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A Theory of Innovation through Global Collaboration and Wage Inequality

Yuichi Furukawa*

* School of Economics, Chukyo University. Email: you.furukawa@gmail.com

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Yuichi Furukawa*

School of Economics, Chukyo University

101–2 Yagoto-honmachi, Showa-ku, Nagoya 466–8666, Japan.

Tel: +81–52–835-7494.

Email address: you.furukawa@gmail.com

Abstract

This paper considers a North-South model of innovation in which firms can internationally collaborate on research projects. Firms based in the northern economy decide whether to develop innovations entirely with domestic researchers or in collaboration with researchers in southern countries. The major finding is that as the market size of the southern countries increases, northern firms tend to respond by fostering North-South research collaboration (offshoring). Innovation through global collaboration also increases the wage inequality in southern countries. The relationship between market size and wage inequality is either upward sloping or inverted U-shaped.

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Keywords: North-South model; wage gap; globalization; research and development (R&D); global sourcing

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1 Introduction

Global collaborations to exploit economic opportunities at the firm and country levels have been a prominent issue in the international trade and business literature. This paper investigates a specific mechanism of innovation through global collaboration and its relationship to market size. In a nutshell, saving costs and gaining synergies are now strong incentives for research firms to innovate by collaborating with skilled researchers in foreign countries. But firms still have the traditional alternative of using only domestic researchers. The decision of whether to accomplish research projects *locally or globally* will depend in part on the market size and openness of the foreign countries available for collaboration. As a foreign market increases in size and strength, competition for its research resources will intensify, further accelerating the process of innovation through global collaboration.

My theory brings new insights into the recent widening of wage inequality in developing countries, a key issue in the globalization debate. As shown by the IMF (2007), over the past two decades globalization has contributed to the increasing trends in wage and income inequality observed in most developing countries and some developed countries.[1] This fact contradicts the theoretical prediction of standard trade models (e.g., the Heckscher-Ohlin model) that growing trade integration shifts the demand for unskilled workers from skill-rich developed regions to developing regions, thereby reducing wage inequality in the latter. This paper reconciles fact and theory in a dynamic setting by arguing that the usual inequality-reducing effect of globalization is accompanied by an accelerated process of collaborative innovation, which tends to increase the level of inequality in developing countries.

The starting point of this model is the possibility of collaboration between different regions. This phenomenon has become increasingly common in the R&D market, as intensively argued in the business literature (MacCormack et al. 2007a, b). One obvious example is the creation of a joint innovative solutions lab (OZONE) in 2008 by Oracle in California and Wipro in Bangalore. Another example is Boeing's 787 Dreamliner aircraft, which was developed by an international collaboration with more than 50 partners in over 130 locations.

[1]At first glance, this observation seems to be consistent with a view upheld by opponents of globalization, that "globalization has dramatically increased inequality between and within nations" (Mazur, 2000). However, as emphasized by Becker (2007), the IMF report also shows that the poor in developing countries have become better off in that they have more to spend on goods that they desire. Thus, increased wage inequality is not necessarily a *bad* result of globalization.

The economic literature has largely focused on the international disintegration of production, along with evidence illustrating this trend (Feenstra and Hanson 1996, Campa and Goldberg 1997). Theoretical papers have addressed "issues that arise from the choice of outsourcing versus integration and home versus foreign" in North-South models (Antràs and Helpman 2004).[2] Empirical work suggests that "firms jointly make innovation and export-market-participation decisions" (Costantini and Melitz 2008). Another branch of this literature links innovation and wage inequality in a globalizing world (Verhoogen 2008).

This paper develops a simple, two-region dynamic model of innovation where skilled researchers based in the northern (domestic) economy may collaborate on projects with researchers in the southern (foreign) economy. The South possesses a smaller knowledge base than the North. An international research firm chooses the composition of its innovation program (the ratio of domestic researchers to foreign researchers) so as to maximize the market value of the firm.

I use this framework to investigate the consequences of growing market size and openness in the South. The major finding is that a larger labor market may increase the wage inequality (skill premium) in southern countries, as it encourages collaboration between northern and southern researchers. The long-run relationship between market size and inequality is either upward sloping or inverted U-shaped. This result is supported in Section 4 by a discussion of the empirical evidence that globalization is accompanied by increasing wage inequality in developing countries.

2 A Model of Innovation through Global Collaboration

In this section, I will develop a model of innovation through global R&D collaboration. I consider a dynamic general equilibrium model à la Grossman and Helpman (1991), with two regions: the research firm's home country (referred to as the North) and a set of similar foreign countries (referred to as the South). The two regions are integrated both financially and through trade, differing essentially in their capability for innovation. In each region, the representative consumer is endowed with the following intertemporal utility function: $U = \int_0^{\infty} e^{-\rho t} \ln u_t dt$. The time argument t will be dropped when doing so causes no confusion. In the standard manner, u is defined as a constant elasticity of sub-

[2] See also Antras and Helpman (2008) and Grossman and Helpman (2002, 2005).

stitution utility function on a continuum of differentiated consumption goods: $u = \left(\int_0^n x(j)^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}}$, where $\sigma > 1$. After normalizing the instantaneous aggregate spending to 1 at each date, dynamic optimization is found to require the equality of the discount rate and interest rate: $\rho = r_t$. The instantaneous aggregate demand for good j with price $p(j)$ is then given by $x(j) = p(j)^{-\sigma} / \int_0^n p(j)^{1-\sigma} dj$.

The representative consumer inelastically supplies two types of resources: unskilled labor used in the creation of final goods, denoted "production workers", and skilled labor used for innovation research, denoted "researchers". The North supplies R^N researchers and L^N production workers; the South supplies R^S researchers and L^S production workers.

2.1 Global and Local Innovation

There are three possible research sectors: a global research sector, and the two local research sectors in the North and the South. R&D firms in these sectors hire skilled workers as researchers to create new consumption goods and sell the resulting innovations as exclusive licenses to manufacturing firms in the consumption goods sector.

In the global research sector, there are potentially a number of perfectly competitive R&D firms. Each global firm hires researchers from both regions, the North and the South, in an international collaboration. To model the collaboration, I assume that the elasticity of substitution between researchers in the two regions is constant at $\epsilon > 0$. An innovation requires h^N units of Northern researchers and h^S units of Southern researchers such that

$$1 = \left[\gamma (A^N h^N)^{\frac{\epsilon-1}{\epsilon}} + (1-\gamma)(A^S h^S)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}}, \tag{1}$$

where $\gamma \in (0, 1)$ determines the proportion of Northern researchers and A^i represents the cumulative knowledge stock of region i ($i = N, S$). Since the knowledge stock of a region is determined by the cumulative experience of its native researchers, $A^N = n$ and $A^S = n^C$ are assumed as standard. While R&D firms are competitive, the unit cost of a global collaborative innovation at date t, denoted c_t, is represented by

$$c = \left[\gamma^{\epsilon} (w_R^N / A^N)^{1-\epsilon} + (1-\gamma)^{\epsilon} (w_R^S / A^S)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}, \tag{2}$$

where w_R^i is the wage rate of researchers in region i.

What of local R&D firms in the North? Allowing for $\gamma = 1$ in (2), the unit cost of a northern local R&D activity, denoted d_t, is

$$d = \frac{w_R^N}{A^N}. \tag{3}$$

To focus on the role of global collaboration, I assume that Southern local research is highly inefficient. I set its cost to $d^S = \varphi w_R^S / A^S$, where φ is sufficiently large to ensure that $c < d^S$ in equilibrium. That is, by construction Southern innovations are not profitable in equilibrium, and this research sector plays no further role in the model.

