Preliminary Draft, Comments Welcome

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 can reduce the measure of multinational 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, imitation, product cycle

JEL Classification:

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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.[1] The recent surge of FDI to the developing countries stemmed from a host of factors, including the reduction in transport and communication costs, the decline in tariffs and non-tariff barriers, the emergence of bilateral/multilateral investment treaties, and others.

In the traditional product cycle model as proposed by Vernon (1966) multinational firms serve as the main channel of North-South technology transfer. In this setting, entrepreneur firms participate in R&D races to innovate new products. The winner of the R&D 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, Northern 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

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[1] See UNCTAD/PRESS/PR/2005/031/05/09/05.

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.[2] 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.

The literature on endogenous technology transfer and growth has expanded substantially in the past five years.[3] One common feature of this literature 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 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]

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[2] See Naghavi and Ottaviano (2005) for an excellent discussion on the nature and extent of company-level global integrated production networks. See also *Business Week*, "Speed Demons" March 27, 2006,pp 70-76 for an extensive survey of how companies are combining R&D with outsourcing to cut back the time it takes to deliver the new products to the market.

[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.

[4] Need data here, maybe from Scherer.

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 study the effects of globalization and FDI policies on the rates of innovation, outsourcing and North-South wage differential.

Our world economy consists of a continuum of industries. In each industry, Northern firms participate in R&D races to innovate higher quality products (product innovation). For a typical industry, we envision two types of R&D races taking place simultaneously: *local-sourcing-targeted-* and *outsourcing-targeted- R&D races*. Northern entrepreneurs ex-ante choose the type of R&D race to participate in and thereby their eventual location of production. The winner of the local-sourcing-targeted R&D race can only manufacture in the North, facing higher production costs. The winner of the outsourcing-targeted R&D race can immediately manufacture in the South, enjoying lower production cost. We thus 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. We incorporate process innovations into the R&D races by allowing for Northern entrepreneurs choose ex-ante both the challenge and intensity levels of their R&D activities. We assume that by undertaking more challenging R&D ex-ante, Northern entrepreneurs can raise their manufacturing productivity levels ex-post. Since labor is the only factor of production, this type of process innovation essentially refers to labor-saving in manufacturing.

We begin with a simple analytical model in which the only channel of technology transfer is multinationalization (i.e., FDI) without imitation. We solve this model analytically and obtain comparative statics results. We then allow for the Southern firms to imitate the technology of outsourcing firms and thereby add an additional channel of technology transfer. We capture the impact of globalization by considering an increase in the efficiency of outsourcing-targeted R&D activity. 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. In addition, the mass of outsourcing firms increases and the North-South wage gap declines. In contrast to the literature, our modeling of two distinct R&D races enables us to reveal the compositional effects of globalization on R&D. 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 and thus the increased frequency of i-pod cycles is the major growth promoting factor triggered by globalization.[5]

We then examine the effects of Southern FDI policies by considering two policy tools. One is *manufacturing subsidies* which reduce the production costs of outsourcing firms. The other is *technology transfer subsidies* which facilitate the 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 downward pressure on the mass of outsourcing industries. In contrast, technology transfer subsidies do not trigger this type of a labor-saving mechanism since they are directed at pre-production efforts of entrepreneurs. 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.

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[5] Glass and Saggi (2001), Glass (2004) and Dinopoulos and Segerstrom (2005) address the same question in settings where technology transfer strictly follows Northern production. In these papers, there is only local-sourcing-targeted R&D race, and thus this literature cannot address the compositional R&D effects of globalization.

Our findings also 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. And the increased production variety may lead to further knowledge spillovers from outsourcing firms to indigenous Southern firms. Given the importance of technological spillovers in reaping the benefits of FDI (an issue heavily emphasized in the empirical literature), our distinction in policy outcomes can be of practical use to policy makers.

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 relative to the North, 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 the wage of Northern labor relative to Southern labor increases, entrepreneurs engaged in local-sourcing-targeted R&D (which eventually leads to Northern employment) raise their labor saving targets in comparison to entrepreneurs engaged in outsourcing-targeted R&D (which 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.

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 with and without imitation. Section 5 concludes. Proofs of all propositions are relegated to the Appendices available upon request and also on our web sites.

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,

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

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

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

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.

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, three types of industries can emerge: Northern industries, Outsourcing industries and Southern 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. Producers in the North fully internalize their technology advantage. They do not face any threat of imitation from the South but they can be replaced due to successful innovation from the North.

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. Outsourcing firms operate in close proximity to *Southern* firms and thus face the threat of imitation from the South, in addition to the threat of innovation from the North. With exogenous probability μdt the technology of Outsourcing firms fully leaks to the South (μ being the exogenous intensity of Southern imitation), and a fringe of Southern firms start producing the state-of-the-art quality product under perfect competition conditions. We refer to this type of industries as *Southern industries*. Further innovation from the North results in the replacement of Southern firms.[6]

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

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[6] Incorporate the product cycle figure and insert a reference here??

