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Globalization, R&D and Endogenous Choice of Technology

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Abstract

This paper constructs a dynamic scale-free North-South model of trade with endogenous innovation. In the North two types of R&D races take place simultaneously within each industry. One is local-sourcing-targeted R&D race, which results in the winner firm manufacturing in the North. The other is outsourcing-targeted R&D race, which culminates in the winner firm manufacturing in the South. In equilibrium, manufacturing costs are lower in the South, but engaging in outsourcing-directed R&D is more costly than local-sourcing directed R&D. Entrepreneurs optimally choose the degree of challenges associated with their R&D projects and thereby determine their ex-post manufacturing productivity levels. More challenging R&D projects require more resources ex-ante but generate more labor saving in manufacturing ex-post.

We study the effects of globalization by considering a reduction in the resource-requirement in outsourcing-targeted R&D (triggered by reduced communication and transportation costs). Such a change reduces the North-South wage gap and increases the mass of outsourcing industries. The aggregate innovation rate increases despite the possibility of a fall in the rate of local-sourcing directed R&D. We also investigate the effects of Southern policies towards FDI. We find that subsidies that reduce the cost of multinational manufacturing in the South may have an adverse effect by reducing the measure of Outsourcing industries. On the other hand subsidies that facilitate the technology transfer efforts of Northern firms unambiguously increase this measure. An increase in either type of subsidy raises the aggregate innovation rate and diminishes the North-South wage gap.

Keywords: Outsourcing, Foreign Direct Investment, innovation, product cycle, endogenous growth

JEL Classification: F12, F23, O14

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1. Introduction

Developing countries are taking over as the most attractive destinations for Foreign Direct Investment (FDI) in recent years. In 2003, China, the U.S. and India ranked 1st, 2nd, and 3rd as the destinations that attracted the largest amounts of FDI. In a recent **UNCTAD** survey, both FDI experts and executives of multinational corporations answer that the five most attractive business locations globally for the years 2005-2006 are in the following order: China, USA, India, Russia and Brazil (See UNCTAD/PRESS/PR/ 2005/031/05/09/05). The recent surge of FDI to the developing countries stemmed from a host of factors, including especially technology improvements which lead to reductions in transport and communication costs, developing-country policies that attract FDI including subsidies, tax holidays, etc., and the emergence of bilateral/multilateral investment treaties.

In the traditional product cycle model as proposed by Vernon (1966) multinational firms serve as the main channel of North-South technology transfer. Entrepreneur firms participate in R&D races to innovate new products. The winner of each race gains access to technology of producing the next-generation product and starts the manufacturing process immediately in the North. By keeping production in close proximity to R&D workers, the successful innovator can efficiently monitor the production process and make the necessary modifications if needed. Over time as production becomes standardized, firms look for ways of shifting production to the South to exploit low-cost manufacturing opportunities. Success in technology transfer implies the shifting of manufacturing to the South. This cycle is reignited when further innovation in the North renders obsolete the products manufactured in the South.

Increasingly though this type of product-cycle framework is facing a serious threat of creative destruction. With the decline in transportation, communication and trade costs, we have witnessed in the past two decades the emergence of globally-integrated production networks through which Northern innovators can *bypass* the Northern standardization stage and shift manufacturing to the South immediately after innovation success. This essentially implies that Northern entrepreneurs now explore technology transfer opportunities *during* the R&D stage without going through a standardization phase that involves mass manufacturing in the North.

Our prime example in this context is Apple's mini i-pod, the state-of-the-art MP3 player of its time. When mini i-pod was introduced in 2002, the labeling at the back of the product read "designed in California, manufactured in Taiwan". In subsequent periods, the labeling for these i-pods remained the same with one exception: Taiwan was replaced with China! There is no evidence that suggests that mass production of mini i-pods has ever taken place in either California or anywhere else in the United States. Globally-integrated innovation-production networks are increasingly becoming the defining feature of multinational companies. Other examples in this context come from a variety of industries such as Dell, Hewlett-Packard Co., Motorola, and Philips, in electronics; and Glaxo-Smith-Kline and Eli Lilly in pharmaceuticals.[1] Simultaneous design and outsourcing efforts are also prevalent in low-tech industries as observed for clothing/footwear retailers such as Gap and Nike, and for household item makers such as Williams Sonoma, and Crate and Barrel. *Business Week* calls such firms "Speed Demons" (March 27, 2006, pp 70-76), which often combine new R&D with immediate outsourcing and mass production in the South to take advantage of lower manufacturing costs and grasp the potential rents.[2]

The literature on endogenous technology transfer and growth has expanded substantially in the past five years.[3] One common feature is that firms can engage in transfer of technology *only after* successful innovation. Thus, the existing literature misses the *i-pod cycle* which constitutes one major aspect of multinationalization. Another feature of this literature is that firms have no choice over their ex-post manufacturing productivity levels. While in the real world, firms devote their R&D efforts not only

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[1] See Naghavi and Ottaviano (2005) for an excellent discussion on the nature and extent of company-level globally integrated production networks.

[2] For instance, i-pod's main components actually involve highly sophisticated products which can only be manufactured by established producers such as Toshiba and Fujitsu. The inventors of i-pod had a good idea to be put into immediate mass production overseas and thus captured the rents.

[3] Glass and Saggi (2001) analyze fragmented technology transfer to the South with endogenous innovation but without imitation. Glass (2004) extends this fragmentation framework to allow for exogenous imitation. Glass and Saggi (2002) use a quality-ladders growth model to study FDI, with both endogenous innovation and imitation but without fragmentation. Dinopoulos and Segerstrom (2005) study endogenous FDI and innovation in a scale-invariant endogenous growth setting without imitation. In a most recent paper, Lu (2006) shows that the firm with the most advanced technology stays in the North, and the less advanced moves to the South. Industries with high R&D productivity have more of the former firms, while those with medium R&D productivity have more outsourcing firms.

to product innovation (which can be targeted at quality improvements or variety expansion) but also to process innovation (which is targeted at increasing manufacturing productivity).[4]

Thus, our objectives in this paper are twofold. One is to embed this *i-pod cycle* into a standard North-South product-cycle framework, and the other is to incorporate both product and process innovations into R&D races. We then study the effects of globalization and FDI policies on the rates of innovation, outsourcing and North-South wage differential.

Our North-South world economy consists of a continuum of industries. In each industry, Northern entrepreneurs participate in R&D races to innovate higher quality products (product innovation). In a typical industry, two types of R&D races take place simultaneously: *local-sourcing-targeted-* and *outsourcing-targeted- R&D races*. The winner of the local-sourcing-targeted R&D race can only manufacture in the North, facing higher labor costs. The winner of the outsourcing-targeted R&D race can immediately manufacture in the South, enjoying lower labor costs. The Northern entrepreneurs engaged in R&D must make two simultaneous decisions *ex-ante*. First, they choose the type of R&D race to participate in (local-sourcing-targeted vs. outsourcing-targeted) and the intensity of their R&D activities. Second, they choose their *ex-post* manufacturing efficiency levels (process innovation), which in turn determine their R&D technology. Northern entrepreneurs targeting a higher manufacturing productivity level *ex-post* must undertake more technologically-challenging R&D *ex-ante*, that is, more scientists and engineers employed per unit of R&D intensity.

In this setting, we capture the *i-pod cycle* in the context of the outsourcing-targeted-R&D race in which innovation and outsourcing efforts are simultaneously undertaken by Northern entrepreneurs. Participation in an outsourcing-targeted R&D race requires engagement in a broadly-defined R&D activity that involves not only scientists and engineers working on innovations but also a sophisticated management team that globally coordinates the innovation and technology transfer efforts of a multinational firm. In our setting, the Speed Demons correspond to the winners of the outsourcing-

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[4] Scherer (1984) reports that 75.5 percent of R&D expenditures are allocated towards quality improvements and 24.5 percent are

targeted R&D races. These firms realize lower production costs and thus higher profit margins and stock market valuation. In a free-entry R&D equilibrium, it implies that participating in an outsourcing-directed R&D race involves relatively higher investments in comparison to a local-sourcing-directed R&D race.

We capture the impact of globalization by considering an increase in the efficiency of outsourcing-targeted R&D activity. We find that this raises the rate of outsourcing-targeted innovation but exerts an ambiguous effect on the rate of local-sourcing-targeted innovation. The aggregate rate of innovation (the sum of the two innovation rates) unambiguously increases. Also, the mass of outsourcing firms increases and the North-South wage gap declines. Glass and Saggi (2001), Glass (2004) and Dinopoulos and Segerstrom (2005) analyze similar issues, but in settings with only local-sourcing-targeted R&D races and thus do not address the compositional R&D effects of globalization as we do. By modeling two distinct R&D races, we find that the aggregate innovation rate increases despite the *possibility* of a decline in local-sourcing directed R&D. In other words, we argue that the increased intensity of outsourcing-directed R&D (i.e., the increased frequency of i-pod cycles) is a major growth promoting factor triggered by globalization, which induces more outsourcing of multinational activities.

We then examine the effects of Southern FDI policies towards outsourcing by considering two policy tools. One is *manufacturing subsidies* which reduce the ex-post production costs of outsourcing firms. The other is *technology transfer subsidies* which facilitate the ex-ante production shifting efforts of entrepreneurs engaged in outsourcing-targeted R&D. As expected, an increase in either type of subsidy raises the aggregate innovation rate and diminishes the North-South wage gap. However, contrasting results arise such that technology-transfer subsidies unambiguously increase the mass (number) of outsourcing firms whereas manufacturing subsidies can *reduce* this measure under certain parametric restrictions. Modeling of process innovations provides the key mechanism that generates this contrasting outcome. Higher manufacturing subsidies reduce the incentives of Northern entrepreneurs to engage in labor saving in the South. This leads to more employment *within* each outsourcing industry, putting

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allocated to process innovations.

downward pressure on the mass of such industries. On the contrary, technology transfer subsidies being directed at pre-production efforts of entrepreneurs do not trigger this type of labor-saving mechanism. Note that since Glass and Saggi (2001), Glass (2004) and Dinopoulos and Segerstrom (2005) do not model process innovation, such contrasting implications of FDI policies do not arise in their models.