Let V_t denote the intertemporal market value of an innovation at date t.[3] Each R&D firm decides whether or not to innovate a new consumption good. Denote by e_t^C and e_t^D the binary choice variables of global and local R&D firms with respect to entry; if $e_t^C = 1$ (resp. $e_t^D = 1$), a global (resp. local) R&D firm invests in innovation during that period. If the choice variable is zero, it does not. Free entry in the R&D markets ensures that

$$\max_{e_t^C \in \{0,1\}} (V_t - c_t) e_t^C = 0 \quad \text{and} \quad \max_{e_t^D \in \{0,1\}} (V_t - d_t) e_t^D = 0. \tag{4}$$

Denote by n^C and n^N the numbers of goods developed by North-South collaboration and by the North alone ($n = n^C + n^N$). The world economy is initially endowed with $n_0^C \geq 0$ and $n_0^N > 0$ goods. The market clearing constraints for the research resource are given by

$$h^N \dot{n}^C + \dot{n}^N / A^N = R^N, \qquad h^S \dot{n}^C = R^S. \tag{5}$$

Taking into account the condition for the South in (5), $\dot{n}^C > 0$ must hold in equilibrium, implying $e_t^C = 1$ in (4). The equality $V_t = c_t$ therefore holds in equilibrium.

2.2 Manufacturing and the Choice of Locus

Two international markets play a role in the model. The first is a license market for innovations, in which the sellers and buyers are R&D firms and consumption good manufacturers. A successful R&D (global or local) firm sells its innovation

[3] There are two types of innovations that differ in their production loci. *A priori*, each type has a distinct value, but, as shown later, the two innovation values are combined into a single expression, V_t, in equilibrium.

as an *exclusive* license to a manufacturing firm at price V_t (the license fee). The manufacturing firm then monopolistically supplies the good.

A licensed manufacturing firm freely chooses where the good is to be produced. Denote by V^i the market value of a manufacturing firm whose production locus is located in region i.[4] The location choice problem is represented by

$$\max_{i=\{N,S\}} V_t^i = \int_t^{\infty} e^{-(R_\tau - R_t)} \pi_\tau^i d\tau, \tag{6}$$

where R_t is the cumulative interest up to time t and π_t^i represents the instantaneous profit of region i. The non-arbitrage condition for location choice guarantees that each firm is indifferent to the region: $V^i = V$ for any $i \in \{N, S\}$. Together with this result, (6) implies $\pi^i = \pi$ for any $i \in \{N, S\}$.

The second international market is a consumption good market where the sellers and buyers are licensed manufacturing firms and representative consumers. Firms in the North can produce one unit of any consumption good by using one unit of Northern production labor, but firms in the South must use z units of Southern production labor.[5] The manufacturing firm's problem in region i is then $\max_{\{x_t(j),p_t(j)\}} \pi_t^i(j) = p_t^i(j)x_t^i(j) - \Gamma(i)w_t^i x_t^i(j)$, where w_t^i represents the wage rate for production workers in region i and Γ satisfies $\Gamma(N) = 1$ and $\Gamma(S) = z$. Due to the constant price elasticity σ, a licensed manufacturing firm in region i sets its monopolistic price to $p_t^i = \frac{\sigma\Gamma(i)w_t^i}{\sigma-1}$ and earns the profit $\pi^i = \frac{\Gamma(i)w^i(p^i)^{-\sigma}}{(\sigma-1)P^{1-\sigma}}$. This expression, together with $\pi^i = \pi$, yields the conditions $w^N/w^S = z$ and $\pi = 1/(\sigma n)$.

2.3 Labor Markets for Production Workers

The model is closed by describing two labor markets for production workers. Denote by $\theta_t \in (0, 1)$ the fraction of manufacturing firms whose production base is located in the South, which is endogenously determined in equilibrium as follows. It is easy to verify that the aggregate demands for Northern and Southern production workers are given by $(1-\theta)\frac{\sigma-1}{\sigma w^N}$ and $z\theta\frac{\sigma-1}{\sigma w^N}$ respectively. The fraction θ is determined by the labor market clearing conditions in both regions:

$$\theta = \frac{L^S}{zL^N + L^S}. \tag{7}$$

[4]The choice of location is considered irrevocable, and made the first time a product is introduced. However, the equilibrium of the model and the results of this paper do not change at all if manufacturers are free to revise the location *at each date*.

[5]That is, a North-South productivity gap does not exist if $z = 1$.

Equation (7) reflects the fact that an increase in the labor supply L^i reduces the wage w^i, encouraging manufacturing in region i. The wages for production workers are then determined as $w^N = \frac{z(\sigma-1)}{\sigma(zL^N+L^S)}$ and $w^S = \frac{\sigma-1}{\sigma(zL^N+L^S)}$. Note that factor price equalization holds ($w^N = w^S$) if a productivity gap does not exist ($z = 1$).

2.4 Dynamic Equilibrium

The equilibrium dynamics of this economy are quite tractable. (See the Appendix for a detailed analysis.) Two cases exist, one with local R&D and one without. If $GR^S < \gamma^{-\varepsilon}R^N$, where $G \equiv \left(\frac{1-\gamma}{1-\gamma^\varepsilon}\right)^{\frac{\varepsilon}{\varepsilon-1}}$, global and local R&D activities *coexist* in equilibrium.[6] I call this "the coexistence case." If $GR^S \geq \gamma^{-\varepsilon}R^N$, the cost of a global innovation is always less than that of a local innovation: $c_t < d_t$. Therefore, no local R&D takes place in this equilibrium ($\dot{n}^N = 0$). I call this "the complete specialization case."

Before proceeding, it is useful to create a new state variable $\hat{n}^C = \frac{n^C}{n} \leq 1$ representing the fraction of collaborative innovations, referred to as "the rate of North-South collaboration." I can then show from (2), (3), and (5) that $\hat{n}^C$ evolves according to an autonomous, one-dimensional differential equation:

$$\frac{\dot{\hat{n}}^C}{\hat{n}^C} = \begin{cases} g^C\left(1-(1-\gamma^\epsilon)\hat{n}^C\right) - R^N & \text{if} \quad GR^S < \gamma^{-\varepsilon}R^N \\ g^C(1-\hat{n}^C) & \text{if} \quad GR^S \geq \gamma^{-\varepsilon}R^N \end{cases}. \tag{8}$$

The variable g^C stands for the growth rate of global collaborative innovations, $\frac{\dot{n}^C}{n^C}$, and is given by

$$g^C = g^C(\hat{n}_t^C) \equiv \begin{cases} GR^S & \text{if } GR^S < \gamma^{-\varepsilon}R^N \\ \left(\gamma\left(\frac{R^N}{\hat{n}_t^C}\right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)\left(R^S\right)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} & \text{if } GR^S \geq \gamma^{-\varepsilon}R^N \end{cases}. \tag{9}$$

Figure 1 depicts two phase diagrams for (8). The line ψ (Figure 1a) represents the coexistence case, while the curve ψ'' (Figure 1b) represents the complete specialization case. Each diagram has a unique and globally stable steady state: $n^* = \frac{GR^S - R^N}{GR^S(1-\gamma^\epsilon)}$ for the coexistence case, and $n^* = 1$ for the complete specialization case.

[6] The case $R^N \geq GR^S$, where the cost of global innovation is always higher than that of local innovation, is excluded in the following analysis. No international collaborations occur in this case ($\dot{n}^C = 0$), which contradicts the market clearing condition for Southern researchers. Thus, $R^N < GR^S$ is assumed.

