Regional Growth and Development without Scale Effects - a Simple Model of Endogenous Formation of Regions

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Abstract

We present a semi-endogenous model of regional growth and development without scale effects. In this model of a small developing region the world growth rate of technical progress is given. Regional growth is driven by technological change induced by imitation. Imitation is determined by positive externalities from international trade. Regional factor endowments consist of immobile land and human capital which is perfectly mobile between regions. In order to study the endogenous formation of regions we introduce a second region and analyze a non symmetric decrease in international transaction costs. We find agglomeration in the region with better access to international markets, while the less favored region will realize a drop in income and technological capability. Two reactions can be identified. 1. For given resource endowments, the technological imitation process determines the final relative technological steady state positions. 2. Migration between the regions endogenously determines the final resource endowments of the regions. When reaching the no migration equilibrium, the relative development position, the population size and density of the region, as well as comparative advantages are endogenously determined.

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1 Introduction

During the last decade there was a strong revival of regional economics, initiated by a paper series by Krugman (1991a, 1991b, 1993). The new discussion was motivated by new theoretical tools which allow for more tractable modelling. This "new economic geography" has emerged as one of the most exciting areas of contemporary economics.

A major stream of regional economics explains the emerging of core periphery pattern through transportation costs and economies of scale (Krugman, 1991a, 1991b), Krugman and Venables, (1995)). Within a framework of monopolistic competition and scale economies manufactures production will concentrate close to a large market and the market will be large where manufactures production is concentrated. Being close to a large consumer market is the main reason that keeps production in cities.

According to a second stream in the literature the focus for explaining locations of firms in large cities is not interregional transportation costs and closeness to the market, but closeness to technologies and to a pool of human capital and high skilled labor. The advantage of urban areas is given by the density of people, and hence the concentration of human capital and technologies. Informational spillovers lead to more efficient production for clustered firms than for isolated producers. These approaches combine ideas from the "new geography" with contributions from "endogenous growth theory". Endogenous growth theory emphasizes the importance of human capital accumulation (Lucas 1988) and knowledge spillovers (Romer 1986) in economic development. This nonseparability of growth and urbanization has lead to a field of literature which stresses the interaction of geography, agglomeration and endogenous growth of a region, such as Eaton and Eckstein (1997). Further, In a model with centripetal forces Englmann and Walz (1995) and Walz (1996) show that linkages between intermediate and final good producers can lead to a clustering of production and innovation activities in one region. Martin and Ottaviano (1999, 2001) as well as Baldwin and Forslid (1997) illustrate that clustering also happens when consumers love variety of not perfectly tradeable consumer goods. Others, as Rivera-Batiz (1988) and Fujita and Thisse (2002,Ch.11) explain agglomeration in a framework based on increasing returns to scale. The link to trade within this concept is drawn by Eaton and Kortum (2001, 2002), or Baldwin, Martin and Ottaviano (2001) or Baldwin and Martin (2003).

While the merger of "new geography" and "endogenous growth" with monopolistic competition and the invention of new technologies rather explains phenomenons in industrialized countries, we concentrate on LDC's. Backward regions obtain technological advantages not by innovating but imitating. Focusing on imitation allows for a more simple modelling, since we can substitute the innovation sector by a simplified imitation process. We also identify trade as a main transmission channel for technologies. Especially for LDC's trade is suggested to be the decisive link for an access to new technologies. Following ideas of trade based growth models tracing back to Grossman and Helpman (1990, 1991), Rivera-Batiz and Romer (1991) and Young (1991), we develop a model in which endogenous growth and agglomeration is generated by external effects induced by imports. In contrast to the endogenous growth models, we suggest a mechanics which is more close to the semi-endogenous growth literature (Jones (1995) and Young (1998)). The endowment of a region or simply its size has no impact on the long run growth rate of income, but only on the regions relative level. We denote this level "relative technology position" (relatively to the technological leaders).

