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Regional Allocation of Skills*

Etsuro Shioji
Universitat Pompeu Fabra†

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† Balmes 132, 08008 Barcelona, Spain. E-mail: shioji@upf.es

Abstract

This paper addresses three questions: (1) why does the share of skilled workers in regional population tend to be higher in wealthier regions? (2) what determines changes in this share over time? and (3) why is it that internal migration tends to raise average skill levels of the receiving regions relative to that of the sending regions? I construct a two–region dynamic model with agglomeration and congestion to answer these questions. It is shown that, under certain relationship between wages and demand for land, unskilled workers are discouraged more strongly from living in a wealthier region and are less mobile than skilled workers.

1 Introduction

This paper asks three questions concerning regional allocation of skilled and unskilled workers. I approach these questions theoretically.

The first question to be addressed is, why is it that skilled workers tend to make up a greater share of population in wealthier and more densely populated regions? To check this general impression with the data, I use the "fixed weight human capital measure" of Mulligan and Sala-i-Martin (1994)[2] as a proxy for skill levels of the US states. I find that, for 1990, the correlation of this variable with the log of per capita personal income was 0.67. Its correlation with the percentage of urban population (in logs) was 0.48, and its correlation with the percentage of metropolitan population (in logs) was 0.32[3].

The second question is, what are the sources of changes in the regional allocation of skilled and unskilled workers? In Figure 1, I plot the difference in the measure of skill level mentioned above between the Northeast (Census) Region and the US average. There was practically no difference between the two in 1960. But during the 1970s and especially in the 1980s, the value for the Northeast grew much faster than the US average. This is interesting because the period coincided with that of an economic boom in this Region, in particular, in New England in the late 1970s and the 1980s ("Massachusetts miracle"). I will look for the conditions under which shifts in relative allocation of skilled workers occurs. I will also study causes of these shifts.

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[2]This variable is the log of a weighted average of the productivity across groups of people with different educational attainment within each state. The productivity of each group is measured by the average wage level (in 1970) within the group. The weights are the share of each group of people in total adult population of the region. Refer to Mulligan and Sala-i-Martin (1994) for details. In Figure 1, I take differences rather than ratios, because this variable is defined in logs.

[3]I would like to thank Xavier Sala-i-Martin for providing the data on personal income. It is deflated by the National CPI, and excludes income from transfers. Data on urban and metropolitan population was taken from the Statistical Abstract of the US, 1993, and is based on the 1990 census data. All the correlations are taken for 48 states of the US, excluding Alaska, Hawaii and Washington, D.C.

Thirdly, empirical studies on internal migration suggest that skilled people tend to make up greater shares among migrants than among the population of the regions of their origin. For the US, Borjas et. al. (1992) showed, using micro data, that cross-state migrants were on average more skilled than those who stayed within a state. Also, Schultz (1982) showed that migrants in both the US and Venezuela were more skilled than those who did not move. For Japan, Shioji (1995b) showed, using a regression approach, that migration tended to raise the average educational attainment of the receiving regions relative to that of the sending regions. It is interesting to know why there is this difference between groups of people with different skills.

To shed some light on these questions, I construct a two-region model with two types of workers, namely, skilled and unskilled workers. There are two forces in this economy that counteract with each other and determine regional allocation of workers. One is what I call agglomeration effect: regional concentration of skilled workers improves productivity of a region through enabling greater degree of specialization among them. As a consequence, a region with more skilled workers will offer higher wages, which will attract further more skilled workers, as well as unskilled workers. The other force is the congestion effect. A concentration of workers to one region raises the rent for residential land, and this discourages inflow of skilled and unskilled workers. A steady state is obtained when these two forces are balanced. It is shown that, under certain conditions, there are steady states under which the two regions, that are identical ex ante, end up having different numbers of workers and different levels of wages and land rents. These steady states are shown to have saddle-path-properties. An interesting question is whether the two regions differ in the shares of skilled workers in the total population in these steady states. It is shown that an important determinant of these shares is the relationship between skilled-unskilled ratio of wages and that of demand for land. Under certain relationship between these two, unskilled workers are discouraged more strongly from living in the wealthier region than skilled workers, and thus the share of skilled workers is greater in the wealthier region.

Reallocation of workers occurs when the balance between the two forces, agglomeration effect and congestion effect, are shifted due to exogenous shocks. It is shown that, under the same relationship between skilled-unskilled ratio of wages and that of demand for land as mentioned above, skilled workers respond more strongly to exogenous shocks, and thus they tend to make up a greater share among migrants than among non-movers[4]. I study effects of different types of shocks on regional allocation of workers. For example, it is shown that a productivity shock can cause reallocation of workers only when the shock is biased toward either of the two types of technology in this economy, technology that exhibits increasing returns or technology that is land intensive.

Before I move on, let me quickly make a comparison between this model and the model of Harris and Todaro (1970). A similarity between the models is that both consider the persistent income differentials between cities and rural areas as reflecting a compensation for some kind of cost that accompanies working in cities. In the Harris-Todaro model, the cost is higher probability of unemployment. In this model, it is a higher land rent. On the other hand, these two are quite different in other aspects. In particular, while this model features increasing returns, in the Harris–Todaro model decreasing returns is assumed. In addition, the model in this paper considers two types of labor with different levels of skills.

The rest of the paper is organized as follows. Section 2 explains the setup of the model, and section 3 solves for steady states and discusses their local stability. Section 4 conducts comparative steady states analyses, to determine what changes the regional allocation of skilled workers. Section 5 contains the conclusion.

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[4]More precisely, skilled workers make up a greater share among migrants than in the population of the poorer region. Their share among migrants could be greater or smaller than their share in the population of the wealthier region.

2 The Model

An overview

The model is in continuous time, deterministic and agents are assumed to have perfect foresight. The economy consists of two identical regions. Each one of the two regions, called region 1 and 2, is endowed with a given amount of land equal to $\bar{G}$. There are two kinds of workers, skilled and unskilled. Total supplies of skilled and unskilled workers to the economy as a whole are fixed, and are denoted by $\bar{L}$ and $\bar{H}$, respectively. Both kinds of workers are infinitely–lived. They can move across the regions by paying some moving cost, which will be specified later.

Final-good is homogeneous, and is traded freely across the regions. Its price is normalized to unity. It can be produced by two types of technology. Firms can switch between these two with zero cost. Some firms produce with labor technology, which requires both types of workers to produce output. This technology does not require land as an input, though each worker needs a certain amount of residential land to live on. This technology exhibits increasing returns to labor at the regional level, because a larger number of skilled workers enables a deeper division of labor among them. Other firms produce with land technology. In this case they use land and a region specific natural resource for its production. This technology is characterized by decreasing returns to land at the regional level. A piece of land can be used for either of the two types of purposes, residential purposes and production purposes, and can switch between them without cost.

The economy as a whole is assumed to be an open economy in the sense that financial capital flows freely not only across the regions but also between this economy and the outside world. For simplicity, this economy is assumed to face a constant world interest rate, $r^* > 0$.

Consumer–workers

Each consumer-worker supplies one unit of labor inelastically to a firm that adopts labor technology, and receives wage payment. They can accumulate wealth in two ways. First, there is a risk free asset which is traded in the world financial market, whose interest rate is equal to r^*. Secondly, each consumer-worker holds claims on land, which are assumed to have been distributed randomly and equally among them at the beginning of the world. These claims are also freely traded in the world financial market. An owner of a claim to a certain site does not have to be a resident of that site or of the region that the site belongs to. Because a perfect capital market is assumed, returns on these two types of assets should be equal, and they are independent of the holders' location. Hence, decisions made on migration are independent of these returns.

It is assumed that each worker of the same skill type requires the same, fixed amount of residential land to live and work in either region, irrespective of their wealth level. This residential land per worker is denoted ψ_H for skilled workers, and ψ_L for unskilled workers, respectively. It is assumed that $\psi_H \geq \psi_L$. Land rents provide the sole source of the congestion effect considered here. I ignore non-pecuniary costs of congestion such as noise and fatigue from commuting in crowded trains for the sake of tractability of the dynamics of the model.

Migration cost is assumed to be the same for all the movers of the same skill type, as long as they are moving from the same region to the other. It could differ between skilled and unskilled workers. It is also assumed that the cost takes the form of lost utility. The presence of migration cost makes migration a forward-looking decision. Hence, as was argued by Sjaastad (1962), migration has an aspect of investment.

Each consumer-worker has the following utility function:

$$U_{qt} \equiv \int_t^{\infty} c_{q\tau} \cdot e^{-\rho(\tau - t)} \, d\tau - \sum_{\tau \in TI_t} I_{q\tau} \cdot k_q , \tag{1}$$

where $k_{qi\tau} = k_{Hi\tau}$ if individual q is skilled and moving out of region i at time τ,

$k_{qi\tau} = k_{Li\tau}$ if individual q is unskilled and moving out of region i at time τ.

Throughout this paper, subscript t denotes time, subscript i stands for a region, i = 1 and 2, and subscript q stands for an individual consumer-worker. In equation (1), U_{qt} stands for the "life-time" utility of the q th individual. The first part is the utility from consumption and the second part is the loss of utility from moving. The variable c_{qt} is his/her consumption at time t. The parameter ρ is the subjective discount rate. In the second part, I_{qt} is an indicator function that is equal to 1 if he/she decides to move and is equal to zero if he/she decides not to. "TI_t" signifies a set of $\tau \geq t$ at which I_{qt} is equal to 1. The terms k_{Hit} and k_{Lit} are migration costs for those who decide to move <u>out of</u> region i at time t for skilled and unskilled workers, respectively. The consumer-worker maximizes life-time utility in equation (1) subject to the following budget constraint:

$$\dot{W}_{qt} = r^* \cdot W_{qt} + \omega_{qt} - c_{qt}, \tag{2}$$

where $\omega_{qit} = \omega_{Hit}$ if individual q is skilled and living in region i,

$\omega_{qit} = \omega_{Lit}$ if individual q is unskilled, and living in region i,

and $\omega_{Hit} \equiv w_{Hit} - \psi_H \cdot w_{Git}$, and $\omega_{Lit} \equiv w_{Lit} - \psi_L \cdot w_{Git}$.

W_{qt} stands for the wealth of the q th consumer-worker at time t. The "<u>net wage</u>" in region i at time t, namely wage minus land rent payment, is denoted by ω_{Hit} for skilled workers and ω_{Lit} for unskilled workers. Wages for skilled and unskilled workers and rents per unit of land in region i at time t are denoted by w_{Hit}, w_{Lit}, and w_{Git}, respectively.

I assume that $r^* = \rho$. In this case consumption is constant over time:

$$c_{qt} \equiv r^* \cdot (W_{qt} + V_{qt}) \text{, where } V_{qt} \equiv \int_t^{\infty} e^{-r^*(\tau - t)} \cdot \omega_{q\tau} . \tag{3}$$

Plugging this back into (1) yields:

$$U_{qt} = (W_{qt} + V_{qt}) - \sum_{\tau \in TI_t} I_{q\tau} \cdot k_{q\tau} . \tag{4}$$

Note that W_{qt}, which is given at time t, does not affect the marginal utility from the present value of net wages (V_{qt}). Hence, a consumer-worker's optimization problem is simply to maximize V_{qt} minus migration cost, by choosing whether or not to migrate. This means that a consumer-worker's decision on migration is independent of his or her wealth level[5][6]. Four assumptions contribute to this simplification: the assumption of free lending and borrowing, the assumption of the congestion cost being pecuniary, the assumption that the congestion cost is independent of the wealth level, and the assumption of linear utility function.

