy on the southern firms), and generates a profit of π_s so that we can write

$$\pi_s = p_s - w_s a_s (1 - s_s). \tag{7}$$

Since no type-s firm is involved with any manufacturing task, the no-arbitrage condition for a type-s firm is $\pi_s(t)dt = r(t) v_s(t) dt$ or

$$v_s \leq \frac{\pi_s}{r}. \tag{8}$$

Each firm exante chooses its type and R&D intensity to maximize the expected value of the R&D. Free entry in the markets implies that the expected value does not exceed the cost, with equality holding if the R&D intensity is strictly positive. Recall that s_n is the rate of subsidy, representing a friendly policy from the South to encourage R&D outsourcing. We can, therefore, write

$$v_i \le w_n a_o(1-s_n)+p_s \quad \text{with equality for } \iota_i > 0, \quad i = or, oo,$$
$$v_i \le w_n a_n \quad \text{with equality for } \iota_i > 0, \quad i = rr, ro,$$
$$v_s \le w_s a_s(1-s_s) \quad \text{with equality for } \iota_i > 0 \text{ for some } i,$$
$$i \in \{or, oo\}. \tag{9}$$

2.4. Measures of Firms and Labor Markets. Let n_i be the measure of type-i firms, for $i \in J_n$. Since the consumption goods are of measure 1, we get

$$\sum_{i\in J_n} n_i = 1. \tag{10}$$

In the steady-state equilibrium, the measure of type-i firms is a constant for all i in J_n. Thus, we have the following equations describing the instantaneous exit and entry of firms among types:

$$n_{jk}\left(\iota_{rj} + \iota_{oj}\right) = \iota_{jk}(n_{kr} + n_{ko}), \quad \text{for } j = r, o, \; k = r, o, \tag{11}$$

where the LHS of each equation represents the measure of firms which exit from the type and the RHS gives the measure of entry.

Among the labor force of the South L_s, $E/\lambda w_s$ units of labor are allocated in the manufacturing stage, and $a_s \sum_{k=r,o} \iota_{ok} n_{ok}$ units of labor work on innovation, that is,

$$L_s = a_s \sum_{k=r,o} \iota_{ok} n_{ok} + \frac{E}{\lambda w_s}. \tag{12}$$

In the northern labor market, domestic R&D activities require $a_n \sum_{k=r,o} \iota_{rk} n_{rk}$ units of labor and R&D outsourcing require $a_o \sum_{k=r,o} \iota_{ok} n_{ok}$ units of labor. Therefore, we can present the aggregate labor supply n North, L_n, by

$$L_n = a_n \sum_{k=r,o} \iota_{rk} n_{rk} + a_o \sum_{k=r,o} \iota_{ok} n_{ok}. \tag{13}$$

3. The Steady-State Equilibrium

The steady state equilibrium consists of a sequence of variables $(r, E/w_n, p_s/w_s, w_s/w_n, n_i, \iota_i, i \in J_n)$ which satisfies (4) to (13). We can simplify (4) to (13) by taking the symmetries among firms into consideration. The northern firms of the same type face the same exante conditions of production and the same prospects of profitability; therefore, these forward-looking firms should make the same decisions on their R&D intensity and should have the same expected revenue and cost in production. Thus, we define x_j by

$$x_j \equiv x_{jr} = x_{jo} = x_{js} \quad \text{for } x = \iota, v, \pi, \quad j = r, o. \tag{14}$$

Define η as the aggregate rate of innovation,

$$\eta \equiv \iota_o n_o + \iota_r n_r. \tag{15}$$

Equations (4) to (15) are reduced to the following three equations as shown in Appendix B to determine the steady-state values of ι_o, n_o, and η:

$$\begin{aligned} a_s \iota_o n_o + \frac{\phi}{\lambda e}\left(\frac{\iota_o}{n_o} + \rho\right) - L_s &= 0, \\ a_n \eta + \iota_o n_o (a_o - a_n) - L_n &= 0, \\ \eta - 2\iota_o n_o + 2\iota_o - \frac{\iota_o}{n_o} &= 0, \end{aligned} \tag{16}$$

where

$$\phi \equiv \frac{(1+\rho) a_s (1-s_s) a_n}{a_n - a_o(1-s_n)}. \tag{17}$$

Once ι_o, n_o, and η are determined, we can get

$$\begin{aligned} \frac{E}{w_n} &= \frac{\lambda}{\lambda - 1} a_n (\iota_o + \iota_r + \rho), \\ n_{jk} &= \frac{\iota_j \iota_k}{(\iota_r + \iota_o)^2}, \quad \text{for } j = r, o, \; k = r, o. \end{aligned} \tag{18}$$