In what follows, we provide a simple framework to analyze the interaction between trade, development and agglomeration in regions of LDCs. After describing a single region we start with a thought experiment where a country consists of two regions which are originally identical. Factor endowments in the two regions are immobile land and perfectly mobile human capital. We define international transaction costs as a general concept which includes international transport costs as well as explicit and implicit barriers of trade. The central questions we would like to look at are: What determines the endogenous population size and density as well as the final success of a region? Is trade policy important for regional development? Does an agglomerating region develop on expense of the developing opportunities of other regions? What are the comparative advantages of these endogenously formed regions?

The paper is organized as follows. Section 2 presents a simple model for a single backward region, section 3 adds a second region to define a developing country where labor is mobile between the regions, and section 4 analyzes the endogenous formation of regions if international transaction costs non symmetrically change in the regions and human capital can migrate between regions. Section 5 concludes.

2 Model of a Single Region

The economy considered is a small region i integrated into world markets. The region is located in a developing country and characterized by a technological gap towards the leading industrialized world. Factors of production are land L_i and skilled labor or human capital H_i. The final output sector uses both, land and labor to produce a homogeneous final good X_i. The final good is used for domestic consumption and exports. The production of the final consumption good takes place under perfect competition and is described by a Cobb–Douglas technology

$$X_i = A_i L_i^{\alpha} H_i^{1-\alpha}, \tag{1}$$

where A_i is the regional level of technology. The developing region does not create new knowledge, but acquires technologies by decoding and imitating foreign designs from the technological leaders. The process of decoding technologies is driven by positive externalities from international integration.

The ability to increase the domestic stock of technological knowledge is positively related to the technological gap between the backward region and the industrialized world. If the domestic stock of technology is low, it is relatively easy to increase the technology stock by adopting foreign designs. However this process becomes increasingly difficult as the technological gap diminishes. This in fact draws back to the well-known Veblen-Gerschenkron-Hypothesis[1]. As we focus on underdeveloped regions we explicitly exclude the case of innovations in this backward region. Let Im_i denote imports and V the stock of knowledge of the technological leaders, we describe the increase of domestic technologies by imitation activities as

$$\dot{A}_i(t) = Im_i(t)\ \theta_i(t), \tag{2}$$

where t denotes time,

$$\theta_i(t) := 1 - \omega_i(t) \qquad and \qquad \omega_i(t) := \frac{A_i(t)}{V(t)} \tag{3}$$

denotes the relative technological position of the region $\omega_i(t)$, and respectively the technological gap $\theta_i(t)$ between the developing region and the industrialized world.

In order to determine the imports the demand side has to be considered. The household consumes domestic goods C_i and foreign goods Im_i. For simplicity we assume a Cobb–Douglas type utility function

$$U_i = Im_i^{\beta} C_i^{1-\beta}.$$

As we do not consider international borrowing or lending, the representative consumers budget constraint is given by $X_i = C_i + (1+\tau_i)p_i Im_i$, where τ_i is an ad valorem parameter for international transaction costs on imports and p_i is the relative price of imports in terms of the domestic final product. Due to the small country assumption, p_i is exogenously given and supposed to be constant. Solving the households optimization problem we obtain the demand for imports

$$Im_i = \frac{\beta}{(1+\tau_i)p_i} X_i. \tag{4}$$

Using (2), (4), and (1) we obtain a differential equation determining the growth of the stock of knowledge available to the region

$$\dot{A}_i(t) = \frac{\beta}{(1+\tau_i)p_i} A_i(t) L_i^{\alpha} H_i^{1-\alpha} \theta_i(t). \tag{5}$$

While domestic technological knowledge is endogenous for the region the stock of knowledge of the technological leaders $V(t)$ is assumed to grow with a given constant rate n:

$$\dot{V}(t) = nV(t) \tag{6}$$

[1] See Veblen (1915) and Gerschenkron (1963).