Regional Wages

The structure of production of the sector that uses labor technology is similar to those in Fujita (1988), Rivera-Batiz (1988), Abdel-Rahman (1988), and Krugman (1991, 1993)[7] except that there are two types of workers in this model. As the structure is a fairly

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[5]The predictions on the steady state labor allocation would be qualitatively the same without these assumptions. However, in transition to the steady state, aggregate variables would interact with the distribution of wealth across workers in a non–trivial manner. Stability analysis would become intractable.

[6]As a consequence, some other interesting aspects of the interaction between wealth accumulation and migration decisions are beyond the scope of this paper. For example, life-cycle aspects of the migration decision (e.g., why some workers choose to work in Alaska when young and retire to Florida) cannot be studied in this model.

[7]A similar specification of production is frequently used in growth theory as well. Refer to Romer (1990) and Grossman and Helpman (1991), for example.

common one, I leave details of derivation to an appendix that is available upon request from the author. There are two kinds of firms, firms that produce final-goods and ones that produce intermediate-inputs. Final-goods producers employ a variety of intermediate-inputs and unskilled labor to produce final-goods, while each intermediate-input producer hires skilled labor to produce a single variety of intermediate-inputs. Final-good is traded freely across regions as well as with the rest of the world and its market is characterized by perfect competition, while intermediate-inputs are not tradable across regions, and their market is characterized by monopolistic competition with free entry. The production function for a representative final-goods producer is:

$$Q_{it} = A_{Yit} \cdot \left[\int_0^{n_{it}} x_{its}^{a}\, ds\right]^{b/a} \cdot L_{it}^{(1-b)}, \tag{5}$$

where $0 < a < 1$, $0 < b < 1$, $A_{Yit} > 0$, and $n_{it} > 0$. Q_i is the amount of the final-goods produced by labor technology in region i. A_{Yit} is an exogenous Hicks-neutral technology term, n_{it} is the number of varieties of intermediate-inputs available in region i[8], x_{ist} is the amount of the s th intermediate-inputs in region i, and L_{it} is the number of unskilled workers in region i. This production function is of the Cobb-Douglas form between the bundle of intermediate-inputs and unskilled labor. The bundle of intermediate-inputs enter this production function in the symmetric CES or the Dixit-Stiglitz (1977) form.

Intermediate-input producers require c units of skilled workers to maintain their production. One unit of input of skilled worker produces one unit of intermediate-inputs.

In the appendix, it is shown that

$$w_{Hit} = \beta \cdot \delta \cdot A_{Yit} \cdot H_{it}^{\alpha} \cdot [H_{it}/L_{it}]^{\beta-1}, \tag{6a}$$

[8]Note that I am assuming, for convenience, that n_i is a real number. This is justified as an approximation when n_i is fairly large.

and $w_{Lit} = (1-\beta)\cdot\delta\cdot A_{Yit}\cdot H_{it}^{\alpha}\cdot[H_{it}/L_{it}]^{\beta}$. (6b)

where $\delta \equiv a\cdot(1-a)^{b/a-1}\cdot[a/(1-a)]^{b-1}\cdot b\cdot c^{b-b/a}$, $\alpha \equiv b/a - b$, and $\beta \equiv b$.

Note that the wages are increasing in the number of skilled workers, holding constant the H-L ratio. This is because an increase of skilled workers enhances the productivity of the region, through enabling deeper specialization among them (a higher n_{it})[9]. This is the source of the agglomeration economies in this model. Note that an increase in the number of skilled workers increases the productivity of unskilled workers as well. This is because, in the production function of (5), the two types of workers are assumed to be imperfect substitutes.

Regional Land Rents

Land technology does not require intermediate-inputs. It requires only land and natural resources. Details of this sector are discussed in Appendix A. It is shown that the land rents are increasing in the number of both skilled and unskilled workers in a region, because, as more land is used for residential purposes, less land becomes available for production purposes. Thus the marginal product of land rises, because of decreasing returns to land. Specifically, it is shown that

$$w_{Git} = A_{Zit}\cdot R^{1-\eta}\cdot[\overline{G} - \psi_H\cdot H_{it} - \psi_L\cdot L_{it}]^{\eta-1} \quad , \tag{7}$$

where w_{Git} is land rent in region i, A_{Zit} is the exogenous level of technology in the land technology sector of this region, R is the amount of natural resources, and η is a constant between 0 and 1. Note that w_{Git} is an increasing and convex function of the demand for residential land, $\psi_H\cdot H_{it} + \psi_L\cdot L_{it}$. These rising land rents are the sources of the

[9]This interpretation of n_{it} follows that of Ethier (1982).

congestion effect in this model. It is assumed that $\psi_H \cdot \bar{H} + \psi_L \cdot \bar{L} > \bar{G} > (\psi_H \cdot \bar{H} + \psi_L \cdot \bar{L})/2$. The first inequality means that rent payments of a region approach infinity before the whole population becomes concentrated in one region. Because of this property, corner solutions in which the whole population of the economy moves into one region are avoided.

Migration Costs

Migration is costly. The cost is assumed to depend positively on the number of movers in each group of workers in the following way:

$$k_{Hit} = (1/\sigma_H) \cdot M_{Hijt}, \tag{8a}$$

and $$k_{Lit} = (1/\sigma_L) \cdot M_{Lijt}, \tag{8b}$$

where σ_H and σ_L are positive constants. In the above, M_{Hijt} and M_{Lijt} is the number of movers from region i to region j for skilled and unskilled workers, respectively. They are non-negative. If they choose to stay in the region where they live now, this cost is zero. Note that the cost goes to infinity as the number of movers approaches infinity. This excludes a sudden jump in the regional allocation of workers. Note also that the cost is zero when nobody is moving. This means that the steady state allocation is independent of the parameters, σ_H and σ_L, in the above cost functions.

Equilibrium conditions

The labor market equilibrium at each point in time requires two sets of conditions. First, the following two equations must hold:

$$\bar{L} = L_{1t} + L_{2t}, \tag{9a}$$

and $\bar{H} = H_{1t} + H_{2t}$. (9b)

Also, workers must be indifferent between moving and not moving. In Appendix B, I argue that this happens when

$$\dot{H}_{1t} = -\dot{H}_{2t} = \sigma_H \cdot V_{Ht}, \text{ and } \dot{L}_{1t} = -\dot{L}_{2t} = \sigma_L \cdot V_{Lt}, \tag{10}$$

where

$$V_{Ht} \equiv \int_t^{\infty} e^{-r^*(\tau-t)}(\omega_{H1\tau} - \omega_{H2\tau})\, d\tau, \tag{11a}$$

and $$V_{Lit} \equiv \int_t^{\infty} e^{-r^*(\tau-t)}(\omega_{L1\tau} - \omega_{L2\tau})\, d\tau. \tag{11b}$$

Equation (10) means that an equilibrium is obtained when the present discounted value of the net wage difference across regions is equal to the migration cost, which is given by the absolute value of $\sigma_H \cdot \dot{H}_{1t}$ and $\sigma_L \cdot \dot{L}_{1t}$. (Note that, although the migration cost is assumed to depend on the amount of gross migration, gross migration always coincides with net migration for each type of workers. This is because workers of the same type are assumed to be identical except for their current location: two workers of the same type will never have incentives to move in opposite directions.)

Steady State Conditions

This economy is in a steady state when both of the two types of workers no longer have incentives to migrate across regions. This requires that net wages (wages less land rent payment per person) for both of them be equalized:

$$w^*_{H1} - \psi_H \cdot w^*_{G1} = w^*_{H2} - \psi_H \cdot w^*_{G2} \quad , \tag{12a}$$

and $$w^*_{L1} - \psi_L \cdot w^*_{G1} = w^*_{L2} - \psi_L \cdot w^*_{G2} \quad , \tag{12b}$$

where * denotes the steady state values.

In solving for steady states, it is informative to first subtract both sides of (12a) from those of (12b) and to rearrange the resulting equation, to get

$$w^*_{H1} - (\psi_H/\psi_L) \cdot w^*_{L1} = w^*_{H2} - (\psi_H/\psi_L) \cdot w^*_{L2}. \tag{13}$$

These wages and rents in turn depend on regional allocation of workers, as in equations (6a), (6b), and (7). From now on, I am going to assume that A_{Yit} and A_{Zit} are the same across regions for all t. I denote them as $A_{Yt} \equiv A_{Y1t} = A_{Y2t}$ and $A_{Zt} \equiv A_{Z1t} = A_{Z2t}$. Hence, regions are identical ex ante. Under these conditions, (6a), (6b) and (7) for a steady state can be written as:

$$w^*_{Hi} = \beta \cdot \delta \cdot A_{Yt} \cdot H_i^{*\alpha} \cdot [H^*_i/L^*_i]^{\beta-1}, \tag{6a'}$$

$$w^*_{Li} = (1-\beta) \cdot \delta \cdot A_{Yt} \cdot H_i^{*\alpha} \cdot [H^*_i/L^*_i]^{\beta}. \tag{6b'}$$

and $$w^*_{Gi} = A_{Zt} \cdot R^{1-\eta} \cdot [\overline{G} - \psi_H \cdot H^*_i - \psi_L \cdot L^*_i]^{\eta-1}, \tag{7'}$$

Also, from equations (9a) and (9b),

$$L_1^* = \bar{L} - L_2^* \quad \text{and} \quad H_1^* = \bar{H} - H_2^* . \tag{9'}$$

Finally, I substitute equations (6a'), (6b'), (7') and (9') into (12a) and (13), to get the steady state condition that consists of a system of two equations, with two endogenous variables, H_1^* and L_1^*.

Before moving on to the steady state analysis, I impose one condition on the parameters to make the predictions of the model realistic. It is shown in Appendix B that the ratio of the average wages between skilled and unskilled workers is always constant, and is equal to $[\beta/(1-\beta)]\cdot[\bar{L}/\bar{H}]$, irrespective of their allocation across the regions. Hence, I impose a condition that

$$[\beta/(1-\beta)]\cdot[\bar{L}/\bar{H}] > 1,$$

which amounts to assuming that, on average, skilled workers earn more than unskilled workers. I consider this as a realistic situation. It can be shown that, under this assumption, $w_{Hi}^* > w_{Li}^*$ for both regions.

In the next two sub-sections, I solve for the steady state allocation. The solution will follow two steps. In the first step, I will use equation (13) alone to analyze how the relative allocation of unskilled workers across regions (L_1/L_2) changes as that of skilled workers (H_1/H_2) changes. In the second step, I will use equation (12a), together with equation (13), to determine the steady state value of H_1/H_2, and thus determine the full steady state allocation. I omit time subscripts in the next two sub-sections because the whole discussion concerns steady states.

