Fertility, Regional Demographics, and Economic Integration

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Abstract

To explain the links between population distribution and economic integration, we construct a spatial economics model with endogenous fertility. A higher population concentration increases real wages and child-raising costs, thus lowering the fertility rate. However, people migrate to more populated regions to obtain higher real wages. We show that mobility across regions results in more people flowing into highly populated regions, but lowers fertility rates there. The population growth path resembles a logistic curve in the early phase, but population decreases in the last phase. Additionally, economic integration leads to population concentration and decreases population size in the whole economy.

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1. Introduction

It is clear that regional population change is determined by the number of births, deaths, and population migration. In fact, given an initial population size, we can describe completely its change over time as sequences of fertility, mortality, inflow, and outflow rates are determined. Population geography as in Demoko et al. (1970), traditionally explains and predicts regional population change simply by measuring these rates. Generally, such measurements can be credible, if fertility, mortality, inflow, and outflow rates are stable across time and can be measured with high accuracy. However, economists might be dissatisfied with simply measuring them as accurately as possible.

Economists usually suppose that fertility, mortality, and migration depend on economic conditions (e.g., income, commodity prices, and levels of economic development,). For example, many theoretical macroeconomic studies focus on the relationship between economic growth and fertility and most such studies find that a negative relationship exists.[3] New Economic Geography (NEG) shows that real income tends to be high in regions with large markets, and hence, the population tends to concentrate in these regions because of this potential for higher real income.[4] In short, economists may believe that the market has the power to effect population change and that it is, therefore, not sufficient to conduct an analysis that ignores the market.

The purpose of this paper is to construct a simple benchmark model that can describe regional population change in a market economy. Population change itself is a traditional issue in economics. As early as 1798, Malthus already pointed out that population growth is curbed by the power of land to provide human subsistence.[5] Since then, as mentioned earlier, economists have conducted many studies on population change. However, in many

[3]Galor and Weil (1996) argue that wages for women are increasing as economic growth progresses, which raises the opportunity cost for child-rearing and decreases the fertility rate. Becker et al. (1990) propose that people invest more in human capital and have fewer children with advancing economic growth.

[4]For details on NEG, see Fujita et al. (1999).

[5]Malthus was the first to point out that the process of population growth takes the form of a logistic curve. Even though our model does not consider land, it shows that the population growth path of the whole economy takes the form of a logistic curve, which is induced by the market.

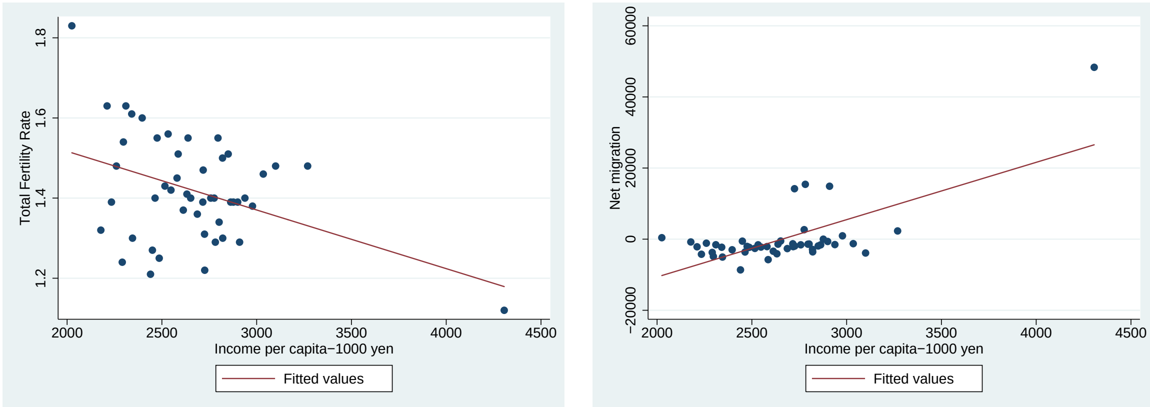
cases, they focused on only country-level population change (i.e., they ignored migration) or migration (i.e., they ignored fertility and mortality). In other words, thus far, natural population change induced by fertility and mortality has been analyzed independently of social population change induced by migration and, except for a few studies, these issues have not been addressed together. In this paper, to fill this gap, we propose a model that considers not only natural population change but also social population change.[6]

We can easily image that in the era of Malthus, the movement of people and goods between regions was difficult. This would justify the exclusion of migration in favor of only one closed region. However, this approach is clearly not appropriate in considering a modern economy. Nowadays, people as well as goods can move among regions much more easily; this is called economic integration. Yet, the majority of economic studies that address population growth have neglected regional differences. Similarly, approaches that address economic integration (e.g., NEG) have also largely ignored population growth, perhaps because of the difficulty of addressing it. The absence of both migration and population growth from the literature has rendered research on the impact of economic integration on population change. Therefore, we set out to explore the relationship between economic integration and population change.

To construct a model to describe regional population change, we must address three important facts. First, population change and economic conditions differ radically across regions. In Figure 1(a), we plot total fertility rates of Japan's 47 prefectures in 2010 according to per-capita income. Regional differences are apparent in prefectures' total fertility rates and per-capita income per capita. Regions in which per-capita income is higher tend to have lower total fertility rates. On the other hand, net migration tends to be higher in regions that have higher per-capita income (see Figure 1(b)). Thus, higher per-capita income may have two opposite effects on regional population changes: lower fertility and higher net migration.

The second important fact is that the existence of differences in regional population

[6]Similar concerns are addressed by Sato and Yamamoto (2005) and Sato (2006). However, their model assumes that fertility rate decreases by the externalities of urbanization. This is a shortcoming of their model because we want to describe population change as adjusted by the market.



(a) Total Fertility Rate (b) Net migration

Figure 1: Total Fertility Rate and Net Migration in Japan in 2010

change may change the population distribution across regions over time. Figure 2 describes the Gini Concentration Ratio for Japan for 1947-2010, which shows an upward trend in this period (we can see the same trend in other countries).[7] This trend means that unequal population distribution across regions becomes larger over time and that people have gathered in particular regions (e.g., Tokyo).

Finally, even though the total fertility rate differs among regions, it has been declining over time at the country level. Figure 2 shows the total fertility rate of Japan in 1947-2010. It clearly indicates a negative trend of the total fertility rate in this period.[8] Especially, we should note that this decline in the total fertility rate seems to be associated with population concentration. Actually, Galor (2011) points out that economic development increases the level of urbanization and Schultz (1985) shows that a progress of urbanization reduces fertility

[7]The Gini Concentration Ratio is derived using the Lorenz curve, which plots the proportion of the total population (on the vertical axis) that is cumulatively held in the total inhabitable area of regions (horizontal axis). Note that the area share is measured by ordering regions according to population density. Here, we use Japan's 47 prefectures as regions, but Okinawa is excluded before 1972. Before 1975, inhabitable area data are not available, so we use 1975 data for inhabitable area before 1975.

[8]The total fertility rate declined sharply in 1966. This is because 1966 was a *bingwu* year according to the Chinese calender; many East Asian people believe that children born in such years will have a bad personality.