Differentiating (3) with respect to time and using (5) and (6) leads to a non linear differential equation

$$\dot{\omega}_i(t) = (\Psi_i - n)\omega_i - \Psi_i\omega_i^2, \tag{7}$$

where

$$\Psi_i := \frac{\beta}{(1+\tau_i)p_i} L_i^{\alpha} H_i^{1-\alpha}. \tag{8}$$

For a given initial value $\omega_i(0)$, the solution of this logistic equation gives the relative growth path of the region compared to the technological leader[2]

$$\omega_i(t) = \frac{\Psi_i - n}{\Psi_i + \left(\frac{\Psi_i - n}{\omega_i(0)} - \Psi_i\right) e^{-(\Psi - n)t}}.$$

This solution implies the possibility of two different dynamic regimes for the time path of technological upgrading depending on the value of Ψ_i. In the following we consider only the case that the region will grow on a path of convergence if, $\Psi_i > n$.[3] To determine the steady state of the region we take the limit for $t \to \infty$.

$$\omega_i^* = \lim_{t\to\infty} \omega_i(t) = 1 - \frac{n}{\Psi_i} \quad with \quad \frac{\partial \omega_i^*}{\partial H_i} > 0, \quad \frac{\partial \omega_i^*}{\partial \tau_i} < 0.^4 \tag{9}$$

As can be seen from (9) the steady state ω_i^* defines the final development position of the region. Even in the long run a final gap n/Ψ_i will remain. An imitating region can never fully close the technological gap.

Therefore the final position of the region is determined by the degree of economic integration and the factor endowments. A reduction of τ_i will increase the speed of technological convergence as well as the final technological position. With a larger endowment the imitation, driven by positive externalities from trade, accelerates and the final position of the region improves

3 Two Regions in a Country

To analyze interregional migration and agglomeration we need to look at more than one region. We consider a country with two regions. Both regions have a

[2] For $\Psi_i \leq n$ the ratio of technological knowledge $\omega_i(t)$ will decrease to zero, *i.e.* the region cannot close the technological gap and will diverge. For $\Psi_i > n$ the ratio of technological knowledge $\omega_i(t)$ will increase and the region will follow a process of technological upgrading.

[3] For given values of p_i, β, L_i and H_i the condition $\Psi_i > n$ can be expressed in terms of the minimal requirements of international integration for successful upgrading:

$$\frac{\beta}{p_i\, n} L_i^{\alpha} H_i^{1-\alpha} > (1+\tau_i).$$

Therefore, the process of transition will be successful, if the region meets these requiements for openess. This condition can also be rearanged to determine the minimum H_i in the region. $H_i > \left(\frac{(1+\tau_i)p_i\, n}{\beta}\right)^{\frac{1}{1-\alpha}} L_i^{-\frac{\alpha}{1-\alpha}}$.

local immobile factor (land) and a perfectly mobile factor, human capital. Both regions ($i = 1, 2$) originally have identical stocks of endowments and identical technologies. The countries total endowment H is normalized at unity and the allocation to the two regions is given by H_1, H_2

$$H = 1 = H_1 + H_2. \tag{10}$$

As there is an interaction of the development position and human capital migration, two conditions, the final development condition and the labor market equilibrium condition (no migration condition) have to be considered next.

Relative Regional Development: From equation (9) in the previous section we know that the steady state position of each region is ω_i^*, the relative steady state position for the two regions with a given endowment is[5]

$$\begin{aligned} \Omega^D &= \frac{\omega_1^*}{\omega_2^*} = \frac{1 - \frac{n}{\Psi_1}}{1 - \frac{n}{\Psi_2}} \\ &= \Omega^D(H_1, H_2, \tau_1) \qquad with \qquad \frac{d\Omega^D}{dH_1} > 0. \end{aligned} \tag{11}$$

We refer to this condition as the *final development condition* which identifies the relative technological position of a region in steady state. In general, this relative final position depends on all parameters of Ψ_1 and Ψ_2 (see (8)) and in particular on the allocation of H in the two regions. The *final development curve* Ω^D can be drawn in a $\Omega - H_1-$diagram (Figure 1). Since originally we have identical regions ($H_1 = H_2$), Ω^D is 1 in the original position point A. In the neighborhood of this starting point and by using the resource constraint (10) we can derive the slope of the *final development-curve* [6]

$$\frac{d\Omega^D}{dH_1} = \frac{2(1-\alpha)}{(\frac{\Psi_i}{n} - 1)H_i}.$$

Regional Migration and Perfect Labor Market: The central idea of the endogenous determination of regions is the issue of an endogenous allocation of mobile factors of production to the different regions. Mobile human capital is mobile and will migrate into locations with higher wage. As long as a region is more attractive for human capital, additional human capital will migrate into this region. Equilibrium in this process of regional development will be reached when all human capital has found an equally attractive location among the

[5] See Appendix 2a.
[6] See Appendix 2b.