Steady State Labor Allocation (1): Relative Population Shares of Skilled Workers

The first step requires using equation (13) to derive L_1/L_2 as a function of H_1/H_2. Appendix C investigates this relationship. As a consequence of this study, relationships between H_1/H_2 and the ratios of skilled and unskilled workers in each region, H_i/L_i, are derived. The results can be summarized as follows:

<u>Important Result 1: Shares of Skilled Workers</u>

Population ratios between skilled workers and unskilled workers in each region, H_i/L_i, are related to how skilled workers are allocated across regions, that is, H_1/H_2. This relationship depends crucially on the relationship between the skilled-unskilled wage ratio, or $[\beta/(1-\beta)]\cdot[\bar{L}/\bar{H}]$, and the skilled-unskilled ratio for the demand for land, ψ_H/ψ_L.

(1) When $[\beta/(1-\beta)]\cdot[\bar{L}/\bar{H}] = \psi_H/\psi_L$, the shares of skilled workers in population is the same across regions for any value of H_1/H_2.

(2) Suppose that the relative demand for land is smaller than the relative wage. That is,

$$[\beta/(1-\beta)]\cdot[\bar{L}/\bar{H}] > \psi_H/\psi_L . \qquad \text{(Condition 1)}$$

Then, a region with a larger number of skilled workers has a larger share of skilled workers in its population. That is, $H_1/H_2 > 1 <=> H_1/L_1 > H_2/L_2$, and vice versa.

(3) Under (Condition 1), the "relative allocation of skilled workers", defined as $[(H_1/L_1)/(H_2/L_2)]$, is increasing in H_1/H_2.

(Condition 1) means that people do not increase their demand for land so much just because they earn more wages. This seems to be a reasonable assumption because, normally, requirement for space to put one's body does not increase proportionally with his or her wages. Note that, under this assumption, land rent payments make up a greater share of wage incomes for unskilled workers than for skilled workers. Hence, the intuition behind the above Result can be described as follows. As more skilled people move into a region, land rents increase. This increased burden of the cost of living falls disproportionately heavily on unskilled workers, because land rents make up a greater share in their wage income. Hence, they are more heavily discouraged to move into the region, and their share in the regional population decreases, relative to that of the other region. Note that their absolute number in the region could still increase. Appendix C also shows the following result.

<u>Important Result 2: Allocation of Unskilled Workers</u>

Assume that (Condition 1) in Result 1 holds. Assume further that

$$1-\beta > \alpha . \qquad \text{(Condition 2)}$$

Then, the following two are true:

(1) If $H_1 > H_2$, *then* $L_1 > L_2$, *and vice versa.*

(2) L_i *is an increasing function of* H_i. *That is, when skilled workers move into one region, unskilled workers always "follow".*

(Condition 2) is a sufficient condition: the converse is not necessarily true. This Result can be interpreted as follows. Under (Condition 2), skilled wages are decreasing in the number of skilled workers (H_i), holding constant L_i (equation (6a')). On the other hand, unskilled wages are increasing in H_i ((6b')). Hence, when H_i increases, holding constant L_i, w_{Hi} decreases, while w_{Li} increases. But in the steady state, $w_{Hi} - (\psi_H/\psi_L)\cdot w_{Li}$ has to be the same across the regions. Hence, L_i has to increase, too, to restore the balance. I consider this case to be more realistic because, empirically, large cities tend to have large numbers of not only skilled workers but also unskilled workers. For this reason, from now on, (Condition 2) will always be imposed.

Figure 2 shows some numerical examples of the relationships described in the above Results. In all the panels, the horizontal axis measures the number of skilled workers. H_1 is measured from the left origin (O_1), and H_2 is measured from the right origin (O_2). The distance O_1O_2 measures $\overline{H}$. All the parameter values used here are as follows:

$\overline{H} = 2$, $\overline{L} = 4$, $\overline{G} = 5.5$, $R = 1$, $\alpha = 0.2$, $\beta = 0.4$, $\eta = 0.7$, $\psi_H = \psi_L = 1$, $c = 0.01$, $A_Y = 0.1$, and $A_Z = 0.1$.

In Panel A, the vertical axis measures the relative allocation of skilled workers, or $[(H_1/L_1)/(H_2/L_2)]$. It is increasing in H_1, as was shown in Result 1. In Panel B, H_1/L_1 is depicted. The relationship is not monotonic. In Panel C, L_1/L_2 is depicted. As in Result 2, it is increasing in H_1, because the parameter values in this Figure satisfy $1 - \beta > \alpha$.

Steady State Labor Allocation (2): Determination of Skilled Labor Allocation

Now I move on to the second stage, and solve for the full steady state allocation. To do that, I need to solve equation (12a), imposing the condition in equation (13). Specifically, it requires equating net wages for skilled workers in the two regions, taking into account the relationships between H_1/H_2 and L_1/L_2 described in the previous sub-section. This is a highly non-linear problem that can be solved numerically. Instead, here, I show the solution graphically in Figures 3 and 4. In Figure 3A, I derive skilled wages as functions of the number of skilled workers in each region, imposing the condition in equation (13) (these curves are called wage curves). In Figure 3B, land rent payments are plotted in the same way (rent curves). The parameter values used here are the same as those for Figure 2. Both wages and land rent payments are increasing in the number of skilled workers in each region. Land rent payments approach infinity before all skilled workers move into one region. Net wages for skilled workers, ω_{Hi}, conditional on the relationship in equation (13), can be derived by taking vertical differences between the two curves (net wage curves). Figures 4 show the results. In these Figures, underlying parameter values are the same as those for Figures 2 and 3, except that A_Y is set to 0.03 in

Figure 4A and 0.1 in Figure 4B. Steady states are obtained when the two net wage curves intersect. There are two cases depending on the parameter values. In Figure 4A, net wage curves are decreasing in the number of skilled workers of the region in the middle (where $H_1^* = H_2^*$). I call this Case A. Typically, in this case, there is only one steady state, point E, in the middle (although I have not been able to show the uniqueness analytically). In Figure 4B, net wage curves are decreasing in the number of skilled workers in the middle. I call this Case B. In this case, there are at least three steady states: one in which skilled workers are split equally across the regions (points E_0 in the Figure), and the other two in which they are split unequally across the regions (points E_1 and E_2).

<u>Important Result 3: Symmetric and Asymmetric Steady States</u>

Assume that (Condition 1) and (Condition 2) hold.

(1) A <u>symmetric steady state</u>, where numbers of both skilled and unskilled workers are equal across the regions, always exists. The two regions have the same wages and land rents.

(2) In Case B, there always exist <u>asymmetric steady states</u>, despite the fact that the regions are identical ex ante. One region becomes a "<u>city</u>", which has larger numbers of both skilled and unskilled workers, while the other becomes a "country-side". Both wages and land rents are higher in the "city" than in the "country-side". Skilled workers make up a greater share of population in the "city" than in the "country-side".

(3) Case B is obtained when A_{Yt} is relatively large in comparison with A_{Zt}.

To see why (3) in the above Result holds, note that Case B is obtained when the net wage is increasing in the number of skilled workers in the region in the middle. The slope of the net wage curve is the difference between the slopes of the wage curves and the rent curves. Hence, it depends positively on the level of technology in the labor technology sector

(A_{Yt}), and negatively on that of the land technology sector (A_{Zt}). Hence, Case B is obtained when A_{Yt} is relatively large compared with A_{Zt}. Mathematical condition under which Case B is obtained is in Appendix D. Finally, another notable characteristic of asymmetric steady states is that the wage ratio between the city and the country-side is smaller for skilled workers. To see that, note that w^*_{Hi}/w^*_{Li}, which is inversely proportional to H^*_i/L^*_i, is lower for the city. Assuming that region 1 is the city,

$$w^*_{H1}/w^*_{L1} < w^*_{H2}/w^*_{L2} \iff w^*_{H1}/w^*_{H2} < w^*_{L1}/w^*_{L2}.$$

This is consistent with the data[10].

Local Stability

Dynamics of the model consists of the following four equations:

$$\dot{H}_{1t} = \sigma_H \cdot V_{Ht}, \quad \dot{L}_{1t} = \sigma_L \cdot V_{Lt}, \tag{10}$$

$$\dot{V}_{Ht} = r^* \cdot V_{Ht} - F_{(H_{1t},L_{1t})}, \quad \dot{V}_{Lt} = r^* \cdot V_{Lt} - G_{(H_{1t},L_{1t})}, \tag{14}$$

where $F_{(H_{1t},L_{1t})} \equiv \omega_{H1t} - \omega_{H2t}$, and $G_{(H_{1t},L_{1t})} \equiv \omega_{L1t} - \omega_{L2t}$.

Equations (14) can be derived by differentiating equations (11) with respect to time. This is a system of four differential equations in two jumping variables (V_{Ht} and V_{Lt}) and two non-jumping variables (H_{1t} and L_{1t}). In Appendix E, I study the local dynamics around the steady states. The following is shown.

[10]For example, Schultz (1982) reported that the regional dispersion of incomes among groups of people with different educational attainment in the US had a tendency to decrease with educational attainment. He found a similar tendency in the wage data in Venezuela. I studied the wage data on new graduates in Japan using Wage Census (Ministry of Labor) for 1991. Wage ratio between Tokyo (prefecture with the highest per-capita income) and Kagoshima (prefecture with one of the lowest per-capita income) was 1.174 for new high school graduates, but was 1.100 for new college graduates.

Important Result 4: Local Stability

Assume that (Condition 1) and (Condition 2) hold.

(1) The symmetric steady state has a saddle-path-property in Case A, and is unstable in Case B.

(2) An asymmetric steady state has a saddle-path-property when, around the steady state, the net wage curve of the "city" crosses that of the "country-side" from the above as the number of skilled workers in the city increases. It is unstable otherwise. For example, in Figure 4B, the two asymmetric steady states have saddle-path-properties.

4 Comparative Steady States

In this section, responses of this model economy to various shocks are studied. All the shocks considered here are common to both regions: region-specific shocks are not out of scope of this paper. I will focus entirely on steady states with saddle-path-properties. First, in the symmetric steady state in Case A, there will be no reallocation of labor across regions in response to common shocks, and the regions will maintain identical characteristics (except when the economy is originally on the border between Cases A and B). The rest of the analysis will focus on asymmetric steady states with saddle-path-properties, such as points E_1 and E_2 in Figure 4B. All the arguments in this section are graphical and intuitive ones. Mathematical derivation is briefly sketched in Appendix F, and the details are given in an appendix that is available upon request from the author.

Productivity Shocks

First, I study the response of this economy to changes in A_{Yt} and A_{Zt}. Note that wages in Figure 3A are proportional to A_{Yt}, while rents in Figure 3B are proportional to A_{Zt}. Suppose that both A_{Yt} and A_{Zt} increased by the same proportion. First of all, it will increase both sides of equation (13) proportionately, and thus preserves the equality between the two. Hence we can focus our attention on equation (12a). Note that both wage curves and rent curves move up by the same proportion, and thus net wage curves in Figure 4B will go up by the same proportion for both regions as well. As a result, the intersection between the two net wage curves will go up vertically, but it will not move horizontally: the steady state levels of H_1^* and H_2^* will remain at the same levels as before. That is, there will be no reallocation of workers.