Our findings thus imply that technology transfer subsidies can be a better policy tool to attract FDI vis-à-vis manufacturing subsidies. The former brings the desired effects without the possibility of generating a compression in Southern production variety, an adverse outcome that may hinder knowledge spillovers from outsourcing firms to indigenous Southern firms. Given the importance of such spillovers in reaping the benefits of FDI (an issue heavily emphasized in the empirical literature), and the variety of incentives offered by the governments to attract FDI, our distinction in policy outcomes can be of practical use to policy makers.[5] In an extensive survey, Hanson (2001) classifies the policies to promote FDI into two broad categories. The first consists of indirect subsidies that offer exemptions from corporate taxes and import duties. These correspond to our manufacturing subsidies. The second consists of direct subsidies that reduce the cost of all infrastructure associated with building the new plant (which may involve building roads and ports to facilitate transportation, providing access to energy, the cost of land for the plant itself and so on). These correspond to our technology transfer subsidies. Hanson states that indirect subsidies are more visible and thus frequently noted in the literature; however, direct subsidies which are usually offered to firms on a case by case basis also appear to be common. As specific examples Hanson (2001) identifies General Motors and Ford in Brazil, Honda in Turkey, Ford and Volkswagen in Portugal, and IBM and Citibank in Ireland. All of these multinational companies have received direct subsidies from the host governments to facilitate their technology transfer efforts.

From a theoretical point of view, our explicit modeling of process innovations brings forth two main implications. First, in our setting lower cost production opportunities in the South arise due to Northern entrepreneurs' targeted labor-saving efforts and not necessarily due to lower Southern wages.

When it is easier to implement labor-saving technologies in the South, production costs in the South turn out to be lower vis-à-vis the North. This differs from the existing literature where wage differentials (not relative North-South labor saving opportunities) are the primary cause of production cost differentials. Second, our model establishes a substitution mechanism between Northern and Southern labor within each industry in response to changes in the North-South relative wage. When this relative wage increases, entrepreneurs engaged in local-sourcing-targeted R&D (whose efforts eventually leads to Northern employment) raise their labor saving targets in comparison to entrepreneurs engaged in outsourcing-targeted R&D (whose efforts eventually leads to Southern employment). This is a new mechanism that differs from the literature where labor productivity levels are fixed by exogenous parameters.

The present paper also complements an emerging literature in which contractual frictions play a key role in determining plant location and whether production takes place within the boundaries of the firm [Antràs, 2003, Antràs and Helpman, 2004, and Antràs, 2005]. In Antràs (2005), which is most closely related to our work, North-South product cycles emerge due to imperfect enforcement of international contracts. Newly innovated products go through a gradual standardization process at an exogenous rate, and the arrival rate of new products is exogenous. In our model, standardization takes place instantaneously via targeted R&D efforts and the arrival of new products is endogenous.

In addition, the present paper is closely related to the recent literature on outsourcing and fragmentation, which so far has focused mainly on why fragmentation and outsourcing occur. For instance, Jones and Kierzkowski (1990) point out that the existence of fixed costs and thus increasing returns favor integrated production at low outputs, but fragmentation at high outputs. Grossman and Helpman (2003) explain outsourcing as tradeoffs between production and search, the latter of which is affected by market thickness and the contracting environment. Kohler (2004) develops a dual representation of fragmentation technology, and investigates outsourcing in response to a decline in the final output price of a multistage industry. Long, Riezman, and Soubeyran (2004) show that services link

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[5] Indeed, Blomström and Kokko (2003) provide abundant evidence not supporting across-the-board incentives to attract FDI,

production blocks, and allow the breaking up of integrated production. Free trade and the growth of the service sector facilitate fragmentation and outsourcing. As a complement to the above, our model shows that technology improvement is a driving force for the recent surge of multinational outsourcing activities.

The rest of the paper is organized as follows. Section 2 outlines the building blocks of the model and establishes the steady-state equilibrium. Sections 3 and 4 present the comparative steady-state results. Section 5 concludes. Proofs of all propositions are relegated to the Appendices available upon request.

2. The Model

We consider a world economy with two countries: the North and the South. There is a continuum of industries indexed by ω. The size of household population in country i at time t for $i \in \{N, S\}$ is $L^i(t) = L_0^i e^{nt}$, where L_0^i is the initial level of population per household, and $n > 0$ is the rate of population growth.

2.1 Household behavior

In each country, there exists a continuum of identical households, which takes goods prices, factor prices, and the interest rate as given and maximizes its utility over an infinite horizon,

$$U^i = \int_0^\infty L_0^i e^{-(\rho-n)t} \log u^i(t)\, dt, \qquad \text{for } i = N, S, \tag{1}$$

where ρ is the subjective discount rate, and $\log u^i(t)$ is the instantaneous utility of each household member defined as:

$$\log u^i(t) \equiv \int_0^1 \log \Big[\sum_j \lambda^j x^i(j,\omega,t)\Big] d\omega, \qquad \text{for } i = N, S, \tag{2}$$

where $x^i(j,\omega,t)$ is the quantity demanded of a product with quality j in industry ω at time t. The size of each incremental quality improvement (the innovation size) is denoted by $\lambda > 1$. Therefore, the total quality of a good after j innovations is λ^j.

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because such FDI incentives alone are not sufficient to attract foreign technology.

Each household in country *i* allocates its per capita consumption expenditure for each product line, $c^i(t)$, to maximize $u^i(t)$ given prices at time *t*. Note that all products within an industry are perfect substitutes; thus, households buy only the products with the lowest quality-adjusted prices. Products enter the utility function symmetrically; therefore, households spread their consumption expenditure evenly across goods. The resulting per capita product demand for each product line is $x^i(j,\omega,t) = c^i(t)/p$, where p is the relevant market price for the product that has the lowest quality-adjusted price.

Given the static demand behavior, the household's maximization problem over all product lines is simplified to maximizing

$$\int_0^\infty L_0^i \, e^{-(\rho-n)t} \log c^i(t)\, dt, \qquad \text{for } i = N, S, \tag{3}$$

subject to the budget constraint $\dot{B}^i(t) = W^i(t) + r^i(t)B^i(t) - c^i(t)L^i(t)$, where $B^i(t)$ denotes the financial assets owned by the household, $W^i(t)$ is the family's expected wage income of the household and $r^i(t)$ is the instantaneous rate of return. The solution to this optimization gives the standard differential equation

$$\frac{\dot{c}^i(t)}{c^i(t)} = r^i(t) - \rho, \qquad \text{for } i = N, S. \tag{4}$$

At the steady-state equilibrium, c^i remains fixed; thus, the market interest rate is equal to the subjective discount rate: $r^i(t) = r = \rho$. From this point on we will focus on the balanced-growth path behavior of the economy; hence, we drop the time index for the variables that remain constant.

2.2 Product Cycle Dynamics

All industries in the continuum are structurally identical. In each industry, Northern entrepreneurs participate in R&D races to innovate higher quality products. Successful innovators gain access to the technology of producing the state-of-the-art quality products. Northern entrepreneurs can *ex-ante* choose the type of R&D that will determine the eventual location of production if they become successful in R&D. More specifically, Northern entrepreneurs choose between *local-sourcing-targeted R&D* which leads to manufacturing in the North and *outsourcing-targeted R&D* which leads to manufacturing in the

South. We assume that no complementarity exists between the two types of R&D so that each entrepreneur just focuses on one type.

All industries in the continuum are targeted by both outsourcing and local-sourcing directed R&D. Entrepreneurs successful in R&D exercise temporary monopoly power in the global market. In this setting, two types of industries can emerge: Northern industries and Outsourcing industries. The transition rates between industries are governed by stochastic Poisson processes. Entrepreneurs successful in local-sourcing-targeted R&D manufacture their top quality products using Northern resources. We refer to this type of industries as *Northern industries*. In a typical industry, the probability of success in local-sourcing-targeted R&D is $\iota_N dt$, where ι_N denotes the intensity of local-sourcing-targeted R&D and dt represents a small interval of time. Entrepreneurs successful in outsourcing-targeted R&D shift production to the South instantaneously and use the South as a platform to supply to the world market. We refer to such industries as *Outsourcing industries*. In a typical industry, the probability of success in outsourcing-targeted R&D is $\iota_O dt$, where ι_O is the intensity of outsourcing-targeted R&D.