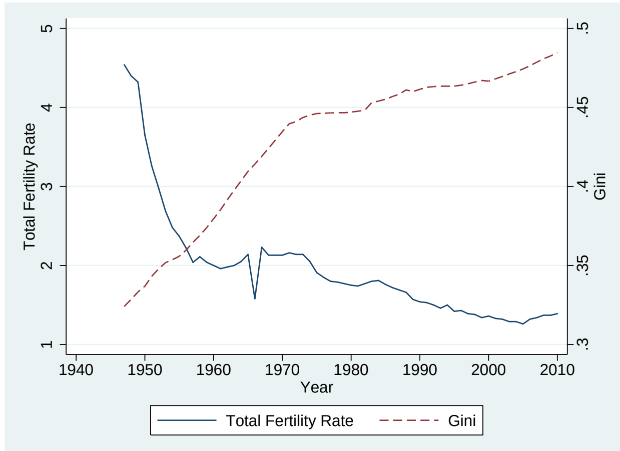


Figure 2: Gini Concentration Ratio and Total Fertility Rate in Japan from 1947 to 2010

rate.

Thus, the model that we construct in this paper should be able to explain these facts. To this end, it must consists of multiple regions (at least two) and take into account migration, fertility and trade. For this purpose, we construct a basic NEG model with endogenous fertility.[9]

Today, NEG is the standard model to explain why the distribution of population and economic activities among regions is radically uneven. In the NEG model, real income tends to be high in highly populated regions and people migrate to these regions to gain higher real income. Figure 3 describes the relationship between population density and per-capita income in Japan in 2010. This shows that highly populated regions tend to offer higher incomes. Moreover, as illustrated in Figure 1(b), net migration tends to be higher in regions with higher real income. These facts justify use of NEG model to describe regional population change.

To endogenize fertility, we employ a framework introduced by Becker (1965) that considers time allocation problem between working and child-rearing in which parents obtain utility from the number of children.[10] When substitutability between consumption goods

[9] Mortality is excluded from our model for simplicity.

[10] The endogenous fertility choice problem was studied by Becker and Lewis (1973), Eckstein and Wolpin (1985), Becker and Barro (1988), Barro and Becker (1989), Becker et al. (1990), Galor and Weil (1996),

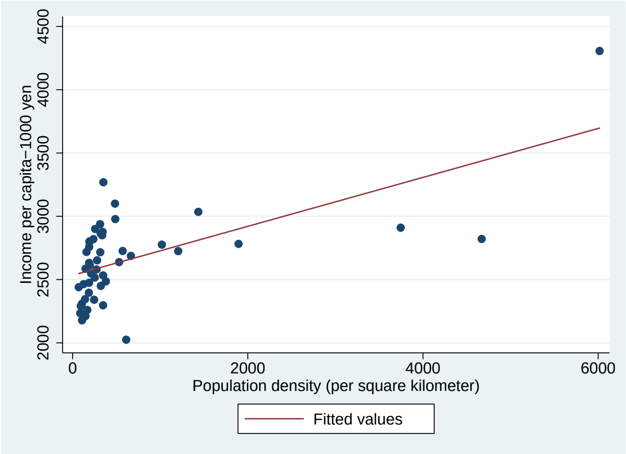


Figure 3: Population Density and Income per Capita (in Thousands of Yen) in Japan in 2010

and children is strong, an increase in the real wage reduces the fertility rate by raising the opportunity cost of rearing children relative to the price of consumption goods. Note that the NEG model employs monopolistic competition of the Dixit and Stiglitz (1977) type. Then, population growth expands the variety of consumption goods which increases the real wage and thus reduces the fertility rate.[11] This mechanism is originally proposed by Maruyama and Yamamoto (2010) which does not address multiple regions. We expand this model to the NEG framework.

Then, using this model, we analyze the regional population change, focusing on the effects of economic integration (i.e., higher migration and trade freeness among regions). We show that if people cannot migrate between regions, regional differences related to the initial population disappear in the long run. This result is contrary to the aforementioned facts. On the other hand, if migration is permitted, we obtain quite different results. Even though there are only subtle differences between regions, these differences become sufficiently large through migration with a snowball effect as the population concentrates in a region with an initially lager larger population share. Moreover, the region in which the population is

Shoven (2008)), and so on.

[11]For example, Docquier (2004) and Jones and Tertilt (2008) show negative relationship between income and the fertility rate in the United States. Borg (1989) finds the same relationship in Korea.

concentrated has a higher real income, which results in a decreased fertility rate and increased net migration compared to less concentrated regions. Thus, in the long run, regions exhibit differences in population change and economic conditions. Typically, higher trade freeness brings about a more concentrated population, which leads to more regional differences. Additionally as population concentration lowers the fertility rate in large regions, the population in the whole economy is suppressed. These results are consistent with the facts and imply that economic integration has a huge impact on population change in regional economies as well as the whole economy.

The remainder of this paper is organized as follows. In Section 2, we construct a basic model without time and generations. In Section 3, we present an extension of the model that introduces time and generations for demographic analysis. Numerical simulations are conducted in Section 4 with several example. Finally, Section 5 concludes.

2. The Basic Model

In this section, we construct a basic model without times and generations. Consider an economy with a finite set of regions, R (the number of regions is represented by $|R|$). The economy consists of one differentiated goods sector characterized by monopolistic competition following Dixit and Stiglitz (1977).

2.1. Preference and Demand

We assume that all individuals obtain utility from the consumption of a composite of differentiated goods, X, and their number of children, n. All individuals share the same preference for the composite differentiated goods and number of children, which is represented by the following utility function:

$$U = \left[\alpha X^{\rho} + (1-\alpha) n^{\rho}\right]^{\frac{1}{\rho}}, \qquad 0 < \alpha < 1, \tag{1}$$

where ρ is the substitution parameter, and in this specification, σ ($\equiv 1/(1-\rho)$) represents the elasticity of substitution between the composite differentiated goods and the number of children. α represents the intensity of the preference for the consumption of differentiated goods. When ρ is close to zero (i.e., when the utility function is close to the Cobb-Douglas form), α becomes the expenditure share of differentiated goods.

We assume that the composite index X is, in turn, a constant elasticity of substitution function defined over a continuum of varieties of differentiated goods. Taking $x(\gamma)$ and $\varGamma$ as the consumption of each available variety γ and the set of available varieties respectively, X is given by

$$X \equiv \left[\int_{\varGamma} x(\gamma)^{\rho_X} d\gamma \right]^{\frac{1}{\rho_X}}, \quad 0 < \rho_X < 1,$$

where ρ_X is the substitution parameter for variety in differentiated goods and σ_X ($\equiv 1/(1 - \rho_X)$) is the elasticity of substitution between any two varieties. A smaller ρ_X (i.e., a smaller σ_X) means that differentiated goods are more highly differentiated or that individuals have a stronger preference for variety.

We assume that individuals have one unit of time and that they allocate it to working and rearing children. Following Becker (1965) and others, in order to have a child, individuals must spend time b to rear a child, where b is a positive constant. Then, given the wage rate w_i in region i and price $p_{ji}(\gamma)$ for each variety that is produced in region j and sold in region i, the budget constraint of individuals in region i becomes

$$\sum_{j \in R} \left(\int_{\varGamma_j} p_{ji}(\gamma) x(\gamma) d\gamma \right) \leqq w_i(1 - bn), \quad i \in R,$$

where $\varGamma_j$ is the set of varieties produced in region j. The measure of $\varGamma_j$ denoted by N_j is interpreted as the number of varieties produced in region j.

