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AGGLOMERATION AND GROWTH

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An attempt is made to assess how agglomeration per se contributes to economic growth. A one-factor-two-good innovation model has been used to show how agglomeration of firms accounts for the expansion of innovation (that is, growth rate) through localized externalities. This simple theoretical model shows how agglomeration itself may add extra gains to economic growth independent of the common factors of economic growth that have been controlled for. The contribution of agglomeration to growth is inferred from the difference in innovation rates between regionally concentrated innovation and regionally diverse and symmetric one.

While indisputably helpful to growth at the local level, agglomeration may not induce growth on a larger scale, for example, at the national level or at the global one. Agglomeration may also cause uneven income distribution as it does not uniformly increase real income across regions and may sustain the wage rate gap across regions.

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I. INTRODUCTION

How does spatial agglomeration[1] contribute to economic growth?

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[1] Clustering is synonymous with agglomeration. These two words are interchangeably used in the literature.

Factor mobility,[2] increasing returns,[3] and local externalities[4] have been identified in the literature as most instrumental in establishing the seeming agglomeration-growth nexus. Various types of models show how agglomeration brought about by these factors contributes to economic growth. For example, in Bertola (1993) factor mobility and increasing returns to scale expedite the concentration of industrial activities and cause concurrent economic growth. In Walz (1996), transport costs and factor mobility determine the location of final-goods production and R&D activity. Then the local linkages between R&D activity and final-goods production are formed in that location to induce regional growth.

Among the factors involved in the agglomeration process, however, the presence of localized externalities is deemed to be the most influential factor in establishing the agglomeration-growth nexus. Martin and Ottaviano (1999) relate the influence of location on growth to the extent of R&D spillovers. If R&D spillovers are global in their effect, geography has no influence on growth. On the other hand, if R&D spillovers between industries are local, all R&D activities will locate in the place where the R&D cost is lowest, and geography (R&D concentration) determines the number of firms producing differentiated products and hence, the growth rate. In a similar context, Baldwin and Martin (2004) show how localized technology spillovers make agglomeration conducive to growth. Audretsch and Feldman (2004) emphasize the role of localized technology spillovers in explaining the determinants of innovation and technological change.

[2] Labor mobility explains how different labor productivities between regions or countries cause economic growth through agglomeration. The process that mobile labor induces economic growth through agglomeration is set off by population concentration and increase in wages. Without labor mobility, geographic concentration would not materialize, since the cumulative process of agglomeration would not start.

[3] Increasing returns relates spatial agglomeration to economic growth through the effects of agglomeration on improved resource allocation. The process of agglomeration starts either from the availability of various intermediate goods, which lowers costs of final good production, or from the existence of a large final goods market, which provides a large local market for intermediate goods. The linkage of agglomeration to growth would be influenced by those parameters such as transport costs. See Fujita et al. (1999, Chapters 14, 15).

[4] Local externalities link agglomeration to growth through a “circular causality” in which growth and location decisions are jointly determined. Growth destabilizes the symmetric equilibrium, and causes geographic concentration, which results in real income growth. See Baldwin and Forslid (1999).

The importance of localized externalities (the nature of knowledge spillovers) in shaping the agglomeration-growth nexus is maintained even when production location is mobile across countries. In Baldwin and Forslid (1999), economic integration allows changes in the location of industrial activities across countries. In the absence of knowledge spillovers, industry and/or R&D activities tend to be concentrated in a certain region and in a certain country. While production activities can be dispersed across countries, agglomeration still expedites regional growth through localized learning externalities and through an establishment of an industrial base.[5] With global knowledge spillovers, however, the tendency toward agglomeration is mitigated. A purely trade-cost reducing integration would encourage agglomeration. Yet integration facilitates the exchange of ideas and reduces the possibilities of localized learning externalities as it lowers the cost of trading information. Integration brings into play both mitigating and intensifying forces of agglomeration.[6] Depending on the extent of knowledge spillovers, integration could promote agglomeration or cause dispersion. Again, the strength of agglomeration is inversely related to the extent to which learning externalities are localized.

The apparent relationship between agglomeration and growth has caused few attempts to be made in the literature for assessing the "contribution" of agglomeration itself to growth. Instead, attention has been drawn to related issues such as how agglomeration (which itself is caused by the same factors that lead to growth) changes the pattern of long-run growth, and how the introduction of endogenous growth changes a growth-linked cycle of circular causality.

The existing models invariably demonstrate that agglomeration is pro-growth at the local level. Yet this agglomeration-growth nexus may emerge if both agglomeration and economic growth are brought about by the common factors. So it is not necessarily a causal one.[7] However, with

[5] Without knowledge spillovers, the fast-growing region accumulates capital faster and attracts more labor. This change in factor supply would increase the growth rates gap between the region and the outside world.

[6] Coe and Helpman(1995) show that foreign R&D has beneficial effects on domestic productivity. On the other hand, Branstetter (2001) finds strong evidence of intra-national (local) R&D spillovers, but little evidence of global R&D spillovers.

[7] At the same time, causality might run the opposite direction: growth gives rise to

the respective contribution of these common factors to agglomeration and growth each taken account of, it can be shown that a causal link from agglomeration to growth exists.

This paper is an attempt to assess the influence of agglomeration *per se* on growth. It provides conditions under which agglomeration itself contributes to growth in a one-factor-two-good innovation model. Agglomeration of firms' innovation activity accounts for the expansion of innovation (that is, growth rate) which is contingent on localized externalities.[8] This simple theoretical model shows how agglomeration itself may add extra gains to economic growth independent from the common factors of economic growth that have been controlled for. Given that the agglomeration-growth nexus depends on the nature of localized technological externalities, the contribution of agglomeration proper to growth is inferred from the difference in innovation rates between regionally concentrated innovation and regionally diverse and symmetric one.

This paper also shows that, while indisputably helpful to growth at the local level, agglomeration may not induce growth on a larger scale, for example, at the national level or at the global one. Agglomeration may also cause uneven income distribution as it does not uniformly increase real income across regions.[9] As a result, it may help sustain the wage rate gap across regions.

The rest of the paper is organized as follows. Section II of this paper is devoted to reviewing the related literature. Section III introduces a model and Section IV its equilibrium solutions. Section V provides implications and Section VI some concluding remarks.

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agglomeration and speeds the process of agglomeration. Innovation or cost savings brings about total factor productivity gains, which in turn start the agglomeration process. That is, growth causes agglomeration. One implication of this two-way causal-link is that the distinction between the "dependent" and "independent" variables is not clear-cut in this agglomeration-growth nexus. Yet it is too obvious that there exists a direct link from agglomeration to growth and vice versa.

[8] Agglomeration may alternatively cause economic growth through changes in total factor productivity gains, innovation capacity enhancement (R&D intensity), factor supply increase, and per capita income growth.

[9] In Baldwin and Forslid (1999), however, it is the case that real income and consumption growth rates are identical among regions in either the core-periphery or the symmetric (interior) equilibrium.