In addition, by (4) to (15), we derive

$$\begin{aligned} r = \rho, \qquad \frac{p_s}{w_s} &= (1+\rho)(1-s_s) a_s, \\ \frac{w_s}{w_n} &= \frac{a_n - a_o(1-s_n)}{(1+\rho) a_s (1-s_s)}. \end{aligned} \tag{19}$$

Proposition 1. *Given $w_s/w_n < 1$ and $s_n = s_s = 0$ in the steady-state equilibrium, we have $d(w_s/w_n)/ds_n = a_o/(1+\rho)a_s$ and $d(w_s/w_n)/ds_s = (a_n - a_o)/(1+\rho)a_s$.*

Proposition 1 states that a marginal increase in the rate of subsidy on R&D in the South raises the southern relative wage. Particularly, subsidizing southern firms generates a larger (smaller) effect than subsidizing northern outsourcing firms if S-share is larger (smaller) than N-share.

Total differentiation of (16) evaluating at $s_n = s_s = 0$ yields

$$A \begin{bmatrix} d\eta \\ d\iota_o \\ dn_o \end{bmatrix} = \begin{bmatrix} -\left(\iota_o n_o + \dfrac{\Phi}{a_s}\right) da_s + \Phi ds_s + \dfrac{\Phi a_o}{a_n - a_o} ds_n + dL_s \\ dL_n \\ 0 \end{bmatrix}, \tag{20}$$

where

$$A = \begin{bmatrix} 0 & a_s n_o + \dfrac{\phi}{\lambda e}\dfrac{1}{n_o} & a_s \iota_o - \dfrac{\phi}{\lambda e}\dfrac{\iota_o}{n_o}\dfrac{1}{n_o} \\ a_n & n_o(a_o - a_n) & \iota_o(a_o - a_n) \\ 1 & -2n_o + 2 - \dfrac{1}{n_o} & -2\iota_o + \dfrac{\iota_o}{n_o}\dfrac{1}{n_o} \end{bmatrix}, \tag{21}$$

$$\Phi \equiv \frac{\phi(\iota_o/n_o + \rho)}{\lambda e}.$$

Proposition 2. *In the steady-state equilibrium, we have $dx/dL_s = \Phi^{-1} dx/ds_s = (a_o \Phi/(a_n - a_o))^{-1} dx/ds_n = -(\iota_o^2/(\iota_r + \iota_o) + \Phi/a_s)^{-1} dx/da_s$, for $x = \eta, \iota_o, n_o$.*

Proposition 2 derived from (20) tells that an increase in L_s, in s_s, in s_n and a decrease in a_s generate the same qualitative impact on η, ι_o and n_o. If S-share is larger (smaller) than N-share, s_n generates a larger (smaller) effect than s_s.

Propositions 1 and 2 imply some welfare consequences of R&D friendly policy. For example, suppose that the government of the South chooses to raise *one* of s_n and s_s around the steady state and that S-share is greater than 1/2. If the impacts mentioned in Proposition 2 are negative, raising s_s is better than raising s_n, since the former increases the southern relative wage more and reduces the aggregate rate of innovation less. On the other hand, if the impacts are positive then it is ambiguous whether raising s_s is better than raising s_n because raising s_s increases the southern relative wage more but it increases the aggregate rate of innovation less. In addition, if the impacts in Proposition 2 are negative, an increase in R&D subsidy and/or an increase in labor productivity in R&D aimed to encourage R&D outsourcing will get the contrary results—a smaller ι_o or a smaller n_o.