Solving the utility maximization problem, individual demand for both the composite index and for children in region i is given by

$$X_i = X(w_i, P_i) \equiv \frac{\mu(w_i, P_i) w_i}{P_i}, \quad i \in R, \tag{2}$$

$$n_i = n(w_i, P_i) \equiv \frac{1 - \mu(w_i, P_i)}{b}, \quad i \in R; \tag{3}$$

then, individual demand in region i for variety γ produced in region j can be written as

$$x_{ji}(\gamma) = x(w_i, p_{ji}(\gamma), P_i) \equiv \frac{\mu(w_i, P_i) w_i}{P_i} \left(\frac{P_i}{p_{ji}(\gamma)} \right)^{\sigma_X}, \quad \gamma \in \varGamma_j, \; j, i \in R, \tag{4}$$

where P_i is the price index for differentiated goods in region i, which is defined by

$$P_i \equiv \left[\sum_{j \in R} \left(\int_{\varGamma_j} p_{ji}(\gamma)^{1-\sigma_X} d\gamma \right) \right]^{\frac{1}{1-\sigma_X}}, \quad i \in R, \tag{5}$$

and $\mu(\cdot)$ is the expenditure share of the composite differentiated goods, which is given by

$$\mu(w_i, P_i) \equiv \frac{\alpha^\sigma P_i^{1-\sigma}}{\alpha^\sigma P_i^{1-\sigma} + (1-\alpha)^\sigma (bw_i)^{1-\sigma}} = \frac{\alpha^\sigma}{\alpha^\sigma + (1-\alpha)^\sigma (bw_i/P_i)^{1-\sigma}}, \quad i \in R. \qquad (6)$$

Let us denote the real wage in region i as ω_i ($\equiv w_i/P_i$). A rise in the real wage has two opposite effects on the number of children per individual. Clearly, because children are superior goods, the rise in the real wage increases the number of children (income effect). The rise in the real wage, however, increases the opportunity costs of having children, which raises the relative price of children and reduces the number of children (substitution effect). If the elasticity of substitution between the composite differentiated goods and the number of children is larger than one, this latter effect is sufficiently large to outweigh the former, and thus, a rise in the real wage reduces the number of children. This can be checked easily by

$$\frac{\omega_i}{\mu(\omega_i, 1)} \frac{\partial \mu(\omega_i, 1)}{\partial \omega_i} = (\sigma - 1)(1 - \mu(\omega_i, 1)), \quad i \in R,$$

and (3). Thus, a rise in the real wage actually reduces the number of children per individual. We propose this result.

Proposition 1. *If $\sigma > 1$ holds, then a rise in the real wage reduces the fertility rate.*

In the remainder of this paper, we restrict the range of parameters to $1 < \sigma < \sigma_X$. One reason for this restriction is, of course, to ensure that a rise in the real wage reduces the fertility rate. Another reason is to ensure that demand for each variety decreases when the price index falls. If the amount of composite differentiated goods is fixed at a given level, fall of the price index always reduces the demand for a single variety because it is substitutable for other varieties. However, since fall of the price index also increases the demand for composite differentiated goods, in general, it is unclear whether the demand for a single variety becomes smaller with a smaller price index. The restriction $1 < \sigma < \sigma_X$ makes this point clear. Note that an increase in the range of varieties available reduces the price index. We show in the following subsection that the equilibrium output of any active firm, q^*, is constant and that the profits of a single firm becomes positive or negative as its output becomes larger or smaller than q^*. Thus, this limitation is important for the stability of the long-run equilibrium characterized by the zero-profit condition.

Substituting the demand for composite differentiated goods and for children (see (2) and (3)) into the utility function (1), we can express the maximized utility as a function of the real wage as follows:

$$V_i = V(\omega_i) \equiv \frac{\omega_i}{[\alpha^\sigma + (1-\alpha)^\sigma (b\omega_i)^{1-\sigma}]^{\frac{1}{1-\sigma}}}, \quad i \in R.$$

We can also easily derive the following relationship:

$$\frac{\omega_i}{V_i}\frac{\partial V(\omega_i)}{\partial \omega_i} = \mu(\omega_i, 1) > 0, \quad i \in R. \tag{7}$$

In the Section 3, we assume that individuals move to the regions where they can gain higher utility. Relationship (7) ensures that it is sufficient to compare the real wages among regions to determine the movement of individuals.

2.2. Production

Next, we turn to the production side of the economy. Each variety γ of differentiated goods is produced by a firm indexed by γ under increasing-returns technology, using labor only, and each firm behaves as monopolist. All firms in all regions use the same technology, with a fixed input of f and marginal input requirement a. Then, the labor input requirement for the production of a quantity $q_j(\gamma)$ of any variety $\gamma \in \mathit{\Gamma}_j$ at any given region j is given by $l_j(\gamma) = f + aq_j(\gamma)$.

Differentiated goods can be shipped between regions, but they must incur transport costs in shipment. For simplicity, we assume the *iceberg form* of transport costs: that is, if one unit of any variety $\gamma \in \mathit{\Gamma}_j$ of differentiated goods is shipped from region j to region i, $1/\tau_{ji}$ ($\tau_{ji} \geqq 1$, $\tau_{jj} = 1$) units of it actually arrive.[12] Thus, τ_{ji} units of the variety must be sent from the origin for one unit to arrive at the destination. Given the demand for each variety in (4) and transportation technology, the output of firm γ in region j is equal to

$$q_j(\gamma) = \sum_{i \in R} \tau_{ji} x_{ji}(\gamma) L_i, \quad \gamma \in \mathit{\Gamma}_j,\ j \in R,$$

[12]The iceberg form of transport costs is first introduced by von Thünen (1826) and then formalized by Samuelson (1952).

where L_i is the number of individuals (workers) in region i. Then, with given prices in each region, firm γ's profit is given by

$$\pi_j(\gamma) = \sum_{i \in R} p_{ji}(\gamma) x_{ji}(\gamma) L_i - w_j \left(f + a \sum_{i \in R} \tau_{ji} x_{ji}(\gamma) L_i \right).$$

Each firm γ chooses its prices, $p_{ji}(\gamma)$, to maximize profit. It is well known that each firm has a pricing rule given by the following form:

$$p_{ji}(\gamma) = p_{ji} \equiv \frac{a}{\rho_X} \tau_{ji} w_j, \quad \gamma \in \Gamma_j, \ i, j \in R, \tag{8}$$

which represents the familiar result that each monopolistic firm will charge a markup over the marginal cost.

We suppose that there is free entry and exit of firms. Then, as long as some firms are producing, the profits of any active firm must be driven to zero. Given pricing rule (8), the profit of firm γ in region j becomes

$$\pi_j(\gamma) = w_j \left[\frac{a q_j(\gamma)}{\sigma_X - 1} - f \right], \quad \gamma \in \Gamma_j, \ i, j \in R.$$

Therefore, the zero-profit condition ensures that the equilibrium output of active firms is constant and common to every active firm in all regions as $q^* = (\sigma_X - 1) f / a$, which implies that the associated equilibrium labor input becomes $l^* \equiv f + a q^* = \sigma_X f$. Note that the labor supply per individual in region j is $\mu(w_j, P_j)$. Therefore, in equilibrium, the number of firms located in region j is given by

$$N_j^* \equiv \frac{\mu(w_j, P_j) \lambda_j L}{f \sigma_X}, \quad j \in R, \tag{9}$$

where L is the total number of workers and λ_j ($\equiv L_j / L$) is the share of workers in region j.