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 with probability μdt, the outsourcing firm's technology can fully leak to the South. In either event, the stockholders realize a loss in value of $V_O(t)$. With probability $1 - (\iota_O + \iota_N + \mu)dt$, 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 $dt \to 0$):

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

Finally, consider the valuation of a Southern firm $V_S(t)$. Since Southern production takes place in a perfectly competitive market, it follows that $\pi_S(t) = 0$ and thus $V_S(t) = 0$.

2.4 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:

$$a_i(m_i) = A_i m_i^{-\phi_i}, \qquad \text{for } i \in \{N,O\}, \tag{7}$$

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:

$$\frac{a_i'(m_i)m_i}{a_i(m_i)} = -\phi_i. \qquad \text{for } i \in \{N,O\}. \tag{8}$$

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 improving their ex-post manufacturing productivity (process innovation). By intensifying their labor-saving 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]

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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.

2.5 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]

$$\frac{\partial V_N}{\partial m_N} = w\frac{\partial a_N}{\partial m_N}X_N(t). \tag{9}$$

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

$$V_N(t) = wa_N X_N(t). \tag{10}$$

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

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

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

$$\frac{\partial V_O}{\partial m_O} = w\frac{\partial a_O}{\partial m_O}(1-\sigma_{\iota O})X_O(t), \tag{11}$$

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

$$V_O(t) = wa_O(1-\sigma_{\iota O})X_O(t)\,. \tag{12}$$

2.6 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: $MC_O = m_O(1-\sigma_O)$,

[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 $a_N'' > 0$.

where σ_O is the subsidy rate for outsourced manufacturing. In Southern industries, the unit labor requirement is set to one without loss of generality, resulting in the marginal cost of production: $MC_S = 1$. 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)* Southern producers enjoy lower marginal production costs compared to outsourcing firms. Hence, manufacturing costs must comply with:

$$\lambda > MC_N > MC_O > MC_S = 1 \qquad \Rightarrow \qquad \lambda > m_N w > m_O(1 - \sigma_{\iota O}) > 1. \tag{13}$$

Following the literature, we assume that every time an innovation takes place in the North, the inferior technology becomes common knowledge to all firms in the global economy.[10] With marginal costs given as in (13), this implies that Southern firms 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 $\lambda MC_S - \varepsilon = \lambda - \varepsilon$ (where ε is an 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:

$$\pi_N(t) = \frac{E(t)}{\lambda}(\lambda - MC_N), \tag{14}$$

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:

$$\pi_O(t) = \frac{E(t)}{\lambda}(\lambda - MC_O). \tag{15}$$

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.

2.7 Equilibrium Levels of Manufacturing Productivity

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

From the equation pairs (9)-(10) and (11)-(12), 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 (8), 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 (8) 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.*

Lemma 1 establishes an endogenous substitution mechanism between Southern and Northern labor *within* each industry. To the best of our knowledge, such a substitution mechanism has not been considered in the context of 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 (13) 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 are lower in the South than in the North.*[11]

Combining (17), (18) and (13) yields some restrictions on the model. Specifically, combining (17) with $\lambda > m_N w$ implies $w > \phi_N/(1 + \phi_N)$. And combining (18) with $m_O(1 - \sigma_{\iota O}) > 1$ implies $\phi_O > 1/[\lambda/(1 - \sigma_O) - 1]$. 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 (7).

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

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

Denote with n_N, n_O and n_S the fraction of Northern, Outsourcing, and Southern industries, respectively. Constant industry shares in equilibrium require that flows in and out of each industry must be exactly balanced. First, 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 a Southern or 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 $(\iota_N n_O + \iota_N n_S)$. Constant n_N requires:

$$(n_O + n_S)\,\iota_N = \iota_O n_N\,. \tag{22}$$

Next, consider the Southern industries. Every time a Northern entrepreneur participating in a local-sourcing or outsourcing-targeted R&D race that is directed at a Southern industry becomes successful, the Southern industry is transformed into a Northern or an Outsourcing industry. Hence, the aggregate flow out of the Southern industry pool is $(\iota_O + \iota_N)n_S$. On the other hand, every time the technology of an Outsourcing industry fully leaks to the South, the Outsourcing industry is transformed into a Southern industry. Thus, the aggregate flow into the Southern industry pool is μn_O. Constant n_O requires:

$$(\iota_O + \iota_N)n_S = \mu n_O. \tag{23}$$

Finally, when the above flow conditions hold, we must have

$$n_N + n_O + n_S = 1, \tag{24}$$

which ensures that n_O also becomes constant.