Suppose, instead, that only A_{Yt} increased and A_{Zt} stayed the same as before. In this case, too, both sides of equation (13) increase by the same proportion, so we can focus our attention on equation (12a). In this case, only wage curves shift up. They shift up by the same proportion for any value of H_1^*/H_2^*. Note that the wage curve for the "city" is higher than that for the "country-side" around an asymmetric steady state. This means that, in terms of the size of the shifts, the wage curve for the city shifts up more than that for the country-side does. This in turn means that the net wage curve for the city shifts up more than that for the country-side. As a result, this steady state will shift outwards, meaning that the city will attract more population than before. This is shown graphically in Figure 5. In this Figure, it is assumed that region 1 is the city. All the underlying parameter values for this Figure are the same as those for Figure 2 etc., except for A_Y. It is assumed that A_Y was originally 0.05, and then increased to 0.06. As is shown in the Figure, net wage curves shift up for both regions (from the ones denoted "old" to the ones denoted "new"), but that for region 1 shifts up more. As a consequence, the steady state shifts from point E_1 to E_1', and H_1^* increases. The results of the above discussions are summarized as follows.

<u>Important Result 5: Productivity Shocks</u>

(1) When there is a "balanced productivity growth", that is, when A_{Yt} and A_{Zt} increase by the same proportion, there will be no reallocation of workers.

(2) <u>An "unbalanced productivity growth" will cause migration.</u> If A_{Yt} increases more than proportionally with A_{Zt}, the "city" will attract more skilled workers. The number of unskilled workers in the city will also increase. There will be regional divergence in wages and rents.

(3) From Result 1, (3), when there is an unbalanced productivity growth, the share of skilled workers in the city's population relative to that in the country-side increases. This implies that, taking the whole process of adjustment to the new steady state, the share of skilled workers is higher among the migrants than in the population of the sending region (the country-side). Their share could be higher or lower compared with that of the population of the receiving region (the city).

Shocks to Demand for Land

Next I consider what happens when both ψ_H and ψ_L, the required amounts of residential land for both types of workers, decreased by the same proportion, leaving ψ_H/ψ_L unchanged. This could be thought of as an improvement of public capital or introduction of technology that enables construction of taller buildings, which makes it possible to put more people on a given amount of land than before. Again, equation (13) is unaffected, so we can focus our attention on equation (12a). This shock will leave wage curves in Figure 3A unchanged, while lowering rent curves in Figure 3B. This has an effect similar to that of the productivity growth in A_{Yt}. Because the rent curve is higher in the city before the shock, the curve for the city shifts down more than that for the country-side does, around an asymmetric steady state. As a consequence, the steady state will shift outwards, and the resulting reallocation will be qualitatively similar to (2) and (3) in Result 5[11].

<u>Important Result 6: Decrease in Demand for Land</u>

A proportional decrease in ψ_H and ψ_L causes divergence in wage income, population and skill composition across regions.

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[11]This result suggests an alternative way of thinking about benefits of public capital. Empirical measurement of the benefits of public capital in the literature has usually taken the production function approach. In this literature, it is assumed that public capital is an input in production, and empirical work estimates the elasticity of output with respect to public capital. For example, Aschauer (1989) used time series data and came up with a large estimated effect of public capital on output. However, more recent studies used cross sectional or panel data of the US states and came up with small and often insignificant estimates of this elasticity (Garcia-Mila, McGuire and Porter (1993), and Crihfield and Panggabean (1995), for example). According to my model, public capital might not enter directly into the production function and yet still could improve the productivity: a better public capital might ease the congestion effect and thus facilitate further concentration of economic activities into the city. This enables taking greater advantage of the productivity gain from concentration.

Population Increase

Next, I consider what happens if the total population increases, leaving the ratio $\bar{H}/\bar{L}$ unchanged. Without loss of generality, I assume that region 1 is the city. As analytical approach did not yield conclusive results, I performed a number of numerical examples to determine likely effects of this shock. In all the cases I tried, both H_1 and L_1 decreased. This means that region 2 not only absorbs all the workers added to the economy, but also takes some workers away from region 1. To see why, suppose that, at the beginning, all the workers added to the economy were allocated to region 2. This leaves wages and land rents in region 1 unchanged, while it increases both wages and land rents in region 2. But it is likely that wages in region 2 increase more than land rents. This is indicated by the fact that, as is shown in Figure 4B, around an asymmetric steady state, the net wage curve of the country-side is increasing in its number of workers[12]. Hence, workers in region 2 will be better off. This will cause migration from region 1 to region 2. Hence, population increase results in relatively more equal allocation of workers across regions, and accompanies wage income convergence. Also, in all the examples I tried, it turned out that, in response to this type of shocks, $(H_1/L_1)/(H_2/L_2)$ decreases. That is, the relative allocation of skilled workers becomes less unbalanced across regions. The intuition is the familiar one: because land rents in the country-side are now higher than before, those who are willing to move in there are on average more skilled than the original population in the country-side.

Important Result 7: Population Increase

A population increase tends to result in convergence in wage income, population sizes and skill composition.

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[12]Of course, this argument is not exact, because, when all the additional workers are put in the country-side, equation (13) is not satisfied, and thus the economy does not move along the old net wage curves.

Skill Shift

Finally I consider what happens if the economy becomes more skilled, i.e., when $\bar{H}/\bar{L}$ increases leaving the total population, $\bar{H} + \bar{L}$, unchanged. There are two opposing effects. First, an increase in the number of skilled workers strengthens the agglomeration effect. Secondly, because the demand for residential land per worker is larger for skilled workers than for unskilled workers, an increase in the population share of skilled workers increases the overall demand for residential land. This strengthens the congestion effect.

The question is which of the two effects dominates. As analytical approach did not yield a conclusive result, I performed a number of numerical examples. Again, I assumed that region 1 was the city. In all the examples that I tried, both H_1/H_2 and L_1/L_2 increased. That is, this change strengthens the agglomeration effect more than the congestion effect, and there will be further concentration of workers into the city. It was also found that, in most but not all the cases, $(H_1/L_1)/(H_2/L_2)$ decreases. That is, the differential in the share of skilled workers tends to diminish. Finally, in all the cases that I have tried, there was divergence in average wages (over both skilled and unskilled workers) across regions.

<u>**Important Result 8: Skill Shift**</u>

When the share of skilled workers in the total population of the economy increases, there tends to be divergence in wage incomes, population and skill composition.

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5 Conclusion

This paper developed a two-region model of agglomeration and congestion. The model could produce a pair of asymmetric steady states, where two regions that are identical ex ante end up having very different characteristics. One region becomes a "city" with a larger population, higher wages and higher land rents, while the other becomes a "country-side" with opposite characteristics. Conditions under which this type of steady states exist and have saddle-path-properties were obtained.

This model was used to answer some questions about regional allocation of skilled and unskilled workers. It was shown that the relationship between the skilled-unskilled wage ratio and the skilled-unskilled ratio of demand for land was important. When the latter is smaller, that is, when rent payments make up a greater share of wage income for unskilled workers, the congestion effect is "felt" more strongly by those workers. Hence, in an asymmetric steady state, the share of skilled workers in regional population is higher in the "city", where land rents are higher. Population share of skilled workers in an asymmetric steady state could change due to exogenous shocks such as "unbalanced" productivity growth. In response to those shocks, migration occurs to bring the economy to a new steady state. Skilled workers make up a relatively greater share among those migrants, compared with their share in the population of the sending region. This is because migration is accompanied by an increase in land rents in the receiving region. This discourages potential unskilled migrants more strongly than skilled migrants, because land rents make up a higher share of wage incomes for unskilled workers than for skilled workers. This offers an explanation to why, empirically, skilled people tend to make up a greater share among migrants than among the population of the sending regions.

Appendix

A: Land Technology and Determination of Land Rents

Land technology uses land and natural resources to produce final-goods. It is characterized by the following production function:

$$z_{i\kappa t} = B(A_{Zit}, R, Z_{it}) \cdot g_{i\kappa t}, \quad B_1 > 0, B_2 > 0, \text{ and } B_3 < 0, \tag{A-1}$$

where $z_{i\kappa t}$ is output of the κ th firm that adopts land technology in region i at time t, and $g_{i\kappa t}$ is land in region i used by this firm as an input at time t. Hence, the production function is linear in privately held inputs (land). This assumption and the assumption of perfect competition means zero profits for these firms. $B_{(\cdot)}$ is the productivity term that this firm takes as given. It depends on three variables. A_{Zit} is the exogenous level of technology in region i at time t. R is each region's supply of the natural resource. It is assumed to be a public good subject to pollution[13]. Every firm can use it freely and costlessly. However, its productivity declines as the intensity at which it is used becomes higher. This intensity is measured by the total regional output that is produced with land technology, Z_{it}. Hence Z_{it} has a negative external effect on each firm's productivity[14]. And, though each firm's output is linear in land (equation (A-1)), aggregate production in each region exhibits decreasing returns to land.

The productivity term $B_{(\cdot)}$ is assumed to take the following form:

$$B(A_{Zit}, R, Z_{it}) = A_{Zit}^{\frac{1}{\eta}} \cdot [R/Z_{it}]^{\frac{1}{\eta}-1}. \tag{A-2}$$

where $0 < \eta \leq 1$. Therefore, the production function in (A-1) can be rewritten as

$$z_{i\kappa t} = A_{Zit}^{\frac{1}{\eta}} \cdot [R/Z_{it}]^{\frac{1}{\eta}-1} \cdot g_{i\kappa t}. \tag{A-1'}$$

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[13]Technically, the negative externality does not have to be due to pollution. Here I call it "pollution" instead of using a more generic term "congestion", simply to avoid confusion between this congestion externality and the congestion effect that arises due to population concentration in one region (an increase in land rents).

[14]For example, imagine that there is a river in each region, and that this technology requires the river water for irrigation purposes. As output produced by this technology increases, the river is used more intensively, and the water becomes more polluted and thus less suitable for production purposes. This specification is similar to the ones that were used for aggregate production functions in the models of Braun (1993) and Barro and Sala-i-Martin (1995, chapter 9). While they assumed that congestion was a function of the population size, I am assuming that it is a function of output.

Aggregating (A-1') over the land technology firms in region i yields

$$Z_{it} = A_{Zit} \cdot R^{1-\eta} \cdot G_{it}^{\eta} \quad , \tag{A-3}$$

where G_{it} is the amount of land in region i that is devoted to production in this sector. The above equation indicates that η is the measure of the degree of decreasing returns to land in this sector. G_{it} is equal to the total amount of land less land used for residential purposes:

$$G_{it} = \overline{G} - \psi_H \cdot H_{it} - \psi_L \cdot L_{it} \, . \tag{A-4}$$

Equation (A-4) implies that there is a physical upper limit to the regional population, because G_{it} has to be non-negative. This means $\psi_H \cdot H_{it} + \psi_L \cdot L_{it}$ cannot be greater than $\overline{G}$[15].