2.3. Price Index Effect and Home Market Effect

We can now explore the *agglomeration force* in the economy, which causes a concentration of the population in particular regions. First, using the pricing rule (8), we write the price index (5) in the following form:

$$P_i = \left[\sum_{j \in R} \left(N_j p_{ji}^{1-\sigma_X} \right) \right]^{\frac{1}{1-\sigma_X}} = \frac{a}{\rho_X} \left[\sum_{j \in R} \phi_{ji} N_j w_j^{1-\sigma_X} \right]^{\frac{1}{1-\sigma_X}}, \quad i \in R, \tag{10}$$

where ϕ_{ji} ($\equiv \tau_{ji}^{1-\sigma_X} \in (0,\, 1]$) is a measure of the freeness of trade from region j to region i, which increases as τ_{ji} falls and is equal to 1 when trade is free (i.e., $\tau_{ji} = 1$). Suppose now that a fraction of firms in region j changes their location to region i, holding other things constant. Then, the relationship between the change in the number of firms in region j and that in region i is represented by $dN_j = -dN_i$. Using this relationship and differentiating the above price index while keeping all other things constant, we obtain

$$\frac{N_i}{P_i}\frac{dP_i}{dN_i} = \frac{N_i}{\sigma_X - 1}\frac{\phi_{ji}w_j^{1-\sigma_X} - w_i^{1-\sigma_X}}{\sum_{k\in R}\phi_{ki}N_k w_k^{1-\sigma_X}} \lesseqgtr 0 \;\Leftrightarrow\; \frac{w_i}{w_j} \lesseqgtr \tau_{ji}, \quad i, j \in R.$$

Thus, when transport costs from region j to region i are sufficiently high, the price index of region i declines because of the relocation of firms. In particular, if the wage rates in region j and region i are the same, the price index in region i always falls. This is called the *Price Index Effect*; it means that the region with the larger number of firms has a lower price index because a smaller proportion of this region's consumption of differentiated goods bears transport costs.

Next, because firms making no profits is equivalent to the condition that they produce the equilibrium output q^*, any active firm in region i must allocate q^* to consumers in each region, that is,

$$\sum_{j\in R}\tau_{ij}x_{ij}(\gamma)L_j = q^*, \quad \gamma \in \varGamma_i,\ i \in R.$$

Using the demand function for each variety (4) and the pricing rule (8), this equation yields the following wage equation:

$$w_i = w_i^P \equiv \left(\frac{a}{\rho_X}\right)^{\frac{1-\sigma_X}{\sigma_X}} \left[\frac{1}{\sigma_X f}\sum_{j\in R}\phi_{ij}\mu_j Y_j P_j^{\sigma_X-1}\right]^{\frac{1}{\sigma_X}}, \quad i \in R, \tag{11}$$

where $\mu_j = \mu(w_j, P_j)$ and $Y_j = w_j L_j$. Given the income levels, wage rates, price indexes, and transportation costs, w_i^P gives the wage rate that firms can afford to pay in region i. In the short run, the actual wage rate in region i may differ from w_i^P. If the actual wage rate in region i is lower than w_i^P, firms in region i can gain rent due to being protected from competition with other firms. In this case, however, through the entry of firms, the wage rate in region i must be adjusted to w_i^P and the rent disappears in the long run. In this regard, we call w_i^P the *Wage Potential* in region i; this is the wage rate that workers can potentially gain in region i.

Suppose that a fraction of the income in region j is transfered to region i and that all other things are constant. Then, the relationship between the change in the income level of region j and that of region i is represented by $dY_j = -dY_i$. Using this relation, differentiating w_i^P given by (11), keeping all other things constant, we obtain the following relationship:

$$\frac{Y_i}{w_i^P}\frac{dw_i^P}{dY_i} = \frac{Y_i}{\sigma_X}\frac{\mu_i P_i^{\sigma_X -1} - \phi_{ij}\mu_j P_j^{\sigma_X -1}}{\sum_{k\in R}\phi_{ik}\mu_k Y_k P_k^{\sigma_X -1}} \gtreqless 0 \;\Leftrightarrow\; \frac{\mu_i}{\mu_j}\left(\frac{P_i}{P_j}\right)^{\sigma_X -1} \gtreqless \phi_{ij}, \quad i,j\in R.$$

Thus, when the trade freeness from region i to region j is sufficiently high, the wage potential in region i rises because of the transfer of income. Specifically, if the price indexes and the expenditure shares of differentiated goods are the same between regions j and i, the wage potential always rises. This is called the *Home Market Effect*; it means that, all other things being equal, the region with the larger home market has the higher wage potential and the wage rate in this region tends to be high.[13]

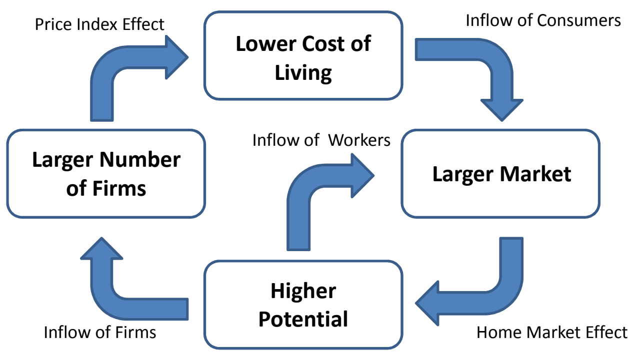


Figure 4: Circular Causality in Agglomeration

Figure 4 depicts the circular causality in the spatial agglomeration. Because the region with the larger number of firms has the lower a cost of living, consumers migrate to that region. This, in turn, induces an increase in the market size of the region with the larger number of firms. On the other hand, because the region with the larger market has the higher wage potential, workers and firms flow into it. This makes the number of firms and

[13]Here, we consider the home market effect keeping all other things constant. Since, in reality, other things need not be constant, the home market effect may not hold. Conditions under which the home market effect holds are studied by Davis (1998), Yu (2005) and Behrens et al. (2009).

the size of the market in that region larger. Obviously, this circular causality leads to a concentration of population in particular regions.

2.4. Equilibrium Wage Rate

The expenditure share of the composite of differentiated goods is the function of the wage and the price index as in (6). From (9) and (10), region i's price index can be expressed as a function of L, $\boldsymbol{\phi}_i = (\phi_{1i}, \cdots, \phi_{|R|i})$, $\boldsymbol{\lambda} = (\lambda_1, \cdots, \lambda_{|R|})$, $\boldsymbol{w} = (w_1, \cdots, w_{|R|})$ and $\boldsymbol{\mu} = (\mu_1, \cdots, \mu_{|R|})$: $P_i = P(L, \boldsymbol{\phi}_i, \boldsymbol{\lambda}, \boldsymbol{w}, \boldsymbol{\mu})$. Then, the equilibrium share of the composite of differentiated goods, μ_i^*, is given by

$$\mu\left(w_i, P\left(L, \boldsymbol{\phi}_i, \boldsymbol{\lambda}, \boldsymbol{w}, \boldsymbol{\mu}^*\right)\right) = \mu_i^*, \quad i \in R.$$

Thus, we can express μ_i^* as a function of L, $\boldsymbol{\phi}_1$, $\cdots$, $\boldsymbol{\phi}_{|R|}$, $\boldsymbol{\lambda}$ and $\boldsymbol{w}$. It is easily verifiable that μ_i^* is linearly homogeneous for $\boldsymbol{w}$.

In equilibrium, the wage rate in region i equals region i's wage potential, that is, $w_i^* = w_i^P$. Therefore, from (11), the equilibrium wage rate vector $\boldsymbol{w}^*$ is determined by the following:

$$\left[\sum_{j \in R} \frac{\phi_{ij}\lambda_j\mu_j^* w_j^*}{\sum_{k \in R}\phi_{kj}\lambda_k\mu_k^*(w_k^*)^{1-\sigma_X}}\right]^{\frac{1}{\sigma_X}} = w_i^*, \quad i \in R.$$

We can then express $\boldsymbol{w}^*$ as a function of L, $\boldsymbol{\phi}_1$, $\cdots$, $\boldsymbol{\phi}_{|R|}$, and $\boldsymbol{\lambda}$. Clearly, if $\boldsymbol{w}^*$ is an equilibrium wage rate vector, for all $c > 0$, $c\boldsymbol{w}^*$ is also an equilibrium wage rate vector. Hence, without loss of generality, we can normalize wage rates as $\sum_{i \in R} w_i = 1$.