2.9 Labor Markets

In the North, the labor market equilibrium implies:

$$L^N(t) = \iota_N a_N X_N(t) + \iota_O a_O X_O(t) + n_N(E(t)/\lambda)m_N, \tag{25}$$

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:

$$L^S(t) = n_S E(t) + n_O(E(t)/\lambda)m_O, \tag{26}$$

where $n_S E$ and $n_O(E(t)/\lambda)m_O$ measures the manufacturing labor demand coming from Southern and 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, n_S, 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. Using the flow conditions (22), (23) and (24), the industry fractions can be expressed in terms of the endogenous variables ι_N and ι_O. More specifically,

$$n_N = \frac{\iota_N}{\iota_N + \iota_O}, \quad n_S = \frac{\mu \iota_O}{(\iota_N + \iota_O)(\mu + \iota_O + \iota_N)}, \quad n_O = \frac{\iota_O}{(\mu + \iota_O + \iota_N)}. \tag{27}$$

The steps are as follows. Solving (24) for n_N and substituting into (22) gives $n_N = n_N(\iota_N, \iota_O)$ above. Substituting n_O from (23) into (24) using $n_N(\iota_N, \iota_O)$ gives $n_S = n_S(\iota_N, \iota_O)$. Substituting $n_S(\iota_N, \iota_O)$ into (23) yields $n_O = n_O(\iota_N, \iota_O)$.

Substituting the industry fractions from (27) into (25) and (26), 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.

$$1/(1+\eta^S) = \iota_N a_N(w) k_N + \iota_O a_O k_O + n_N(\iota_N, \iota_O)(c/\lambda) m_N(w), \qquad (c, \iota_N, \iota_O, w) \qquad (28)$$

$$\eta^S/(1+\eta^S) = n_S(\iota_N, \iota_O)c + n_O(\iota_N, \iota_O)(c/\lambda)m_O. \qquad (c, \iota_N, \iota_O) \qquad (29)$$

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 (10) and $\pi_N(t)$ from (14) into (5) using (21) and $c(t) \equiv E(t)/L(t)$ gives:

$$wa_N(w)k_N = \frac{c/(1+\phi_N)}{\rho + \iota_N + \iota_O - n}. \qquad (c, \iota_N, \iota_O, w) \qquad (30)$$

Similarly substituting $V_O(t)$ from (11) and $\pi_O(t)$ from (15) into (6) using (21)and $c(t) \equiv E(t)/L(t)$ gives:

$$wa_O(1-\sigma_{\iota O})k_O = \frac{c/(1+\phi_O)}{\rho + \mu + \iota_N + \iota_O - n}. \qquad (c, \iota_N, \iota_O, w) \qquad (31)$$

Conditions(28)-(31) 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).

2.11 Steady-State Equilibrium (The case of no imitation $\mu = 0$)

Under no imitation, $\mu = 0$ and thus $n_S = 0$. 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 (30) and (31), respectively. This yields:

$$K \equiv \frac{a_N(m_N(w))}{a_O(m_O)(1-\sigma_{\iota O})}\frac{k_N}{k_O} = \frac{1+\phi_O}{1+\phi_N} \equiv \Pi, \qquad (32)$$

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 (32) 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 outsourcing-targeted R&D is more costly than local-sourcing-targeted R&D. Thus, only entrepreneurs undertaking the relatively more costly R&D projects can have a shot at successfully shifting production to the South.

We can obtain a closed form solution for w^* by substituting for $a_N(w)$ and a_O from equation (20) into (32), which gives:

$$w^* = \frac{\lambda\phi_N}{(1+\phi_N)}\left(\frac{(1+\phi_N)}{A_R k_R (1-\sigma_{\iota O})(1+\phi_O)}\left(\frac{\lambda\phi_O}{(1-\sigma_O)(1+\phi_O)}\right)^{\phi_O}\right)^{-1/\phi_N}, \tag{33}$$

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 (33) 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.

$$a_N^* = a_N(\overset{+}{A_R}, \overset{-}{\sigma_{\iota O}}, \overset{-}{\sigma_O}) \qquad a_O^* = a_N(\overset{+}{A_R}, \overset{0}{\sigma_{\iota O}}, \overset{-}{\sigma_O}) \tag{34a}$$

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

Next, we substitute w^* from (33) into (28), to express c in terms of (ι_N, ι_O). This yields:

$$c(\iota_N, \iota_O) = (\rho + \iota_N + \iota_O - n)\phi_N A_N k_N \lambda \left(\frac{(1+\phi_N)}{A_R k_R (1-\sigma_{\iota O})(1+\phi_O)}\left(\frac{\lambda\phi_O}{(1-\sigma_O)(1+\phi_O}\right)^{\phi_O}\right)^{-(1+\phi_N)/\phi_N} \tag{35}$$

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 (35) into (28), we can express the Northern and Southern labor market equilibrium conditions solely in terms of ι_N and ι_O

$$\frac{1}{1+\eta^S} = \iota_N a_N {}^* k_N + \iota_O a_O {}^* + [\, n_N(\overset{+}{\iota_N}, \overset{-}{\iota_O})\, c(\overset{+}{\iota_N}, \overset{+}{\iota_O})\, m_N {}^* / \lambda \,] \,, \tag{36}$$

$$\frac{\eta^S}{1+\eta^S} = n_O(\overset{-}{\iota_N}, \overset{+}{\iota_O})\, c(\overset{+}{\iota_N}, \overset{+}{\iota_O})\, m_O {}^* / \lambda \,. \tag{37}$$

where a_i* and m_i* for $i \in \{N,O\}$ are as in (34a) and (34b), and n_N and n_O come from (27).