For each firm, the land rent, w_{Git}, should be equalized with its private marginal product. As each firm takes $B_{(A_{Zit}, R, Z_{it})}$ in equation (A-2) as given, the marginal product is given by $B_{(\cdot)}$. Hence, the rent per unit of land in region i is given by

$$w_{Git} = A_{Zit}^{\frac{1}{\eta}} \cdot [R/Z_{it}]^{\frac{1}{\eta}-1} = A_{Zit} \cdot R^{1-\eta} \cdot G_{it}^{\eta-1}$$

$$= \quad A_{Zit} \cdot R^{1-\eta} \cdot [\overline{G} - \psi_H \cdot H_{it} - \psi_L \cdot L_{it}]^{\eta-1}. \tag{A-5}$$

Hence, as more people move into a region, land for the production purposes becomes more scarce, and the land rent goes up. This is because the total output for each region, Z_{it}, exhibits decreasing returns to land as in (A-3). Note that this is a convex function in the demand for residential land, so, as more people flow in, the land rent increases at an increasing rate. Note also that, as $\psi_H \cdot H_{it} + \psi_L \cdot L_{it}$ approaches its maximum, $\overline{G}$, the land rent approaches infinity.

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[15]Note that $\psi_H \cdot H_{it} + \psi_L \cdot L_{it}$ cannot be larger than $\psi_H \cdot \overline{H} + \psi_L \cdot \overline{L}$, either. The regional population reaches this limit when everybody lives in the same region. It is assumed that $\psi_H \cdot \overline{H} + \psi_L \cdot \overline{L} > \overline{G}$, so that this constraint is never binding. It is also assumed that $\overline{G} > (\psi_H \cdot \overline{H} + \psi_L \cdot \overline{L})/2$, because otherwise the total amount of land required to accommodate the country's population exceeds the total supply of land for the country. These assumptions imply that the area of each region is not large enough to contain the whole population of the country, but is large enough so that the whole population can fit the area when divided into half.

B: Equilibrium Conditions

In this section of the Appendix, it is shown that equations (10a) and (10b) in the text are equivalent to conditions under which migrants and stayers enjoy an equal present value of utility. Without loss of generality, suppose that region 1 has a lower present value of net wages (for one type of workers) than region 2. Workers compare the "value" of staying, defined as $U_{qt} - W_{qt}$, that they would enjoy if they decide to stay in region 1, with the "value" of moving, namely the $U_{qt} - W_{qt}$ that they would enjoy in region 2 from now on minus the moving cost that they have to pay now. In equilibrium, those two have to be equalized. Now what is the "value" of living in a region? The preceding argument suggests that, at any point in time after time t, the value for those who move out of region i is equal to that of those who stay. Hence, the value for those who decide to stay in region 1 at time t is equal to the value of those who will stay in region 1 forever, from time t onwards. The latter is equal to the present value of net wages in region 1. Hence equilibrium requires the following:

$$V_{H1t} = V_{H2t} - k_{H1t} \text{ if } M_{H12t} \geq 0,\ V_{H2t} = V_{H1t} - k_{H2t} \text{ if } M_{H21t} \geq 0, \tag{B-1a}$$

and $V_{L1t} = V_{L2t} - k_{L1t}$ if $M_{L12t} \geq 0$, $V_{L2t} = V_{L1t} - k_{L2t}$ if $M_{L21t} \geq 0$, (B-1b)

where V_{Hit} and V_{Lit} denote the present value of net wages for region i at time t for skilled and unskilled workers, respectively, who will stay in that region forever. That is,

$$V_{Hit} \equiv \int_t^\infty e^{-r^*(\tau - t)} \omega_{Hi\tau} d\tau, \text{ and } V_{Lit} \equiv \int_t^\infty e^{-r^*(\tau - t)} \omega_{Li\tau} d\tau. \tag{B-2}$$

Note that $M_{H12t} > 0$ only when $V_{H1t} < V_{H2t}$, and $M_{H21t} > 0$ only when the opposite is true. A similar relationship holds for unskilled workers. This means that there will be no workers moving from region 1 to 2 when others of the same skill type are moving from region 2 to 1, and vice versa. That is, gross migration and net migration coincide. Hence,

$$-\dot{H}_{1t} = \dot{H}_{2t} = M_{H12t} \text{ if } M_{H12t} \geq 0, \text{ and } \dot{H}_{1t} = -\dot{H}_{2t} = M_{H21t} \text{ if } M_{H21t} \geq 0 \tag{B-3}$$

A similar argument applies to unskilled workers. Also, define k_{Ht} as follows:

$$k_{Ht} \equiv k_{H1t} \text{ if } M_{H12t} \geq 0,\ k_{Ht} \equiv -k_{H2t} \text{ if } M_{H21t} \geq 0.$$

A variable k_{Lt} for unskilled workers can be defined in a similar manner. Using these notations, conditions (B-1) can be simplified as

$$V_{H1t} = V_{H2t} - k_{Ht},\ V_{L1t} = V_{L2t} - k_{Lt}\,. \tag{B-4}$$

Conditions (B-3) can be rewritten as

$$\dot{H}_{1t} = -\dot{H}_{2t} = -\sigma_H \cdot k_{H1t}, \text{ and } \dot{L}_{1t} = -\dot{L}_{2t} = -\sigma_L \cdot k_{L1t}. \tag{B-5}$$

Combining (B-4) and (B-5),

$$\dot{H}_{1t} = -\dot{H}_{2t} = \sigma_H \cdot (V_{H1t} - V_{H2t}), \text{ and } \dot{L}_{1t} = -\dot{L}_{2t} = \sigma_L \cdot (V_{L1t} - V_{L2t}). \tag{B-6}$$

Defining $V_{H1t} - V_{H2t}$ as V_{Ht} and $V_{L1t} - V_{L2t}$ as V_{Lt}, equations (10a) and (10b) in the text are obtained.

C: The Relative Wage between Skilled and Unskilled Labor

In this section of the Appendix, I show that the ratio between the average skilled wage and the average unskilled wage is constant.

Define the average skilled wage as

$$w_{Ht} \equiv \frac{1}{H_{1t}+H_{2t}} \cdot (w_{H1t} \cdot H_{1t} + w_{H2t} \cdot H_{2t}) \ . \tag{C-1}$$

The average unskilled wage can be defined in a similar manner. The relative average wage is defined as the ratio between the average skilled wage and the average unskilled wage:

$$w_{HLt} \equiv \frac{w_{H_{1t}} \cdot H_{1t} + w_{H_{2t}} \cdot H_{2t}}{w_{L_{1t}} \cdot L_{1t} + w_{L_{2t}} \cdot L_{2t}} \cdot \frac{L_{1t} + L_{2t}}{H_{1t} + H_{2t}} \ . \tag{C–2}$$

Note that, from the labor market equilibrium conditions,

$$L_{1t} + L_{2t} = \overline{L} \ , \tag{C–3}$$

$$H_{1t} + H_{2t} = \overline{H} \ . \tag{C–4}$$

From equations (6a) and (6b) in the text,

$$w_{H1t} \cdot H_{1t} + w_{H2t} \cdot H_{2t} = \beta \cdot \delta \cdot A_{Yit} \cdot [H_{1t}^{\alpha+\beta} \cdot L_{1t}^{1-\beta} + H_{2t}^{\alpha+\beta} \cdot L_{2t}^{1-\beta}], \tag{C–5}$$

and $$w_{L1t} \cdot L_{1t} + w_{L2t} \cdot L_{2t} = (1-\beta) \cdot \delta \cdot A_{Yit} \cdot [H_{1t}^{\alpha+\beta} \cdot L_{1t}^{1-\beta} + H_{2t}^{\alpha+\beta} \cdot L_{2t}^{1-\beta}]. \tag{C–6}$$

From equations (C–2) to (C–6),

$$w_{HLt} = \frac{\beta}{1-\beta} \cdot \frac{L_{1t} + L_{2t}}{H_{1t} + H_{2t}} = \frac{\beta}{1-\beta} \cdot \frac{\overline{L}}{\overline{H}} \ . \tag{C–7}$$

D: Steady State Allocation

In this section of the Appendix, steady state allocation is discussed. Throughout this section, the superscript * which signifies a steady state value and the time subscripts are both omitted, because this whole section concerns steady states. In the text, it was shown that, in a steady state,

$$w_{H1} - (\psi_H/\psi_L)\cdot w_{L1} = w_{H2} - (\psi_H/\psi_L)\cdot w_{L2} \ , \tag{13}$$

where

$$w_{Hi} = \beta\cdot\delta\cdot A_Y\cdot H_i^{\alpha}\cdot [H_i/L_i]^{\beta-1} \ , \tag{6a'}$$

$$w_{Li} = (1-\beta)\cdot\delta\cdot A_Y\cdot H_i^{\alpha}\cdot [H_i/L_i]^{\beta} \ , \tag{6b'}$$

where i = 1 and 2. I introduce several new notations:

$h_i \equiv H_i/L_i$, i = 1 and 2, $\bar{h} \equiv \bar{H}/\bar{L}$, $\psi \equiv \psi_H/\psi_L$, $(1-\beta)/\beta \equiv \gamma$,

$k \equiv h_1/h_2$, $h \equiv H_1/H_2$, and $l \equiv L_1/L_2$.

This section of the Appendix studies how k and l are related to h through equation (13). With the above simplifying notations, (13) can be rewritten as

$$1-\psi\cdot\gamma\cdot h_1 = h^{-\alpha}\cdot k^{1-\beta}\cdot(1-\psi\cdot\gamma\cdot h_2) \ . \tag{D-1}$$

<u>Lemma 1</u>: When $\psi = \gamma^{-1}\cdot\bar{h}^{-1}$, $h_1 = h_2 = \bar{h}$.

Proof: It can be shown that one of the following three relationships has to hold between h_1, h_2, and $\bar{h}$:

$$h_1 = \bar{h} = h_2, \text{ or } h_1 > \bar{h} > h_2, \text{ or } h_1 < \bar{h} < h_2 \ . \tag{*}$$

On the other hand, if $\psi = \gamma^{-1}\cdot\bar{h}^{-1}$, from equation (D-1),

if $h_1 = \bar{h}$, it has to be that $h_2 = \bar{h}$,

if $h_1 > \bar{h}$, it has to be that $h_2 > \bar{h}$, (**)

and if $h_1 < \bar{h}$, it has to be that $h_2 < \bar{h}$.

Conditions (*) and (**) are compatible only when $h_1 = \bar{h} = h_2$. (Q.E.D.)

From now on, I will assume that

$$\psi < \gamma^{-1} \cdot \bar{h}^{-1}. \tag{***}$$

I first consider what is happening to k. Equation (D-1) implies that either ($\psi \cdot \gamma \cdot h_1 > 1$ and $\psi \cdot \gamma \cdot h_2 > 1$), or ($\psi \cdot \gamma \cdot h_1 < 1$ and $\psi \cdot \gamma \cdot h_2 < 1$) must hold. But from the condition (*), the former violates the assumption that $\psi \cdot \gamma \cdot \bar{h} < 1$. Hence,

$$\psi \cdot \gamma \cdot h_1 < 1 \text{ and } \psi \cdot \gamma \cdot h_2 < 1 . \tag{****}$$

<u>Lemma 2</u>: Under condition (***), $h > 1$ is necessary and sufficient for $k > 1$.

Proof: <1> First, assume that $h > 1$. Suppose that $k = h_1/h_2 \leq 1$. This implies $1 - \psi \cdot \gamma \cdot h_1 \geq 1 - \psi \cdot \gamma \cdot h_2$. From equation (D-1), this implies

$$h^{-\alpha} \cdot k^{1-\beta} \geq 1 . \tag{D-2}$$

But (D-2) cannot be true when $h > 1$ and $k \leq 1$. Hence it has to be that $k > 1$.