3. Extension of the Model for Demographic Analysis

In this section, we introduce times and generations to the model. Time is discrete, and each individual lives for two periods: childhood and adulthood. We denote the number of adults in region i in period t as $L_{i,t}$ and the total number of adults in time t as L_t $(= \sum_{i \in R} L_{i,t})$. In adulthood, individuals choose the regions they live in, supply labor in those regions, and decide their amount of consumption and number of children.

3.1. Population Dynamics

At the beginning of period t, each adult in region i has $n_{i,t}$ children. In this model $n_{i,t}$ also represents the fertility rate in region i at time t, and thus $n_{i,t}L_{i,t}$ is the number of children in region i at time t. The average fertility rate in the economy at time t, $\bar{n}_t$, is given by

$$\bar{n}_t \equiv \sum_{i \in R} \lambda_{i,t} n_{i,t}, \quad t \in \mathbb{N},$$

where $\lambda_{i,t}$ ($\equiv L_{i,t}/L_t$) is region i's share of adults (workers) at time t. Since $\bar{n}_t L_t$ children grow to adulthood in the economy in period $t+1$, we have the following law of motion of the total number of adults:

$$L_{t+1} = \bar{n}_t L_t = \left(\prod_{r=0}^{t} \bar{n}_r \right) L_0, \quad t \in \mathbb{N}. \tag{12}$$

3.2. Dynamics of Inter-regional Population Movement

Next, we consider inter-regional migration. We assume workers choose the regions in which they live and subsequently choose their number of children and amount of consumption in that region. We first define $\lambda_{i,t+1}^{pre}$ as region i's share of pre-movement workers at time $t+1$:

$$\lambda_{i,t+1}^{pre} \equiv \frac{n_{i,t} L_{i,t}}{\sum_{j \in R} n_{j,t} L_{j,t}} = \frac{\lambda_{i,t} n_{i,t}}{\bar{n}_t}, \quad i \in R, \ \ t \in \mathbb{N}. \tag{13}$$

Similar to Fujita et al. (1999), we assume workers gradually move to regions where they can gain a higher real wage, that is, higher utility (see (7)). We capture this adjustment process by the following dynamics:

$$\lambda_{i,t+1} - \lambda_{i,t+1}^{pre} = \nu \left(\frac{\omega_{i,t}}{\bar{\omega}_t} - 1 \right) \lambda_{i,t}, \quad i \in R, \ \ t \in \mathbb{N},$$

where $\bar{\omega}_t$ ($\equiv \sum_{i \in R} \lambda_{i,t} \omega_{i,t}$) is the average real wage among regions at time t and ν (> 0) is the adjustment parameter. Using (13), we can rewrite the above system as follows:[14]

$$\lambda_{i,t+1} - \lambda_{i,t} = \left(\frac{n_{i,t}}{\bar{n}_t} - 1 + \nu \left(\frac{\omega_{i,t}}{\bar{\omega}_t} - 1 \right) \right) \lambda_{i,t}, \quad i \in R, \ \ t \in \mathbb{N}. \tag{14}$$

[14] The dynamics given by (14) are essentially equivalent to the replicator dynamics that are often used in evolutionary game theory (see Weibull (1995)). We introduce the natural change of the population into these dynamics.

Then, we have the following law of motion of the number of workers in region i:

$$L_{i,t+1} = \left(\frac{n_{i,t}}{\bar{n}_t} + \nu \left(\frac{\omega_{i,t}}{\bar{\omega}_t} - 1 \right) \right) \bar{n}_t L_{i,t}, \quad i \in R \quad t \in \mathbb{N}. \tag{15}$$

3.3. Definition of Steady State

In a steady state, both the total number of workers in the economy, L^*, and the share of workers in each region, λ_i^* are stationary such that

$$L_{t+1} = L_t = L^*,$$
$$\lambda_{i,t+1} = \lambda_{i,t} = \lambda_i^*, \quad i \in R.$$

From (12) and (14), this steady state is given by $\bar{n}^* = 1$ and

$$\left(\frac{n_i^*}{\bar{n}^*} - 1 + \nu \left(\frac{\omega_i^*}{\bar{\omega}^*} - 1 \right) \right) \lambda_i^* = 0, \quad i \in R, \tag{16}$$

where n_i^* and ω_i^* are the fertility rate and the real wage, respectively, in region i corresponding to L^* and λ_i^*.

Note that in the usual NEG model, spatial equilibrium is defined as the state in which no agents have an incentive to change location. In this regard, in spatial equilibrium, the share of workers in each region, λ_i^S, is defined by

$$\left(\frac{\omega_i^S}{\bar{\omega}^S} - 1 \right) \leqq 0, \quad i \in R,$$
$$\left(\frac{\omega_i^S}{\bar{\omega}^S} - 1 \right) \lambda_i^S = 0, \quad i \in R,$$

where the superscript S represents the value in the spatial equilibrium. If the share of workers in each region is in spatial equilibrium, the real wage is equalized in all regions that have a positive share, which leads to identical fertility rates in these regions. Therefore, (16) is satisfied in the spatial equilibrium. However, the steady state may not be the spatial equilibrium. If some region has a higher real wage, there will be a population inflow, but the fertility rate will be lower in that region. Therefore, it is possible for (16) to be satisfied in a steady state that is not the spatial equilibrium. This result differs completely from the usual NEG model.

4. Numerical Examples

In this section, we analyze how economic integration affects population demographics. Since our model is highly non-linear, it is, unfortunately, difficult to obtain analytical results. Therefore, we employ a numerical simulation method and show some examples. For our analysis, it is useful to define the natural change in population, $NC_{i,t}$, and social change in population, $SC_{i,t}$, of each region at each time as

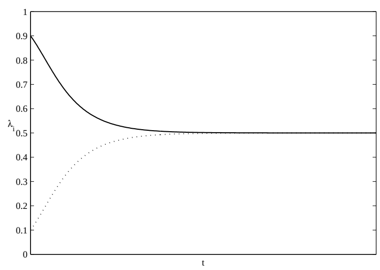
$$NC_{i,t} = (n_{i,t} - 1)L_{i,t}, \quad i \in R,\ t \in \mathbb{N},$$
$$SC_{i,t} = \nu \left(\frac{\omega_{i,t}}{\bar{\omega}_t} - 1 \right) \bar{n}_t L_{i,t} \quad i \in R,\ t \in \mathbb{N}.$$

From (15), the total change of workers in region i at time t, $TC_{i,t}$ ($\equiv L_{i,t+1} - L_{i,t}$), is given by $TC_{i,t} = NC_{i,t} + SC_{i,t}$.

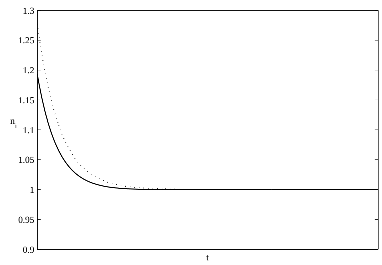
4.1. The Case of Two-Region

Here, we show a two-region case, first with no migration and then with migration. Figure 5 describes the demographics for no migration, in which workers cannot move between regions. The economy initially has one unit of labor (workers) and region 1's initial share of workers is set as 0.9. Then, we illustrate the dynamic paths of the share of workers ($\lambda_{i,t}$), fertility rate ($n_{i,t}$), real wage ($\omega_{i,t}$), number of workers ($L_{i,t}$), natural and social change ($NC_{i,t}$ and $SC_{i,t}$, respectively) in each region.