II. RELATED LITERATURE

What causes agglomeration of industrial activities in the first place? Several reasons can be given. First, deliberate efforts made to reduce ‘trade costs’ (the penalty of distance) often result in clustering or agglomeration. Scale economies create conditions for spatial agglomeration as they mitigate the burden of trade costs. (Hanson, 2005; Redding and Venables, 2004) Second, clustering may be sought as a means of reducing uncertainty. Clustering reduces uncertainty by making timely delivery of components possible. (Harrigan and Venables, 2004) Third, spatial clustering may emerge as the need for coordination or cooperation arises among vertically or horizontally related sectors. A communication-based model of global production fragmentation belongs to this category. For example, the efforts to foster cooperation (to produce trust) among local producers create spatial clustering. (Schmitz, 1999) Fourth, given an uneven distribution of natural resources across regions, the efforts on the part of economic agents to improve the natural constraints may lead to a perpetual imbalance in the location of economic activities. (Ottaviano and Thisse, 2004)

Once the agglomeration process sets off, an uneven pattern emerges of local specialization and industry formation. Locally uneven distribution of industrial activities comes about out of the interaction of two groups of opposing forces: centrifugal forces that suppress spatial agglomeration and centripetal forces that promote it. Economies from localization generate centripetal forces for agglomeration, while diseconomies from localization centrifugal ones. The relative strength of these two groups of opposing forces determines the pattern of agglomeration. (Barrell and Pain, 1999: p.926)

Proximity constitutes centripetal forces as it reduces costs by creating external economies based on the local availability of skilled labor or scientific knowledge as well as direct links with other firms. (Venables, 1996) Bigger local markets also make agglomeration easier as industries locate themselves close to large markets with a view to exploiting economies of scale. Technology can be part of centrifugal forces. Internal economies of scale at the firm level evolve with technology. Thus, the tendency toward agglomeration may weaken as the minimum efficient scale decreases. National borders could belong to both forces as they may affect industrial structures by facilitating agglomeration in some cases and suppressing it in other cases.[10]

The balance between centripetal and centrifugal forces of agglomeration can be tipped by external forces such as liberalization (or economic integration). Integration may decrease the costs of market entry and hence stimulate agglomeration. Yet further integration may eventually setback agglomeration as factors and goods prices rise to outweigh the gains from agglomeration. Diseconomies of agglomeration emerge with liberalization.[11]

On the other hand, if integration is brought about by reduction in transport (or transaction) costs, it could promote concentrated innovation and production activities. Integration strengthens the centripetal forces toward agglomeration. (Walz, 1996: p.689) High transaction costs protect the developers of differentiated goods in the smaller market from outside competition. Outside competition is thwarted by a smaller number of local rivals developing new varieties for the local market. As production activities tend to be concentrated, specialization increases and intra-industry trade declines. Yet, as Baldwin and Forslid (1999) maintain, economic integration could also lower the cost of trading information. In that case, integration decreases the importance of localized externalities and so do the centripetal forces toward agglomeration.

Information technology is another force that could tip the balance between centripetal and centrifugal forces of agglomeration. Jones (2000) maintains that increasing returns in the provision of services link promotes a spread of industrial activities as it reduces the costs of communication. Improvements in the costs of providing service links will mitigate some of the forces that encourage agglomeration.[12]

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[10] For example, De Simone (2005) compares the relative contributions of agglomeration forces (geography) and dispersion forces (fragmentation of production) to show how they reshape the industrial localization across Central Eastern European Countries.

[11] When most of intermediate inputs used in the production process is imported from abroad and most of final output assembled with intermediate inputs is exported to foreign markets, the need for product linkages becomes less important. (Fujita et al. 1999, p.330)

[12] Since the marginal costs of production are an increasing function of transport costs and a decreasing function of fragmentation, the greatest source of increasing returns in production comes from the costs embodied in the service links such as transportation, communication, coordination, and service link costs. These costs rise as the production process becomes more fragmented. Yet

III. MODEL

In order to see how much agglomeration contributes to economic growth, it is necessary to abstract the influence of those factors that commonly set forth both agglomeration and growth on forming a strong correlation between agglomeration and growth. The usual assumptions about the common factors are made in the following model: factor mobility, increasing returns, and local externalities. With these common factors, contribution that agglomeration *per se* makes to economic growth can be inferred from the differences in growth rates of regionally concentrated innovation and diversified one.

The model used is a one-factor-two-good-two-region innovation model. It has its origin in the hysteresis model of Grossman and Helpman (1991, Chapter 8) and the core-periphery model of Fujita, Krugman, and Venables (1999, Chapter 5).

In the model, the representative consumer in region i maximizes utility over an infinite time horizon, which can be expressed as a maximization problem

$$\max U_t^i = \int_t^\infty e^{-\rho(\tau-t)}\left[\delta \ln C_Y^i(\tau) + (1-\delta)\ln C_Z^i(\tau)\right] d\tau \left(0<\delta<1\right) \quad (1)$$

subject to an intertemporal budget constraint

$$\int_t^\infty e^{-\left[R(\tau)-R(t)\right]}\left[C_Y^i + p_Z(\tau)C_Z^i(\tau)\right] d\tau < \int_t^\infty e^{-\left[R(\tau)-R(t)\right]} w^i(\tau)\, d\tau$$

where C_Z^i represents the consumption of the traditional good Z, C_Y^i that of an index of differentiated goods Y coming from two regions (*A* and *B*), δ is the consumption share of Y, and $R(\tau) \equiv \int_0^\tau r(s)ds$.[13]

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the information-and-communication technology revolution and deregulation on service activities (such as insurance, banking, and transportation) have all encouraged greater degrees of international fragmentation of production. Fragmentation feeds on technological progress and prompts a more rapid adoption of newly developed technologies. Consequently, the various phases of production are now spatially separated and undertaken at locations where costs are lowest. (Jones, 2000)

[13] The time variable will be suppressed whenever no confusion.

Labor is the only factor of production and is mobile between the two regions. One unit of labor produces one unit of Z or one unit of a variety of Y. Labor also can be put into expanding the set of producible varieties.

Z is manufactured in the region where the production cost is the lowest. So, if w^i and w^j are wage rates in regions i and j respectively and $w^i > w^j$, then $Z^i = 0$. Shipping Z is assumed to cost nothing.[14] Let $s_z^i = \frac{Z^i}{Z^A + Z^B}$ denote the share of region i in the production of Z.

If prices are normalized so that consumption expenditure is equal to one ($E(t) = 1$) for all t, then $r = \rho$ at every moment in time. The representative consumer maximizes the utility function (1) by allocating a fraction $(1-\delta)$ of its spending to the traditional good so that $p_Z\left(Z^A + Z^B\right) = (1-\delta)$ or $p_Z Z^i = (1-\delta)s_Z^i$.

The consumption of Z in region i can be alternatively expressed as

$$Z^i = \frac{(1-\delta)s_Z^i}{p_Z} = \frac{(1-\delta)s_Z^i}{\min\left(w^A, w^B\right)} \tag{2}$$

The consumption index of Y is expressed as $C_Y^i = \left[\sum_{i,j=A,B}\sum_{k_i=1}\left(x_j^{ik_j}/T_j^i\right)^{\frac{1-\sigma}{\sigma}}\right]^{\frac{\sigma}{1-\sigma}}$ where $x_j^{ik_j}$ is the quantity of a variety k_j produced in region j, but consumed in region i. The elasticity of substitution is greater than one ($\sigma > 1$). Transporting Y from region j to region i costs T_j^i, which equals 1 if $i = j$, but T if $i \neq j$.