2.3 Stock Market Valuations

Given the above product cycle dynamics, it is straightforward to derive the stock market valuations of firms. Consider first the determination of $V_N(t)$, the value of a successful Northern innovator producing in the North. Over a time interval dt, the stockholders of this firm receive $\pi_N(t)$ as dividend payments. With probability $(\iota_O + \iota_N)\, dt$, further innovation may take place in this industry. In this event the stockholders realize a loss of $V_N(t)$. With probability $1 - (\iota_O + \iota_N)dt$, no further innovation takes place, and the firm's valuation changes by $\dot{V}_N\, dt$. Investors fully exploit the arbitrage opportunities; thus the expected rate of return from a stock issued by a Northern firm must be equal to the risk-free market interest rate $\rho(t)$. This implies (taking limits as $dt \to 0$):

$$V_N(\omega,t) = \frac{\pi_N(t)}{\rho + \iota_N + \iota_O - [\dot{V}_N(t)/V_N(t)]} \tag{5}$$

Consider now the valuation of an Outsourcing firm $V_O(t)$. Over a time interval dt, the stockholders of this firm receive $\pi_O(t)$ as dividend payments. With probability $(\iota_O + \iota_N)\,dt$, further innovation may take place in this industry and the stockholders realize a loss in value of $V_O(t)$. With probability $1 - (\iota_O + \iota_N)\,dt$, the outsourcing firm maintains its leadership position, and the firm's value changes by $\dot{V}_O(t)$. Again, the no-arbitrage condition requires (taking limits as $dt \to 0$):

$$V_O(\omega,t) = \frac{\pi_O(t)}{\rho + \iota_N + \iota_O + [\dot{V}_O(t)/V_O(t)]}. \tag{6}$$

2.4 Manufacturing and Product Markets

In Northern industries, the unit labor requirement in final good manufacturing is m_N. Hence marginal cost of production is $MC_N = m_N w$. In Outsourcing industries, the unit labor requirement is m_O. Since the wage rate in South is normalized to one, the marginal cost of production is: $MC_O = m_O(1 - \sigma_O)$, where σ_O is the subsidy rate for outsourced manufacturing. Following the literature, we assume that every time an innovation takes place in the North, some technology diffusion takes place. More specifically, the inferior technology becomes common knowledge to all firms in the global economy.[6] For follower firms, who have access to the one-step-down technology, the unit labor requirement of production is set to one without loss of generality. We restrict attention to the steady-states in which *i)* Northern producers realize positive profits, *ii)* marginal manufacturing costs in the North are higher than those in the South *iii)* the Northern relative wage satisfies $w > 1$. Hence, manufacturing costs must comply with:

$$\lambda > MC_N > MC_O > 1 \qquad \Rightarrow \qquad \lambda > m_N w > m_O(1 - \sigma_O) > 1. \tag{7}$$

With $w > 1$, the Southern followers can always undercut their Northern counterparts in a Bertrand pricing game. That is, only Southern followers can effectively compete with Northern quality leaders. In a typical product market, a Northern quality leader charges the limit price $\lambda MC_S - \varepsilon = \lambda - \varepsilon$ (where ε is an

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[6] See for instance see Glass and Saggi (2001) and Sayek and Sener (2006).

infinitely small positive number) and drives the Southern followers out of the market. Thus, the profit flow of a quality leader manufacturing in the North is:

$$\pi_N(t) = \frac{E(t)}{\lambda}(\lambda - MC_N), \tag{8}$$

where $E(t) = c^N L^N(t) + c^S L^S(t)$ stands for the global consumption expenditure in each product line. Similarly, the profit flow of a quality leader outsourcing production to the South is:

$$\pi_O(t) = \frac{E(t)}{\lambda}(\lambda - MC_O). \tag{9}$$

Since $MC_N > MC_O$, we must have $\pi_O > \pi_N$, which implies that outsourced production generates larger profit flows compared to local production.

2.5 Endogenous Labor Saving Technology

Northern entrepreneurs employ Northern workers to perform R&D activities. Let X_N and X_O denote respectively the difficulty of conducting local-sourcing- and outsourcing-targeted R&D. These are introduced to remove the scale effects from the endogenous growth setting. The unit labor requirement for the two types of R&D can be written respectively as $a_N X_N$ and $a_O X_O$. Further denote with m_O and m_N the unit labor requirement in manufacturing of final goods for Outsourcing and Northern industries respectively. In addition to their ex-ante choice of which R&D race to participate in (local-sourcing or outsourcing-directed R&D race), each entrepreneur determines its ex-post manufacturing productivity level by choosing ex-ante the challenge level for its R&D activity. Specifically, as the target level of m_i decreases (i.e., manufacturing productivity increases) for $i \in \{N,O\}$, it becomes more challenging to innovate and thus the unit labor requirement per unit of R&D activity a_i increases. This scheme is captured by the following specification:

$$a_i(m_i), \qquad \text{with } a_i'(m_i) < 0 \text{ and } a_i''(m_i) > 0 \quad \text{for } i \in \{N,O\}.$$

The second derivative being positive implies that as m_i falls, it becomes more challenging to generate a given decline in m_i and thus a larger increase in a_i is required.

To obtain closed form solutions we assume:

$$a_i(m_i) = A_i m_i^{-\phi_i}, \qquad \text{for } i \in \{N,O\}, \tag{10}$$

where $A_i > 0$ is a constant. And $\phi_i > 0$ is the elasticity that measures the percentage change in $a_i(m_i)$ divided by the percentage change in m_i, because:

$$\frac{a_i'(m_i)m_i}{a_i(m_i)} = -\phi_i . \qquad \text{for } i \in \{N,O\}. \tag{11}$$

The lower the level of ϕ_i, the larger is the labor-saving efficiency of the R&D technology.

A few points of clarification can be made here. As in the standard quality-ladders growth literature, success in R&D implies that the entrepreneur gains access to the technology of producing a product that is λ times better than the existing one (product innovation). Moreover, firms can target their R&D efforts at labor saving (process innovation). By intensifying these efforts, firms can realize gains in profit margins and thereby raise their stock market valuations. However, engaging in labor-saving technology is costly as reflected in increased R&D resource requirements. As we will see below, the optimal level of m_i will be derived from an optimality condition which equates the incremental gain in firm valuation to the incremental increase in R&D costs.[7]

2.6 Optimal Choices of R&D Intensities and Productivity Targets

We normalize the wage rate in the South to one and define w as the wage rate of Northern labor relative to Southern labor. A typical entrepreneur firm indexed by j engaged in local-sourcing-targeted R&D chooses its target manufacturing productivity level m_N to maximize:

$$V_N(m_N, t)\,\iota_{Nj}\,dt - wa_N(m_N)\,X_N(t)\,\iota_{Nj}dt.$$

The first order condition for m_N is (for an interior solution):[8]

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[7] This is in the same spirit as Grossman and Helpman (1991, p. 100) who endogenize innovation size λ. In contrast, we endogenize production technology, which is more relevant to issues involving outsourcing. Glass and Saggi (2002) also have endogenous innovation size and consider licensing and direct investment in a symmetric two-country economy.

[8] The second order condition (soc) for a maximum is $V_N''(m_N) - w\,X_N(t)\,a_N''(m_N) < 0$, which holds with $V_N'' = 0$ and $a_N'' > 0$.

$$\frac{\partial V_N}{\partial m_N} = w \frac{\partial a_N}{\partial m_N} X_N(t) . \tag{12}$$

Free-entry in local-sourcing-targeted R&D races drives expected profits down to zero. Thus,

$$V_N(t) = w a_N X_N(t). \tag{13}$$

Similarly, a typical entrepreneur firm engaged in outsourcing-targeted R&D chooses its target manufacturing productivity level m_O to maximize:

$$V_O(t)\, \iota_{Oj}\, dt - w a_O(m_O)\, (1 - \sigma_{\iota O}) X_O(t)\, \iota_{Oj}\, dt,$$

where $\sigma_{\iota O}$ is the subsidy rate for outsourcing-targeted R&D. The first order condition for m_O is:[9]

$$\frac{\partial V_O}{\partial m_O} = w \frac{\partial a_O}{\partial m_O} (1 - \sigma_{\iota O}) X_O(t) , \tag{14}$$

Free-entry in outsourcing-targeted R&D races drives expected profits down to zero. Thus,

$$V_O(t) = w a_O (1 - \sigma_{\iota O}) X_O(t) . \tag{15}$$

2.7 Equilibrium Levels of Manufacturing Productivity

From the equation pairs (12)-(13) and (14)-(15), it immediately follows that:

$$\frac{V_i'}{V_i} = \frac{a_i'}{a_i} \qquad \text{for } i \in \{N,O\}, \tag{16}$$

where $V_i' = \partial V_i / \partial m_i$ and $a_i' = \partial a_i / \partial m_i$. One can obtain expressions for V_N'/V_N and a_N'/a_N from (5) and (11), respectively. Substituting these into (16) and solving for m_N gives the optimal level of m_N as:

$$m_N(w) = \frac{\lambda \phi_N}{w(1 + \phi_N)} . \tag{17}$$

where $\partial m_N / \partial w < 0$. Similarly, one can obtain expressions for V_O'/V_O and a_O'/a_O from (6) and (11) respectively. Substituting these into (16) and solving for m_O gives the optimal level of m_O as:

$$m_O = \frac{\lambda \phi_O}{(1 + \phi_O)(1 - \sigma_O)} . \tag{18}$$

It follows that the relative unit labor requirements between local and outsourced manufacturing is

$$\frac{m_N}{m_O}=\frac{(1-\sigma_O)\left(1+\frac{1}{\phi_O}\right)}{w\left(1+\frac{1}{\phi_N}\right)} \tag{19}$$

Lemma 1: *As the Northern relative wage w increases, entrepreneurs raise their relative labor-saving targets in the North, which translates into a reduction of* m_N/m_O, *i.e., the North-South ratio of the unit labor requirement in manufacturing falls.*

Lemma 1 establishes an endogenous substitution mechanism between Southern and Northern labor *within* each industry. To the best of our knowledge, such a mechanism has not been considered in existing R&D-based North-South product-cycle models, where m_N and m_O are fixed by construction.

Substituting for m_N and m_O in (7) using (17) and (18), we find that $MC_N > MC_O$ if and only if $\phi_N > \phi_O$. Recall that ϕ_i is an elasticity term that measures the percentage change in $a_i(m_i)$ divided by the percentage change in m_i. Hence, the condition $\phi_N > \phi_O$ implies in percentage terms that a given increase in the challenge of R&D generates a larger productivity gain in outsourced production compared to locally-sourced production.

Lemma 2: *Low cost production opportunities in the South are endogenously tied to the degree with which implementability of labor-saving technologies differ between the North and the South. When it is easier to implement labor-saving technologies in the South relative to the North, i.e.,* $\phi_N > \phi_O$, *production costs become lower in the South than in the North.*[10]

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[9] Note again that the soc for a maximum is $V_O''(m_O) - w X_O(t)\, a_O''(m_O)(1-\sigma_O) < 0$, since $V_O'' = 0$ and $a_O'' > 0$ hold.