To figure out the sign of the impact, $|A|$ is computed according to (20) and

$$|A| = \frac{2a_n a_s \iota_o}{n_o}\left[n_o - 1 + \left(\frac{a_n + a_o}{a_n} - \frac{1}{n_o}\right)\frac{(1+\rho)a_n}{(\lambda - 1)(a_n - a_o)}\right]$$
$$\equiv \frac{2a_n a_s \iota_o}{n_o}X. \tag{22}$$

Appendix C shows that we can define n_o^*, $0 < n_o^* < 1$ such that $|A| = 0$ when $n_o = n_o^*$. Since $dX/dn_o > 0$, we get that if $n_o > n_o^*$ then $|A| > 0$ and if $n_o < n_o^*$ then $|A| < 0$. That the initial steady-state scale of R&D outsourcing, that is, n_o, is not too large means $n_o < n_o^*$. Particularly, by (22), we have $|A| < 0$ if $n_o \leq a_n/(a_n + a_o)$ and we also get that $1/2 < a_n/(a_n + a_o) < n_o^*$. In Appendix D, some results of comparative statics are derived and the results with unambiguous signs are summarized in Proposition 3 and Figure 1.

Proposition 3. *In the steady-state equilibrium with* $|A| < 0$, *we get* $d\eta/dL_s > 0$ *and* $dn_o/dL_n < 0$ *for* $n_o \in (0, n_o^*)$; $d\eta/dL_s > 0$, $dn_o/dL_n < 0$, *and* $d\iota_o/dL_s > 0$ *for* $n_o \in (0, a_n/(a_n + a_o))$; $d\eta/dL_s > 0$, $dn_o/dL_n < 0$, $d\iota_o/dL_s > 0$, $d\eta/dL_n > 0$, *and* $dn_o/dL_s > 0$ *for* $n_o \in (0, 1/2]$. *In the steady-state equilibrium with* $|A| > 0$, *we get* $d\eta/dL_s < 0$, $d\eta/dL_n > 0$, *and* $dn_o/dL_n > 0$ *for* $n_o \in (n_o^*, 1)$.

Proposition 3 indicates that the comparative statics mentioned in Proposition 2 are with negative signs if n_o is greater than n_o^*. Thus, many policy implications depend on if the scale of R&D outsourcing is large or is small.

In contrast with the general result in the literature (e.g., [7, 10, 17]) that an increase in the labor force for R&D raises the aggregate rate of innovation, Proposition 3 tells that an increase in the labor force in the North generates an indeterminate effect on the aggregate rate of innovation if $n_o \in (1/2, n_o^*)$ and that an increase in the labor force in the South reduces the aggregate rate of innovation if $n_o > n_o^*$. That a larger L_s corresponds to a smaller η when $n_o > n_o^*$ is mainly because L_s are employed in two ways, R&D and manufacturing. As n_o increases, the southern labor for manufacturing becomes more scarce. When n_o is sufficiently large, a marginal increase in L_s will be allocated to manufacturing and will result in a smaller ratio of employment in R&D to employment in manufacturing and, therefore, a reduction in η.

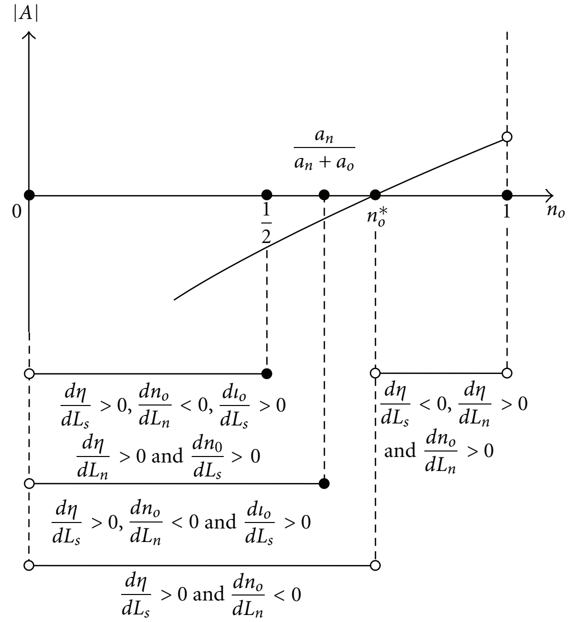

Figure 1: Results of Comparative Statics.

Though n_o is implied by (16), unfortunately it is not easy to tell what values of the parameters facilitate us to derive an analytical solution to n_o or how n_o is affected by each of the parameters. Nonetheless, Figure 1, together with Propositions 1 and 2, offers a guideline for policymakers once the steady-state equilibrium is realized and n_o is known.