A profit-maximizing producer of Y in region i maximizes operating profits at time t

$$\max\ \pi_i = p^i x_i^{ik_i} - w^i x_i^{ik_i}$$

[14] This is an unrealistic but convenient assumption. Grossman and Helpman (1991, Chapter 8)

The producer sets the price at a markup over the unit production cost, where

$$p^i = \frac{\sigma w^i}{(\sigma - 1)} \tag{3}$$

Then operating profits are expressed as

$$\pi^i = \frac{\delta s^i}{\sigma n_i} \tag{4}$$

where s^i is the share of total spending on Y produced in region i.[15] By assumption $s^i = s_A^i + s_B^i$, where s_j^i denotes the share of region j's spending on Y produced in region i. $s_A^i = \frac{n^i (p^i)^{1-\sigma}}{n^i (p^i)^{1-\sigma} + n^j (p^j T)^{1-\sigma}}$ and $s_B^i = \frac{n^i (p^i T)^{1-\sigma}}{n^i (p^i T)^{1-\sigma} + n^j (p^j)^{1-\sigma}}$, where n^i and n^j denote the number of Y produced in region i and j. Similarly, $s^j = s_A^j + s_B^j$, where $s_A^j = \frac{n^j (p^j T)^{1-\sigma}}{n^i (p^i)^{1-\sigma} + n^j (p^j T)^{1-\sigma}}$ and $s_B^j = \frac{n^j (p^j)^{1-\sigma}}{n^i (p^i T)^{1-\sigma} + n^j (p^j)^{1-\sigma}}$. The goods sold outside the region in which they are produced include in their prices transport costs $\left(T_j^i = T > 1\right)$ between the two regions.

Product market equilibrium requires that the total value of Y produced equals its consumption spending.

$$p^i n^i x^i = \delta s^i \tag{5}$$

Each new variety of Y is developed as a result of innovation.

[15] In each region, all varieties would have the same price and the amount of quantities produced would be the same for every variety. Yet across regions the consumption shares would be different if the number of innovations (or varieties produced) in each region is different.

Innovation itself generates *local* knowledge spillovers. Each region accumulates knowledge capital in proportion to its own research activity $K_n^i = n^i$. Due to this specificity of knowledge capital along with the local nature of externalities, $\frac{1}{n^i}$ units of labor are needed in region i to develop each new variety.[16] Entry into innovation activity is free so that the value of a firm producing a variety of Y is no greater than the cost of developing a new product. The value of a firm at time equals the present discounted value of its profit stream at time t.

$$v(t) = \int_t^\infty e^{-[R(\tau)-R(t)]}\pi(\tau)d\tau$$

With new products, the value of the representative high-technology firm in region i[17] v^i can be expressed as

$$v^i = \frac{w^i}{n^i} \tag{6}$$

The no-arbitrage condition for v^i stipulates

$$\pi^i + \dot{v}^i = \rho v^i \tag{7}$$

where ρ is the interest rate.

Finally, factor market equilibrium requires that labor demand equals labor supply.

$$\frac{\dot{n}^i}{n^i} + n^i x^i + Z^i = L^i \tag{8}$$

Substituting $g^i \equiv \frac{\dot{n}^i}{n^i}$ into equation (8) yields

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[16] This assumption is crucial to the following analysis. In both the static and dynamic models, relaxing the locality of the spillover effects eliminates any tendency for the increasing returns activity to concentrate in a single location. Grossman and Helpman (1991, p.213)

[17] If wages are equalized across regions, prices and sales of all varieties are equal, and so are the values of high-technology firms. Grossman and Helpman (1991, p.209)

$$g^i + \frac{(\sigma-1)\delta s^i}{\sigma w^i} + \frac{(1-\delta)s_Z^i}{w^i} = L^i \qquad (8')$$

where

$$s^i = \frac{2n^i n^i p_i^{1-\sigma} p_i^{1-\sigma} T^{1-\sigma} + n^i n^j p_i^{1-\sigma} p_j^{1-\sigma}\left(1+T^{2(1-\sigma)}\right)}{2\left(n^i p_i^{1-\sigma} + n^j p_j^{1-\sigma} T^{1-\sigma}\right)\left(n^i p_i^{1-\sigma} T^{1-\sigma} + n^j p_j^{1-\sigma}\right)},$$

$$s^j = \frac{2n^j n^j p_j^{1-\sigma} p_j^{1-\sigma} T^{1-\sigma} + n^i n^j p_i^{1-\sigma} p_j^{1-\sigma}\left(1+T^{2(1-\sigma)}\right)}{2\left(n^i p_i^{1-\sigma} + n^j p_j^{1-\sigma} T^{1-\sigma}\right)\left(n^i p_i^{1-\sigma} T^{1-\sigma} + n^j p_j^{1-\sigma}\right)}.$$

VI. EQUILIBRIUM SOLUTIONS

Solutions of the model that involve the steady-state values of w^A, w^B, g^A, g^B, s^A, s^B, s_Z^A, and s_Z^B are summarized in the following lemmas.[18] There are four types of steady states, the two of which are asymmetric but stable, and the other two of which are symmetric but unstable. The equilibrium dynamics involve the time paths of wage and market share equations.

Lemma 1 (Steady States: Grossman and Helpman, 1991)

(1-A) **Concentrated R&D with equal wages** $\left(w^A = w^B = w\right)$:

In the steady state, $g^B = 0$, $s^A = 1$, and $s^B = 0$. The steady-state values of $w^A = w^B = w$, g^A, s_Z^A, and s_Z^B satisfy the following condition.

$$\frac{\delta}{\sigma w} = \rho + g^A \qquad \text{(9-A)}$$

$$g^A + \frac{(\sigma-1)\delta}{\sigma w} + \frac{s_Z^A(1-\delta)}{w} = L^A \qquad \text{(10-A)}$$

[18] Agglomeration is assumed to occur in region *A*. Then R&D is carried out only in region *A* and region *A* alone innovates. A completely analogous line of reasoning can be applied to the case in which region *B* alone innovates.

$$\frac{s_Z^B(1-\delta)}{w} = L^B \tag{11-A}$$

$$s_Z^A + s_Z^B = 1$$

(1-B) **Concentrated R&D with unequal wages** $\left(w^A > w^B\right)$:

In the steady state, $g^B = 0$, $s^A = 1$, $s^B = 0$, $s_Z^A = 0$, and $s_Z^B = 1$. The steady-state values of w^A, w^B, and g^A satisfy the following condition.

$$\frac{\delta}{\sigma w^A} = \rho + g^A \tag{9-A'}$$

$$g^A + \frac{(\sigma-1)\delta}{\sigma w^A} = L^A \tag{10-A'}$$

$$\frac{(1-\delta)}{w^B} = L^B \tag{11-A'}$$

(2-A) **Diversified R&D with equal wages** $\left(w^A = w^B = w\right)$:[19]

In the steady state, w^A, w^B, $g^A = g^B = g$, s^A, s^B, s_Z^A, and s_Z^B satisfy the following condition.

$$\frac{\delta s^A}{\sigma w} = \rho + g \tag{9-B-1}$$

$$\frac{\delta s^B}{\sigma w} = \rho + g \tag{9-B-2}$$

$$g + \frac{(\sigma-1)\delta s^A}{\sigma w} + \frac{s_Z^A(1-\delta)}{w} = L^A \tag{10-B-1}$$

$$g + \frac{(\sigma-1)\delta s^B}{\sigma w} + \frac{s_Z^B(1-\delta)}{w} = L^B \tag{10-B-2}$$

$$s^A = s^B = \frac{1}{2}$$

$$s_Z^A + s_Z^B = 1$$

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[19] When both regions engage in innovation, their growth rates cannot be different. The market share of the region whose growth rate is the smaller shrinks to zero, which contradicts the no-arbitrage condition. See Grossman and Helpman (1991, p.217) and Lemma 2 below.