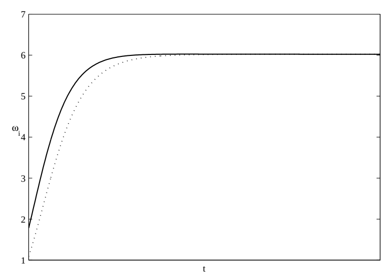
Because of the home market effect and the price index effect, the highly populated region has a higher real wage and, thus, the real wage of region 1 is higher than that of region 2. From Proposition 1, this leads to a lower fertility rate in region 1 compared to region 2. Therefore, if workers cannot move between regions, the share of workers would equalize gradually over time (see Figure 5(a)). On the other hand, the number of workers monotonically increases in regions 1 and 2, which raises real wages in both regions (see Figures 5(c) and 5(d)). This rise of real wage results in fertility rates decreasing (see Figure 5(b)). Natural changes in regions 1 and 2 become large at an early phase, but reach their peak at a certain point in time and thereafter decrease until zero (see Figure 5(e)). Because we consider the case of no migration case, the social change is always zero (see Figure 5(f)).



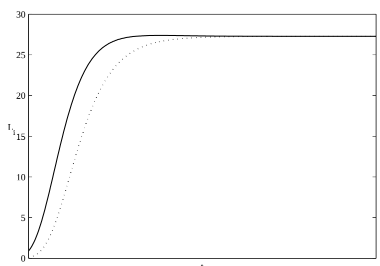
(a) Share of workers



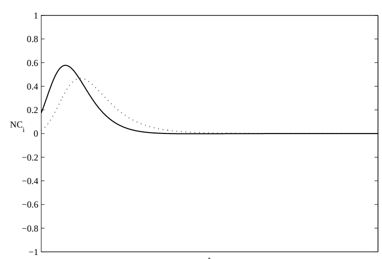
(b) Fertility rate



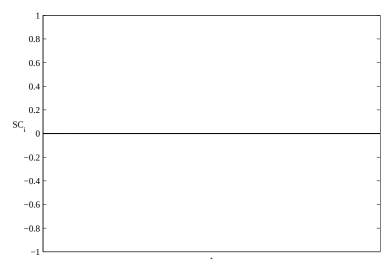
(c) Real wage



(d) Number of workers



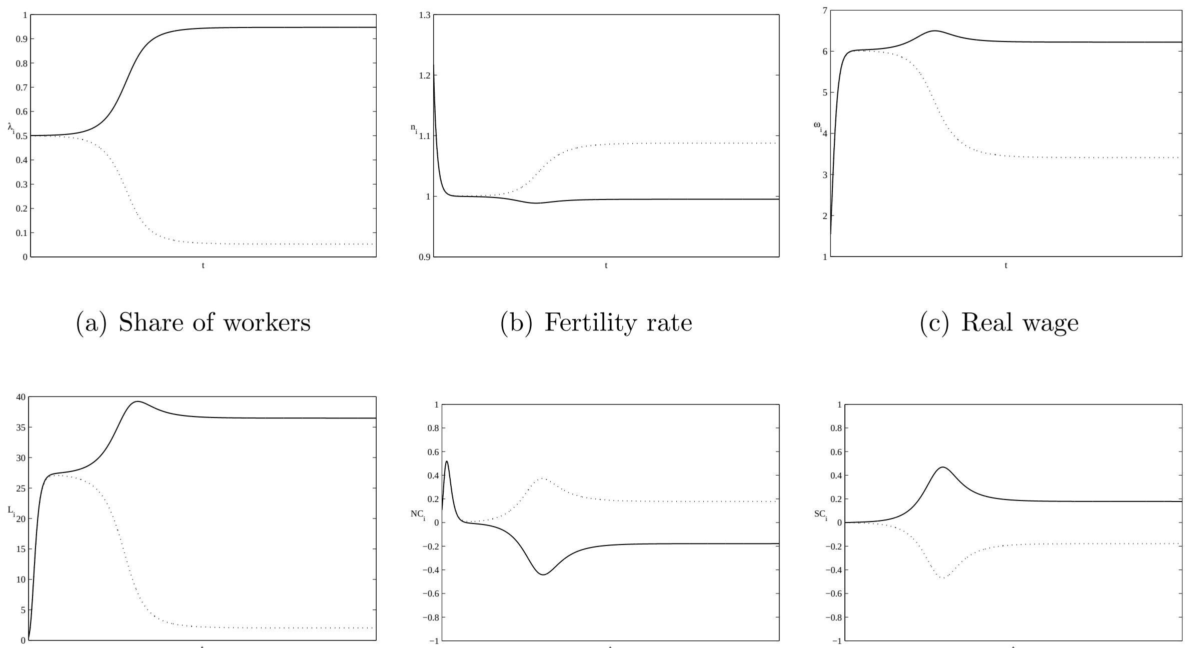
(e) Natural increase



(f) Social increase

Figure 5: Demographics with No Migration

$\sigma = 1.2,\ \sigma_X = 4,\ \alpha = 0.7,\ b = 0.25,\ \phi_{12} = \phi_{21} = 0.25,\ f = 1/3,\ a = 1/3,\ \nu = 0$



(a) Share of workers (b) Fertility rate (c) Real wage

(d) Number of workers (e) Natural increase (f) Social increase

Figure 6: Demographics with Migration

$\sigma = 1.2$, $\sigma_X = 4$, $\alpha = 0.7$, $b = 0.25$, $\phi_{12} = \phi_{21} = 0.25$, $f = 1/3$, $a = 1/3$, $\nu = 0.2$

Next, we consider the case with migration, in which workers can move between regions. Figure 6 describes the dynamic paths of the variables under the same parameters as the case of no migration except for the migration adjustment parameter, ν.

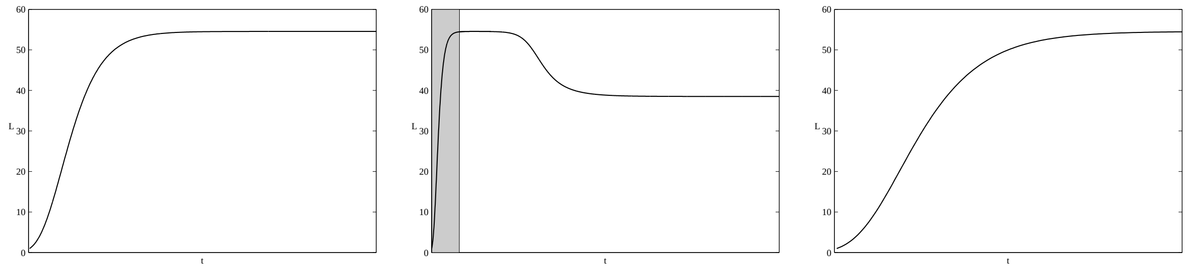
In the case of no migration, if the home market effect and the price index effect always make the real wage higher in the highly populated region, the fertility rate there will be lower than in the less populated region since a higher real wage rate means a lower fertility rate. Consequently, in this case, the home market effect and the price index effect make the population distribution over the regions tend toward uniformity, as shown in Figure 5. We call this *dispersion force.*[15]

However, if the migration of workers is permitted, the above argument may not hold. In Figure 6, we set the initial share of workers to be almost the same in both regions, but the share in region 1 is slightly larger.[16] As the home market effect and the price index effect make the real wage of region 1 higher than that of region 2, the social change, $SC_{i,t}$, is positive in region 1, but negative in region 2 (see Figure 6(f)). This agglomeration force encourages the share of workers in region 1 to increase over time (see Figure 6(a)). On the other hand, the natural change, $NC_{i,t}$, is small in region 1 and large in region 2 (see Figure 6(e)) since a higher real wage reduces the fertility rate (dispersion force). When the difference in the share of workers between regions becomes large, the agglomeration force and the dispersion force are balanced and the economy is in a steady state. Interestingly, in this steady state, the social change of region 1 is positive, which means that this economy is not in spatial equilibrium. In particular, in the steady state, the two regions differ in characteristics: one has a positive natural change but a negative social change, while the other has a positive social change but negative natural change.