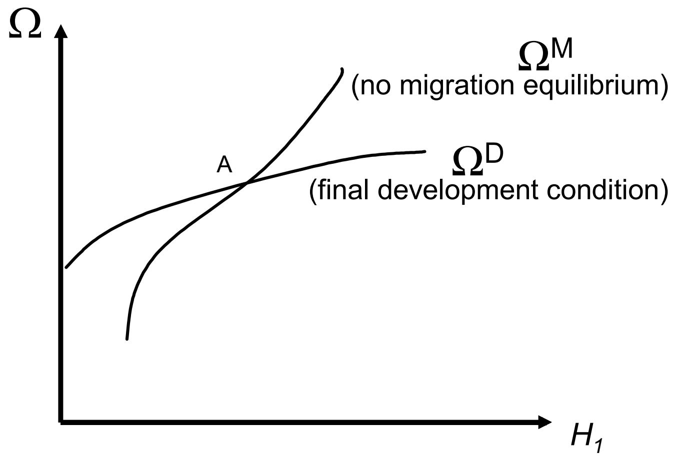

Figure 1: Orginal Steady State, Identical Regions

regions. To determine the allocation of human capital, we assume that human capital is perfectly mobile and allocates between the regions according to the no wage arbitrage condition.

$$\frac{w_{H1}}{w_{H2}} = 1 \tag{12}$$

At every time human capital migrates instantaneously between the regions, such that the no wage arbitrage condition (12) always holds.[7]

$$\begin{aligned} \Omega^M &= \frac{\omega_1}{\omega_2} = \frac{L_2^\alpha H_2^{-\alpha}}{L_1^\alpha H_1^{-\alpha}} \\ &= \Omega^M(H_1, H_2) \qquad with \qquad \frac{d\Omega^M}{dH_1} > 0 \end{aligned} \tag{13}$$

We refer to this condition as the *no migration-condition*. Under the assumption of originally identical regions and by using the countries human capital constraint (10) the slope of the no migration-curve is

$$\frac{d\Omega^M}{dH_1} = \frac{2\alpha_1}{H_1} > 0.$$

[7] As we assume perfect competion in the final goods market, factor prices (and wages alike) are determined by their marginal productivity $w_{Hi} = A_i L_i^\alpha H_i^{-\alpha}$. For the derivative $\frac{d\Omega_2}{dH_1}$ see Appendix 3a.

The *no migration-curve* can also be drawn into the $\Omega - H_1-$diagram. In this diagram the slope of the final development condition is smaller than the slope of the no migration condition. Appendix 4 shows that the respective condition is not restrictive.

4 Endogenous Formation of Regions

For originally identical regions we analyze the effects of an outward looking policy in region one. Even if tariffs do not belong to the instruments of regional policy, many bureaucratic instruments belong to region specific non-tariff trade barriers. If a region decreases international transaction and information costs, it may be able to generate a decisive advantage in competitiveness over other regions. Another situation to consider is the case that a decrease in international transaction costs affects mainly region 1, while region 2 cannot realize the full effect. This non symmetric decrease of international transactions cost can be translated in the model by $d\tau_1 < 0$. The result is an upward shift of the *final development curve* Ω^D in figure 2. In the neighborhood of the original equilibrium point A the two regions will move toward the new equilibrium point B. The change in international transaction costs will trigger two mutually dependent reactions. First, a change in the relative technological development of the two regions, and second, a migration process towards the faster growing region. As immigration of human capital and faster growth of technological abilities are mutually favorable, an agglomerating process is initiated.