(2-B) **Diversified R&D with unequal wages** $\left(w^A > w^B\right)$:

In the steady state, $s_Z^A = 0$, and $s_Z^B = 1$. The steady-state values of w^A, w^B, $g^A = g^B = g$, s^A, and s^B satisfy the following condition.

$$\frac{\delta s^A}{\sigma w^A} = \rho + g \qquad \text{(9-B'-1)}$$

$$\frac{\delta s^B}{\sigma w^B} = \rho + g \qquad \text{(9-B'-2)}$$

$$g + \frac{(\sigma - 1)\delta s^A}{\sigma w^A} = L^A \qquad \text{(10-B'-1)}$$

$$g + \frac{(\sigma - 1)\delta s^B}{\sigma w^B} + \frac{(1-\delta)}{w^B} = L^B \qquad \text{(10-B'-2)}$$

$$s^A + s^B = 1$$

(***Proof***) See Appendix. □

Lemma 1 (1-A) relates to the case in which R&D is concentrated in region *A*, but traditional goods are produced in both regions (region *A* and region *B*). In this case, the steady state is characterized by positive innovation (growth) and positive differentiated-goods production in region *A*, but no growth and no differentiated-goods production in region *B*. Lemma 1 (1-B) is about the case in which R&D is concentrated in region A and traditional goods are produced only in region *B* ($w^A > w^B$). In this case, the steady state is characterized by positive innovation (growth) and positive differentiated-goods production in region *A* but no growth and no differentiated-goods production in region *B*.

Lemma 1 (2-A) relates to the case in which both R&D activity and traditional-goods production are carried out in both regions (region A and region B). In this case, the steady state is characterized by equal innovation (growth) rates and equal differentiated-good production-shares across regions. Lemma 1 (2-B) is about the case in which R&D is carried out in both regions (region A and region B), but traditional goods are produced only in region *B* ($w^A > w^B$). In this case, the steady state is characterized by equal innovation (growth) rates and unequal differentiated-goods production-shares across regions.

Lemma 2 (Dynamics: Grossman and Helpman, 1991)

(1-A) **Concentrated R&D with equal wages** $\left(w^A = w^B = w\right)$ **:**
The dynamic paths of wage rates are expressed as

$$\frac{\dot{w}}{w} = \left\{ \bar{L} - \frac{(1-\delta)\sigma + (\sigma - 1)\delta}{\sigma w} \right\} + \rho - \frac{\delta s^A}{\sigma w} \tag{12-A}$$

(1-B) **Concentrated R&D with unequal wages** $\left(w^A > w^B\right)$:

The dynamic paths of wage rates evolve as

$$\frac{\dot{w}^A}{w^A} = L^A + \rho - \frac{\delta s^A}{w^A} \tag{12-A'-1}$$

$$\frac{\dot{w}^B}{w^B} = \rho \tag{12-A'-2}$$

(1-C) **Concentrated R&D and the dynamic path of the market shares**:

The path of region A's differentiated-goods market-share can be expressed as[20]

$$\frac{\dot{s}^A}{s^A} = s^A\left(1 - s^A\right)\left(g_A^* - g_B^*\right) \tag{13-A}$$

(2-A) **Diversified R&D with equal wages** $\left(w^A = w^B = w\right)$:
The dynamic paths of wage rates are obtained as

$$\frac{\dot{w}}{w} = \frac{1}{2}\left\{ \bar{L} - \frac{(1-\delta)\sigma + (\sigma - 1)\delta}{\sigma w} \right\} + \rho - \frac{1}{2}\frac{\delta}{\sigma w} \tag{12-B}$$

[20] The equality of wages across regions does not make difference in the discussion of the movement of s^i.

(2-B) **Diversified R&D with unequal wages** $\left(w^A > w^B\right)$:
The dynamic paths of wage rates are expressed as

$$\frac{\dot{w}^A}{w^A} = L^A + \rho - \frac{\delta s^A}{w^A} \tag{12-B'-1}$$

$$\frac{\dot{w}^B}{w^B} = \left\{L^B - \frac{(1-\delta)}{w^B}\right\} + \rho - \frac{\delta s^B}{w^B} \tag{12-B'-2}$$

(2-C) **Diversified R&D and the dynamic path of the market shares**:
The path of region A's differentiated-goods market-share can be expressed as

$$\frac{\dot{s}^A}{s^A} = s^A\left(1 - s^A\right)\left(\tilde{g}_A^* - \tilde{g}_B^*\right) \tag{13-B}$$

(***Proof***) See Appendix. □

Lemma 2 (1-A) relates to the case in which R&D activity is concentrated in region A, but traditional goods are produced in both regions (region A and region B). Lemma 2 (1-B) is about the case in which R&D activity is concentrated in region A, but traditional goods are produced only in region B ($w^A > w^B$).

Lemma 2 (1-C) states that, if the market share of region A is initially not zero and the initial stocks of differentiated products in both regions are not much different, the share of region A's market share is always expanding until it reaches one. Since innovation occurs only in region A, the growth rate in region A is greater than that in region B (i.e. $g_A^* > g_B^*$). Thus, unless s^A is at the extremes, the time derivative of region A's market share is always positive (i.e. $\dot{s}^A > 0$). Therefore the market share s^A increases until it reaches one.

Once set in, interregional differences in the innovation rates persist. A difference in growth rates resulting from uneven innovation across regions leads to a permanent gap in the number of differentiated goods produced in two regions. The region in which R&D activity is concentrated produces an ever increasing share of differentiated-goods.

Lemma 2 (2-A) relates to the case in which both R&D activity and traditional-goods production are carried out in both regions (region *A* and region *B*). Lemma 2 (2-B) is about the case in which R&D activity is carried out in both regions (region *A* and region *B*), but traditional goods are produced only in region *B* ($w^A > w^B$).

Lemma 2 (2-C) states that, if both initial stocks of differentiated products and wage rates are identical, the growth rates in both regions are identical too (i.e. $\tilde{g}_A^* = \tilde{g}_B^*$). Then the market share s^A becomes stationary. Otherwise, the sign of $\dot{s}^A$ is indeterminate. The market share s^A may increase until it reaches one or decrease until it reaches zero. The direction of s^A movement may depend on the values of the parameters such as prices or wages.

Dynamics does not rule out the possibility of unequal wages, prices, and outputs across regions. Results conditioned on the equal-wage trajectories are different from those consistent with the unequal-wage trajectories, as they are shown in Lemma 2. With unequal wage rates, the differences in wage rates across regions could increase and persist in the long run.[21]

V. IMPLICATIONS

Agglomeration facilitates knowledge accumulation whose contribution to economic growth can be assessed as the difference between the growth rate of concentrated innovation and that of diversified one. The conditions under which agglomeration *per se* contributes to economic growth are summarized in the following corollaries to the solutions of the innovation model.