<2> Assume that $k = h_1/h_2 > 1$. Then, $1 - \psi \cdot \gamma \cdot h_1 < 1 - \psi \cdot \gamma \cdot h_2$. From equation (D-1), this means

$$h^{-\alpha} \cdot k^{1-\beta} < 1 . \tag{D-3}$$

Because $k^{1-\beta} > 1$, this implies $h^{-\alpha} < 1$, thus $h > 1$. **(Q.E.D.)**

<u>Corollary to Lemma 2</u>: If $h > 1$, $(w_{H1}/w_{H2}) < (w_{L1}/w_{L2})$.

<u>Lemma 3</u>: Assume that condition (***) holds, and that $h > 1$. Then, $1 - \beta > \alpha$ is a sufficient condition for $l > 1$.

Proof: In Lemma 2, it was shown that $h > 1$ implies $k > 1$. This in turn implies $1 - \psi \cdot \gamma \cdot h_1 < 1 - \psi \cdot \gamma \cdot h_2$. From equation (D-1), this means

$$k^{1-\beta} < h^{\alpha} . \tag{D-4}$$

If $1 - \beta > \alpha$,

$$k^{\alpha} < k^{1-\beta} < h^{\alpha} . \tag{D-5}$$

This implies that

$$k < h . \tag{D-6}$$

As $l = h/k$, this implies that $l > 1$. **(Q.E.D.)**

Lemma 4: If $h > 1$, k is always increasing in h.

Proof: Totally differentiating equation (D-1) yields

$$-\Sigma_1 \cdot d\ln h_1 = -\alpha \cdot d\ln h + (1-\beta) \cdot d\ln k - \Sigma_2 \cdot d\ln h_2, \tag{D-7}$$

where $\Sigma_i \equiv \psi \cdot \gamma \cdot h_i/(1-\psi \cdot \gamma \cdot h_i)$. From the definitions,

$$d\ln h_1 = \left[\frac{1}{1+h} - \frac{1}{1+h/k}\right] \cdot d\ln h + \frac{1}{1+h/k} \cdot d\ln k, \tag{D-8}$$

and $$d\ln h_2 = d\ln h_1 - d\ln k \ . \tag{D-9}$$

Combining (D-7), (D-8), and (D-9) and rearranging yields

$$\frac{d\ln k}{d\ln h} = \left[(\Sigma_2-\Sigma_1)\cdot\left[\frac{1}{1+h} - \frac{1}{1+h/k}\right]+\alpha\right]\cdot\left[(\Sigma_1-\Sigma_2)\cdot\frac{1}{1+h/k} + \Sigma_2 + (1-\beta)\right]^{-1}. \tag{D-10}$$

From (****), $\Sigma_1 > \Sigma_2$.

Also, $k > 1$ implies $\frac{1}{1+h/k} > \frac{1}{1+h}$.

Hence, the right-hand-side of equation (D-10) is positive. (Q.E.D.)

Lemma 5: If $h > 1$, $1-\beta > \alpha$ is a sufficient condition for l to be increasing in h.

Proof: Note that $l = h/k$. Hence,

$$\frac{d\ln l}{d\ln h} = 1 - \frac{d\ln k}{d\ln h}$$
$$= \left[(\Sigma_1-\Sigma_2)\cdot\frac{1}{1+h}+\Sigma_2+(1-\beta)-\alpha\right]\cdot\left[(\Sigma_1-\Sigma_2)\cdot\frac{1}{1+h/k}+\Sigma_2+(1-\beta)\right]^{-1}. \tag{D-11}$$

The last expression is positive if $1-\beta > \alpha$. (Q.E.D.)

Lemma 6 "Case B" in the text is obtained when the net wage curves are increasing in H_i around the mid point, where $H_i = \bar{H}/2$. This condition can be written as:

$$a_H^m + a_L^m \cdot \left[1 - \frac{\alpha}{1-\beta+x}\right]/\bar{h} < 0,$$

where $a_H^m \equiv 2\cdot\left[(1-\beta-\alpha)\cdot w_H^m/(\bar{H}/2) + (1-\eta)\cdot\psi_H\cdot(\psi_H \cdot w_G^m/G^m)\right]$,

$a_L^m \equiv 2\cdot\left[-(1-\beta)\cdot w_H^m/(\bar{L}/2) + (1-\eta)\cdot\psi_H\cdot(\psi_L \cdot w_G^m/G^m)\right]$,

$x \equiv \psi\cdot\gamma\cdot\bar{h}/(1-\psi\cdot\gamma\cdot\bar{h})$,

and w_H^m, w_G^m and G^m are w_{Hi}, w_{Gi}, and $\bar{G}-\psi_H\cdot H_i-\psi_L\cdot L_i$, respectively, evaluated at the mid point where $H_i = \bar{H}/2$ and $L_i = \bar{L}/2$. It can be shown that the left-hand-side of the above inequality is decreasing in w_H^m and $\bar{G}$, and increasing in w_G^m. Hence, the inequality is likely to hold when A_Y is large and A_Z is small. A detailed discussion on this Lemma is in the appendix that is available upon request.

E: Local Dynamics

In this section of the Appendix, local dynamics around a steady state is discussed briefly. Throughout this section, (Condition 1) and (Condition 2) in the text are assumed. The original dynamics is given by the following set of equations in the text:

$$\dot{H}_{1t} = \sigma_H\cdot V_{Ht}\ ,\ \dot{L}_{1t} = \sigma_L\cdot V_{Lt}\ , \tag{10}$$

$$\dot{V}_{Ht} = r^*\cdot V_{Ht} - F_{(H_{1t},L_{1t})}\ ,\ \dot{V}_{Lt} = r^*\cdot V_{Lt} - G_{(H_{1t},L_{1t})}, \tag{14}$$

where $F_{(H_{1t},L_{1t})} \equiv \omega_{H1t} - \omega_{H2t}$, and $G_{(H_{1t},L_{1t})} \equiv \omega_{L1t} - \omega_{L2t}$.

Equations (10) are already linear. Linearizing (14) around a steady state gives

$$\dot{V}_{Ht} = a_H\cdot\hat{H}_{1t} + b_H\cdot\hat{L}_{1t} + r^*\cdot V_{Ht}\ , \tag{E-1}$$

and $$\dot{V}_{Lt} = a_L\cdot\hat{H}_{1t} + b_L\cdot\hat{L}_{1t} + r^*\cdot V_{Lt}\ , \tag{E-2}$$

where $a_H \equiv -F_1$, $b_H \equiv -F_2$, $a_L \equiv -G_1$, and $b_L \equiv -G_2$.

In (E-1) and (E-2), the superscripts "^" signify deviations from the steady state values. Note that the steady state values for V_{Ht} and V_{Lt} are 0. It can be shown that $b_L > 0$, $a_L > b_H$, and, under (Condition 2), $a_H > 0$. Equations (10), (E-1) and (E-2) constitute a system of four linear differential equations. Using *Mathematica*, eigenvalues of the system are derived as

$$\lambda_1,\ \lambda_2,\ \lambda_3, \text{ and } \lambda_4 \equiv r^*/2 \pm \{r^{*2}/4 + (1/2)\cdot[a_H\cdot\sigma_H + b_L\cdot\sigma_L \pm Z^{0.5}\ ]\ \}^{0.5}\ ,$$

where $Z \equiv (a_H \cdot \sigma_H - b_L \cdot \sigma_L)^2 + 4 \cdot a_L \cdot b_H \cdot \sigma_H \cdot \sigma_L$.

First, assume that $Z \geq 0$. Then, the steady state has a saddle-path-property when $a_H \cdot \sigma_H + b_L \cdot \sigma_L \pm Z^{0.5}$ is positive. This is true when

$$a_H \cdot b_L > a_L \cdot b_H$$

holds. In the appendix that is available upon request from the author, it is shown that this is equivalent to having the net wage curve for the city crossing that for the country-side from above, as the number of skilled workers in the city increases. Otherwise, all the (real parts of the) eigenvalues are positive, and thus the steady state is unstable.

Secondly, assume that $Z < 0$. Then, $Z^{0.5} = (-Z)^{0.5} \cdot i$. Write the above eigenvalues as

$$\lambda_j = r^*/2 \pm \{\psi_1 \pm \psi_2 \cdot i\}^{0.5} = r^*/2 \pm (\varphi_1 \pm \varphi_2 \cdot i),$$

where $\psi_1 \equiv r^{*2}/4 + (1/2)^*(a_H \cdot \sigma_H + b_L \cdot \sigma_L)$, and $\psi_2 \equiv (1/2) \cdot (-Z)^{0.5}$,

and φ_1 and φ_2 are implicitly defined by $\varphi_1^2 - \varphi_2^2 = \psi_1$, $2 \cdot \varphi_1 \cdot \varphi_2 = \psi_2$,

$\varphi_1 > 0$, and $\varphi_2 > 0$.

There are two roots with positive real parts and two roots with negative real parts when $\varphi_1 > (1/2) \cdot r^*$. This is always true. To see that, note that ψ_1 is always greater than $(r^{*2}/4)$, because $a_H > 0$, $b_L > 0$, and $\varphi_1^2 > \psi_1$. Hence, when $Z < 0$, the steady state has a saddle-path-property.

Finally, note that $Z < 0$ can happen only when $a_L > 0 > b_H$. Because a_H and b_L are always positive, this immediately implies that $a_H \cdot b_L > a_L \cdot b_H$, which means that the net wage curve of the "city" crosses that of the "country-side" from above, as the number of skilled workers in the city increases.

Hence, the conclusion is that, when the net wage curve of the city crosses that of the country-side from above as the number of skilled workers in the city increases, the steady state has a saddle-path-property. Otherwise, the steady state is unstable.

F: Comparative Steady States

Here, I will briefly sketch the approach. Details can be found in an appendix that is available upon request from the author. Log-linearizing the steady state conditions (12a) and (12b) around the steady state yields:

$$\begin{bmatrix} (H_1\cdot H_2/\bar{H})\cdot a_H & (L_1\cdot L_2/\bar{L})\cdot a_L \\ (H_1\cdot H_2/\bar{H})\cdot b_H & (L_1\cdot L_2/\bar{L})\cdot b_L \end{bmatrix} \cdot \begin{bmatrix} d\ \ln(H_1/H_2) \\ d\ \ln(L_1/L_2) \end{bmatrix}$$

$$= \begin{bmatrix} \theta_{11} & \theta_{12} & w_{H1}-w_{H2} & -\psi_H\cdot(w_{G1}-w_{G2}) & -\Pi \\ \theta_{21} & \theta_{22} & w_{L1}-w_{L2} & -\psi_L\cdot(w_{G1}-w_{G2}) & -\psi^{-1}\cdot\Pi \end{bmatrix} \cdot$$

$$[\mathrm{dln}\ \bar{H} \quad \mathrm{dln}\ \bar{L} \quad \mathrm{dln}\ A_Y \quad \mathrm{dln}\ A_Z \quad \mathrm{dln}\ \psi_L]' , \tag{F-1}$$

where $\theta_{11} \equiv H_1\cdot\frac{\partial\omega_{H1}}{\partial H_1} - H_2\cdot\frac{\partial\omega_{H2}}{\partial H_2}$, $\theta_{12} \equiv L_1\cdot\frac{\partial\omega_{H1}}{\partial L_1} - L_2\cdot\frac{\partial\omega_{H2}}{\partial L_2}$

$\theta_{21} \equiv H_1\cdot\frac{\partial\omega_{L1}}{\partial H_1} - H_2\cdot\frac{\partial\omega_{L2}}{\partial H_2}$, $\theta_{22} \equiv L_1\cdot\frac{\partial\omega_{L1}}{\partial L_1} - L_2\cdot\frac{\partial\omega_{L2}}{\partial L_2}$.