In order to discuss the endogenous formation of regions we look at the effects on central economic characteristics of the regions:

Population Size, Density and Agglomeration: For the system of two stationarity conditions (11) and (13) as well as the resource constraint (10) we solve for the equilibrium reaction of human capital $dH_1/d\tau_1$ in region 1[8]

$$\frac{dH_1}{d\tau_1} = \frac{-nH_1}{(\Psi_1 - \frac{n}{\alpha})(1+\tau_1)\alpha} > 0 \qquad \textit{and} \qquad \frac{dH_2}{d\tau_1} = -\frac{dH_1}{d\tau_1} < 0.$$

The population of region 1 will grow up to an endogenously determined size, while region 2 will face brain drain and shrink. Lower international transaction costs and a better access to international technologies in region 1 will increase technology growth and trigger an advantage for the region which eventually leads to a long run difference between the originally identical locations. Faster imitation increases productivity growth and a wage gap between the regions opens. As human capital is perfectly mobile between the two regions, human capital instantaneously migrates to the high productivity high wage region. Immigration and the resulting additional technological growth will mutually drive an accelerating and agglomerating dynamic process. A process of agglomeration

[8] See appendix 5.

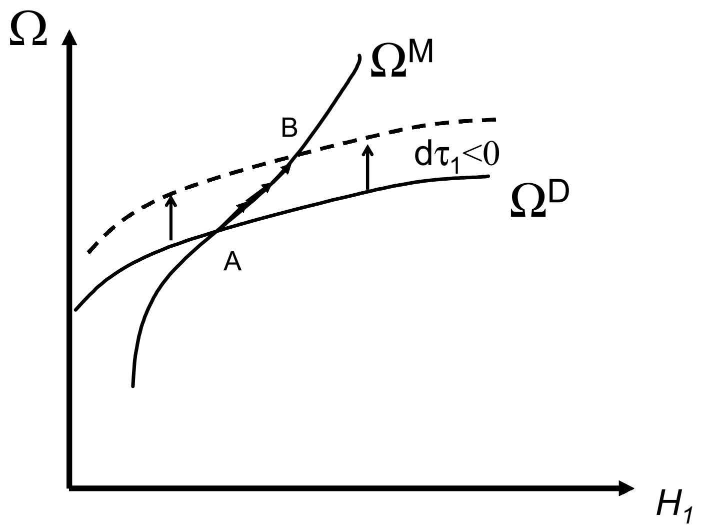

Figure 2: Endgenous Formation of Regions

through "immigration-additional productivity growth and immigration" takes place. As one region absorbs the human capital of the other region to feed the agglomeration process, the success of one region is driven on expense of the other region. The described accelerating process will endogenously terminate. When imitation becomes more difficult, once the region approaches more sophisticated technologies, immigrating human capital (decreasing marginal productivity) will eventually drive down wage growth in the agglomerating region. At the same time emigrating human capital will drive up marginal productivity in the less favored region. Eventually all incentives for additional migration and labor market adjustment disappear between the two regions. A new equilibrium allocation of mobile human capital is reached.

Income: The second central question to look at, is the development of income in both regions as well as the total income of the country. If we adjust the domestic technology level for the level of the technological leader (V) we obtain for the relative GDP position of region i

$$Y_i^* = \frac{X_i^*}{V} = \omega_i^* L_i^{\alpha} H_i^{1-\alpha}.$$

Taking account of the budget constraint (10) equilibrium income reactions in the two regions are

$$\frac{dY_1^*}{d\tau_1} = \overbrace{L_1^\alpha H_1^{1-\alpha}\frac{d\omega_1^*}{d\tau_1}}^{\langle 1\rangle} + \left(\overbrace{\frac{d\omega_1^*}{dH_1}L_1^\alpha H_1^{1-\alpha}}^{\langle 2\rangle} + \overbrace{(1-\alpha)\omega_1^* L_1^\alpha H_1^{-\alpha}}^{\langle 3\rangle}\right)\frac{dH_1}{d\tau_1} > 0,$$

$$\frac{dY_2^*}{d\tau_1} = -\left(\frac{d\omega_2^*}{dH_2}L_2^\alpha H_2^{1-\alpha} + (1-\alpha)\omega_2^* L_2^\alpha H_2^{-\alpha}\right)\frac{dH_1}{d\tau_1} < 0.$$

Income is driven by three channels, a direct improvement of the technology $\langle 1\rangle$ and two effects from interregional migration $\langle 2\rangle$ and $\langle 3\rangle$. Immigrating human capital drives up the relative level of technology and increases the regions factor endowment and production capacity. Both migration effects are mutually reinforcing. They are positive in one region and negative in the other. The total income effect is

$$dY^* = dY_1^* + dY_2^* = \frac{d\omega_1^*}{d\tau_1}L_1^\alpha H_1^{1-\alpha} > 0 \quad for \quad identical \quad regions.$$

Adjusting for the symmetric mutually compensating migration effects in both regions we are left with the original positive technology shock in region 1. When the access to international technologies improves at least in one region, imitation accelerates and a better steady state position can be reached. The country on average is better off.