For simplicity of notation, let the aggregate rate of innovation (growth) be expressed as $g \equiv \frac{\dot{n}}{n} = \sum_i s^i g^i$ where $g^i \equiv \frac{\dot{n}^i}{n^i}$ and s^i is the share of differentiated-goods production in region i. Define the difference in the growth rates between concentrated and symmetric innovations as $\Delta g = g_1 - g_2$ where subscript 1 indicates concentrated innovation and subscript 2 diversified innovation, where $g_1 = s_1^A g_1^A + s_1^B g_1^B$ and

[21] Grossman and Helpman (1991, p.221-229)

$g_2 = s_2^A g_2^A + s_2^B g_2^B$. Also, define the wage gap between concentrated and symmetric innovations as $\Delta w = w_1 - w_2$ where $w_1 = s_1^A w_1^A + s_1^B w_1^B$, $w_2 = s_2^A w_2^A + s_2^B w_2^B$, and $1 = s_i^A + s_i^B$. Since wages do not have to be equalized across regions even with factor mobility, two cases are considered for each corollary.

Corollary 1 (Agglomeration and Growth)

(1) **Equal wages** $\left(w^A = w^B = w\right)$:

(1-A) The difference in the growth rates between concentrated and symmetric innovations is derived as

$$\Delta g = \frac{\delta}{2\sigma}\bar{L} > 0 \tag{14}$$

(1-B) The gap in the wage rates in both regions between concentrated and symmetric innovations is expressed as

$$\Delta w = \frac{\rho}{\left(\bar{L}+\rho\right)\left(\bar{L}+2\rho\right)} \tag{15}$$

(***Proof***) From Lemma 1 (1-A), concentrated equilibrium growth and wage rates can be derived as $g_1^A = \frac{\delta}{\sigma}\bar{L} + \frac{\left(\delta-\sigma\right)}{\sigma}\rho$, and $w_1^A = w_1^B = \frac{1}{\left(\bar{L}+\rho\right)}$. From Lemma 1 (2-A), symmetric equilibrium growth and wage rates can be derived as $g_2^A = g_2^B = \frac{\delta}{2\sigma}\bar{L} + \frac{\left(\delta-\sigma\right)}{\sigma}\rho$, $w_2^A = w_2^B = \frac{1}{\left(\bar{L}+2\rho\right)}$. Then it can be shown that $\Delta g = \frac{\delta}{2\sigma}\bar{L} > 0$ and $\Delta w = \frac{\rho}{\left(\bar{L}+\rho\right)\left(\bar{L}+2\rho\right)}$. □

(2) **Unequal wages** $\left(w^A > w^B\right)$: Suppose $L_B > L_A$ and

$\frac{\delta}{1-\delta} > \frac{L_A+\rho}{L_B}$.[22]

(2-A) The difference in the growth rates between concentrated and symmetric innovations is derived as

$$\Delta g = 0 \tag{14'}$$

(2-B) The gap in the wage rates in each region between concentrated and symmetric innovations is expressed as

$$\Delta w_A = \frac{1-\delta}{L_B - L_A} \tag{15'-1}$$

$$\Delta w_B = \frac{-(1-\delta)L_A}{(L_B - L_A)L_B} \tag{15'-2}$$

(***Proof***) From Lemma 1 (1-B), concentrated equilibrium growth and wage rates can be derived as $g_1^A = \frac{L_A + (1-\sigma)\rho}{\sigma}$, $w_1^A = \frac{\delta}{L_A+\rho}$, and $w_1^B = \frac{1-\delta}{L_B}$. From Lemma 1 (2-B), symmetric equilibrium growth and wage rates can be derived as $g_2^A = g_2^B = \frac{L_A + (1-\sigma)\rho}{\sigma}$, $w_2^A = \frac{\delta(L_B+\rho)-(L_A+\rho)}{(L_B - L_A)(L_A+\rho)}$, and $w_2^B = \frac{1-\delta}{L_B - L_A}$. Since $\Delta g = g_1 - g_2$ and $\Delta w = w_1 - w_2$, it can be shown that $\Delta g = 0$, $\Delta w_A = \frac{1-\delta}{L_B - L_A}$, and

[22] These are two necessary conditions for symmetric innovations to be feasible when wages are not equalized across regions. First, it should be satisfied that $L_B > L_A$. Otherwise, region *B* cannot meet the labor demand for R&D activity and production of both differentiated goods and traditional goods. Second, for unequal wages to be maintained continuously throughout the agglomeration process $(w^A > w^B)$, it should be satisfied that $\frac{\delta}{1-\delta} > \frac{L_A+\rho}{L_B}$ and $\frac{\delta}{2-\delta} > \frac{L_A+\rho}{L_B+\rho}$. However, if the first inequality holds, the second inequality holds, too. So the second condition is redundant.

$$\Delta w_B = \frac{-\left(1-\delta\right)L_A}{\left(L_B - L_A\right)L_B}. \square$$

When wages are equal and traditional goods are produced in both regions, concentration of R&D activity in a particular region contributes to growth as opposed to symmetric R&D activity across regions. When wage rates are not equalized across regions so that only one region produces traditional goods, however, concentration of R&D activity in the high-wage region does not contribute to growth.

In the case of equal wages $\left(w^A = w^B\right)$, diversified R&D generates an additional demand for labor in differentiated-goods production in region *B*, which does not exist when R&D activity is concentrated in region *B*. As the amount of labor employed in the production of differentiated-goods in region *B* increases, labor put into R&D activity decreases in comparison with concentrated R&D and so does the innovation rate. Consequently, the overall innovation rate is lower with diversified innovation than with concentrated innovation.

The extent to which agglomeration contributes to growth depends on the share of differentiated goods in consumption expenditure, the elasticity of substitution among the differentiated goods, and the size of labor supply. First, the growth effect increases with the increase in the share of differentiated goods in consumption. If the consumption share of differentiated goods increases, the total value of differentiated goods increases so that the potential gains from agglomeration increases. As agglomeration progresses, the contribution of agglomeration to growth increases. Second, the growth effect decreases if the substitution possibility increases among the rival differentiated goods. With an increase in the substitution possibility, the profits of each variety decrease. So does the incentive for developing a new variety and the tendency toward agglomeration. Third, the larger is the size of the market (approximated by labor supply), the growth effect gets larger as access to bigger markets increases the benefits of agglomeration.

If factor prices are not equalized across regions $\left(w^A > w^B\right)$, agglomeration does not contribute to economic growth in a sense that the innovation rates of concentrated and diversified innovations are not different from each other. When wage rates are higher in region *A*, traditional goods are not produced in region *A*. With R&D concentrated in region *A*, the extent of innovation is determined by the wage rate (and the amount of labor supply) in region *A*. With R&D diversified across regions, region *A* still can put the same amount of labor input into R&D activity as when it alone innovates since it does not produce traditional-goods. At the same time, the demand for labor to be put into R&D activity emerges in region *B* and the demand for labor in differentiated-goods production also emerges there. This new demand for labor in differentiated-goods production may be suspected to reduce the amount of labor put into R&D activity in region *B* as in the case of equal wages. But it may not. Since region *B*'s share of differentiated-goods production is less than half (as opposed to half in the case of equal wages), region *B* can put as large an amount of labor as region *A* into R&D activity besides labor put aside for the production of traditional-goods. Factor market equilibrium requires a change in the wage rate in region *B*. The wage rate in region *B* adjusts up to the point where the amount of labor employed in R&D activity is the same as that in region *A*. As the amount of labor employed in each region with diversified innovation is equal to that of concentrated innovation, the net gain in the innovation rate in each region approaches zero.