We are now in a position to establish the steady-state equilibrium by plotting (36) and (37) 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.[12] 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 (36), 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 (35)]. To sum up, 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

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

discussed for ι_N). However, as $\rho - n \to 0$, these two effects exactly cancel out. To sum up, equation (36) implies an inverse relationship between ι_O and ι_N. Hence, the downward sloping LN curve in Figure 1.

Equation (37), 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. First, it reduces the proportion of Outsourcing industries n_O and thus the Southern labor demand. Second, it 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 (37). This implies that the equilibrium level of ι_O is solely determined by (37). Hence the vertical LS curve in Figure 1.[13]

3. Comparative Steady-State Analysis (The case of no imitation $\mu = 0$)

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 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^*,

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[13] 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: $\lambda\phi_N\phi_O > \eta_S(1+\phi_N)\left(\frac{(1+\phi_N)}{(1+\phi_O)(A_R k_R)}\left(\frac{\lambda\phi_O}{1+\phi_O}\right)^{\phi_O}\right)^{1/\phi_N}$.

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.*

Let us first identify the wage impact using (32). 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 $\partial[wa_N(w)/a_O]/\partial w > 0$.

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 (30) and (31), there must be a fall in the rewards coming from sales and hence a decline in c.

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[14] Self note: More concrete evidence on transport and communication costs and how it led to a more efficient monitoring of outsourced production and etc. along with some stories can be given here. This should be straight forward.

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 (36) 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 (35) that cm_N* declines. Thus, the third and fourth effects combined leads to reduced labor demand. To sum up, the aggregate demand for Northern labor declines. For a given ι_O, this relaxes the Northern resource constraint, allowing for an expansion in local-sourcing-directed R&D ι_N. Hence, the LN curve shifts to the right.

For the LS curve, defined by (37), 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 industries outsourcing to the South can occur *concurrently*. Regarding the aggregate innovation rate $\iota_A = \iota_N + \iota_O$, the rise in ι_O increases ι_A whereas the change in ι_N may reinforce or counteract this effect. We find that ι_A* unambiguously increases despite the indeterminacy regarding ι_N*.

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.

3.3 Changes in Outsourcing policies of the South

We consider two policy changes towards outsourcing than 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. A higher σ_O may involve providing larger tax breaks or larger direct 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 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 $\phi_N > \phi_O$ which is assumed). 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^*,

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

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* $\sigma_{\iota O} < \phi_O/(1+\phi_O)$,

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

[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.

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 $\mu > 0$. In this case μn_O measures the flow of North-South knowledge spillovers that occurs through the Southern production variety channel n_O. Numerical simulations imply that when $\mu > 0$, the main results in Proposition 3 remain intact. Thus, the model explicitly shows that technology-transfer subsidies increase the production variety in the South (by increasing n_O) and thereby generate additional knowledge spillovers in the North-South direction (by increasing μn_O).

On the other hand higher manufacturing subsidies in the form of an increase σ_O may not be the optimal policy to attract FDI. An increase in σ_O increases the frequency of i-pod cycles ι_O only under certain parametric restrictions and it 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. To sum up, our model suggests that technology transfer subsidies dominate production subsidies when the Southern government's objective is to increase the extent of production variety in the South and realize the associated knowledge spillovers.

4. Comparative Steady-State Analysis (The case of positive imitation $\mu > 0$)

How robust are our main findings to allowing for imitation? The model becomes substantially complicated in this case, and thus we rely on numerical simulations. However, we can shed light on the simulation results by identifying the additional effects that stem from imitation. When $\mu > 0$, the equation for w in (32) needs to be modified as:

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

where the adjusted discount rates emerge on the RHS as additional terms. Hence, with $\mu > 0$, there will be an endogenous impact on w^* that works through ι_A. An increase in ι_A raises the replacement rate for Northern producers by more than it increases the replacement rate for Outsourcing producers. Consequently, the relative profitability of local-sourcing directed R&D declines and hence the North-South relative wage. Thus, $dw/d\iota_A < 0$.

In addition, the equation for c in (35) needs to be modified as:

$$c(\iota_A) = (A_R k_R)^{\frac{1+\phi_N}{\phi_N}}(\rho+\iota_A-n)\lambda^{\frac{\phi_N-\phi_O(1+\phi_N)}{\phi_N}}\Gamma\left(\frac{\rho+\iota_A-n}{\rho+\iota_A+\mu-n}\right)^{-\frac{(1+\phi_N)}{\phi_N}},$$

which again identifies an additional impact coming from ι_A with the last term. There are now two effects on an increase in ι_A on c. The first works through the lower w, which puts downward pressure on the level of c that maintains the free-entry conditions. The second works by reducing R&D profitability and thereby putting upward pressure on the level of c. One can show that $dc/d\iota_A > 0$ if and only if $\mu < \phi_N(\rho - n + \iota_A)$.