Immobile Factors: While a perfectly integrated labor market will lead to identical wages in both regions, the factor price for immobile land ρ_i will be non-symmetrically affected.

$$\rho_1 = \frac{\partial X_1}{\partial L_1 V} = \alpha\omega_1^*\left(\frac{H_1}{L_1}\right)^{1-\alpha} \qquad and \qquad \rho_2 = \frac{\partial X_1}{\partial L_2 V} = \alpha\omega_2^*\left(\frac{H_2}{L_2}\right)^{1-\alpha}$$

$$\frac{d\rho_1}{d\tau_1} = \left(\frac{d\omega_1^*}{d\tau_1} + \frac{d\omega_1^*}{dH_1}\frac{dH_1}{d\tau_1}\right)\alpha L_1^{\alpha-1}H_1^{1-\alpha} + \alpha(1-\alpha)\omega_1^* L_1^{\alpha-1}H_1^{-\alpha}\frac{dH_1}{d\tau_1} > 0$$

$$\frac{d\rho_2}{d\tau_1} = \left(\frac{d\omega_2^*}{dH_2}\frac{dH_2}{dH_1}\frac{dH_1}{d\tau_1}\right)\alpha L_2^{\alpha-1}H_2^{1-\alpha} + \alpha(1-\alpha)\omega_2^* L_2^{\alpha-1}H_2^{-\alpha}\frac{dH_2}{dH_1}\frac{dH_1}{d\tau_1} < 0$$

The factor price (relative to the technological leader) for land ρ_i will increase in the agglomerating region and relatively decrease in the less favored region. This can be expected, as in the agglomerating region land becomes less abundant than in less favored regions where human capital has emigrated and the population density has decreased.

Comparative advantages: As the described process determines the relative final technological position of the region, technologically driven Riccardian comparative advantages are directly determined by the technological development of the region. But also comparative advantages through Heckscher-Ohlin-trade is endogenously determined. If the production function for the final good is identified as Findlay's *foreign exchange productions function*[9] the link to trade theory and endogenous determination of comparative advantages is straight forward. According to this concept real output can be multiplied with the given world market prices. The production function becomes a value function in international prices. For a given vector of world market prices and a continuum of goods, each location fully specializes in the production of one good. Factor abundance determines the factor intensity in production and hence the particular industry of specialization. A human capital abundant location will specialize in a human capital intensive industry. Therefore, the inflow of human capital and the endogenous termination of immigration will also determine the H-O position of the region. The more human capital flows into the region, the more human capital intensive will be the domestic output, which also determines the (H-O) specialized export product. Therefore, the process determines not only the size and agglomeration of the region, but also comparative advantages according to neoclassic trade theory.

5 Summary

In this paper we analyze the endogenous formation of regions through the interaction between trade growth and agglomeration. A region in a developing country is described by a growth model with endogenous imitation for a given exogenous international process of technological growth. The endogenous imitation of the backward region is driven by positive externalities from trade. The degree of international integration as well as the factor endowment determines the regions steady state position relative to the technological leaders. We introduce a decrease in international transaction costs which affects basically one region. We analyze how this change leads to a formation of different regions. Two processes will drive the development in each region: 1. For a given resource endowment, technological imitation determines the relative regional development and 2. migration between regions endogenously determines the resource endowments of each region. This mutually depended process terminates once the no migration equilibrium is reached. The no migration equilibrium endogenously determines the population size and density as well as per capita income and comparative advantages in a regions. There will be agglomeration in the region with easy access to international markets, while the less favored region will realize a relative drop in income and technological capability.

[9] See Findlay (1973, 1985).