What happens to wages? A self-reinforcing advantage in differentiated-goods production enables one region to pay higher wages than the other region. Wages are a decreasing function of interest rates and labor supply. From the no-arbitrage condition (7), a higher interest rate should be matched by a lower profit stream to the producer of a typical variety. Other things being equal, a lower firm value implies lower wages. At the same time, wages are inversely related to labor supply. The larger the labor supply, the lower is the wage rate.

With initially equal wages across regions, concentration of R&D activity in region *A* causes a net increase in the wage rates in both regions. Speeds of innovation in the core when R&D activity is concentrated there is greater than those when R&D activity is evenly distributed across regions. The innovation rates of diversified R&D are less than those of concentrated R&D. The demand for labor in the innovation sector increases faster in the case of concentrated innovation. With agglomeration, therefore, the wage gap widens. This wage gap depends on the initial interest rates and labor supply. The higher the initial interest rate rises, the bigger is the wage increase in the wake of agglomeration. The wage gap gets smaller with a larger labor supply.

With initially unequal wages, concentration of R&D activity in region *A* causes an even larger increase in the wage rates in the higher wage region. The demand for labor in the higher wage region increases more when R&D activity is concentrated in the higher wage region (region *A*) than when R&D activity is carried out in both regions. On the other hand, concentration of R&D activity in region *A* causes a decrease in the wage rates in the lower wage region. When R&D activity is concentrated in the higher wage region, the demand for labor in the lower wage region decreases compared to when R&D activity is carried out in both regions.[23]

How does agglomeration (interregional asymmetry in innovation activity) arise in the present model?[24] Innovation activity which is essential to the production of differentiated-goods is costly to transfer across regions due to the local nature of spillover effects. It is profitable to concentrate innovation activity where the average cost of R&D activity is lowest, which in turn depends on the share of differentiated-goods production. Agglomeration occurs where the share of differentiated-goods production is greatest. Consequently, even the perfect mobility of skilled workers between regions does not necessarily induce equal growth and innovations. Instead, linkages between researchers and differentiated-goods producers would create a core-periphery setting, in which all differentiated-goods producers and innovators are concentrated in one region. If more innovations are carried out in the core, then a larger share of differentiated-goods relying on these innovations would be produced there, too, in order to save transaction (transport) costs. This, in turn, would induce the developers of differentiated-goods to locate their R&D activity in the core as well. A cumulative process would arise and lead to localized growth with innovation and concentrated production activities

[23] One implication of this result is that concentrated R&D increases the wage gap between the regions when initial wages are unequal across regions.

[24] A geography model would help answer this question. A typical example can be found in Walz (1996, p.674), which is summarized in the following.

in the core.

In this core-periphery setting, the core emerges where the share of differentiated-goods production is greatest. The production share is in turn a function of the number of initial differentiated-goods produced in each region and the transport costs. This relationship is summarized in the following corollary.

Corollary 2 (Agglomeration and the Emergence of a Core-Periphery Pattern)

(1) **Equal wages** $\left(w^A = w^B = w\right)$: When both regions (*A* and *B*) produce traditional-goods, the relative shares of differentiated-goods production, the ratio of $n^A x^A$ to $n^B x^B$, can be expressed as a function of the ratio of n^A to n^B, and transport costs T.

$$\frac{n^A x^A}{n^B x^B} = \frac{2\left(\frac{n^A}{n^B}\right)^2 T^{1-\sigma} + \left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}{2T^{1-\sigma} + \left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)} \tag{16}$$

(***Proof***) From equation (5), $p^i = \frac{\delta s^i}{n^i x^i}$. From equation (3), $p^i = \frac{\sigma w^i}{(\sigma - 1)}$.

So wage can be expressed as $w^i = \left(\frac{\sigma - 1}{\sigma}\right)\frac{\delta s^i}{x^i n^i}$. Replacing s^i with its equilibrium value yields $w^i = \left(\frac{\sigma}{\sigma - 1}\right)\left(\frac{\delta}{x^i}\right)\left\{\frac{2p^i n^i p^i T^{1-\sigma} + p^i n^j p^j \left(1+T^{2(1-\sigma)}\right)}{2\left(n^i p^i T^{1-\sigma} + n^j p^j\right)\left(n^i p^i + n^j p^j T^{1-\sigma}\right)}\right\}$ for $i = A, B$.

Dividing the wage equation for region i by that for region j yields $\frac{w^A}{w^B} = \left(\frac{x^B}{x^A}\right)\left\{\frac{2p^A n^A p^A T^{1-\sigma} + p^A n^B p^B \left(1+T^{2(1-\sigma)}\right)}{2p^B n^B p^B T^{1-\sigma} + p^A n^A p^B \left(1+T^{2(1-\sigma)}\right)}\right\}$, which can be simplified as $\frac{w^A}{w^B}=\left(\frac{x^B}{x^A}\right)\left\{\frac{2\left(\frac{n^A}{n^B}\right)\left(\frac{p^A}{p^B}\right)T^{1-\sigma}+\left(1+T^{2(1-\sigma)}\right)}{2\left(\frac{p^B}{p^A}\right)T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}\right\}$. Substituting $\frac{p^A}{p^B}=\frac{w^A}{w^B}=1$ into the wage ratio equation and collecting terms yields $\frac{x^A}{x^B}=\frac{2\left(\frac{n^A}{n^B}\right)T^{1-\sigma}+\left(1+T^{2(1-\sigma)}\right)}{2T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}$. Multiplying both sides of the ratio of x^A to x^B with $\left(\frac{n^A}{n^B}\right)$ yields (16). □

(2) **Unequal wages** $\left(w^A > w^B\right)$: When only region B produces traditional-goods, the ratio of $n^A x^A$ to $n^B x^B$ can be expressed as an implicit function of transport costs T and the initial vales of n^A and n^B.

$$\frac{n^A x^A}{n^B x^B} > \frac{2\left(\frac{n^A}{n^B}\right)^2 T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}{2T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)} \tag{17}$$

(***Proof***) Substituting $\frac{w^A}{w^B}$ for $\frac{p^A}{p^B}$ in $\frac{w^A}{w^B}=\left(\frac{x^B}{x^A}\right)\left\{\frac{2\left(\frac{n^A}{n^B}\right)\left(\frac{p^A}{p^B}\right)T^{1-\sigma}+\left(1+T^{2(1-\sigma)}\right)}{2\left(\frac{p^B}{p^A}\right)T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}\right\}$ and collecting terms yields $\frac{w^A}{w^B}=\frac{2T^{1-\sigma}-\left(\frac{x^B}{x^A}\right)\left(1+T^{2(1-\sigma)}\right)}{2\left(\frac{x^B}{x^A}\right)\left(\frac{n^A}{n^B}\right)T^{1-\sigma}-\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}$.

The numerator and the denominator of the relative wage rate should have the same signs. Otherwise, the wage ratio is negative. In fact, each of them has a negative sign. That is, $\frac{x^A}{x^B} < \frac{1+T^{2(1-\sigma)}}{2T^{1-\sigma}}$ and $\frac{x^B}{x^A} < \frac{1+T^{2(1-\sigma)}}{2T^{1-\sigma}}$. These conditions are satisfied for all values of $T > 1$ and $\sigma > 1$ since $1 < \left(\frac{1+T^{2(1-\sigma)}}{2T^{1-\sigma}}\right)^2$.

As $w^A > w^B$, it is necessary for the relative wage ratio to be feasible that $2T^{1-\sigma} + \left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right) > 2\left(\frac{x^B}{x^A}\right)\left(\frac{n^A}{n^B}\right)T^{1-\sigma} + \left(\frac{x^B}{x^A}\right)\left(1+T^{2(1-\sigma)}\right)$.