3 Market Size and Global Collaboration: The Effects on Wage Inequality

The previous section proposed a dynamic model of innovation through North-South collaboration, and showed that the dynamic equilibrium of the model is stable. In this section, I will demonstrate that North-South research collaboration is a source of local wage inequality in the South. I use the relative sizes of the skilled and unskilled labor markets to link the concepts of collaboration and wage inequality. Specifically, I will show that a growing supply of skilled labor in the South increases wage inequality in the South by accelerating the process of innovation through collaboration.

Consider the changes implied by an increase in the southern market for skilled researchers, R^S. As shown in Figure 1a, when R^S is initially small and satisfies $GR^S < \gamma^{-\varepsilon} R^N$, the graph of $\dot{\hat{n}}^C / \hat{n}^C$ shifts up from line ψ to the dotted line ψ'. The rate of North-South collaboration therefore increases, in the long run converging to a new steady state n': $\frac{\partial n^*}{\partial R^S} > 0$. If the increase is very large so that R^S now satisfies $GR^S \geq \gamma^{-\varepsilon} R^N$, the graph changes to curve ψ'' in Figure 1b, and the collaboration rate converges to $n^* = 1$: $\frac{\partial n^*}{\partial R^S} = 0$. Increases in the northern market for skilled researchers, R^N, have the opposite effect.[7]

The intuitive explanation is as follows. An increase in the supply of southern skilled researchers relaxes resource scarcity, reduces their wage rate, and decreases the unit cost c for an R&D collaboration. This effect encourages global firms to engage in North-South collaboration. An increase in the supply of northern skilled researchers also reduces their wage, decreasing the costs of both global and local R&D activities. However, the effect on local innovations is greater:

$$\left| \frac{\partial c_t}{\partial w_R^N} \right| < \left| \frac{\partial d_t}{\partial w_R^N} \right|.$$

This inequality can easily be verified. From (2), $\frac{\partial c}{\partial w_R^N} = \gamma^{\varepsilon} c^{\varepsilon} \frac{(w_R^N)^{-\varepsilon}}{(A^N)^{1-\varepsilon}}$. Together with the free entry condition $c = d = \frac{w_R^N}{A^N}$, this result implies $\frac{\partial c}{\partial w_R^N} = \frac{\gamma^{\varepsilon}}{A^N}$, which is smaller than $\frac{\partial d}{\partial w_R^N} = \frac{1}{A^N}$.

Increasing the skilled labor supply in the North thus discourages collaboration. Finally, for a sufficiently large (small) endowment for the South (North) to satisfy $GR^S \geq \gamma^{-\varepsilon} R^N$, the wage of Northern researchers is (relatively) too high for local R&D to take place.

[7] Note that $\frac{\partial n^*}{\partial R^N} < (=) 0$ for $GR^S < (\geq) \gamma^{-\varepsilon} R^N$.

The long-run relationships between market size and collaboration are summarized in the following proposition:

Proposition 1 *The long-run rate of North-South collaboration, n^*, increases with an increase in the supply of Southern researchers, R^S, and decreases with an increase in the supply of Northern researchers, R^N. The rate is 100% when the supply of Southern $($Northern$)$ researchers is sufficiently large $($small$)$ to satisfy $GR^S \geq \gamma^{-\varepsilon} R^N$.*

Proposition 1 can be interpreted as a version of the *Rybczynski effect* in international economics. To understand how, interpret the innovation market of the present model as a two-good, two-factor market. The two goods are collaborative and local innovations, and their flows (measured by the total number of innovations) are represented by $\frac{\dot{n}^C}{n}$ and $\frac{\dot{n}^N}{n}$ respectively. The two factors are the supplies of southern and northern researchers, represented by R^S and R^N.

Figure 2 depicts the southern and northern resource constraints for innovation activities in steady-state equilibrium (lines S and N). As shown in the Appendix, these constraints can be expressed analytically as $\frac{\dot{n}^C}{n} = GR^S - \frac{\dot{n}^N}{n}$ and $\frac{\dot{n}^C}{n} = \gamma^{-\varepsilon}\left(R^N - \frac{\dot{n}^N}{n}\right)$. The slope of line S (equal to -1) is shallower than that of line N (equal to $-\gamma^{-\varepsilon} < -1$). This difference in slopes captures the fact that the global R&D sector uses Southern researchers *relatively intensively*, and ensures the existence of a unique equilibrium at the intersection (point Ψ).[8]

Figure 2 also shows the effects of increasing the endowment of either factor. An increase in the South (R^S) leads to an upward shift from S to S', moving the equilibrium from point Ψ to point Ψ'. This change therefore increases the flow of global innovation, $\frac{\dot{n}^C}{n}$, and decreases the flow of local innovation, $\frac{\dot{n}^N}{n}$. Moreover, if the increase in R^S is sufficiently large to meet $GR^S \geq \gamma^{-\varepsilon} R^N$, the case will shift to "complete specialization." This situation corresponds to line S'', where the equilibrium Ψ'' lies on the vertical axis. The same argument goes for the North: an increase in R^N leads to a rightward shift from N to N', resulting in an equilibrium shift from Ψ to Ψ'''. It follows that $\frac{\dot{n}^C}{n}$ decreases and $\frac{\dot{n}^N}{n}$ increases.

Remark 1 (The Rybczynski effect) *Proposition 1 is a version of the Rybczynski theorem. Raising the Southern endowment R^S increases the output of Southern-factor-intensive global R&D sector $\dot{n}^C$ and decreases the output of Northern-factor-intensive local R&D sector $\dot{n}^N$. Conversely, raising the Northern endowment R^N leads to an increase in $\dot{n}^C$ and a decrease in $\dot{n}^N$.*

[8] The existence of a steady-state equilibrium is guaranteed by the assumption $GR^S > R^N$. If this does not hold, line S passes through the shaded area and cannot intersect with line N.

I will now turn to the wage inequality that emerges from the North-South collaboration. Define $\omega(R^N, R^S) \equiv \frac{\frac{1}{\sigma}\left(\gamma\left(R^N\right)^{\frac{\varepsilon-1}{\varepsilon}}+(1-\gamma)\left(R^S\right)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{1}{\varepsilon-1}}}{\rho+\left(\gamma(R^N)^{\frac{\varepsilon-1}{\varepsilon}}+(1-\gamma)(R^S)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}}$. The following theorem completely characterizes the long-run wage rates of skilled researchers in both regions. (The proof appears in the Appendix.)

Theorem 1 *In the steady state equilibrium, the wage rate for Northern researchers is given by*

$$w_R^N = \begin{cases} \frac{1}{\sigma(\rho+GR^S)} & \textit{if } GR^S < \gamma^{-\varepsilon}R^N \\ \gamma(R^N)^{-\frac{1}{\varepsilon}}\omega(R^N, R^S) & \textit{if } GR^S \geq \gamma^{-\varepsilon}R^N \end{cases} \tag{10}$$

and the wage rate for Southern researchers is given by

$$w_R^S = \begin{cases} \frac{GR^S - R^N}{\sigma R^S(\rho+GR^S)} & \textit{if } GR^S < \gamma^{-\varepsilon}R^N \\ (1-\gamma)(R^S)^{-\frac{1}{\varepsilon}}\omega(R^N, R^S) & \textit{if } GR^S \geq \gamma^{-\varepsilon}R^N \end{cases}. \tag{11}$$

Equations (10) and (11) establish relationships between the supplies of researchers and their wage rates. In the North, the standard negative relationship between labor supply (R^N) and wage (w_R^N) always holds. The South displays different and more interesting behavior. As shown in Figure 3, there is a *positive* relationship between the skilled labor supply R^S and its wage w_R^S for small values of R^S (such that $GR^S < \gamma^{-\varepsilon}R^N$). As a result, the global shape of (11) is an inverted 'U'.