To sum up, w now responds to shocks through the ι_A channel, and c also responds to changes in ι_A. The resource requirements are also subject to additional effects. Given $dw/d\iota_A < 0$, it follows that $dm_N/d\iota_A > 0$ and $da_N/d\iota_A < 0$. Also, when $\mu > 0$ it follows that the fraction of Southern industries is strictly positive $n_S > 0$. Thus the new flows in and out of the Southern industry pool will also have an impact on the steady-state outcomes.

Using the results in the basic model, we can make informed conjectures. Proposition 1 implies that a fall in A_O leads to a higher ι_A. This should put additional downward pressure on w, which is consistent with the direction of change in w^* as implied by Proposition 1. Thus, the impact coming from

w^* on LN and LS curves qualitatively remain the same. One can apply this methodology for other propositions as well.

To check the robustness of the results, we calibrate the imitation model fully. Table 2 shows the benchmark simulations. Extensive numerical simulations imply that under a wide range of parameters the findings stated in the Proposition remain intact. The only exceptions as we have already discussed are for the case of manufacturing subsidies as stated in Proposition 3.

5. Conclusion

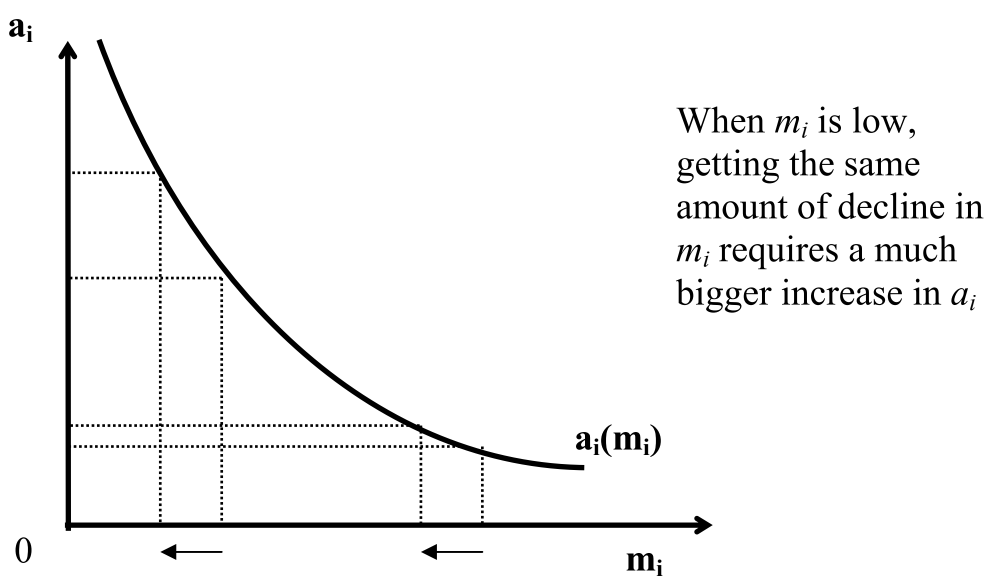
In this paper, we incorporated what we called the i-pod cycle into the traditional product cycle setting. To this end, we categorized R&D races into two: outsourcing-targeted- and local-sourcing-targeted R&D races. Entrepreneurs target their eventual location of production by choosing which R&D race 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. We find 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 the increased outsourcing-targeted R&D efforts of Northern entrepreneurs is the robust factor that fosters aggregate innovation.

We argue that 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 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.

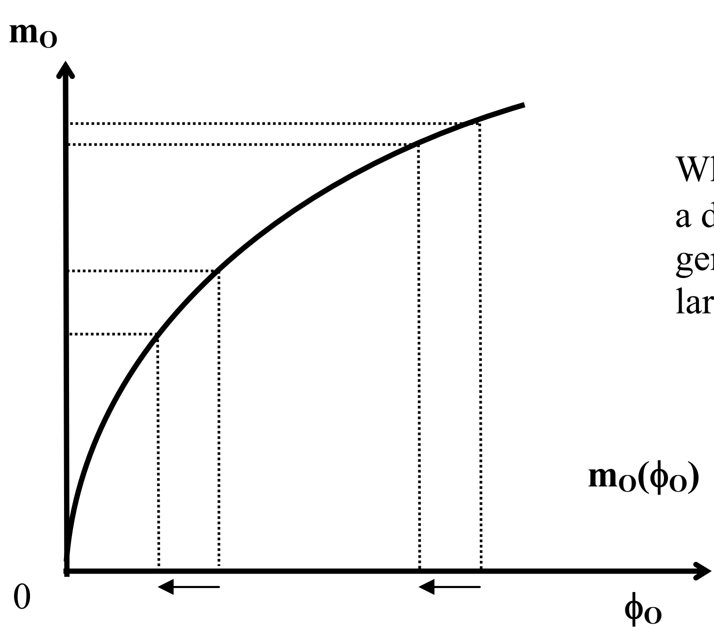
We have only looked into some aspects of the globalization process. Other aspects such as tariff reductions are also important and their impacts remain to be analyzed. Also, imitation intensity in the South per industry is exogenous. It would be interesting to endogenize it and investigate how globalization affects the South's incentives for imitation. Finally, one might 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. It should be noted that we 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.