That is, it should be the case that $\frac{x^A}{x^B} > \frac{2\left(\frac{n^A}{n^B}\right)T^{1-\sigma} + \left(1+T^{2(1-\sigma)}\right)}{2T^{1-\sigma} + \left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}$.

At the same time, $\frac{2\left(\frac{n^A}{n^B}\right)T^{1-\sigma} + \left(1+T^{2(1-\sigma)}\right)}{2T^{1-\sigma} + \left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)} < \frac{1+T^{2(1-\sigma)}}{2T^{1-\sigma}}$ since $\left(\frac{n^A}{n^B}\right)\left(1-T^{2(1-\sigma)}\right)^2 > 0$. So the range of $\frac{x^A}{x^B}$ is not empty.

Multiplying both sides of the ratio of x^A to x^B with $\left(\frac{n^A}{n^B}\right)$ yields (17). □

It can be inferred from equations (16) and (17) that with equal wages agglomeration occurs in region *A* if its initial stock of knowledge capital is greater than region *B*'s. For agglomeration to occur in region *A*, the share of region *A*'s differentiated-goods should be greater than that of region *B*'s. For the ratio of region *A*'s differentiated-goods share to region B's to be greater than one, it should be that $\frac{n^A x^A}{n^B x^B} =$

$$\frac{2\left(\frac{n^A}{n^B}\right)^2 T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}{2T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}>1 \quad \text{or} \quad 2T^{1-\sigma}\left\{\left(\frac{n^A}{n^B}\right)^2-1\right\}>0 \text{ , which}$$

can be satisfied if $\left(\frac{n^A}{n^B}+1\right)\left(\frac{n^A}{n^B}-1\right)>0$. That is, if n^A is greater than n^B, region *A*'s production share is greater than region *B*'s. Then agglomeration occurs in region *A*.

With equal wages in both regions, a core-periphery setting does not emerge by itself. Instead, a symmetric equilibrium is expected for equal-sized regions. In a symmetric equilibrium with equal wages, the market shares of differentiated-goods are equal. However, this symmetric equilibrium is unstable. A small shock would cause the production share of differentiated-goods to deviate from the symmetric steady state level toward one of the other two concentrated asymmetric equilibria (i.e. concentration either in region A or in region B).[25] Which region is chosen depends on the initial innovation rates.

With unequal wages, however, it is still possible that agglomeration occurs in region *A* even if its initial stock of knowledge capital (the number of differentiated-goods produced) is smaller than region *B*'s. The ratio of region *A*'s differentiated-goods share to region *B*'s $\frac{n^A x^A}{n^B x^B}$ is always greater than $\frac{2\left(\frac{n^A}{n^B}\right)^2 T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}{2T^{1-\sigma}+\left(\frac{n^A}{n^B}\right)\left(1+T^{2(1-\sigma)}\right)}$. The refore, the former can be greater than one even if the latter is not.

With unequal wages maintained across regions, if region *A*'s initial innovation rate is greater than region *B*'s, then agglomeration again occurs at region *A*. However, this condition is not necessary. Region *B* with an initial disadvantage in innovations has a comparative advantage

[25] In the present case where region *A*'s wage rate is greater than region *B*'s, agglomeration occurs at region *A*.

in producing traditional-goods. It specializes in the production of traditional-goods, and ends up becoming the periphery.

VI. CONCLUDING REMARKS

It is a contribution of this paper that the hysteresis model of Grossman and Helpman (1991) can be used to explain the contribution of agglomeration *per se* to economic growth. The hysteresis model was developed to explain how the initial conditions determine specialization (trade) patterns and growth rates when technological knowledge is location specific. The hysteresis model predicts that a country with initial advantage in technical knowledge accumulates knowledge more quickly than its trade partners and sustains its productivity lead over them, which in turn determines long-run trade patterns and rates of output growth. The agglomeration of innovation model in this paper stipulates how agglomeration itself plays a crucial role in shaping the favorable conditions for knowledge accumulation, and how agglomeration of firms' innovation activity accounts for the expansion of innovation (that is, growth rate) which is contingent on localized externalities.

Agglomeration induced by transport costs, scale economies and local externalities occurs where the linkages between researchers and differentiated-goods producers create a core-periphery setting. The core emerges where the share of differentiated-goods production is greatest. As more and more innovations are made in the core, a larger share of differentiated-goods relying on these innovations would be produced there too. Clustering of production saves transaction (transport) costs. The developers of differentiated-goods would be induced to locate their R&D activity in the core as well. As a result, a cumulative process would set off and lead to localized growth with innovation activity and concentrated production carried out in the core. Even the perfect mobility of skilled workers between regions does not lead to equal growth and innovations.

When wages are equal and traditional goods are produced in both regions, concentration of R&D activity in a particular region increases the overall growth rate. That agglomeration conditioned on local externalities contributes to economic growth is inferred from the difference in innovation rates between regionally concentrated innovation and regionally diverse one. When wage rates are not equal across regions so that only one region produces traditional goods, however, concentration of R&D activity in the high-wage region does not contribute to growth. Agglomeration is beneficial only if it induces more resources to be employed in the innovation sector, which does not occur when wages are not equalized across regions. Despite a positive relationship between agglomeration and growth at the local level, the same relationship might not exist at the national or global level.

When agglomeration does not contribute to growth, it leads to uneven income distribution. For initially equal wages across regions, concentration of R&D activity in region *A* causes a net increase in the wage rates in both regions as well as gains in growth rates. However, for initially unequal wages across regions, agglomeration does not uniformly increase real income. The low income region will suffer a decrease in wage rates when agglomeration occurs in the high income region. In the case of unequal wages, agglomeration is beneficial to workers in the high wage region but detrimental to workers in the low wage region. Consequently, agglomeration may help maintain the wage rate gap across regions.

Appendix

Proof of Lemma 1 (Steady States: Grossman and Helpman, 1991)

(1-A) **(*Proof*)** If R&D activity is concentrated in region *A*, then $s^A = 1$. For equal wages, traditional goods are produced in both regions. Without R&D activity, the only goods produced in region *B* are traditional goods. So $g^B = 0$ and $s^B = 0$. Substituting $g^A > g^B = 0$, $s^A = 1$, and $s^B = 0$ into (4), (6), and (7) yields $\frac{\delta}{\sigma w} = \rho + g^A$. The factor market equilibrium condition (8') requires $g^A + \frac{(\sigma-1)\delta}{\sigma w} + \frac{s_Z^A(1-\delta)}{w} = L^A$ and $\frac{s_Z^B(1-\delta)}{w} = L^B$. Since $s_Z^A + s_Z^B = 1$, $\frac{L^B}{L^A+\rho} \le \frac{1-\delta}{\delta}$.□

(1-B) **(*Proof*)** If R&D activity is concentrated in region *A*, then $s^A = 1$. For $w^A > w^B$, traditional goods are produced only in region *B*. So $s_Z^A = 0$ and $s_Z^B = 1$. Since $g^A > g^B = 0$, $s^A = 1$, $s^B = 0$, $s_Z^A = 0$, and $s_Z^B = 1$, it can be shown from (4), (6), and (7) that $\frac{\delta}{\sigma w^A} = \rho + g^A$. It also can be shown from (8') that $g^A + \frac{(\sigma-1)\delta}{\sigma w^A} = L^A$ and $\frac{(1-\delta)}{w^B} = L^B$. Since $w^A > w^B$, $\frac{L^B}{L^A+\rho} \ge \frac{1-\delta}{\delta}$.□