This nonlinear relationship between skilled labor supply R^S and the wage w_R^S can be explained by considering simplified demand and supply curves in the Southern labor market. These are depicted in Figure 4 as lines D and S respectively. An increase in R^S leads to a rightward shift of the supply curve to S', which immediately decreases the wage rate, w_R^S, from E down to E' (this is the usual price effect). The distinguishing feature of the model, however, is the dynamic effect that follows. Due to the Rybczynski effect (Remark 1), the rate of North-South collaboration, n^*, increases in the long run, stimulating the demand for Southern researchers. This produces an *endogenous* upward shift of the demand curve to curve D'. Consequently, although wage w_R^S moves from E down to E' in the short run, it rises to E^* in the long run. This results in the positive relationship between labor supply R^S and wage w_R^S in the long run. The negative static effect and positive dynamic effect can be verified by calculating the transitional trajectory for w_R^S implied by an increase in R^S; see Figure 5.[9]

However, for a very large supply of southern skilled researchers such as $GR^S \geq \gamma^{-\varepsilon} R^N$, the story differs. There is still a rightward shift from S' to S'', as indicated by line (1)' in Figure 4(b), but no dynamic effect is possible because the rate of North-South collaboration, n^*, is constant at 100 percent. There is therefore no way to produce an endogenous upward shift of the demand curve. Consequently, the wage w_R^S moves from E^* down to E^{**} as a result of the usual price effect. This implies the standard negative relationship between R^S and w_R^S.

Proposition 2 *As the population of Southern skilled researchers, R^S, increases, their wage, w_R^S, decreases in the short run but may increase in the long run. The long-run relationship between R^S and w_R^S is inverted U-shaped.*

The purpose of this section is to clarify the relationship between the market size vector $(R^S, L^S)^{10}$ and the wage inequality $\frac{w_R^S}{w^S}$. Recall that the wage for unskilled production workers, $w^S = \frac{\sigma - 1}{\sigma(zL^N + L^S)}$, is a decreasing function of L^S. Using this fact and Proposition 2, I can prove that the following relationship holds.

Proposition 3 *As the market size of the South (R^S, L^S) increases, the wage inequality in the South, $\frac{w_R^S}{w^S}$, first rises (in the coexistence case) then falls or continues to rise (in the complete specialization case). The configuration is thus either upward sloping or inverted U-shaped.*

This proposition is my core result. Its implication is that a growing labor market in the South encourages R&D firms in the North to collaborate with the South on innovations. This effect shifts labor demand in the South from unskilled production workers to skilled researchers, producing a wider wage gap (skill premium) in Southern countries. One can therefore state that *North-South research collaboration is a source of wage inequality in the South.*

4 Globalization and Wage Inequality

In this section, I relate the results of previous sections to the globalization debate. In discussing the effects of globalization, I follow the analysis of Dinopou-

[9] It can be formally demonstrated that the static effect is negative. The proof is available upon request.

[10] In this paper, "an increase in (R^S, L^S)" is defined to mean that either R^S or L^S increases, or both.

los and Segerstrom (2004, 2007). In the last three decades, some developing countries such as China, India, and Mexico have undertaken trade liberalization. In the present model, the economic integration of developing economies into the world trading system is equivalent to an increase in the market size of the South, (R^S, L^S). I therefore associate globalization with an increase in the market size of the South.[11] Finally, based on Propositions 1-3, I can make the following statement.

Remark 2 (Globalization and Local Inequality) *When globalization increases the market size of the developing South, wage inequality may rise in the South. Innovation firms respond to the increased market size by fostering North-South research collaborations, an endogenous bias that increases wage inequality in the South.*

The positive relationship between globalization and local inequality also holds if the extent of globalization is measured by an increase in *foreign direct investment in the South.* This measure is often used in the empirical literature on globalization. Noting (7), an increase in (R^S, L^S) leads to an increase in the fraction of Northern firms making foreign direct investment into the South. Therefore, the relationship between foreign direct investment and wage inequality in the South is also either upward sloping or inverted U-shaped.

Finally, I will point out some empirical evidence on globalization and inequality. I first focus on the case of Mexico, which joined the GATT in 1985 and embarked on a broad program liberalizing trade and foreign investment. As discussed in Kremer and Maskin (2006), from mid-1985 to the end of 1987 the share of foreign direct investment rose from 1.4 percent to 9.8 percent of the total annual investment. Over the period 1984-1990, real white-collar wages increased 13.4 percent and blue-collar wages decreased 14.0 percent (Feenstra and Hanson 1997; Hanson and Harrison 1999). In other countries, despite their limited data, Lindert and Williamson (2001) find that liberalization tends to be followed by an increase in inequality. In addition, recent panel studies in the literature either find that trade liberalization is positively associated with inequality in poor countries, or else find no strong association (Barro 2000). All this evidence supports the theoretical prediction of the present study.

[11] A representative event would be China's 1978 policy change joining it to the world trade system, or Mexico's 1985 decision to join the GATT.

5 Conclusion

This paper has presented a two-region endogenous growth model that allows research firms the possibility of choosing a North-South collaboration on innovation. In this model, there is an inverted-U relationship between the population of researchers in the developing region and their wage. This novel result relates the globalization movement to increasing wage inequality in developing nations.

Clearly, this model could be extended in several ways. A number of restrictions were imposed in this paper to keep the initial analysis as simple as possible. First, it was assumed that Southern countries are highly inefficient when innovating alone. Second, the model considers neither (incomplete) contracts between international research firms nor the distribution of benefits in a network of research firms. Third, international financial capital flows were assumed to be perfect. Relaxing any of these assumptions could alter the relationship between global research collaboration and wage inequality, enriching the interpretation of this model.

APPENDIX

A. Dynamics in the coexistence case

By differentiating (2) with respect to (w_R^N, w_R^S), we obtain

$$h^N = \left(\frac{\gamma c}{w_R^N}\right)^{\epsilon} n^{\epsilon-1} \text{ and } h^S = \left(\frac{(1-\gamma)c}{w_R^S}\right)^{\epsilon} (n^C)^{\epsilon-1}. \tag{12}$$

Using (12), the free entry condition $c = d$ can be rewritten as

$$\frac{w_R^N}{w_R^S} = \left(\frac{1-\gamma^{\epsilon}}{(1-\gamma)^{\epsilon}}\right)^{\frac{1}{\epsilon-1}} \frac{1}{\hat{n}^C}. \tag{13}$$

The relation $\dot{n}^N = \dot{n} - \dot{n}^C$, (12), and (13) can be used to cancel out $\dot{n}^C$ from both sides of (5). The resulting relation is $\frac{\dot{n}}{n} = R^N + R^S \left(\frac{(1-\gamma)^{\epsilon}}{1-\gamma^{\epsilon}}\right)^{\frac{1}{\epsilon-1}} \hat{n}^C \equiv g$, where g stands for the growth rate of total innovation. A second differential equation is be obtained by substituting $c = w_R^N/n$, (13), and (12) into (5), namely $\frac{\dot{n}^C}{n^C} = GR^S \equiv g^C$. These differential equations, g and g^C, are used to derive (8) and (9).

Define a new variable representing the total value of all innovations, $v \equiv nV$. The Bellman equation is obtained from (6) and $\pi = 1/\sigma n$ as $\dot{v} = (\rho + g)\, v - \frac{1}{\sigma}$.