4. Concluding Remarks

This model incorporates southern innovation into product cycles and is structured as simple as possible while it still keeps the key character that the latest innovation through R&D replaces outdated products. It is shown that there are certain boundary conditions of the scale of R&D outsourcing which affect policy implications. Particularly, according to Propositions 1 and 2, when the scale of R&D outsourcing is large, the aggregate rate of innovation is negatively related with the rate of R&D subsidy. Therefore, a friendly policy to promote R&D outsourcing (given that all manufacturing tasks are outsourced from the North to the South) may be beneficial for both of the North and the South only if the scale of R&D outsourcing is small. This finding is in contrast to the result of Glass and Saggi [7] that the rate of innovation is raised by outsourcing (they only consider manufacturing outsourcing); therefore, international outsourcing can potentially create gains sufficient to offset the decline in the northern wage and to benefit the North as well as the South.

In general, I find that the results of comparative statics are affected by the sign of $|A|$ and by the scale of R&D outsourcing as shown in Figure 1, which indicates that considering R&D in the South through outsourcing is important. These contraries of comparative statics under different environments may offer a guideline for making policies to affect the relative wage and the rate of innovation.

Appendices

A.

Though innovative ability is not easy to gauge, patent statistics might be close measurements. Table 1 lists the patent statistics in Science and Engineering (S&E) Indicators 2008, which shows that Asia's share of patents granted at USA patent and Trademark Office (USPTO) and that granted in the European Patent Office (EPO) exhibit increasing trends between 1985 and 2006 mainly due to the performances of the developing countries such as China, India, South Korea, and Taiwan. These two patent offices are among the largest in the world in terms of volume of patents and have a significant share of applications and grants from foreign inventors. Table 1 shows that South Korea and Taiwan, respectively, have the share (in percentage) of 0.06 and 0.24 on USPTO, 0.01 and 0.06 on EPO in 1985, and the share is raised to 3.03 and 3.56 on USPTO in 2005, to 1.23 and 0.26 on EPO in 2006. In particular, Asia's inventors also patent more intensively in information and communications technology (ICT). S&E indicator particularly documents ICT and biotechnology patents due to their profound impact on global economy. ICT patents have helped to create new industries and products such as home computers, cellular phones, and wireless devices. ICT technology has revolutionized and improved productivity in non-ICT industries and services, such as the health, finance, and retail sectors. Asia has the smallest share of biotechnology patents from both patent offices compared with those of the United States and the EU, so we omit this part of report.

B.

Consider the equilibrium where the measure of type-i firm is strictly positive for all i in J_n. First of all, plugging in the following six conditions:

$$\begin{aligned}
&(1)\quad \frac{\dot{v}_i}{v_i} = \frac{\dot{E}}{E} = r - \rho = 0, \quad i \in J_n,\\
&(2)\quad x_j \equiv x_{jr} = x_{jo} = x_{js} \quad \text{for } x = \iota, v, \pi, j = r, o,\\
&(3)\quad \pi_i = \frac{E}{\lambda w_s}(\lambda w_s - w_s) = E\left(1 - \frac{1}{\lambda}\right), \quad i \in J_n,\\
&(4)\quad n_o \equiv n_{or} + n_{oo} + n_{os},\\
&(5)\quad n_r \equiv n_{rr} + n_{ro} + n_{rs},\\
&(6)\quad p_s = (1+\rho) w_s a_s (1 - s_s),
\end{aligned} \tag{B.1}$$

into (4) to (14), we get the equilibrium conditions:

$$w_n a_n = \left(1 - \frac{1}{\lambda}\right) \frac{E}{\iota_o + \iota_r + \rho}, \tag{B.2}$$

$$w_n a_o (1 - s_n) + (1+\rho) w_s a_s (1 - s_s) = \left(1 - \frac{1}{\lambda}\right) \frac{E}{\iota_o + \iota_r + \rho}, \tag{B.3}$$

$$\sum_{i \in J_n} n_i = 1, \tag{B.4}$$

$$n_{jk}(\iota_r + \iota_o) = \iota_j n_k, \quad j = r, o, \ k = r, o, \tag{B.5}$$

$$L_s = a_s \iota_o n_o + \frac{E}{\lambda w_s}, \tag{B.6}$$

$$L_n = a_n \iota_r n_r + a_o \iota_o n_o. \tag{B.7}$$

Equations (B.2) and (B.3) give

$$\begin{aligned}
\frac{w_s}{w_n} &= \frac{a_n - a_o(1 - s_n)}{(1+\rho) a_s (1 - s_s)},\\
\frac{E}{w_s} &= \frac{\lambda}{\lambda - 1} \frac{(1+\rho) a_s (1 - s_s) a_n}{a_n - a_o(1 - s_n)} (\iota_o + \iota_r + \rho).
\end{aligned} \tag{B.8}$$