The paths of the number of workers in the whole economy in the cases of no migration and migration are described in Figure 7. In the case of no migration, the path has the form of a logistic curve (see Figure 7(a)). When there are few workers in the economy, since the

[15] In NEG, "dispersion force" is usually used to describe a power that provides a clear incentive to migrate from large to small regions (e.g., congestion). In this paper, we use the term in a different sense: here, "dispersion force" means a power that equalize population distribution.

[16] We set $\lambda_{1,0} = 1001/2000$ and $\lambda_{2,0} = 999/2000$.



(a) No-migration case (b) Migration case (c) Shadow area of (b)

Figure 7: Number of Workers in the Whole Economy

$\sigma = 1.2$, $\sigma_X = 4$, $\alpha = 0.7$, $b = 0.25$, $\phi_{12} = \phi_{21} = 0.25$, $f = 1/3$, $a = 1/3$ $\nu = 0.2$

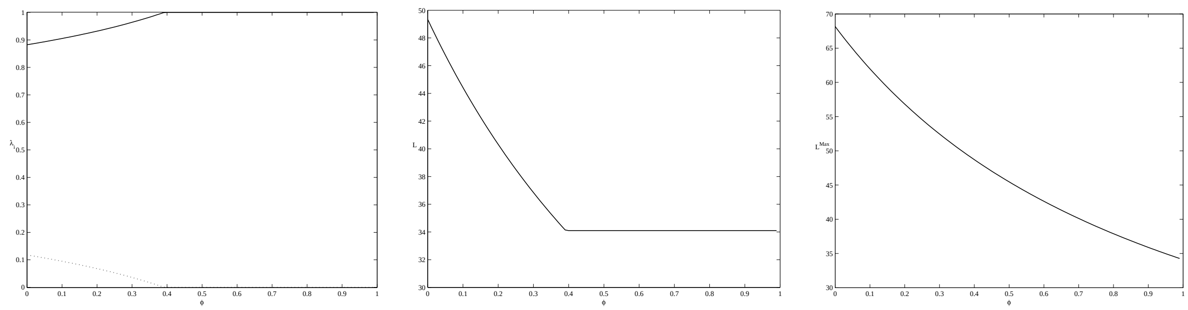
real wage is low the fertility rate is high and the population grows rapidly. As the population grows, the real wage becomes higher and this suppresses the fertility rate (Proposition 1). Therefore, population growth gradually decreases and the economy reaches a steady state.

However, in the case of migration, the shape of the path differs, as in Figure 7(b). The population becomes largest along the path before the steady state and then decreases. In the early phase, because the difference in the shares of workers between regions is not sizable, the real wages in both regions are nearly the same. Hence, the migration rate of workers is small and the population growth path in the economy is similar to that of the case of no-migration. Figure 7(c) illustrates this phase, which corresponds to the shaded area of Figure 7(b). In this phase, the path of the population growth is also the form of a logistic curve.

After the early phase, however, workers migrate to the region with the higher real wage and gradually congregate there, which increases the real wage in the highly populated region (region 1) and decreases the real wage in the less-populated region (region 2). This brings about further migration and reduces the fertility rate in region 1. When the difference between the shares of workers becomes large enough, the fertility rate is less than 1 in region 1. Thus, total population growth becomes negative, even though region 2 has a fertility rate over 1, and this overall negative growth continues until the negative natural change in region 1 is canceled out by positive natural change in region 2.

4.2. How Integration of the Economy Affects Population size and Spatial Structure

Next, we show how integration of the economy affects population size and spatial structure. We examine how the share of workers in each region and the number of workers in the whole economy are affected by changing transportation costs (trade freeness) and the migration adjustment. We set the initial distribution of workers and all parameters to be the same as in the migration case in Section 4.1, except for ϕ and ν.



(a) Share of workers (b) Number of workers (c) Max number of workers

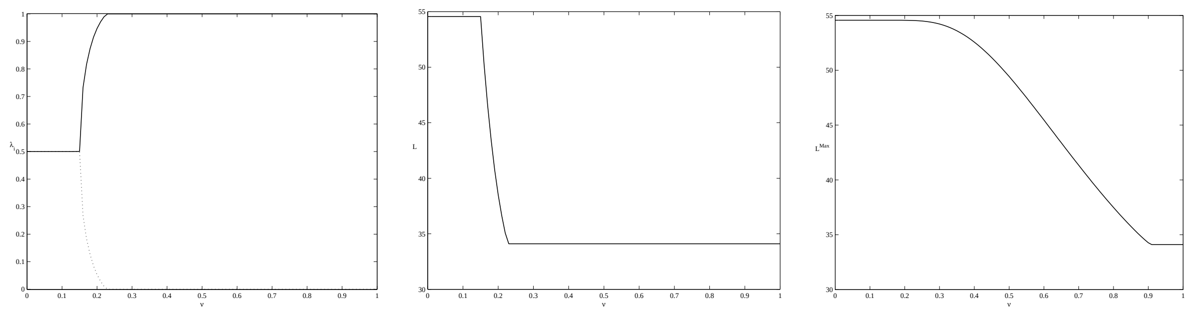
Figure 8: Effects of the Change of Trade Freeness

$\sigma = 1.2$, $\sigma_X = 4$, $\alpha = 0.7$, $b = 0.25$, $f = 1/3$, $a = 1/3$, $\nu = 0.2$

First, we show the effects of changing trade freeness.[17] Figures 8(a) and (b) describe the share of workers in each region and the number of workers in the whole economy, respectively, in the steady state corresponding to ϕ. Increased trade freeness increases the steady-state share of workers in region 1. Above $\phi = 0.4$, the economy completely agglomerates. Moreover, the number of workers in the economy decreases as trade freeness increases. Note that an increase in trade freeness raises the real wage not only directly, but also indirectly by inducing population concentration. This lowers the fertility rate. After complete agglomeration, trade freeness does not affect the number of workers in the steady state since, in this case, there is only one region in the economy. On the other hand, the maximum number of workers on the transition path decreases monotonically with increased trade freeness. This is shown in Figure 8(c), which illustrates the maximum number of workers on each transition path. Since the number of workers reaches the maximum level on the path before workers

[17] We assume symmetry trade freeness: $\phi_{12} = \phi_{21} = \phi$

agglomerate in region 1, the maximum number of workers in the economy is influenced by trade freeness.



(a) Share of workers (b) Number of workers (c) Max number of workers

Figure 9: Effects of Change of the Migration Adjustment Parameter

$\sigma = 1.2$, $\sigma_X = 4$, $\alpha = 0.7$, $b = 0.25$, $\phi_{12} = \phi_{21} = \phi = 0.25$, $f = 2/3$, $a = 1/3$

Next, we show the effects of changing the migration adjustment parameter, ν. Figures 9(a) and (b) describe the share of workers in each region and the number of workers in the whole economy, respectively, in the steady state corresponding to ν. It is obvious that the share of workers in the steady state is affected by the migration adjustment parameter. If ν is small, it is difficult for workers to move even if there is a difference in the real wages between regions. However, the fertility rate is lower in the highly populated regions; this occurs irrespective of the level of ν. Hence, the distribution of workers between regions tends to be uniform, as in the case of no migration in the steady state. Conversely, if ν is sufficiently large, that is, if it is easy to move, a positive social change always overcomes a negative natural change in the large region. Thus, the steady state of the spatial structure of the economy is full agglomeration. Given a moderate ν, the economy does not converge to be both symmetric and in full agglomeration. In the steady state, the social change balances with the natural change, and the economy is in partial agglomeration.