In the steady-state equilibrium, since $\dot{v} = 0$, $v^* = \frac{1}{\sigma(\rho+g^*)}$. It is straightforward to show that a dynamic path for $v(t)$ and its initial value $v(0)$ are uniquely determined by the transversality condition.

B. Dynamics in the complete specialization case

It will be first shown that $\dot{n}^N = 0$ when $\frac{R^S}{R^N} \geq \frac{1}{G\gamma^\varepsilon}$. From (2), (3), (5), and (12), $\frac{c}{d} = \gamma^{\frac{\varepsilon}{1-\varepsilon}} \left(1 + \frac{1-\gamma}{\gamma}\left(\left(\frac{A_N}{A_S}\right)\left(\frac{R^N}{R^S} - \frac{\dot{n}^N}{\hat{n}^C A^N h^S}\right)\right)^{\frac{1-\epsilon}{\varepsilon}}\right)^{\frac{1}{1-\epsilon}}$, which is decreasing in $\dot{n}^N$. Hence, $\frac{c}{d} < 1$ for any $\dot{n}^N \geq 0$ if and only if the $\frac{c}{d}$ evaluated at $\dot{n}^N = 0$ is less than 1–or equivalently $\frac{R^N}{GR^S} < \gamma^\varepsilon \frac{A_N}{A_S}$. Thus, when $\frac{R^N}{GR^S} \leq \gamma^\varepsilon$, $\frac{c}{d} < 1$ for any $\dot{n}^N \geq 0$ (noting $\frac{A_N}{A_S} > 1$). This argument proves $\dot{n}^N = 0$.

The dynamics of $\hat{n}^C$ in the complete specialization case will now be shown. Noting $\dot{n}^N = 0$, the relative wage of international researchers becomes $\frac{w_R^N}{w_R^S} = \frac{\gamma}{1-\gamma}\left(\hat{n}^C\right)^{\frac{1-\varepsilon}{\varepsilon}}\left(\frac{R^N}{R^S}\right)^{-\frac{1}{\varepsilon}}$. This, together with (2), (12) and (5), implies that $\frac{\dot{n}^C}{n^C} = g^C(\hat{n}^C)$ as in (9). Because $\frac{\dot{n}}{n} = \hat{n}^C\frac{\dot{n}^C}{n^C}$ if $\dot{n}^N = 0$, $g = \hat{n}^C g^C(\hat{n}^C)$, and $\hat{n}^C$ evolves according to the equation $\frac{\dot{\hat{n}}^C}{\hat{n}^C} = g^C(\hat{n}^C)(1-\hat{n}^C)$ as in (8). The dynamics of v obey the same differential equation that was derived for the coexistence case, except that $g = \hat{n}^C g^C(\hat{n}^C)$.

C. Proof for Theorem 1

For the coexistence case, w_R^N is equal to $v^* = \frac{1}{\sigma(\rho+GR^S)}$ due to the free entry condition $V = d$ and $g^* = GR^S$. Together with (5), (9) and (12), the free entry condition $c = d$ implies that $w_R^S = w_R^N\hat{n}^C(1-\gamma)G^{\frac{1}{\varepsilon}}$. Substituting (10) into this equation yields $w_R^S = \frac{GR^S - R^N}{\sigma R^S(\rho+GR^S)}$; note that $n^* = \frac{GR^S-R^N}{GR^S(1-\gamma^\epsilon)}$. For the complete specialization case, free entry ensures only $c = V$, implying $w_R^N = v\gamma\left(\gamma + (1-\gamma)\left(\left(\hat{n}^C\right)^{\frac{1}{\varepsilon}}\left(\frac{R^N}{R^S}\right)^{-\frac{1}{\varepsilon}}\right)^{\varepsilon-1}\right)^{\frac{1}{\varepsilon-1}}$, where use has been made of (2), (5), and (12). After using (9) with $n^* = 1$ and $v^* = \frac{1}{\sigma(\rho+g^*)}$, this equation results in (10) and (11).

D. On the configurations of the curves in Figure 3

Fix R^N, and consider the coexistence case with $R^S \in (\frac{R^N}{G}, \frac{R^N}{\gamma^\varepsilon G}) \equiv (\delta_L, \delta_H)$. Note that by differentiating (11), $\frac{\partial w_R^S}{\partial R^S} \gtreqless 0$ when $R^S \lesseqgtr \frac{1}{G}\left(R^N + \sqrt{(R^N)^2 + \rho R^N}\right) \equiv \Delta$. *A priori*, there are three possible cases: (a) $\frac{\partial w_R^S}{\partial R^S} < 0$ globally holds if $\Delta \leq \delta_L$, (b) $\frac{\partial w_R^S}{\partial R^S} > 0$ globally holds if $\Delta \geq \delta_H$, and (c) $\frac{\partial w_R^S}{\partial R^S} \lesseqgtr 0$ for $R^S \gtreqless \Delta$ holds if $\delta_L < \Delta < \delta_H$. Case (a) does not exist because $\Delta \leq \delta_L$ implies $\sqrt{(R^N)^2 + \rho R^N} \leq 0$, a contradiction. For Case (b), $\Delta \geq \delta_H$ implies $R^N(1 - 2\gamma^\varepsilon) \leq \gamma^{2\varepsilon}\rho$. If $1 \leq 2\gamma^\varepsilon$, $\Delta \geq \delta_H$ (i.e., $\frac{\partial w_R^S}{\partial R^S} > 0$) holds, and if $1 > 2\gamma^\varepsilon$, $\Delta \geq \delta_H$ holds when $R^N \leq \frac{\gamma^{2\varepsilon}\rho}{1-2\gamma^\varepsilon}$. Case (c) corresponds to $1 > 2\gamma^\varepsilon$ and $R^N > \frac{\gamma^{2\varepsilon}\rho}{1-2\gamma^\varepsilon}$. To summarize, when $1 \leq 2\gamma^\varepsilon$, the configuration is upward sloping, and when $1 > 2\gamma^\varepsilon$, it is upward sloping for $R^N \leq \frac{\gamma^{2\varepsilon}\rho}{1-2\gamma^\varepsilon}$ and inverted U-shaped for $R^N > \frac{\gamma^{2\varepsilon}\rho}{1-2\gamma^\varepsilon}$.

E. Formal derivation of the steady-state resource constraints

In the coexistence case, taking into account the free entry condition $c = d$, combining (5) and (12) into a single expression results in $\frac{\dot{n}^C}{n} = \gamma^{-\varepsilon}\left(R^N - \frac{\dot{n}^N}{n}\right)$. This is the steady-state factor constraint for the North. Since $0 < \gamma < 1$, the slope of line N in Figure 4 is less than -1. Next, using equations (5), (12), (13) and $c = d$, $\frac{\dot{n}^C}{n} = GR^S\hat{n}^C$ can be derived. This implies that $\frac{\dot{n}^C}{n} = \frac{GR^S - R^N}{1-\gamma^\varepsilon}$ in the steady state, since $n^* = \frac{GR^S - R^N}{GR^S(1-\gamma^e)}$. By rewriting the Northern constraint as $R^N = \gamma^\varepsilon\frac{\dot{n}^C}{n} + \frac{\dot{n}^N}{n}$ and incorporating this expression into $\frac{\dot{n}^C}{n} = \frac{GR^S - R^N}{1-\gamma^\varepsilon}$, we obtain an equation for S: the line $\frac{\dot{n}^C}{n} = GR^S - \frac{\dot{n}^N}{n}$, whose slope is -1.

References

Antras, Pol, and Elhanan Helpman. 2004. "Global Sourcing." *Journal of Political Economy*, 112: 552–580.