Equations (B.4) and (B.5) give

$$\begin{aligned}
\iota_o n_r &= \iota_r n_o,\\
n_r &= \frac{\iota_r}{\iota_r + \iota_o},\\
n_o &= \frac{\iota_o}{\iota_r + \iota_o},\\
n_{jk} &= \frac{\iota_j \iota_k}{(\iota_r + \iota_o)^2}, \quad j = r, o, \ k = r, o.
\end{aligned} \tag{B.9}$$

Define η as the aggregate rate of innovation, $\eta \equiv \iota_o n_o + \iota_r n_r$. η, together with (B.6) and (B.7), gives us (16). Total differentiation of the above three equations evaluating at $s_n = s_s = 0$ yields (20).

C.

Let

$$\theta \equiv \frac{(1+\rho)(a_n + a_o)}{(\lambda - 1)(a_n - a_o)} - 1. \tag{C.1}$$

By

$$(n_o^*)^2 + \theta n_o^* - \frac{(1+\rho) a_n}{(\lambda - 1)(a_n - a_o)} = 0, \tag{C.2}$$

we know that there is only one positive solution to n_o^* and

$$n_o^* = \frac{1}{2}\left(-\theta + \sqrt{\theta^2 + 4 \frac{(1+\rho) a_n}{(\lambda - 1)(a_n - a_o)}}\right). \tag{C.3}$$

If $n_o^* = 0$, the LHS of (C.2) is less than zero; if $n_o^* = 1$, the LHS of (C.2) is equal to a_o. Thus, we get $n_o^* \in (0, 1)$. Let

$$X \equiv n_o - 1 + \left(\frac{a_n + a_o}{a_n} - \frac{1}{n_o}\right) \frac{(1+\rho) a_n}{(\lambda - 1)(a_n - a_o)}. \tag{C.4}$$

Table 1: World Share of patents granted by USPTO and EPO, by inventors from selected regions/countries.

Agency/region/country	1985	1990	1996	2001 (1)	2004	2005	2006	1985	1990	1996	2001 (2)	2004	2005	2006
USPTO														
United States	55.20	52.44	55.73	52.76	51.29	51.90	NA	51.89	47.30	50.00	51.54	50.48	50.55	50.37
EU	21.56	19.72	15.33	16.38	15.16	14.69	NA	17.23	14.92	10.80	10.88	10.99	11.09	10.79
Asia	18.16	22.83	24.38	25.97	28.83	28.76	NA	27.27	34.52	36.18	34.14	34.73	34.50	34.61
China	0.04	0.11	0.12	0.26	0.44	0.48	NA	0.03	0.10	0.10	0.13	0.28	0.39	0.48
India	0.01	0.03	0.03	0.11	0.22	0.27	NA	0.01	0.01	0.03	0.06	0.16	0.26	0.28
Japan	17.79	21.61	21.03	20.01	21.52	21.10	NA	27.09	33.57	31.97	26.08	26.33	25.49	25.09
Malaysia	0.00	0.00	0.01	0.02	0.05	0.06	NA	0.00	0.00	0.00	0.03	0.05	0.09	0.09
Singapore	0.01	0.01	0.08	0.18	0.27	0.24	NA	0.01	0.02	0.11	0.36	0.47	0.38	0.34
South Korea	0.06	0.25	1.36	2.13	2.70	3.03	NA	0.03	0.42	2.57	3.84	3.93	4.35	4.77
Taiwan	0.24	0.81	1.73	3.23	3.61	3.56	NA	0.10	0.38	1.39	3.62	3.47	3.52	3.52
Thailand	0.00	0.00	0.01	0.01	0.01	0.01	NA	0.00	0.00	0.01	0.01	0.01	0.00	0.01
All others	0.00	0.00	0.00	0.00	0.00	0.01	NA	0.01	0.00	0.00	0.00	0.00	0.00	0.00
EPO														
United States	21.90	22.59	24.53	23.68	23.17	23.41	22.63	25.64	27.22	27.25	28.62	26.58	25.45	25.48
EU	57.70	53.66	45.51	50.70	51.40	50.83	49.93	50.60	43.45	30.84	37.13	41.32	43.05	40.12
Asia	13.29	17.38	24.46	19.79	19.18	19.45	21.09	18.54	25.41	38.56	30.29	27.18	26.70	29.17
China	0.00	0.05	0.08	0.07	0.15	0.19	0.23	0.00	0.02	0.04	0.03	0.11	0.17	0.25
India	0.06	0.02	0.03	0.05	0.16	0.18	0.21	0.00	0.00	0.02	0.00	0.06	0.07	0.09
Japan	13.15	17.20	24.01	19.00	17.79	17.82	19.02	18.48	25.32	38.09	29.31	25.16	24.44	26.16
Malaysia	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.01	0.01	0.02	0.02
Singapore	0.01	0.02	0.05	0.09	0.09	0.09	0.10	0.00	0.05	0.08	0.17	0.20	0.16	0.19
South Korea	0.01	0.02	0.18	0.48	0.77	0.90	1.23	0.00	0.00	0.28	0.71	1.40	1.64	2.20
Taiwan	0.06	0.07	0.10	0.08	0.20	0.23	0.26	0.07	0.02	0.05	0.06	0.22	0.20	0.23
Thailand	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.01
All others	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(1) are patents granted, (2) are ICT patents granted.
Source: Science and Engineering Indicators 2008 [18], Tables 39–46.