FIGURE 1



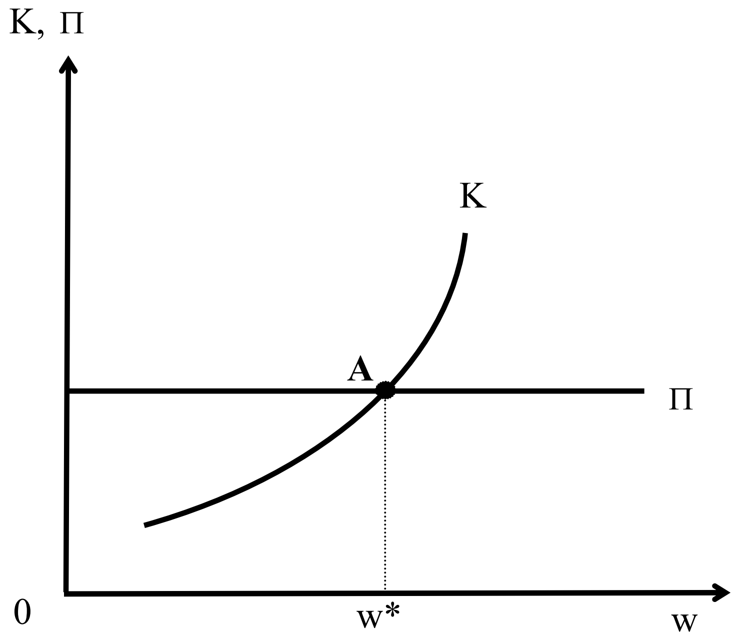
a_i
When m_i is low, getting the same amount of decline in m_i requires a much bigger increase in a_i
$a_i(m_i)$
0
m_i

FIGURE 2



When ϕ_O is low,
a decline in ϕ_O
generates a much
larger decline in m_O

FIGURE 3: Steady-State Equilibrium



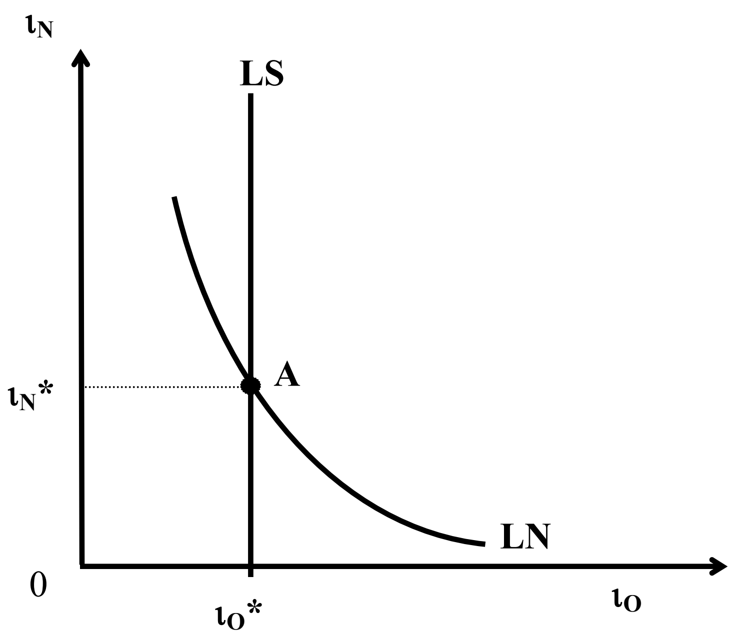
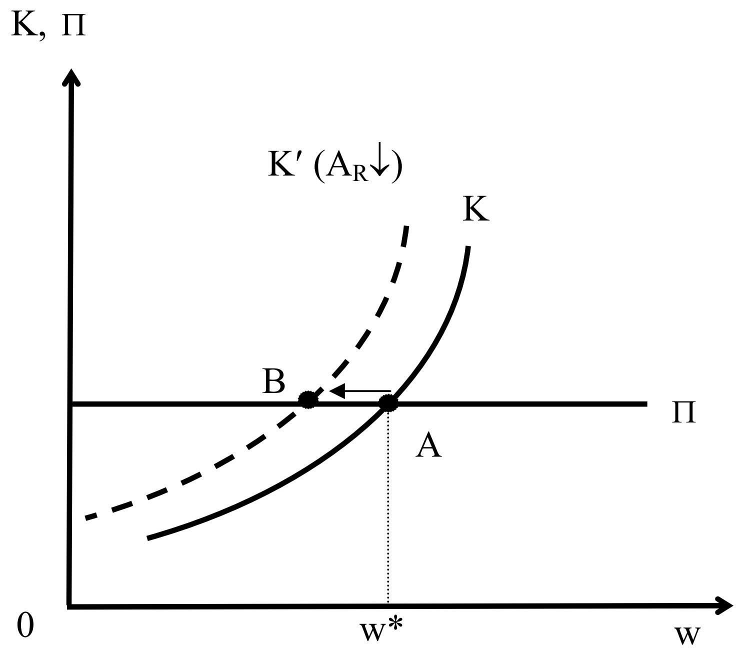