6 Appendix

Appendix 1: Partial derivatives of ω_i^* :

$$\begin{aligned}
\frac{\partial \omega_i^*}{\partial H_i} &= \frac{n}{\Psi_i^2}\frac{\partial \Psi_i}{\partial H_i} = \frac{n}{\Psi_i^2}(1-\alpha)\frac{\beta}{(1+\tau_i)p_i}L_i^{\alpha}H_i^{-\alpha} = \frac{(1-\alpha)n}{\Psi_i H_i} > 0 \\
\frac{\partial^2 \omega^*}{\partial H_i^2} &= -\frac{(1-\alpha)n}{(\Psi H_i)^2}(\frac{\partial \Psi}{\partial H_i}H_i + \Psi_i) = -\frac{(1-\alpha)n}{(\Psi H_i)^2}(\frac{(1-\alpha)n}{\Psi_i} + \Psi_i) < 0
\end{aligned}$$

$$\frac{\partial \omega^*}{\partial \tau} = \frac{n}{\Psi^2}\frac{\partial \Psi}{\partial \tau} = -\frac{n}{\Psi^2}\frac{\beta}{p(1+\tau)^2}L^{\alpha}H^{1-\alpha} = -\frac{n}{\Psi(1+\tau)} < 0$$

Appendix 2a: Slope of the final development curve Ω^D :

$$\begin{aligned}
\Omega^D &= \Omega^D(H_i, \tau_i) = \frac{1-\frac{n}{\Psi_1}}{1-\frac{n}{\Psi_2}} \qquad and \qquad H = H_1 + H_2 \\
d\Omega^D &= \frac{\omega_2^*}{(\omega_2^*)^2}\frac{\partial \omega_1}{\partial H_1}dH_1 - \frac{\omega_1^*}{(\omega_2^*)^2}\frac{\partial \omega_2}{\partial H_2}dH_2 = \frac{1}{(\omega_2^*)^2}(\omega_2^*\frac{\partial \omega_1}{\partial H_1} + \omega_1^*\frac{\partial \omega_2}{\partial H_2})dH_1 \\
\frac{d\Omega^D}{dH_1} &= \frac{1}{(\omega_2^*)^2}(\omega_2^*\frac{\partial \omega_1}{\partial H_1} + \omega_1^*\frac{\partial \omega_2}{\partial H_2}) = \frac{1}{(\omega_2)^2}(\omega_2^*\frac{n}{\Psi_1^2}\frac{\partial \Psi_1}{\partial H_1} + \omega_1^*\frac{n}{\Psi_2^2}\frac{\partial \Psi_2}{\partial H_2}) \\
&= \frac{1}{(\omega_2^*)^2}(\omega_2^*\frac{(1-\alpha_1)n}{\Psi_1 H_1} + \omega_1^*\frac{(1-\alpha_2)n}{\Psi_2 H_2}) > 0
\end{aligned}$$

Appendix 2b: Slope of the final development curve Ω^D, identical regions:

$$\begin{aligned}
\frac{d\Omega^D}{dH_1} &= \frac{1}{(\omega_2)^2}(\omega_2\frac{\partial \omega_1}{\partial H_1} + \omega_1\frac{\partial \omega_2}{\partial H_2}) = \frac{2}{\omega_i}\frac{\partial \omega_i}{\partial H_i} \\
&= \frac{2}{\omega_i}\frac{(1-\alpha)n}{\Psi_i H_i} = \frac{2}{(\frac{\Psi_i}{n}-1)\frac{n}{\Psi_i}}\frac{(1-\alpha)n}{\Psi_i H_i} \\
&= \frac{2(1-\alpha)}{(\frac{\Psi_i}{n}-1)H_i} > 0 \qquad for \quad identical \quad regions
\end{aligned}$$