If $n_o = 1$ we get $X = (1+\rho)a_o/(\lambda-1)(a_n - a_o) > 0$. If $n_o \to 0$ we get $X \to -\infty$. Since

$$\frac{dX}{dn_o} = 1 + \frac{1}{n_o^2}\frac{(1+\rho)a_n}{(\lambda-1)(a_n-a_o)} > 0, \tag{C.5}$$

we get that $X = 0$ for some $n_o^* \in (0,1)$. Thus, if $n_o > n_o^*$ then $|A| > 0$; if $n_o < n_o^*$ then $|A| < 0$.

D.

According to (20), we derive

$$\begin{aligned}
&(1)\quad \frac{\partial \eta}{\partial L_s} = \frac{2}{|A|}\frac{\iota_o}{n_o}(n_o-1)(a_n-a_0),\\
&(2)\quad \frac{\partial \eta}{\partial L_n} = \frac{2}{|A|}\frac{a_s\iota_o}{n_o}\left[n_o - 1 + \left(2-\frac{1}{n_o}\right)\frac{(1+\rho)a_n}{(\lambda-1)(a_n-a_o)}\right],\\
&(3)\quad \frac{\partial \iota_o}{\partial L_s} = \frac{1}{|A|}\frac{\iota_o}{n_o^2}(a_n+a_o)\left(n_o^2 - \frac{a_n}{a_n+a_o}\right),\\
&(4)\quad \frac{\partial \iota_o}{\partial L_n} = \frac{1}{|A|}\frac{a_s\iota_o}{n_o}\left[\frac{(1+\rho)a_n}{(\lambda-1)(a_n-a_o)}\frac{1}{n_o} - n_o\right],\\
&(5)\quad \frac{\partial n_o}{\partial L_s} = \frac{a_n}{|A|}\left[2 - \frac{1}{n_o} - n_o\left(\frac{a_n+a_o}{a_n}\right)\right],\\
&(6)\quad \frac{\partial n_o}{\partial L_n} = \frac{1}{|A|}\left(a_s n_o + \frac{\phi}{\lambda e}\frac{1}{n_o}\right).
\end{aligned} \tag{D.1}$$

Each of the six equations is discussed in the following:

(1) If $|A| > 0$ then $\partial\eta/\partial L_s < 0$. If $|A| < 0$ then $\partial\eta/\partial L_s > 0$.

(2) Since

$$\begin{aligned}
\frac{\partial \eta}{\partial L_n} &= \frac{2}{|A|}\frac{a_s\iota_o}{n_o}\left[n_o - 1 + \left(2-\frac{1}{n_o}\right)\frac{(1+\rho)a_n}{(\lambda-1)(a_n-a_o)}\right],\\
X &\equiv n_o - 1 + \left(\frac{a_n+a_o}{a_n} - \frac{1}{n_o}\right)\frac{(1+\rho)a_n}{(\lambda-1)(a_n-a_o)},
\end{aligned} \tag{D.2}$$

we know that if $X > 0$ then $|A| > 0$ and $\partial\eta/\partial L_n > 0$. Since

$$\frac{1}{2} < \frac{a_n}{a_n + a_o} < n_o^*, \tag{D.3}$$

we know that if $n_o \leq 1/2$ then $|A| < 0$ and $\partial\eta/\partial L_n > 0$.