From the above equation, responses of the regional labor allocation to various shocks can be evaluated. For example, to analyze the effect of population increase, assume thatdln$\bar{P}$ $\equiv$ dln$\bar{H}$ = dln$\bar{L}$ > 0. Then,

$$\mathrm{dln}(H_1/H_2)/\mathrm{dln}\bar{P}=\Omega^{-1}\cdot(L_1\cdot L_2/\bar{L})\cdot[(\theta_{11}+\theta_{12})\cdot b_L-(\theta_{21}+\theta_{22})\cdot a_L], \tag{F-2}$$

where $\Omega \equiv (H_1\cdot H_2/\bar{H})\cdot(L_1\cdot L_2/\bar{L})\cdot(a_H\cdot b_L-b_H\cdot a_L)$.

Note that Ω is positive around a steady state with a saddle-path-property. In this case, it was not possible to determine the sign of the right-hand-side. Hence, I performed a number of numerical examples. First, I solved for the steady state values of H_1 etc. using the GAUSS 386 application NLSYS for a given set of parameter values. From these steady state values, the value of the right-hand-side was computed. In all the cases that I have tried, the value was positive. Whenever the sign of an effect was not determined analytically, I followed the same procedure.

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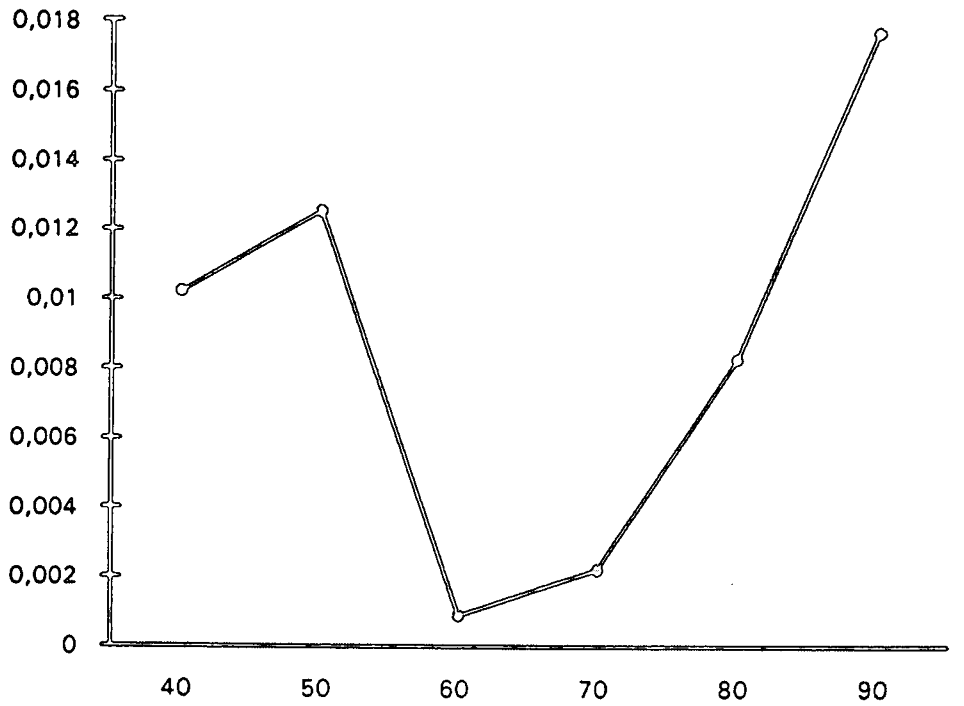
Figure 1: Relative Human Capital, Northeast-US



Note: Human Capital Index is taken from Mulligan and Sala-i-Martin (1994) ("Fixed weight measure").

Figure 2A: (H1/L1)/(H2/L2)