Antras, Pol, and Elhanan Helpman. 2008. "Contractual Frictions and Global Sourcing," in Helpman, E., D. Marin, and T. Verdier, ed., *The Organization of Firms in a Global Economy*, Cambridge, MA: Harvard University Press.

Barro, Robert J. 2000. "Inequality and Growth in a Panel of Countries." *Journal of Economic Growth*, 5: 5-32.

Becker, Gary S. 2007. "Globalization and Inequality," *The Becker-Posner Blog*. Available at:
http://www.becker-posner-blog.com/archives / 2007/10/globalization_a_1.html

Campa, Jose M. and Linda S. Goldberg. 1997. "The Evolving External Orientation of Manufacturing: A Profile of Four Countries." *Federal Reserve Bank of New York. Economic Policy Review.* 3: 53–81.

Costanini, James A. and Marc J. Melitz. 2008. "The Dynamics of Firm-Level Adjustment to Trade Liberalization," in Helpman, E., D. Marin, and T. Verdier, ed., *The Organization of Firms in a Global Economy*, Cambridge, MA: Harvard University Press.

Dinopoulos, Elias, and Paul Segerstrom. 2004. "A Theory of North–South Trade and Globalization." *CEPR Discussion Paper* No. 4140. Available at SSRN: http://ssrn.com/abstract=481302

Dinopoulos, Elias, and Paul Segerstrom. 2007. "North–South Trade and Economic Growth."
Available at: http://bear.cba.ufl.edu/dinopoulos/PDF/NorthSouthTrade.pdf

Feenstra, Robert C. and Gordon Hanson. 1996. "Globalization, Outsourcing, and Wage Inequality." *American Economic Review Papers and Proceedings*, 86: 240–245.

Feenstra, Robert C. and Gordon Hanson. 1997. "Foreign Direct Investment and Relative Wages: Evidence from Mexico's Maquiladoras." *Journal of International Economics*, 42: 371-393.

Grossman, Gene M. and Elhanan Helpman. 1991. *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press.

Grossman, Gene M. and Helpman, Elhanan. 2002. "Integration versus Outsourcing in Industry Equilibrium." *Quarterly Journal of Economics*, 117: 85-120.

Grossman, Gene M. and Elhanan Helpman. 2005. "Outsourcing in a Global Economy." *Review of Economic Studies*, 72: 135–159.

Hanson, Gordon, and Ann Harrison. 1999. "Trade, Technology and Wage Inequality in Mexico.” *Industrial and Labor Relations Review*, 52: 271-288.

IMF. 2007. “World Economic Outlook: Globalization and Inequality.” Available at: http:www.imf.orgexternalpubsftweo200702pdftext.pdf

Kremer, Michael, and Eric Maskin. 2006.“Globalization and Inequality.” Available at: http://www.economics.harvard.edu/faculty/kremer/files/GlobalizationInequality_Oct06.pdf

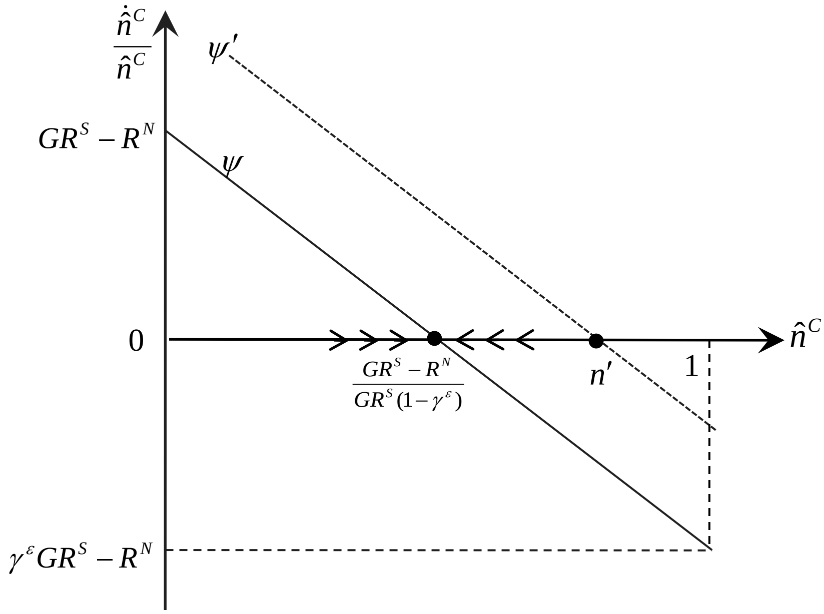
Lindert, Peter H. and Jeffrey G. Williamson. 2001. “Does Globalization Make the World More Unequal?” *NBER Working Paper* No. 8228, National Bureau of Economic Research, Cambridge, MA.

MacCormack, Alan., Theodore Forbath, Peter Brooks, and Patric Kalaher. 2007a. “Innovation through Global Collaboration: A New Source of Competitive Advantage.” Harvard Business School Working Paper 07-079.

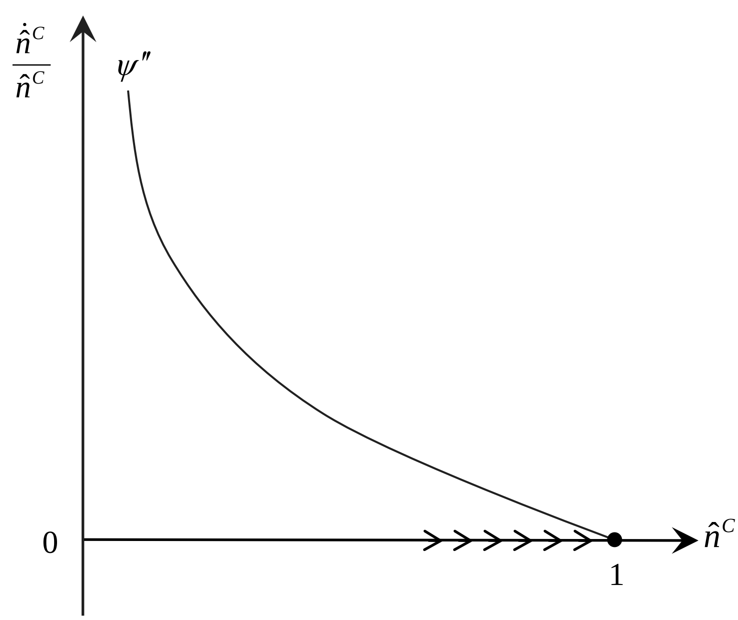
MacCormack, Alan, Theodore Forbath, Peter Brooks, and Patric Kalaher. 2007b. “From Outsourcing to Global Collaboration: New Ways to Build Competitiveness.” Harvard Business School Working Paper 07-080.

Mazur, Jay. 2000. “Labor’s New Internationalism.” *Foreign Affairs*, Jan/Feb. 2000.

Verhoogen, Eric A. 2008. “Trade, Quality Upgrading, and Wage Inequality in the Mexican Manufacturing Sector.” *Quarterly Journal of Economics*, 123: 489–530.