Combining (18) with $m_O(1 - \sigma_{\iota O}) > 1$ from (7) implies the restriction $\phi_O > 1/[\lambda/(1 - \sigma_O) - 1]$, which we assume to hold. Note that for $\sigma_O = 0$, this requires $\phi_O > 1/(\lambda - 1)$. Hence, if $\lambda < 2$, we need to have $\phi_O > 1$; and if $\lambda > 2$, we need to have $\phi_O < 1$. Using (17) and (18) we obtain the unit labor requirements in local-sourcing- and outsourcing-targeted R&D as

$$a_N(w) = A_N\left(\frac{\lambda\phi_N}{w(1+\phi_N)}\right)^{-\phi_N} \text{ and } a_O = A_O\left(\frac{\lambda\phi_O}{(1+\phi_O)(1-\sigma_O)}\right)^{-\phi_O}, \tag{20}$$

where A_N and A_O are constants as given in (10).

Note that from (17) and (18) the profit margins of a Northern and a Southern firm can be simplified as:

$$\lambda - MC_N = \frac{\lambda}{(1+\phi_N)} \text{ and } \lambda - MC_O = \frac{\lambda}{(1+\phi_O)}. \tag{21}$$

2.8 Industry flows

Denote with n_N and n_O the fraction of Northern and Outsourcing industries, respectively. Constant industry shares at the steady-state require that flows in and out of each industry must be exactly balanced. Consider the Northern industries. Every time a Northern entrepreneur participating in an outsourcing-targeted R&D race that is directed at a Northern industry becomes successful, the Northern industry is transformed into an Outsourcing industry. Hence, the aggregate flow out of the Northern industry pool is $\iota_O n_N$. On the other hand, every time a Northern entrepreneur participating in a local-sourcing-targeted R&D race that is directed at an Outsourcing industry becomes successful, the industry to which the R&D is directed becomes a Northern industry. Thus, the aggregate flow into the Northern industry pool is $\iota_N n_O$. Constant n_N requires:

$$n_O \iota_N = \iota_O n_N. \tag{22}$$

Finally, we have

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[10] Note that when $\phi_N > \phi_O$, for local-sourcing directed R&D to take place, we also need $k_N L(t)\, a_N(m_N) < k_O L(t) a_O(m_0)$ to hold. In

$$n_N + n_O = 1, \tag{23}$$

which ensures that n_O also becomes constant.

2.9 Labor Markets

In the North, the labor market equilibrium implies:

$$L^N(t) = \iota_N a_N X_N(t) + \iota_O a_O X_O(t) + n_N(E(t)/\lambda)m_N, \tag{24}$$

where $\iota_N a_N X_N(t)$ and $\iota_O a_O X_O(t)$ respectively capture the labor demand coming from local-sourcing and outsourcing-targeted R&D, and $n_N(E(t)/\lambda)m_N$ measures the manufacturing labor demand coming from Northern industries.

In the South, the labor market equilibrium implies:

$$L^S(t) = n_O(E(t)/\lambda)m_O, \tag{25}$$

where $n_O(E(t)/\lambda)m_O$ measures the manufacturing labor demand coming from Outsourcing industries.

2.10 Steady-State Equilibrium

We begin the steady-state analysis by removing the scale effects in the spirit of Dinopoulos and Thompson (1996, 2000). In particular, we set $X_N(t) = k_N L(t)$ and $X_O(t)= k_O L(t)$, where $k_N > 0$, $k_O > 0$ and $L(t)= L^S(t) + L^N(t)$. With scale effects removed the system can now be expressed in per capita terms. Define per capita consumption expenditure of a representative global citizen as $c(t) \equiv E(t)/L(t)$, and the size of the Southern population relative to the Northern one as $\eta^S \equiv L^S(t)/ L^N(t)$. It follows that $L^N(t)= L(t)/(1+\eta^S)$ and $L^S(t) = L(t)\eta^S/(1+\eta^S)$.

At the steady-state equilibrium a_N, a_O, ι_N, ι_O, n_N, n_O, w, and c remain constant whereas $V_N(t)$, $V_O(t)$, $X_O(t)$, $X_N(t)$, $\pi_N(t)$, $\pi_O(t)$, $E(t)$ grow at the rate of n. All of these variables are endogenously determined.

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the Appendix we show that this condition indeed holds under $\phi_N > \phi_O$.

Using the flow conditions (22) and (23), the industry fractions can be expressed in terms of the endogenous variables ι_N and ι_O:

$$n_N = \frac{\iota_N}{\iota_N + \iota_O}, n_O = \frac{\iota_O}{\iota_N + \iota_O} \tag{26}$$

Substituting the industry fractions from (26) into (24) and (25), using the specifications for $X_O(t)$ and $X_N(t)$ along with $c(t) \equiv E(t)/L(t)$, $L^N(t) = L(t)/(1+\eta^S)$ and $L^S(t) = L(t)\eta^S/(1+\eta^S)$, one can express the Northern and Southern labor market conditions in four unknowns c, w, ι_N and ι_O.

$$1/(1+\eta^S) = \iota_N a_N(w) k_N + \iota_O a_O k_O + n_N(\iota_N, \iota_O)(c/\lambda) m_N(w), \qquad (c, \iota_N, \iota_O, w) \tag{27}$$

$$\eta^S/(1+\eta^S) = n_O(\iota_N, \iota_O)(c/\lambda) m_O. \qquad (c, \iota_N, \iota_O) \tag{28}$$

To complete the system, we need to use the stock market valuation and zero-profit conditions for local-sourcing and outsourcing-targeted R&D. Substituting $V_N(t)$ from (13) and $\pi_N(t)$ from (8) into (5) using (21) and $c(t) \equiv E(t)/L(t)$ gives:

$$w a_N(w) k_N = \frac{c/(1+\phi_N)}{\rho + \iota_N + \iota_O - n}. \qquad (c, \iota_N, \iota_O, w) \tag{29}$$

Similarly substituting $V_O(t)$ from (14) and $\pi_O(t)$ from (9) into (6) using (21)and $c(t) \equiv E(t)/L(t)$ gives:

$$w a_O(1-\sigma_{\iota O}) k_O = \frac{c/(1+\phi_O)}{\rho + \iota_N + \iota_O - n}. \qquad (c, \iota_N, \iota_O, w) \tag{30}$$

Conditions(27)-(30) constitute a system of four equations in four unknowns (c, ι_N, ι_O, w). The rest of the endogenous variables can be derived in a recursive fashion using the equilibrium levels of (c, ι_N, ι_O, w).

We label the steady-state equilibrium levels by "*". We obtain an expression for w by taking ratio of the zero-profit conditions in outsourcing and local-sourcing targeted R&D, equations (29) and (30), respectively. This yields:

$$K \equiv \frac{a_N(m_N(w))}{a_O(m_O)(1-\sigma_{\iota O})} \frac{k_N}{k_O} = \frac{1+\phi_O}{1+\phi_N} \equiv \Pi, \tag{31}$$

K measures the *relative unit cost* between local-sourcing and outsourcing targeted R&D, whereas *Π* measures the *relative profit margin* between locally-sourced and outsourced production $\frac{\lambda - MC_N}{\lambda - MC_O}$. Note that $\partial(a_N(w)/a_O)/\partial w > 0$; thus, *K* is an increasing function of *w*, as shown by the upward sloping curve in Figure 1. Intuitively, an increase in *w* raises Northern production costs and induces entrepreneurs engaged in local-sourcing-targeted R&D to raise their productivity targets (i.e., a fall in m_N). This in turn renders local-sourcing-targeted R&D more challenging and thus increases the relevant resource requirement $a_N(w)$. On the other hand *Π* does not respond to variations in *w* and is shown by a horizontal curve in Figure 1. The intersection of the two curves determines the equilibrium level w^*. Observe that by equation (31) any parameter change that leads to an increase in the profitability of local-sourcing directed R&D relative to outsourcing-targeted R&D raises the Northern relative wage w^*. Also when $\phi_N > \phi_O$, we have $K < 1$, implying that participating in an outsourcing-targeted R&D case is more costly than participating in a local-sourcing-targeted R&D.

We can obtain a closed form solution for w^* by substituting for $a_N(w)$ and a_O from equation (20) into (31), which gives:

$$w^* = \frac{\lambda\phi_N}{(1+\phi_N)}\left(\frac{(1+\phi_N)}{A_R k_R (1-\sigma_{\iota O})(1+\phi_O)}\left(\frac{\lambda\phi_O}{(1-\sigma_O)(1+\phi_O)}\right)^{\phi_O}\right)^{-1/\phi_N}, \qquad (32)$$

where $A_R \equiv A_O/A_N$ and $k_R \equiv k_O/k_N$. Observe that *w* is pinned down by the parameters of the model. Substituting for w^* from (32) into (17)~(20) immediately gives the equilibrium levels of m_i^* and a_i^* for $i \in \{N,O\}$ in terms of the parameters as well. For future use, we note the partial derivatives with respect to the parameters of interest A_R, $\sigma_{\iota O}$ and σ_O.

$$a_N^* = a_N(\overset{+}{A_R}, \overset{-}{\sigma_{\iota O}}, \overset{-}{\sigma_O}) \qquad a_O^* = a_N(\overset{+}{A_R}, \overset{0}{\sigma_{\iota O}}, \overset{-}{\sigma_O}) \qquad (33a)$$

$$m_N^* = m_N(\overset{-}{A_R}, \overset{-}{\sigma_{\iota O}}, \overset{+}{\sigma_O}) \qquad m_O^* = m_O(\overset{0}{A_R}, \overset{0}{\sigma_{\iota O}}, \overset{+}{\sigma_O}) \qquad (34b)$$

Next, we substitute w^* from (32) into (28), to express *c* in terms of (ι_N, ι_O). This yields:

$$c(\iota_N,\iota_O)=(\rho+\iota_N+\iota_O-n)\phi_N A_N k_N \lambda\left(\frac{(1+\phi_N)}{A_R k_R(1-\sigma_{\iota O})(1+\phi_O)}\left(\frac{\lambda\phi_O}{(1-\sigma_O)(1+\phi_O}\right)^{\phi_O}\right)^{-(1+\phi_N)/\phi_N} \tag{34}$$

Note that $c(\iota_N,\iota_O)=c(\overset{+}{\iota_N},\overset{+}{\iota_O},\overset{+}{A_R},\overset{-}{\sigma_{\iota O}},\overset{-}{\sigma_O})$.