FIGURE 4: A Decline in A_R



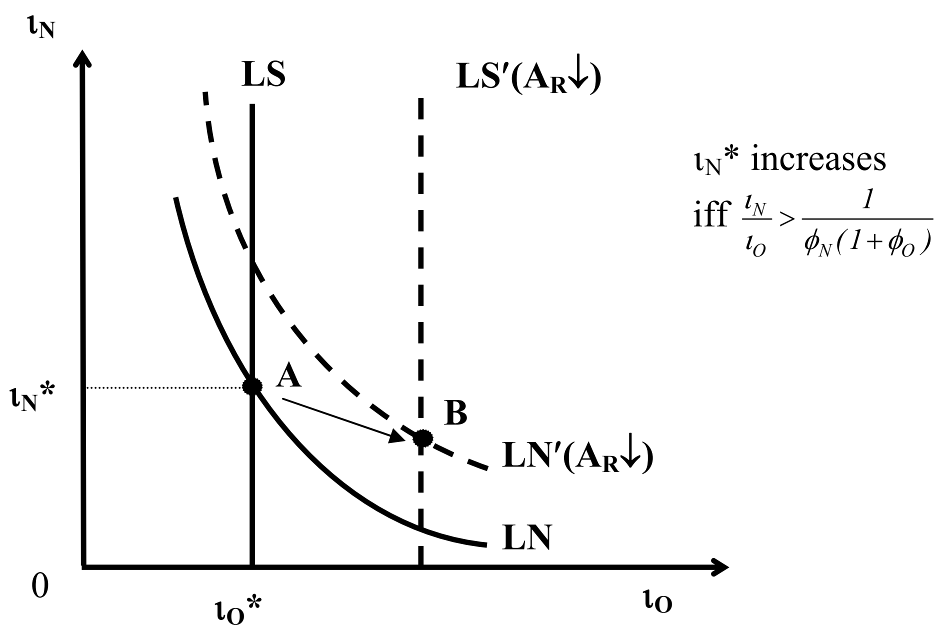
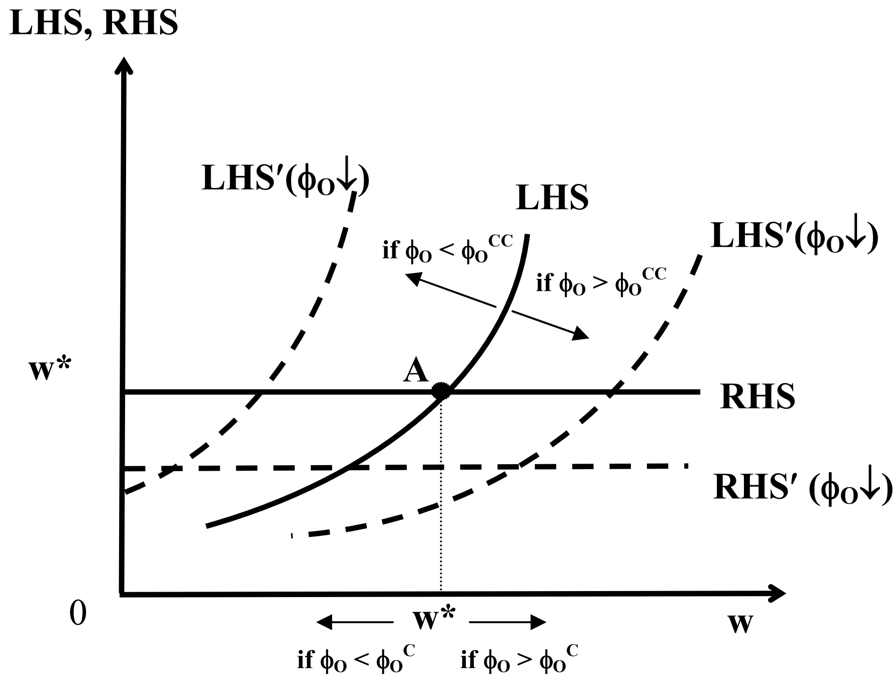