Appendix 3a: Slope of the *no migration curve* for identical regions:

$$\begin{aligned}
\Omega^M &= \Omega^M(H_1, H_2) \\
\Omega^M &= \frac{\omega_i}{\omega_j} = \frac{L_2^{\alpha}H_2^{-\alpha}}{L_1^{\alpha}H_1^{-\alpha}} = \frac{L_2^{\alpha}H_1^{\alpha}}{L_1^{\alpha}H_2^{\alpha}} \\
\frac{d\Omega^M}{dH_1} &= \frac{L_2^{\alpha}}{L_1^{\alpha}}\frac{H_1^{\alpha}H_2^{\alpha}}{(H_1^{\alpha})^2}\left(\frac{\alpha}{H_1} + \frac{\alpha}{H_2}\right) > 0
\end{aligned}$$

Appendix 3b: Slope of the *no migration curve,* identical regions:

$$\frac{d\Omega^M}{dH_1} = \frac{L_2^\alpha}{L_1^\alpha}\frac{H_1^\alpha H_2^\alpha}{(H_1^\alpha)^2}\left(\frac{\alpha}{H_1}+\frac{\alpha}{H_2}\right) > 0$$

$$\frac{d\Omega^M}{dH_1} = \frac{2\alpha}{H_1} > 0$$

Appendix 4: Relative slope of the *final development position* and the *no migration condition* for identical regions:

$$\begin{aligned}
\frac{d\Omega^D}{dH_i} &< \frac{d\Omega^M}{dH_i} \\
\frac{2(1-\alpha)}{(\frac{\Psi_i}{n}-1)H_i} &< \frac{2\alpha}{H_i} \\
1-\alpha &< \alpha(\frac{\Psi_i}{n}-1) \\
n-\alpha n &< \alpha\Psi_i - \alpha n \\
n/\alpha &< \Psi_i
\end{aligned}$$

Appendix 5: Equilibrium reaction of human capital allocation:

$$
\begin{aligned}
\frac{\partial \Omega^M}{\partial H_1} dH_1 + \frac{\partial \Omega^M}{\partial H_2} dH_2 &= \frac{\partial \Omega^D}{\partial H_1} dH_1 + \frac{\partial \Omega^D}{\partial H_2} dH_2 + \frac{\partial \Omega^D}{\partial \tau_1} d\tau_1 \\
\frac{dH_1}{d\tau_1} &= \frac{-\frac{n}{\omega_2 \Psi(1+\tau_1)}}{\frac{2\alpha}{H_i} - \frac{2(1-\alpha)}{(\frac{\Psi_i}{n}-1)H_i}} = \frac{-\frac{n}{\omega_2 \Psi(1+\tau_1)}}{\left(\alpha - \frac{(1-\alpha)}{(\frac{\Psi_i}{n}-1)}\right)\frac{2}{H_i}} \\
&= \frac{-\frac{n}{\omega_2 \Psi(1+\tau_1)}}{\left(\alpha(\frac{\Psi_i}{n}-1) - (1-\alpha)\right)\frac{2}{H_i}\frac{1}{(\frac{\Psi_i}{n}-1)}} \\
&= \frac{-\frac{n}{\omega_2 \Psi(1+\tau_1)}}{(\alpha\Psi_i - \alpha n - n + n\alpha)\frac{2}{nH_i}\frac{1}{(\frac{\Psi_i}{n}-1)}} \\
&= \frac{-\frac{n}{\omega_2 \Psi(1+\tau_1)}}{(\Psi_i - \frac{n}{\alpha})\frac{\alpha 2}{nH_i}\frac{1}{(\frac{\Psi_i}{n}-1)}} \\
&= \frac{-\frac{1}{\omega_2 \Psi(1+\tau_1)}}{(\Psi_i - \frac{n}{\alpha})\frac{2\alpha}{nH_i}\frac{1}{(1-\frac{n}{\Psi_i})\frac{\Psi_i}{n}}} \\
&= \frac{-\frac{n}{\omega_2 \Psi(1+\tau_1)}}{(\Psi_i - \frac{n}{\alpha})\frac{\alpha}{H_i}\frac{1}{(1-\frac{n}{\Psi_i})\Psi_i}} \\
&= \frac{-n}{(\Psi_i - \frac{n}{\alpha})\frac{\alpha}{H_i}(1+\tau_1)} \\
&= \frac{-nH_i}{(\Psi_i - \frac{n}{\alpha})(1+\tau_1)\alpha} > 0
\end{aligned}
$$

7 References

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