Substituting for c from (34) into (27), we can express the Northern and Southern labor market equilibrium conditions solely in terms of ι_N and ι_O

$$\frac{1}{1+\eta^S}=\iota_N a_N{}^* k_N+\iota_O a_O{}^*+[n_N(\overset{+}{\iota_N},\overset{-}{\iota_O})c(\overset{+}{\iota_N},\overset{+}{\iota_O})m_N{}^*/\lambda], \tag{35}$$

$$\frac{\eta^S}{1+\eta^S}=n_O(\overset{-}{\iota_N},\overset{+}{\iota_O})c(\overset{+}{\iota_N},\overset{+}{\iota_O})m_O{}^*/\lambda. \tag{36}$$

where a_i* and m_i* for $i\in\{N,O\}$ are as in (33a) and (34b), and n_N and n_O come from (26).

We are now in a position to establish the steady-state equilibrium by plotting (35) and (36) in (ι_N, ι_O) space. To simplify the exposition, we will evaluate the derivatives and intercepts as the net discount rate $\rho-n$ approaches zero. This is a standard assumption commonly invoked in quality-ladder models of growth.[11] We conducted extensive numerical simulations to check the robustness of our results. Unless otherwise noted, the main results are robust to assuming positive levels for $\rho-n$.

Equation (35), which summarizes the Northern labor market equilibrium, identifies a downward sloping curve in (ι_N, ι_O) space labeled as **LN** in Figure 1. For a given ι_O, a higher ι_N affects the Northern labor demand via three channels. First, it raises the level of employment in local-sourcing-targeted R&D $\iota_N a_N k_N$. Second it increases the proportion of Northern industries n_N. These two effects work to raise the Northern labor demand. Third, a higher ι_N indirectly puts upward pressure on per capita consumption expenditure c and thus reinforces the increased Northern labor demand. To see this, note that a higher ι_N increases the replacement rate within each industry and thus lowers the stock market valuation of firms. Maintaining the zero-profit conditions in R&D requires an increase in c [equation (34)]. To sum up,

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[11] See for instance Glass and Saggi (1999, 2002) among others.

restoring equilibrium calls for a fall in ι_O, which reduces the level of employment in outsourcing-targeted R&D $\iota_O a_O k_O$ and thus the demand for Northern labor. The lowered ι_O also exerts two competing effects on the Northern labor demand by increasing n_N and reducing c (via the same replacement channel discussed for ι_N). However, as $\rho - n \to 0$, these two effects exactly cancel out. To sum up, equation (35) implies an inverse relationship between ι_O and ι_N. Hence, the downward sloping LN curve in Figure 1.

Equation (36), which summarizes the Southern labor market equilibrium, identifies a vertical line in (ι_N, ι_O) space labeled as **LS** in Figure 1. For a given ι_O, a higher rate of local-sourcing-targeted R&D ι_N triggers two opposing forces on the Southern labor demand: it reduces the proportion of Outsourcing industries n_O and thus the Southern labor demand, but raises the replacement rate and thus increases the level of c that is required to maintain the R&D zero profit condition. When $\rho - n \to 0$, these two forces exactly offset each other and thus variations in ι_N exert no influence on equation (36). This implies that the equilibrium level of ι_O is solely determined by (36). Hence the vertical LS curve in Figure 1.[12], [13]

3. Comparative Steady-State Analysis

3.1 Globalization in the form of a decline in A_O

We first examine the case of a decline in A_O which reflects an increase in the efficiency of outsourcing-targeted R&D. It leads to a fall in $A_R \equiv A_O/A_N$. This exercise is motivated by the substantial decline in

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[12] The existence and uniqueness of the equilibrium can be easily established by evaluating the limits when $\rho - n \to 0$. To simplify notation, we set the subsidy rates $\sigma_{\iota O} = \sigma_O = 0$. On the LN curve as $\iota_O \to 0$, $\iota_N \to 1/[(1+\eta_S)(a_N{}^* k_N + \Lambda m_N{}^*)]$, where $\Lambda \equiv (A_R k_R)^{\frac{1+\phi_N}{\phi_N}} \lambda^{\frac{-\phi_O(1+\phi_N)}{\phi_N}} \Gamma$, and as $\iota_N \to 0$, $\iota_O \to 1/[(1+\eta_S)a_O{}^* k_O{}^*]$. On the LS curve $\iota_O \to \eta_S/[(1+\eta_S)\Lambda m_O{}^*]$. The necessary and sufficient condition for uniqueness is $1/[(1+\eta_S)a_O{}^* k_O{}^*] > \eta_S/[(1+\eta_S)\Lambda m_O{}^*]$. Substituting in the relevant expressions this condition boils down to: $\lambda\phi_N\phi_O > \eta_S(1+\phi_N)\left(\frac{(1+\phi_N)}{(1+\phi_O)(A_R k_R)}\left(\frac{\lambda\phi_O}{1+\phi_O}\right)^{\phi_O}\right)^{1/\phi_N}$.

[13] Combining the wage equation (32) with the existence and uniqueness condition above implies $w^* > \eta_S$. In words, when the existence and uniqueness condition is satisfied, the Northern wage turns out to be larger than the Southern wage if and only if the South is more populated than the North, a condition which has real world relevance.

transportation and communication costs observed in the past three decades, which we view as the main factor that facilitated the simultaneous innovation-outsourcing efforts of Northern entrepreneurs.[14]

PROPOSITION 1: *An increase in the efficiency of outsourcing-targeted R&D captured by a fall in* A_O,

a. *reduces the wage rate of Northern labor relative to Southern labor* w^*,
b. *increases the rate of innovation in outsourcing-targeted R&D* ι_O^*,
c. *increases the rate of innovation in local-sourcing-targeted R&D* ι_N^* *iff* $\iota_N/\iota_O > 1/[\phi_N(1+\phi_O)](1 - \sigma_{\iota O})$,
d. *increases the aggregate rate of innovation* ι_A^*,
e. *increases the proportion of Outsourcing industries* n_O,
f. *increases the labor requirement in local-sourcing manufacturing* m_N *and leaves the resource requirement in outsourcing manufacturing* m_O *the same; thus,* m_N^*/m_O^**increases.*

Proposition 1 shows that technology improvement is a driving force for the recent surge of multinational outsourcing activities, which complements the explanations offered in the existing literature, such as Jones and Kierzkowski (1990), Long, Riezman, and Soubeyran (2004), and Grossman and Helpman (2003), etc. Note also that in Glass and Saggi (2001), Glass (2004) and Dinopoulos and Segerstrom (2005), there is only local-sourcing-targeted R&D race, and thus they do not address the compositional R&D effects of globalization.

Now let us identify the wage impact using (31). A decline in A_O triggers a fall in a_O/a_N and thereby increases the profitability of outsourcing-targeted R&D relative to local-sourcing-targeted R&D. For a given w, the K curve in Figure 2 shifts up. Equilibrium is restored via a fall in w^*, which reduces the relative profitability of outsourcing-targeted R&D because $\partial[wa_N(w)/a_O]/\partial w > 0$.

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[14] See Tang (2006, Figures 2 and 3) for detailed evidence on declining transport and communication costs, and Feenstra (1998) for a discussion of how such cost declines improve the efficiency of international outsourcing.

The reduction in w^* discourages the labor-saving efforts of Northern entrepreneurs engaged in local-sourcing-targeted R&D. As a result, the relative unit labor requirement between locally-sourced and outsourced manufacturing m_N^*/m_O^* increases [See equation (19)]. With less ambitious productivity targets, entrepreneurs engaged in local-sourcing-targeted R&D can now hire fewer units of scientists and engineers per unit of R&D. This implies a reduction in the relative R&D labor requirement a_N^*/a_O^*. Note that with Southern wages normalized to one, m_O and a_O do not actually respond to variations in w^*. Thus the relative increase in m_N^*/m_O^* translates into an absolute increase in m_N^* and the relative decrease in a_N^*/a_O^* implies an absolute decrease in a_N^*.

Before analyzing the labor market effects, it is useful to examine the change in c holding ι_N and ι_O constant. The reduction in w^* induced by the lower A_O decreases the R&D costs. To maintain the zero profit condition in R&D implied by (29) and (30), there must be a fall in the rewards coming from sales and hence a decline in c.

Next, we examine the changes in ι_N^* and ι_O^* by identifying the shifts in LN and LS. Holding ι_N and ι_O constant, we observe from (35) which characterizes the LN curve that a fall in A_O affects the Northern labor demand via four channels. First, a lower A_O directly reduces a_O and thus the labor demand coming from outsourcing-targeted R&D. Second, the reduction in a_N^* induced by a lower A_O decreases the labor demand coming from local-sourcing-targeted R&D. Third, the increase in m_N^* induced by a lower A_O raises the demand for Northern manufacturing labor. Fourth, the downward pressure in c triggered by the lower A_O reduces product sales and thereby the demand for Northern manufacturing labor. It follows from (34b) and (34) that cm_N^* declines. The last two effects combined lead to reduced labor demand, and as a consequence, the sum of all effects lowers the demand for Northern labor. For a given ι_O, this relaxes the Northern resource constraint, allowing for an expansion in local-sourcing-targeted R&D ι_N. Hence, the LN curve shifts to the right.