FIGURE 5: A Decline in ϕ_O



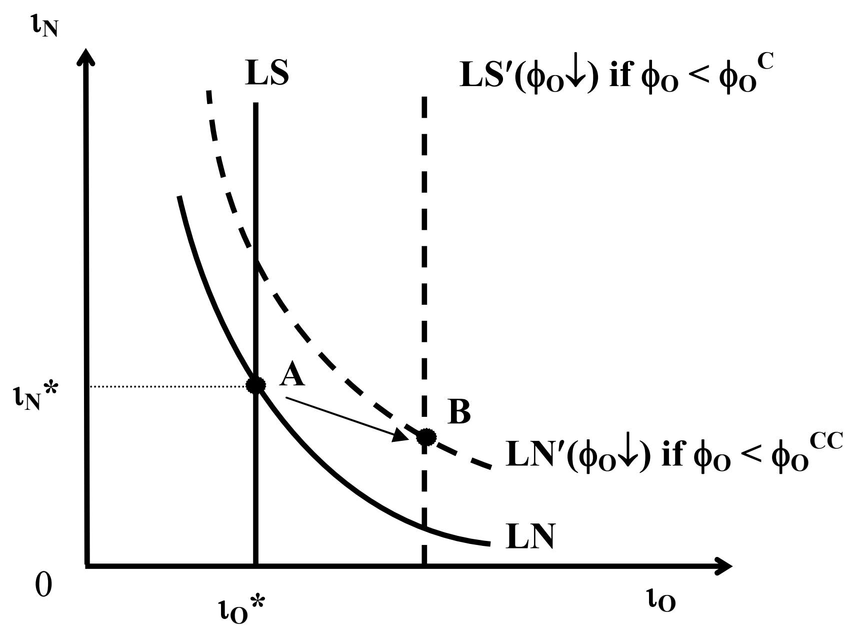
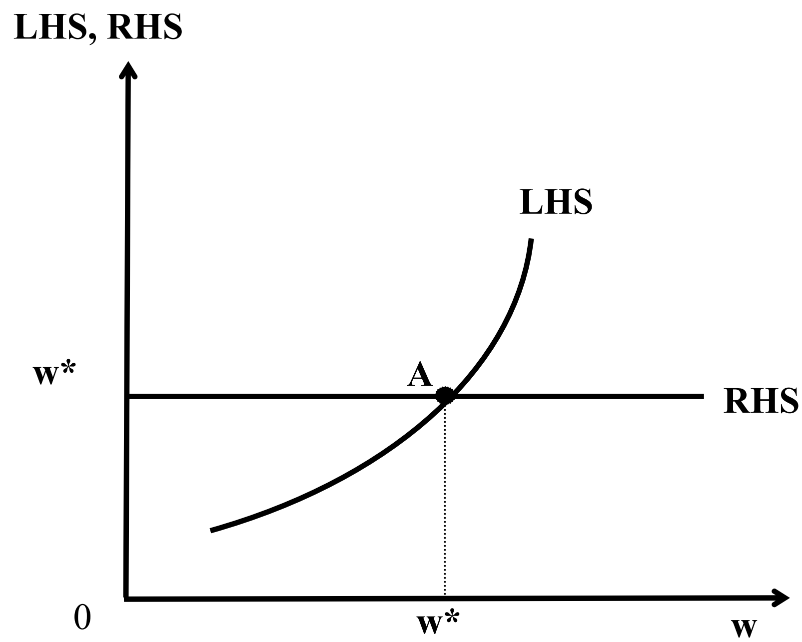
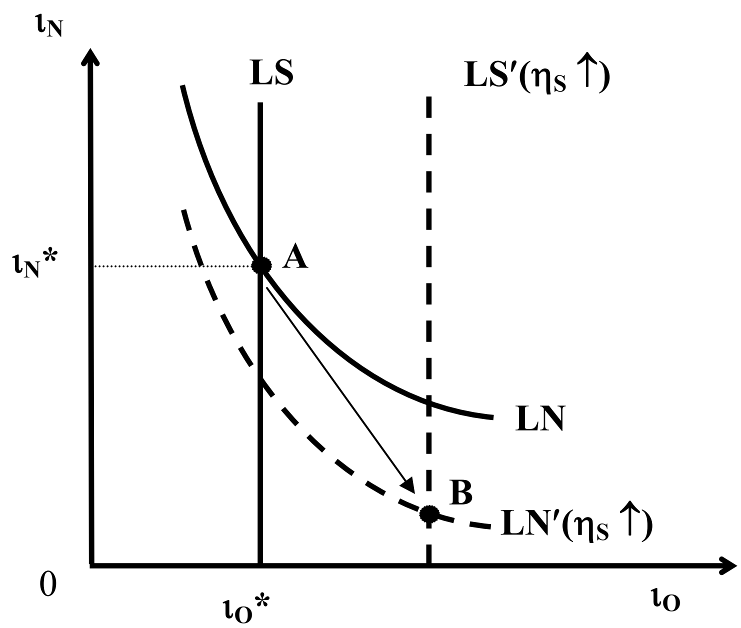


FIGURE 6: An Increase in η_S





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