(2-A) **(*Proof*)** If R&D is done in both regions, s^A and s^B are non-zero. Since it is not possible for both regions to innovate at unequal rates in the long run, $g^A = g^B = g$. Then, from the non-arbitrage condition (7), it can be shown that $s^A = s^B = \frac{1}{2}$. Also, for equal wages, traditional goods are produced in both regions, so that s_Z^A and s_Z^B are non-zero. Since $g^A = g^B = g$ and $s_Z^A + s_Z^B = 1$, it can shown from (4), (6), and (7) that $\frac{\delta s^A}{\sigma w} = \rho + g$ and $\frac{\delta s^B}{\sigma w} = \rho + g$. It also can be shown from (8') that $g + \frac{(\sigma - 1)\delta s^A}{\sigma w} + \frac{s_Z^A(1-\delta)}{w} = L^A$ and $g + \frac{(\sigma - 1)\delta s^B}{\sigma w} + \frac{s_Z^B(1-\delta)}{w} = L^B$. Since $s_Z^A + s_Z^B = 1$, $\frac{L^B - L^A}{L^A + \rho} \le \frac{2(1-\delta)}{\delta}$.□

(2-B) **(*Proof*)** If R&D is done in both regions, s^A and s^B are non-zero and $s^A + s^B = 1$. Since both regions cannot innovate at unequal rates without one of their market share shrinking to zero, $g^A = g^B = g$. For unequal wages, traditional goods are produced only in region *B*. So $s_Z^A = 0$ and $s_Z^B = 1$. Since $g^A = g^B = g$, $s_Z^A = 0$, and $s_Z^B = 1$, it can be shown from (4), (6), and (7) that $\frac{\delta s^A}{\sigma w^A} = \rho + g$ and $\frac{\delta s^B}{\sigma w^B} = \rho + g$. It also can be shown from (8') that $g + \frac{(\sigma - 1)\delta s^A}{\sigma w^A} = L^A$ and that $g + \frac{(\sigma - 1)\delta s^B}{\sigma w^B} + \frac{(1-\delta)}{w^B} = L^B$. Since $w^A > w^B$, $\frac{L^B - L^A}{L^A + \rho} \ge \frac{2(1-\delta)}{\delta}$.□

Proof of Lemma 2 (Dynamics: Grossman and Helpman, 1991)

(1-A) **(*Proof*)** Since R&D activity is concentrated in region *A*, it can be inferred from (7), (4), and (6) that $\frac{\dot{w}}{w} = g^A + \rho - \frac{\delta s^A}{\sigma w}$. It also can be inferred from (10) and (11) that $g^A = \bar{L} - \frac{(1-\delta)\sigma + (\sigma - 1)\delta}{\sigma w}$. Substituting g^A into the dynamic wage equation yields $\frac{\dot{w}}{w} = \left\{ \bar{L} - \frac{(1-\delta)\sigma + (\sigma - 1)\delta}{\sigma w} \right\} + \rho - \frac{\delta s^A}{\sigma w}$.□

(1-B) **(*Proof*)** With unequal wages, traditional goods will be produced in a low wage region. For $w^A > w^B$, traditional goods are not produced in region A and $s_Z^A = 0$. Substituting $g^A = L^A - \frac{(\sigma-1)\delta s^A}{\sigma w^A}$ obtained from the factor market equilibrium condition into region A's dynamic wage equation yields $\frac{\dot{w}^A}{w^A} = L^A + \rho - \frac{\delta s^A}{w^A}$. Since $g^B = 0$ and $s^B = 0$, region B's dynamic wage equation becomes $\frac{\dot{w}^B}{w^B} = \rho$.□

(1-C) **(*Proof*)** Suppose that $n_A^* \equiv 2 n^i n^i p_i^{1-\sigma} p_i^{1-\sigma} T^{1-\sigma} + n^i n^j p_i^{1-\sigma} p_j^{1-\sigma} \left(1+T^{2(1-\sigma)}\right)$ and $n_B^* \equiv 2 n^j n^j p_j^{1-\sigma} p_j^{1-\sigma} T^{1-\sigma} + n^i n^j p_i^{1-\sigma} p_j^{1-\sigma} \left(1+T^{2(1-\sigma)}\right)$. Then, $s^A = \frac{n_A^*}{n_A^* + n_B^*}$ or $s^B = 1 - s^A$

Suppose also that $g_A^* = \frac{\dot{n}_A^*}{n_A^*}$ and $g_B^* = \frac{\dot{n}_B^*}{n_B^*}$. Then $\frac{\dot{s}^A}{s^A} = s^A\left(1-s^A\right)\left(g_A^* - g_B^*\right)$. □

(2-A) **(*Proof*)** If R&D is done in both regions, it can be inferred from (7), (4), and (6) that $\frac{\dot{w}}{w} = g + \rho - \frac{\delta s^i}{\sigma w}$ for $i = A, B$. Since $g = \frac{1}{2}\left\{\bar{L} - \frac{(1-\delta)\sigma + (\sigma-1)\delta}{\sigma w}\right\}$ as it can be shown from (10) and (11), the dynamic path of wage rates follows $\frac{\dot{w}}{w} = \frac{1}{2}\left\{\bar{L} - \frac{(1-\delta)\sigma + (\sigma-1)\delta}{\sigma w}\right\} + \rho - \frac{1}{2}\frac{\delta}{\sigma w}$.□

(2-B) **(*Proof*)** With unequal wages, traditional goods will be produced in a low wage region. If $w^A > w^B$, traditional goods are not produced in region A so that $s_Z^A = 0$. Substituting the growth rate $g = L^A - \frac{(\sigma-1)\delta s^A}{\sigma w^A}$ into region A's dynamic wage equation yields

$\frac{\dot{w}^A}{w^A} = L^A + \rho - \frac{\delta s^A}{w^A}$. Since $s_Z^B = 1$, region *B*'s dynamic wage equation becomes $\frac{\dot{w}^B}{w^B} = \left\{ L^B - \frac{(1-\delta)}{w^B} \right\} + \rho - \frac{\delta s^B}{w^B}$. □

(2-C) ***(Proof)*** Suppose that $n_A^* \equiv 2 n^i n^i p_i^{1-\sigma} p_i^{1-\sigma} T^{1-\sigma} + n^i n^j p_i^{1-\sigma} p_j^{1-\sigma} \left(1 + T^{2(1-\sigma)}\right)$ and $n_B^* \equiv 2 n^j n^j p_j^{1-\sigma} p_j^{1-\sigma} T^{1-\sigma} + n^i n^j p_i^{1-\sigma} p_j^{1-\sigma} \left(1 + T^{2(1-\sigma)}\right)$. Then, $s^A = \frac{n_A^*}{n_A^* + n_B^*}$ or $s^B = 1 - s^A$

Suppose also that $\tilde{g}_A^* = \frac{\dot{n}_A^*}{n_A^*}$ and $\tilde{g}_B^* = \frac{\dot{n}_B^*}{n_B^*}$. Then, $\frac{\dot{s}^A}{s^A} = s^A \left(1 - s^A\right) \left(\tilde{g}_A^* - \tilde{g}_B^*\right)$. □

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