For the LS curve, defined by (36), the only effect of a fall in A_O works through the induced decline in c, which reduces the demand for Southern manufacturing labor. This generates room for an expansion in outsourcing-directed R&D activity ι_O and thus the LS curve shifts to the right.

Figure 2 shows that a lower A_O unambiguously increases ι_O*. On the other hand, the change in ι_N* appears to be indeterminate. Further algebra reveals that ι_N* increases if and only if $\iota_N/\iota_O > 1/[\phi_N(1+\phi_O)]$. With regards to industry configuration, we observe that the higher ι_O* puts upward pressure on the equilibrium share of Outsourcing industries n_O*, whereas the change in ι_N* counteracts this effect if $\iota_N/\iota_O > 1/[\phi_N(1+\phi_O)]$ and reinforces it otherwise. Comparative statics results imply that n_O* unambiguously increases. Obviously, with $n_O + n_N = 1$, the equilibrium share of Northern industries n_N* declines. Observe that n_O* and m_N*/m_O* both increase in response to the fall in A_R. These findings imply that more labor-saving in Southern production and more outsourcing can occur *concurrently*. Also, we find that the aggregate innovation rate $\iota_A* = \iota_N* + \iota_O*$ unambiguously increases despite that the rise in ι_O increases ι_A whereas the change in ι_N may reinforce or counteract this effect.

Our findings may seem similar to Dinopoulos and Segerstrom (2005) and Glass and Saggi (2001) in that these papers also find that an increase in the efficiency of technology transfer reduces the North-South wage gap, increases the mass of Outsourcing industries and the aggregate innovation rate. However, in this literature, technology transfer takes place only after Northern production, and only local-sourcing-targeted R&D races are considered. Our modeling of two types of R&D races sheds light on the compositional effects of globalization on R&D. We find that due to globalization, Northern entrepreneurs intensify their simultaneous innovation-outsourcing efforts and this may come at the expense of the R&D efforts that target the North for production purposes. Nevertheless, the aggregate innovation rate unambiguously increases and both the Northern and Southern consumers enjoy faster product quality improvements. Hence, skeptics of globalization could be correct in fearing that increased globalization may lead to a fall in the type of R&D that targets the North for production purposes. However, our model clearly shows that globalization raises the aggregate innovation rate. This is mainly driven by the intensified outsourcing-targeted R&D efforts and hence the increase in the i-pod cycle frequency.

How robust is Proposition 1 to adding imitation as an additional channel of technology transfer? In our accompanying working paper (Sener and Zhao, 2006), we consider this scenario by assuming that outsourced industries are subject to imitation threat from the South. Extensive numerical simulations showed that under a wide range of parameters the findings in Proposition 1 remain intact.

3.2 Changes in Outsourcing policies of the South

We consider two policy changes towards outsourcing that can be undertaken by the Southern governments. Southern governments may increase the manufacturing subsidy rate σ_O or the technology transfer subsidy rate $\sigma_{\iota O}$. These are two distinct policies that certainly lie within the policy palette of Southern government (see Hanson, 2001). A higher σ_O may involve providing larger tax breaks or larger subsidies in manufacturing *upon* successful technology transfer. A higher $\sigma_{\iota O}$ on the other hand may involve reducing the technology transfer costs *prior to* success in outsourcing. Such costs involve locating the appropriate production site, setting up the production facility, matching with the production workers, dealing with legal/financial transactions and etc.

PROPOSITION 2: *An increase in the manufacturing subsidy rate to outsourcing firms* σ_O*,*

a. *reduces* w^**,*
b. *increases* ι_O^* *if and only if* $\phi_O > 1 - [1/(1+\phi_N)]$*,*
c. *increases* ι_N^**,*
d. *increases* ι_A^**,*
e. *decreases* n_O^**,*
f. *increases both* m_N *and* m_O*, while reducing* m_N/m_O*.*

A higher σ_O reduces the labor saving incentives of Northern entrepreneurs participating in outsourcing-targeted R&D races and thereby renders this type of R&D less challenging, leading to a fall in the relevant resource requirement; that is, m_O increases and a_O falls. As a result, the profitability of outsourcing-targeted R&D relative to local-sourcing-targeted R&D increases. The K curve in Figure 3 shifts up and w^* decreases.

Before analyzing the labor market equilibrium effects, we investigate the impact on resource requirements. As noted above, m_O increases and a_O falls. On the other hand, the lower w^* reduces the labor saving incentives of Northern entrepreneurs participating in local-sourcing-directed R&D races and thereby relaxes the resource requirement in this type of R&D; that is, m_N increases and a_N falls.[15] It is also useful to investigate the impact on c, holding ι_N and ι_O constant. The fall in w^* induced by a higher σ_O increases the profitability of R&D. For given levels of ι_N and ι_O, this puts upwards pressure on the level of c that maintains the zero profit condition in R&D.

In the Northern labor market, we observe four effects. The lower levels of both a_N and a_O decrease the labor demand coming from R&D activities. The fall in c reduces the demand for labor coming from manufacturing whereas the rise in m_N works to increase it. It can be shown that cm_N declines. Consequently, a larger σ_O reduces the aggregate labor demand in the North via both manufacturing and R&D channels. For a given ι_O, this relaxes the labor constraint in the North and generates room for an increase in local-sourcing-targeted R&D activity ι_N and hence the LN curve shifts up in Figure 3.

In the Southern labor market, we observe two competing effects. The reduction in c reduces the demand for labor whereas the rise in m_O increases it. Further algebra reveals that cm_O falls if and only if $\phi_O > 1 - [1/(1 + \phi_N)]$. Recall that for the model to be well behaved, we must have $\phi_O > 1$ if $\lambda < 2$ and $\phi_O < 1$ if $\phi_O < 1$. In the former case ($\lambda < 2$ and $\phi_O > 1$), it follows that $\phi_O > 1 - [1/(1 + \phi_N)]$ is readily

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[15] It can be shown that the m_N/m_O ratio declines.

satisfied. Thus restoring equilibrium requires a rise in ι_O and therefore a rightward shift of the LS curve in Figure 3. In the latter case ($\lambda > 2$ and $\phi_O < 1$) the "if and only if" condition for ϕ_O applies.[16]

Even though the change in ι_O appears to be ambiguous because of the indeterminate shift of the LS curve, further algebra reveals that ι_N unambiguously increases (actually iff $\phi_N > \phi_O$ which we assumed). The increase in ι_N puts downward pressure on n_O, and the change in ι_O may reinforce or mitigate this effect. We find that despite the indeterminate impact coming from ι_O, n_O falls (again iff $\phi_N > \phi_O$). This is quite an unexpected result because it implies that subsidizing outsourced production more leads to a fall in the fraction of Outsourcing industries! Technically, even if ι_O increases and puts upward pressure on n_O, it falls short of overturning the impact coming from the increase in ι_N. The key mechanism here involves the endogenous labor-saving decisions of firms. Increased manufacturing subsidies by the South reduce the labor-saving incentives of outsourcing firms. This leads to more labor employment *within* each industry. To restore equilibrium, the mass of outsourcing industries n_O must go down. Through numerical simulations we find that this downward pressure on n_O is mitigated as $\rho - n$ increases. Indeed when $\rho - n$ increases above a certain level, an increase in σ_O raises n_O.

What happens to the aggregate innovation rate ι_A? Even though the change in ι_O depends on the parameters of the model, the increase in ι_N turns out to be sufficiently strong to unambiguously raise the aggregate innovation rate ι_A.

PROPOSITION 3: *An increase in the rate of technology transfer subsidies* $\sigma_{\iota O}$,

- *a.* *reduces* w^*,
- *b.* *increases* ι_O^*,
- *c.* *increases* ι_N^* *iff* $\iota_N/\iota_O > (1+\phi_N)/[\phi_N(1+\phi_O)(1-\sigma_{\iota O})]$,
- *d.* *increases* ι_A^* *if* $\sigma_{\iota O} < \phi_O/(1+\phi_O)$,

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[16] Note that with $\phi_N > \phi_O$ we are essentially looking at a particular range $\phi_N > \phi_O > 1 - [1/(1+\phi_N)]$ for this condition to hold.

e. *increases* n_O*,

f. *increases* m_N*, leaves* m_O *unchanged.*

First, we investigate the impact on w^*. An increase in $\sigma_{\iota O}$ directly raises the relative profitability of outsourcing-targeted vs. local-sourcing-targeted R&D; hence the *K* curve in Figure 4 shifts up and w^* decreases. Before analyzing the labor market equilibrium effects, we examine the changes in resource requirements. The lower w^* reduces the labor saving incentives of entrepreneurs engaged in local-sourcing-targeted R&D, rendering this type of R&D less challenging. In other words, m_N increases and a_N falls. On the other hand, the change in $\sigma_{\iota O}$ does not affect m_O and a_O. It is again useful to investigate the impact on *c*, holding ι_N and ι_O constant. The lower w^* increases the profitability of both types of R&D, and restoring the zero profit condition puts downward pressure on *c*.

In the Northern labor market, we observe three effects. The fall in a_N induced by the lower w^* reduces the labor demand coming from outsourcing-targeted R&D. The lower *c* reduces the labor demand coming from manufacturing, whereas the higher m_N works against it. It can be shown that cm_N declines. Consequently, the aggregate demand for Northern labor declines via both R&D and manufacturing channels. For a given ι_O, the relaxation in the Northern labor constraint creates room for an increase in ι_N. As a result, the LN curve shifts to the right in Figure 4. In the Southern labor market, the decline in *c* is the only distortion. The lower *c* reduces the labor demand in manufacturing and relaxes the Southern labor constraint. As a result, ι_O increases and the LS curve shifts to the right in Figure 4.