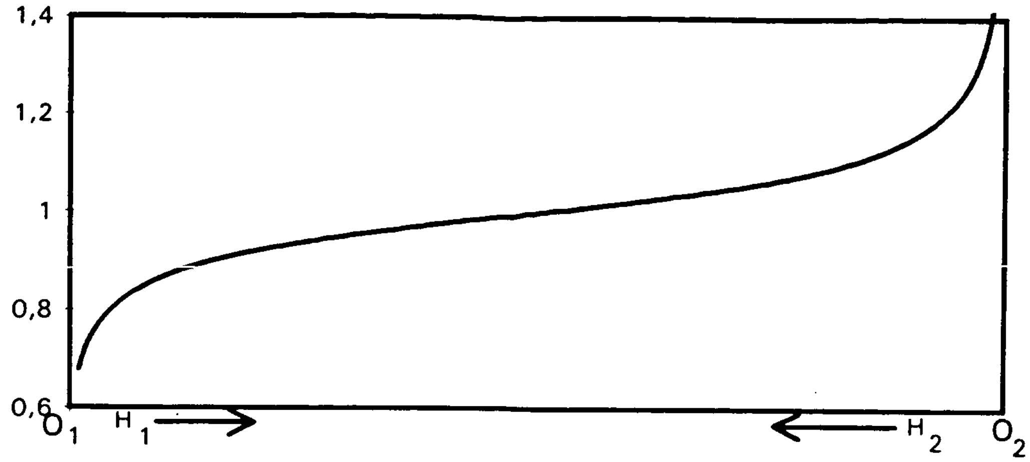


Figure 2B: H1/L1

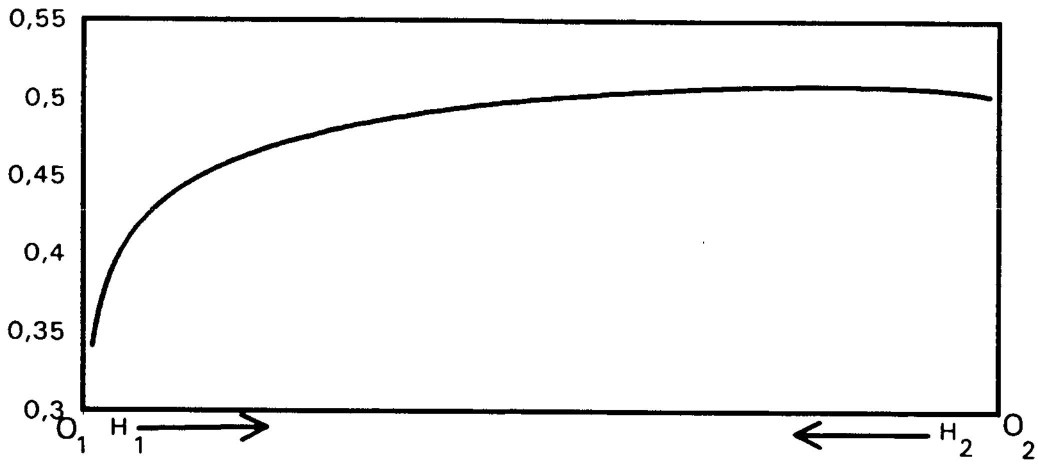


Figure 2C: H1/H2 and L1/L2

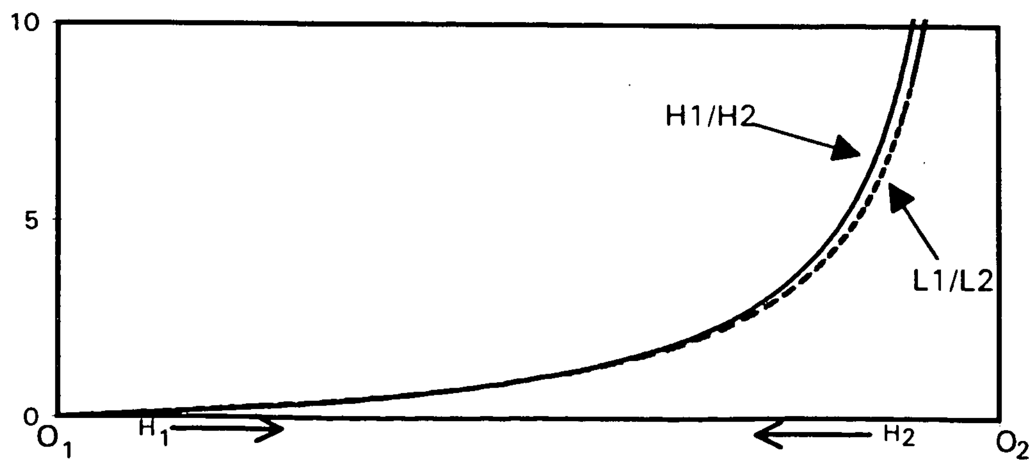


Figure 3A: Wage Curves

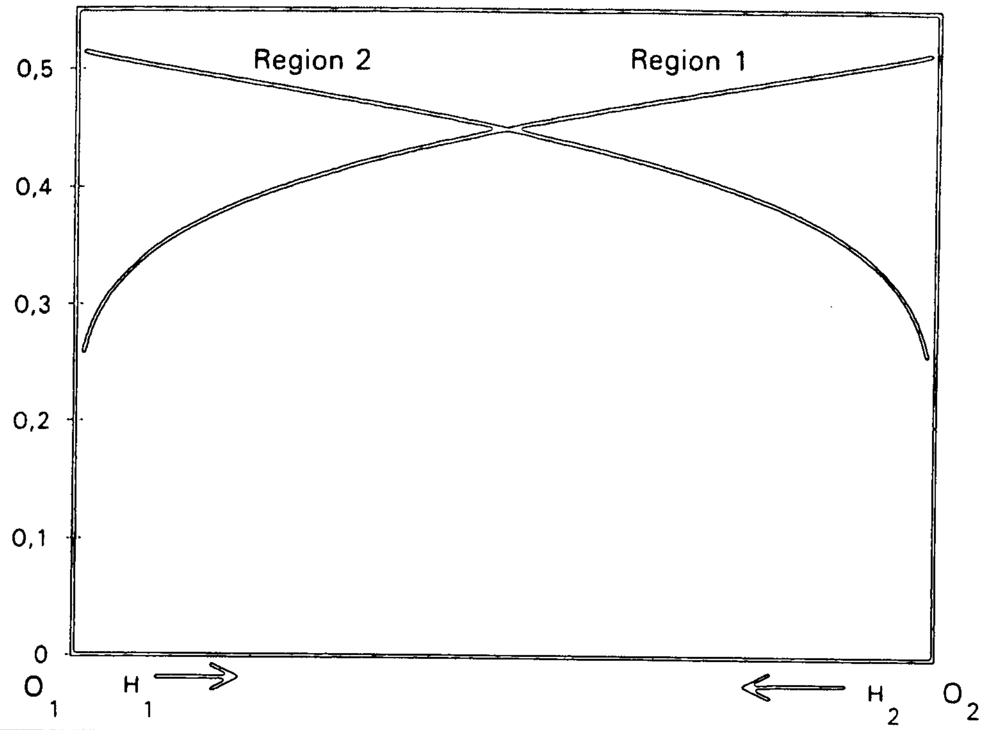


Figure 3B: Rent Curves

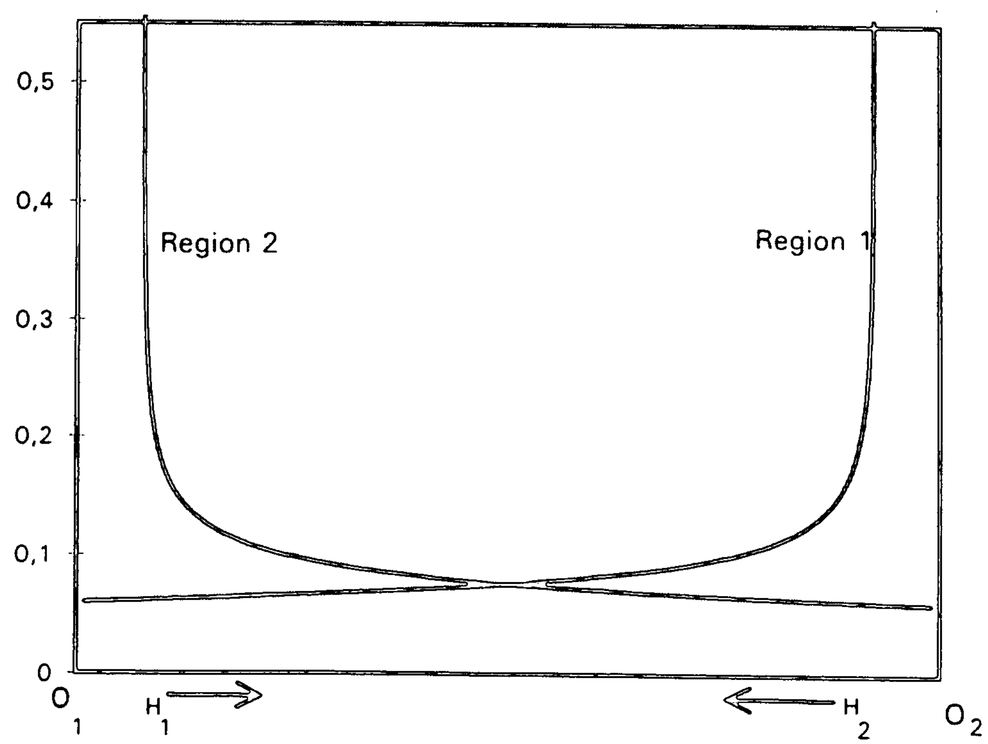


Figure 4A: Net Wage Curves, Case A

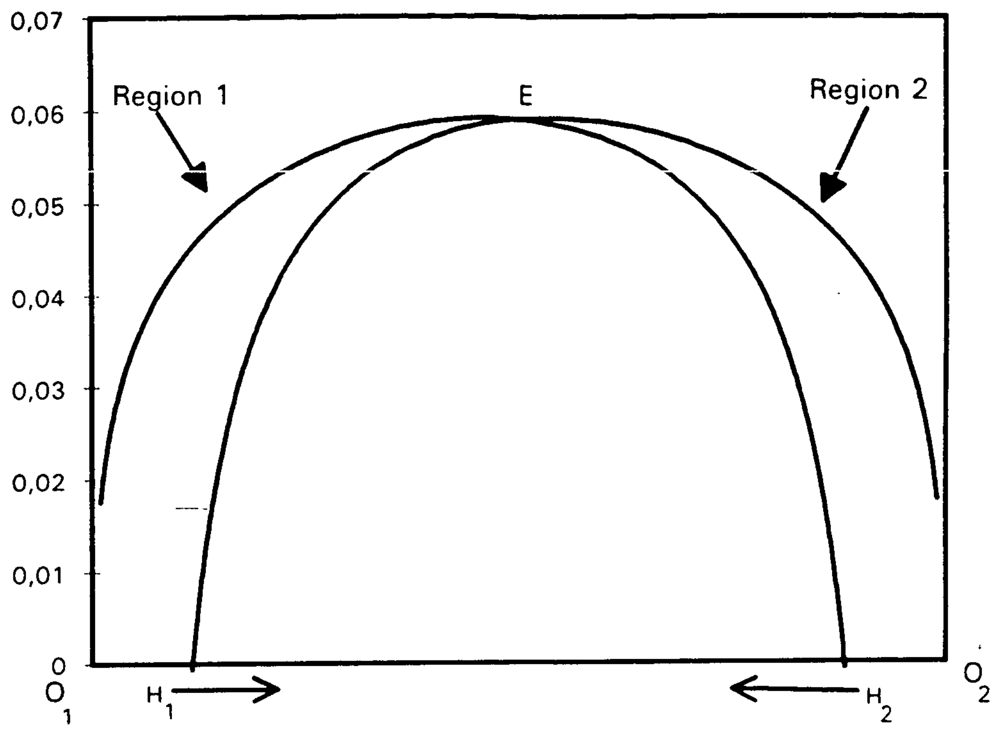
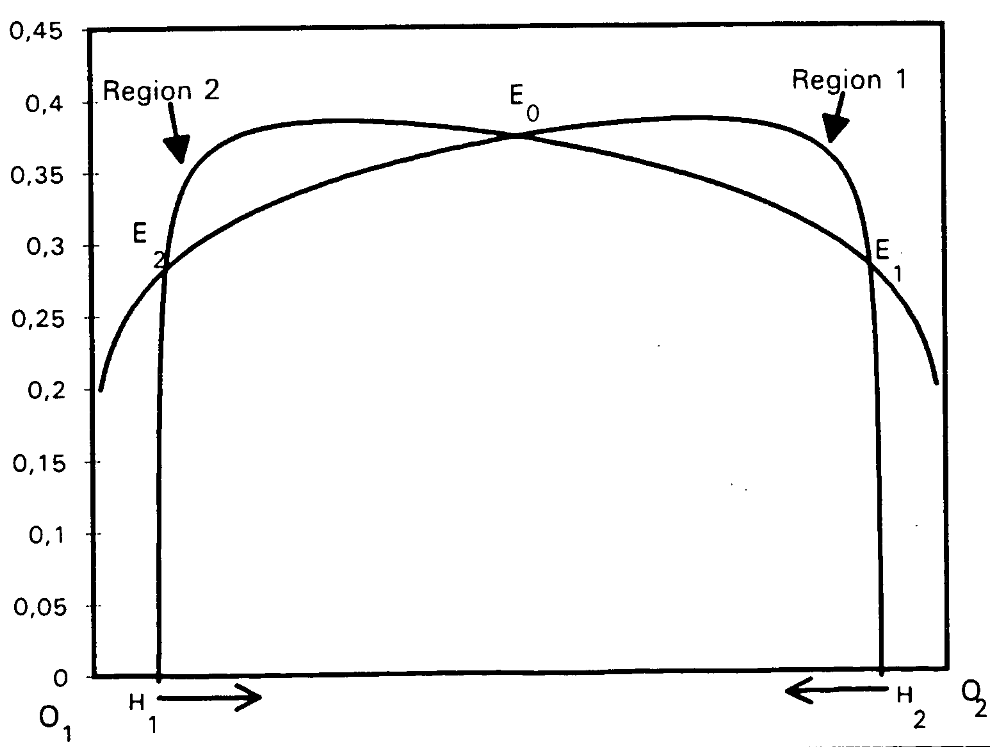
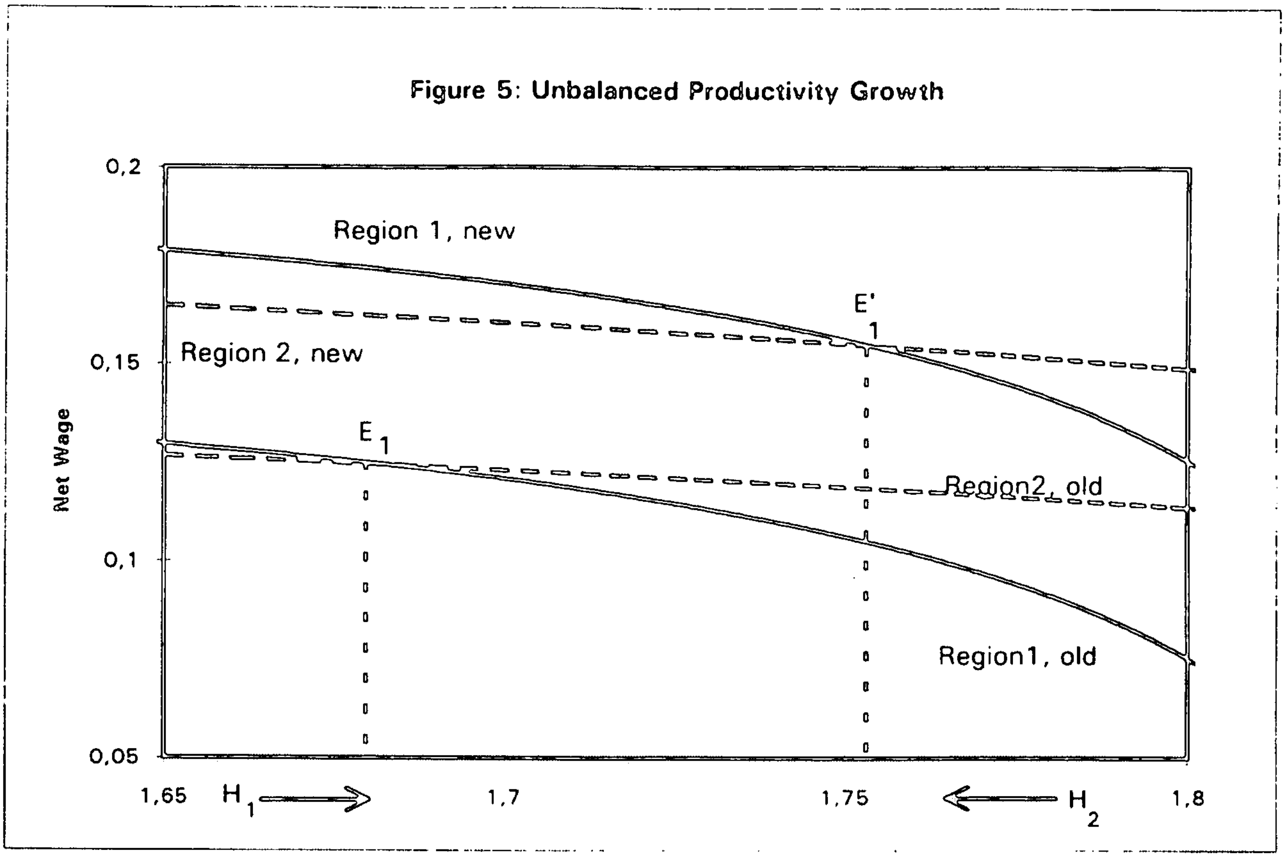


Figure 4B: Net Wage Curves, Case B





Based on numerical examples.
Refer to the text for the underlying parameter values.

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