(3) If $n_o \leq a_n/(a_n+a_o)$ then $n_o^2 < a_n/(a_n+a_o)$ and $|A| < 0$, leading to $\partial\iota_o/\partial L_s > 0$.

(4) Since

$$\frac{(1+\rho)a_n}{(\lambda-1)(a_n-a_o)}\frac{1}{n_o} - n_o = 1 - \frac{(1+\rho)(a_n+a_o)}{(\lambda-1)(a_n-a_o)} - X, \tag{D.4}$$

without further information regarding the sign of $[1-((1+\rho)(a_n+a_o)/(\lambda-1)(a_n-a_o))]$ we can not predict the sign of $\partial\iota_o/\partial L_n$.

(5) If $n_o \leq 1/2$ then $2 - 1/n_o - n_o((a_n+a_o)/a_n) < 0$ and $|A| < 0$, leading to $\partial n_o/\partial L_s > 0$.

(6) If $|A| > 0$ then $\partial n_o/\partial L_n > 0$. If $|A| < 0$ then $\partial n_o/\partial L_n < 0$.

These results are summarized in Figure 1.

Acknowledgments

The author thanks the referees for useful comments. The usual disclaimer applies.

References

[1] K. M. Yi, "Can vertical specialization explain the growth of world trade?" *Journal of Political Economy*, vol. 111, no. 1, pp. 52–102, 2003.

[2] R. Jones, H. Kierzkowski, and C. Lurong, "What does evidence tell us about fragmentation and outsourcing?" *International Review of Economics and Finance*, vol. 14, no. 3, pp. 305–316, 2005.

[3] E. L. C. Lai, "Competition for foreign direct investment in the product cycle," *Japan and the World Economy*, vol. 13, no. 1, pp. 61–81, 2001.

[4] A. J. Glass and K. Saggi, "Intellectual property rights and foreign direct investment," *Journal of International Economics*, vol. 56, no. 2, pp. 387–410, 2002.

[5] C. H. Lu, "Moving up or moving out? A unified theory of R&D, FDI, and trade," *Journal of International Economics*, vol. 71, no. 2, pp. 324–343, 2007.

[6] G. Yang and K. E. Maskus, "Intellectual property rights, licensing, and innovation in an endogenous product-cycle model," *Journal of International Economics*, vol. 53, no. 1, pp. 169–187, 2001.

[7] A. J. Glass and K. Saggi, "Innovation and wage effects of international outsourcing," *European Economic Review*, vol. 45, no. 1, pp. 67–86, 2001.

[8] A. J. Glass, "Outsourcing under imperfect protection of intellectual property," *Review of International Economics*, vol. 12, no. 5, pp. 867–884, 2004.

[9] S. Sayek and F. Şener, "Outsourcing and wage inequality in a dynamic product cycle model," *Review of Development Economics*, vol. 10, no. 1, pp. 1–19, 2006.

[10] F. Şener and L. Zhao, "Globalization, R&D and the iPod Cycle," *Journal of International Economics*, vol. 77, no. 1, pp. 101–108, 2009.

[11] E. L. C. Lai, R. Riezman, and P. Wang, "Outsourcing of innovation," *Economic Theory*, vol. 38, no. 3, pp. 485–515, 2009.

[12] M. Chui, P. Levine, and J. Pearlman, "Winners and losers in a North-South model of growth, innovation and product cycles," *Journal of Development Economics*, vol. 65, no. 2, pp. 333–365, 2001.

[13] H. L. Chu, "Product cycles among three regions with differential R&D abilities," *Economic Modelling*, vol. 26, no. 1, pp. 177–183, 2009.

[14] W. Li, "Global sourcing in innovation: theory and evidence from the information technology hardware industry," 2008.

[15] Economist Intelligence Unit, "Innovation: transforming the way business creates," Tech. Rep., 2007.

[16] M. Nowotarski and L. Nouvelles, "Introducing patents into a major service industry," Markets, Patents & Alliances, LLC, 2003.

[17] G. Grossman and E. Helpman, "Quality ladders and product cycles," *Quarterly Journal of Economics*, vol. 106, pp. 557–586, 1991.

[18] National Science Board, "Science and Engineering Indicators 2008," 2008.