It can be seen graphically from Figure 4 that ι_O unambiguously increases. Further algebra reveals that ι_N increases if and only if $\iota_N/\iota_O > (1+\phi_N)/[\phi_N(1+\phi_O)(1-\sigma_{\iota O})]$. The increase in ι_O raises n_O whereas the change coming from ι_N is indeterminate. In the Appendix we show that n_O increases unambiguously. In addition, we find that ι_A increases if $\sigma_{\iota O}$ is sufficiently low.

What are the policy implications of Propositions 2 and 3? Higher technology-transfer subsidies in the form of an increase in $\sigma_{\iota O}$ certainly attract FDI by increasing the frequency of i-pod product cycles ι_O

and the mass of outsourcing industries n_O. When one considers the possibility of knowledge spillovers from Outsourcing industries to indigenous Southern firms, the positive effects of higher n_O are magnified. In fact, these spillovers can be seen explicitly when we allow for imitation $\mu > 0$ (see Sener and Zhao, 2006). Then μn_O measures the flow of North-South knowledge spillovers that occurs through the Southern production variety channel n_O. Extensive numerical simulations implied that when $\mu > 0$, the main results in Proposition 3 remain intact.

On the other hand higher manufacturing subsidies in the form of an increase in σ_O may not be the optimal policy to attract FDI. This increase raises the frequency of i-pod cycles ι_O only under certain parametric restrictions and leads to a fall in n_O when $\rho - n$ is below a critical level. Thus, such a policy change may limit the flow of North-South knowledge spillovers. When we add imitation $\mu > 0$, numerical simulations imply that a higher σ_O decreases n_O if either μ or $\rho - n$ is below a critical level, confirming the analytical results. To sum up, our model suggests that technology transfer subsidies dominate production subsidies when the South's objective is to increase the extent of production variety in its borders and realize the associated knowledge spillovers. Given the existence of direct and indirect subsidies to attract FDI as documented by Hanson (2001), our theoretical model provides practical guidance to the policy maker who must choose between different policies to generate spillovers. In practice, the direct policy may take the form of subsidies given to multinationals to assist with infrastructure, plant set up and education and training of workers, whereas indirect subsidies may involve corporate tax exemptions and import duty reductions.

Observe that modeling of process innovations provides the key mechanism that generates the contrasting outcomes between the two subsidies. Higher manufacturing subsidies reduce the incentives of Northern entrepreneurs to engage in labor saving in the South. This leads to more employment *within* each outsourcing industry, putting downward pressure on the mass of outsourcing industries.

5. Conclusion

In this paper, we incorporated what we called the i-pod cycle into the traditional product cycle setting. To this end, we categorized R&D races into two: outsourcing-targeted- and local-sourcing-targeted. Entrepreneurs target their eventual location of production by choosing which R&D race to participate in. R&D involves both product and process innovation. We captured the i-pod cycle in the context of outsourcing-targeted R&D races in which participants combine their innovation activities with simultaneous outsourcing efforts. We used the model to examine the effects of globalization and Southern FDI policies on wages, R&D intensities and the fraction of Outsourcing industries.

We find that globalization in the form of an improvement in the efficiency of outsourcing-targeted R&D raises the aggregate rate of innovation while reducing the North-South wage gap. We also identify the compositional effects of globalization on R&D, by finding that the intensity of outsourcing-directed R&D increases whereas the intensity of local-sourcing targeted R&D moves in an ambiguous direction. These findings imply that the higher frequency of i-pod cycles through increased outsourcing-targeted R&D efforts of Northern entrepreneurs is a robust factor that fosters aggregate innovation.

We argue that from the South's perspective, technology transfer subsidies can be a more desirable option vis-à-vis manufacturing subsidies to attract FDI. Manufacturing subsidies directly distort the labor saving incentives of outsourcing firms and thus lead to more employment within each Outsourcing industry, which then puts downward pressure on the mass of Outsourcing industries. This adverse effect is more pronounced when the imitation rate and/or discount rate is lower and can lead to a fall in the equilibrium fraction of Outsourcing industries. In addition, the production variety compression in the South can have further adverse effects as it reduces the extent of North-South knowledge spillovers.

We have only looked into some aspects of the globalization process. Other aspects such as tariff reductions are also important and their impacts remain to be analyzed. One might also incorporate contractual frictions to the product cycle setting along the lines of Antras (2005) and Antras and Helpman (2004), and model the in-house production vs. arm's length contracting decisions of multinational firms. In this paper, we have modeled all outsourcing as taking place within the boundaries of the firm or being outsourced to Southern manufacturers in a frictionless contracting environment. Combining our focus on technology choices with Antràs' (2005) contractual frictions is a fruitful undertaking, which we leave for further research.

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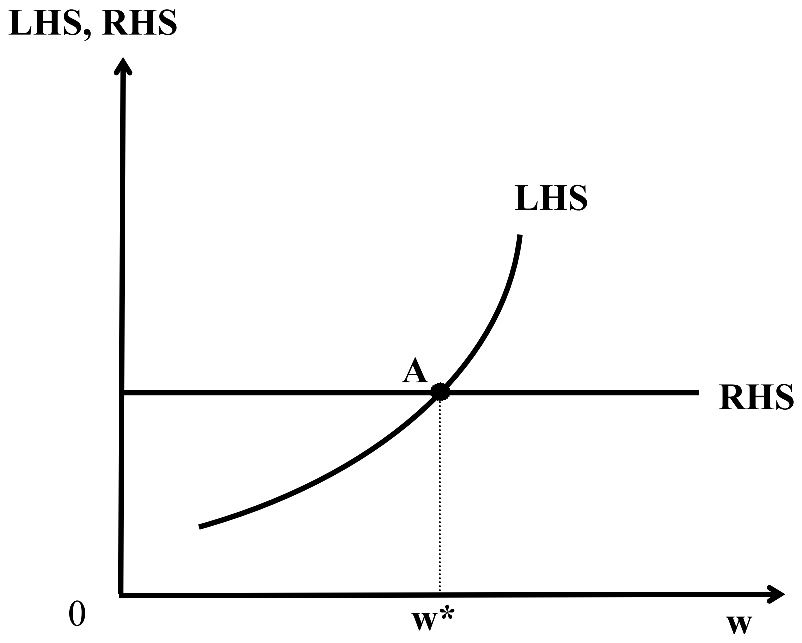
FIGURE 1: Steady-State Equilibrium