(a): the coexistence case where $GR^S < \gamma^{-\varepsilon} R^N$



(b): the complete specialization case where $\gamma^\varepsilon GR^S \geq R^N$

Figure 1: Phase diagrams for the rate of North-South collaboration

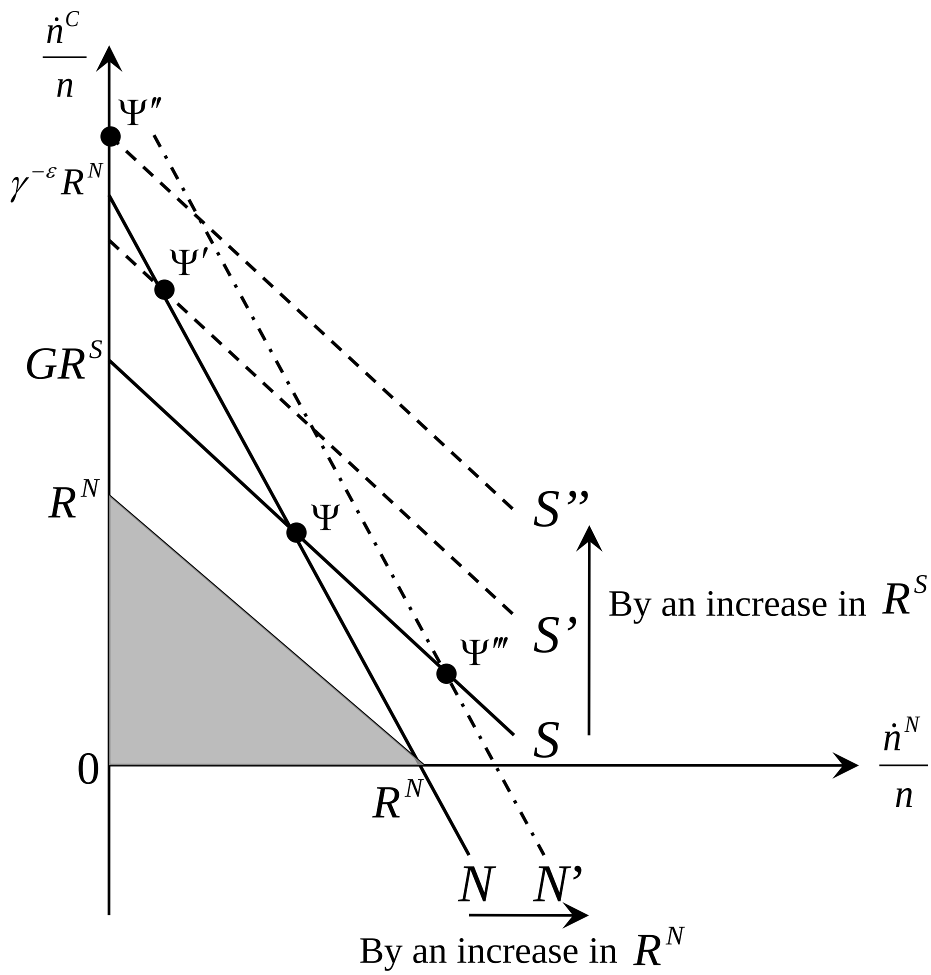


Figure 2: Resources and production possibilities (the Rybczynski effect)

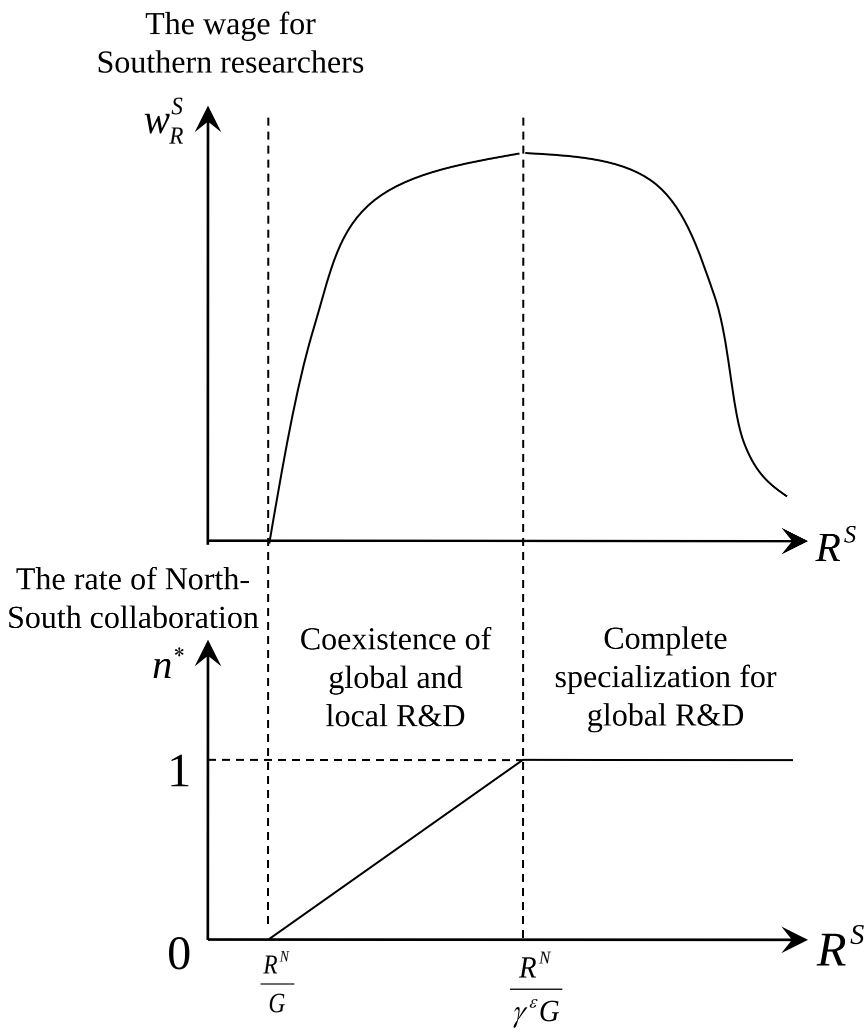
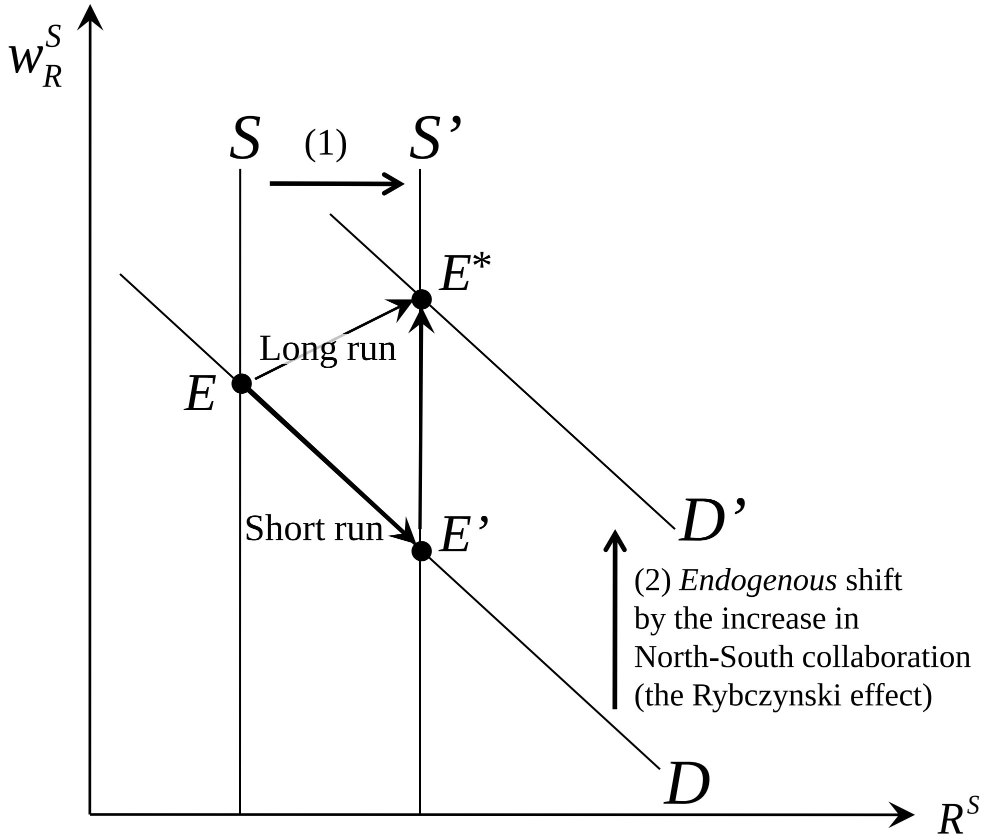
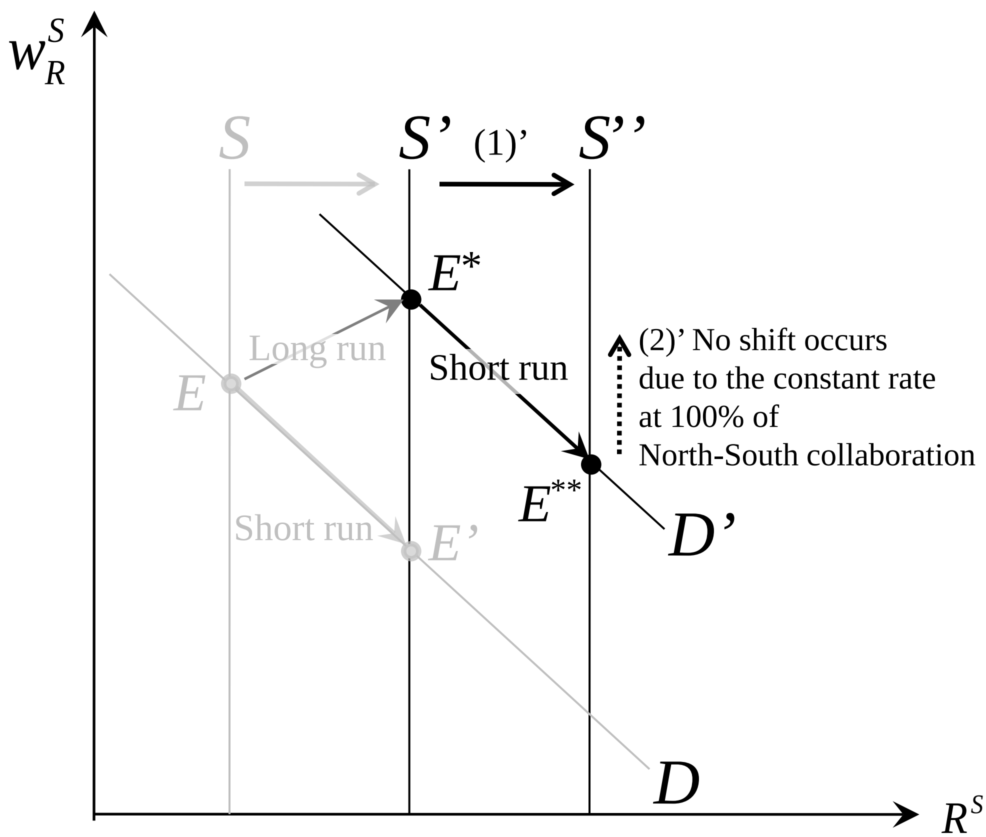