When ν is small, an increase of ν does not affect the steady state number of workers because the distribution of workers is always uniform. Given intermediate ν, which is between symmetry and complete agglomeration, an increase of ν decreases the steady state number of workers because it increases the share of workers in region 1. When ν is sufficiently large, as in the case of a small ν, an increase of ν does not affect the steady state number of workers because workers fully agglomerate to region 1, while the number of workers is smaller than in the symmetry case.

If the steady state share of workers is the same between regions, the maximum number of workers on the transition path equals the steady state number of workers in the whole economy. However, it decreases as the migration adjustment parameter increases if ν is larger than in the symmetric case. When this occurs, the steady state distribution of workers is not uniform and the number of workers reaches its maximum level before reaching the steady state. This is shown described in Figure 9(c).

From the above discussion, we see that if the economy is more integrated, the number of workers decreases. This is why economic integration not only raises the real wage directly (consider the effects of rise of ϕ) but also induces the spatial agglomeration which in turn raises the real wage. Hence, the fertility rate decreases, which results in a decline in the number of workers. This result cannot be obtained in models which consider only natural population change or only social population change.

4.3. The Case of Multi-Region

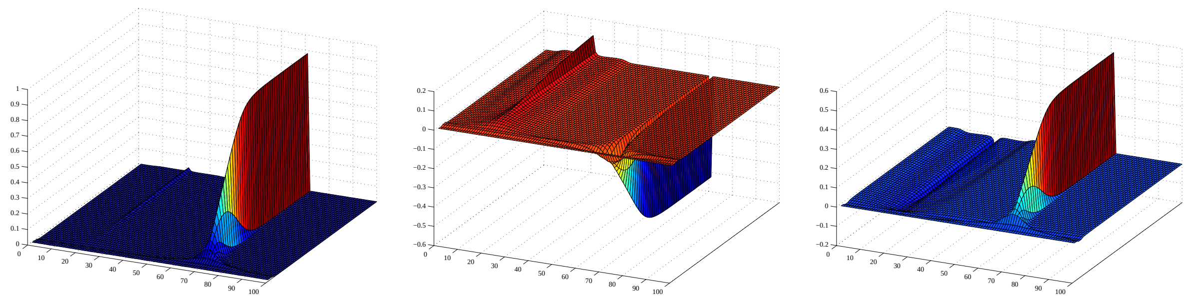
Finally, we examine the multi-region case. If there are many regions, we can consider various geometry of the economy. Here, we focus on the special artificial case known as the *Racetrack Economy* in which each regions are laid out symmetrically around the circumference of a circle.[18] Transportation is possible only along the circumference within the shortest distance. Since we employ iceberg-type transportation costs and regions are located along the circumference at even intervals, the trade freeness between regions i and j becomes

$$\phi_{ij} = \begin{cases} \phi^{|i-j|} & if\ |i-j| \leqq |R|/2 \\ \phi^{|R|-|i-j|} & if\ |i-j| > |R|/2 \end{cases},$$

where $\phi \in (0,1]$ is constant.

In this economy, we can easily confirm that the uniform distribution of workers, called the *Flat Earth* in Fujita et al. (1999), is always a spatial equilibrium. However, the flat earth is not always sustainable; that is, the symmetric spatial equilibrium may turn out to

[18]The racetrack economy is first introduced in NEG by Krugman (1993).



(a) Share of workers (b) Natural increase (c) Social increase

Figure 10: Multi-Region Case

$\sigma = 1.2$, $\sigma_X = 4$, $\alpha = 0.7$, $b = 0.25$, $\phi = 0.95$, $f = 1/3$, $a = 1/3$, $\nu = 0.2$, $|R| = 100$

be unstable. As Figure 10 shows, we start the simulation from an almost flat but randomly deviated distribution of workers.[19] Even though the deviation is very small, the circular causality of agglomeration can break the flat earth: an almost even distribution of workers eventually develops local concentrations of workers. Figure 10(a) shows this process. One hundred regions are arranged along the front axis in numerical order and the share of workers in each region is indicated by the vertical axis. The almost flat earth evolves over time into a very uneven spatial structure in which workers become concentrated in two regions that are positioned opposite to each other on the circumference.

While this result may appear to be the same as that obtained by Fujita et al. (1999), there are some major differences. Figure 10(c) illustrates the social change of each region over time. It shows that workers migrate from small regions to large regions and that the social change of the largest region is extremely positive even after a sufficiently long time. As a result, the region that initially has the largest number of workers tends to be extremely large in the steady state. It has been noted that workers flow from the smaller of two regions in which workers are concentrated. The smaller region has a large share of workers in the steady state because its natural change is highly positive. Figure 10(b) shows the natural change of each region over time. When workers concentrate in one region, the real wage becomes

[19] First we draw L_i randomly from the interval $[0.95,\ 1.05]$. Then we normalize the total number of workers to one.

lower in the opposite region since a larger fraction of consumption must bear transportation costs. This leads to a higher fertility rate and increases the natural change in the region that is positioned opposite to the region with the largest number of workers. Therefore, the two regions in which workers are concentrated have markedly different characteristics and sizes. These results can be obtained only by considering the endogenous fertility rate, which is ignored in Fujita et al. (1999).

5. Conclusion

In this paper, we constructed a model to describe regional population changes in s market economy. Using this model, the effects of economic integration on population change were analyzed.

If workers can migrate among regions, then regional differences in the real wage, the natural population change, and the social population change are become larger with a snowball effect, even though, there are only subtle differences initially. The population concentrates in the region that initially has a larger population share. The region in which the population concentrates has a higher real wage, which results in a lower fertility rate and higher net migration compared to other less-concentrated regions. Thus, in the long run, regions differ in population change and real income. In particular, the difference in the real wage in the long run means that the steady state is not spatial equilibrium, that is, workers have an incentive to change their location. This result differs widely from the usual NEG model and is consistent with the facts we presented in the introduction, which enhances the legitimacy of our model. In addition, we derived a prediction for the population growth path of the whole economy: it resemble a logistic curve in the early phase, but the population decreases in the last phase.

We also showed the following: (i) highly freeness to migrate and trade of goods lead to population concentration, (ii) population concentration leads to a lower fertility rate in highly populated regions, and, as a result, (iii) economic integration decreases the total population. If inter-regional migration is permitted, workers will move to regions where they can earn higher real wages. This increase the populations of regions with higher real wages. Moreover, the existence of transportation costs leads to higher real wages in highly populated regions compared to less-populated regions since a larger fraction of goods must bear transportation costs in the latter case. This circular causality induces a population concentration in a particular region. Specifically, we showed that the more the transportation cost decreases, the more the population is concentrated. On the other hand, higher real wages in highly-populated regions lead to an increase in child-rearing costs and a decrease in the fertility rate. Therefore, increased economic integration leads to a smaller population in the whole economy.

However, in this paper, we dealt only with two overlapping generations, that is, childhood and adulthood. We paid little attention to the composition of the population. In demographic studies, the composition of the population is typically a matter of primary importance, as its structure changes over time just as its size and distribution do. However, for simplicity, we omitted population structure from our analysis. In spite of this limitation, we believe that our analysis identifies new aspects of the relationship between economic integration and population change. We leave the consideration of population structure for future research.

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