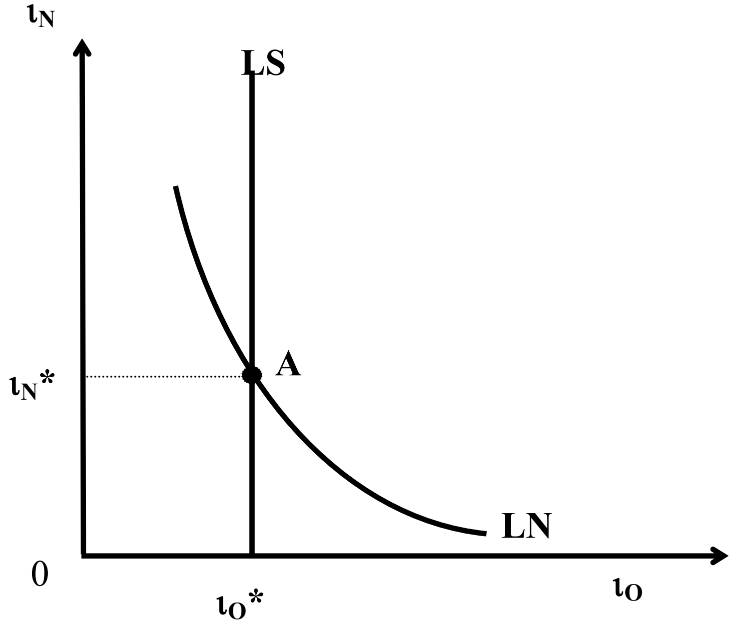
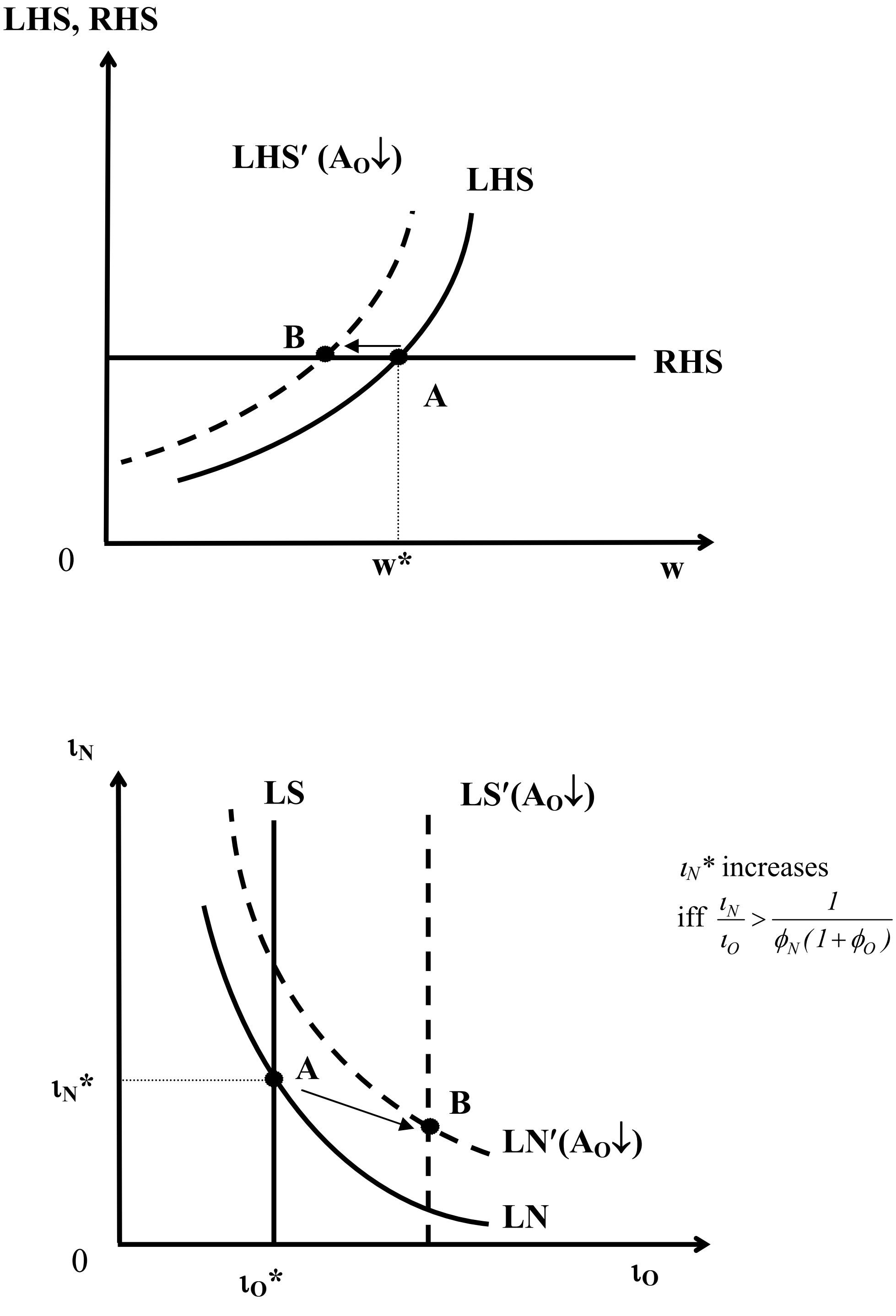
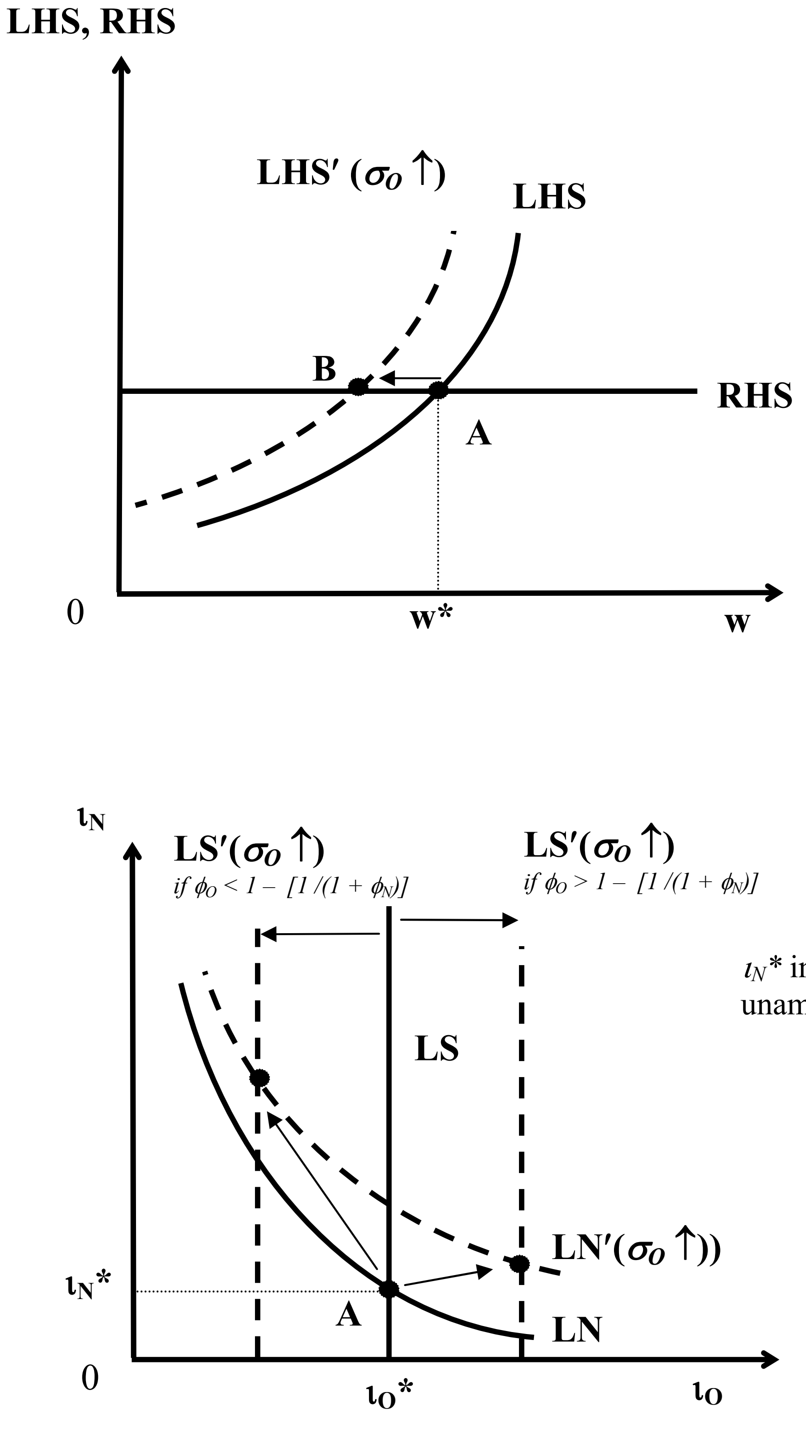


FIGURE 2: A Decline in A_O



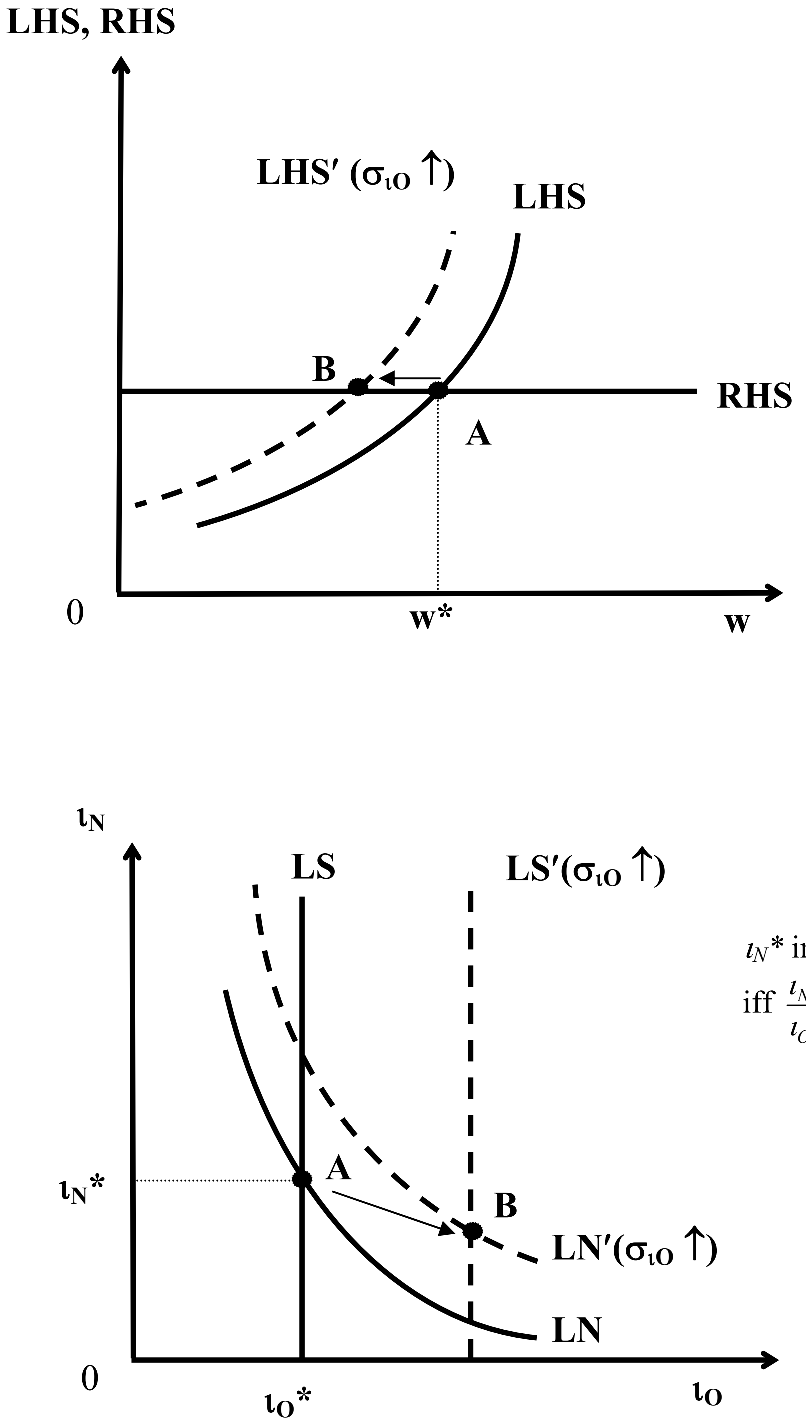
ι_N* increases iff $\frac{\iota_N}{\iota_O} > \frac{1}{\phi_N(1+\phi_O)}$

FIGURE 3: An Increase in σ_O



ι_N* increases unambiguously

FIGURE 4: An Increase in $\sigma_{\iota O}$



ι_N* increases

iff $\frac{\iota_N}{\iota_O} > \frac{1+\phi_N}{\phi_N(1+\phi_O)(1-\sigma_{\iota O})}$

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