Figure 3: The long-run effects on wages of increases in research factor endowments



(a): Coexistence of global and local R&D



(b): Complete specialization for global R&D

Figure 4: An explanation of the inverted U: the demand and supply for Southern researchers

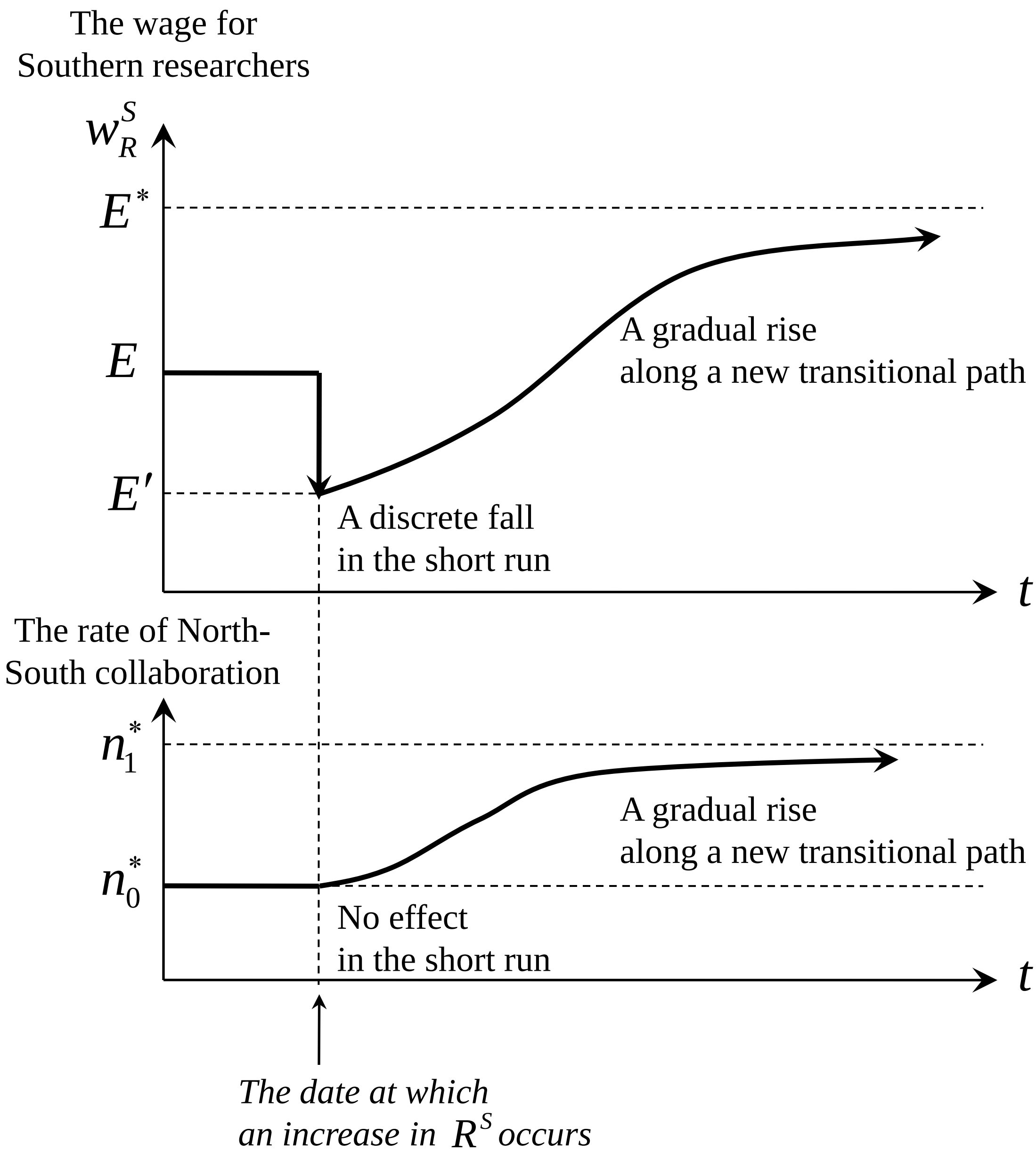


Figure 5: Changes of transitional trajectories
in the coexistence case of global and local R&D