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Technological Innovation and Industrial Location: Theoretical Analysis

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CONTENTS

Key Words

Agglomeration, Deglomeration, Isodapane analysis, Location theory, Technological innovation, Transportation, and Weberian approach

1. Weberian Isodapane Analysis on a Principle of Spatial Agglomeration

Weber (1909, p. 124ff) raised a question on the influence of localization economies upon the close spatial association of several plants belonging to the same industry. In his analysis is asked under what conditions and in which areas several units of production will agglomerate. Isard's neat summary (1956, p. 176) for precise answers which have been provided by Weber himself to the above questions reads "Several individual units of production will agglomerate when (in relation to any assumed unit of agglomeration): (i) their critical isodapanes intersect and (ii) together they attain within the common segment of the requisite quantity of production."

The critical isodapane is a particular type of the iso-transport-cost curve. As to the production site outside the curve of critical isodapane in the two-dimensional space

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should be met the following condition; the difference between "the total transport cost in assembling inputs from resource sites to the production site and shipping the output from that production site to markets" and "the total transport cost required at the optimum production site" exceeds the agglomeration economies consequent upon the spatial juxtaposition of several firms belonging to the same industry. Weber's answers would therefore connotate that (i) the technological innovation in transport services which reduces transport cost, (ii) the technological innovation in large-scale production which reduced average production cost, and (iii) the increase in the magnitude of realized localization economies[1)] which furnish the benefits of external economies with producers, would all be able to serve in enlarging the size of critical isodapanes to amplify the possibility of the agglomeration of production units.

Along the line of these implications, this paper tries to extend the Weberian isodapane approach by investigating diagrammatically how the technological innovation in transport and production activities together with the realization of localization economies would dynamically effect the spatial redistribution patterns of economic activities.

2. Assumptions, Notations, and Solutions

Consider two cities A and B which are connected by a linear road. Suppose that each city has a small-scale plant (*i. e.*, a small-scale firm) a producing commodity z_1. Under these circumstances, let us introduce the following assumptions and notational conventions into our analysis.

(1) Assumptions

Assumption 1 (Assumption of "fixed demand"):

The level of demand for z_1 amounts Q_a in city A and Q_b in city B with zero price elasticity respectively.

Assumption 2 (Assumption of "identical demand level")

$$Q_a = Q_b = Q_0$$

Assumption 3 (Assumption of faithful clients):

The supply level of the small-scale plant located in A at the initial point of time t_0, should meet the level of demand Q_a which is to be generated in city A wherever the plant would move after time t_0, and the same condition should be satisfied for the small-scale plant located in B at the initial time t_0.

Assumption 4 (Assumption of "no-input-substitution"):

The composition of the basket containing all inputs that are necessary for the unit production of z_1 (*i. e.*, the composition of a unit input-basket), is fixed.

Assumption 5 (Assumption of "fixed-price"):
The price for z_1 and that for input-basket, are both fixed.

Assumption 6 (Assumption of "producer's transport cost"):
Producers have to pay transport costs in both assembling the inputs and shipping the product.

Assumption 7 (Assumption of "identical production cost"):
Production cost functions are identical for the two producers.

(2) Notational conventions

$ac_1(Q)$: "Non-aggregated average production cost" function,

$ac_2(Q)$: "Aggregated average production cost" function,

h : Distance between A and B,

d : Distance from A to point X where agglomeration of production activities takes place ($0 \leqq d \leqq h$),

r_1: Transport rate to move one unit of commodity z_1 by a unit distance ($r_1 > 0$),

r_2: Transport rate to move one unit of the input-basket by a unit distance, and

m: Fixed coefficient such that $r_2 = mr_1$ ($m \geqq 0$).

Within the basic framework of the Weberian isodapane approach, the two small-scale plants (one of which is isolatedly located in A and the other in B at the initial point of time t_0) will agglomerate at point X if the following condition can de satisfied at X;

"the non-aggregated average production cost" is equal to or higher than "the sum of the aggregated average production cost and additionally necessary total transport costs."

Based on this Weberian principle of spatial agglomeration, under our seven assumptions, let us try to examine the basic tendency of spatial agglomeration and deglomeration movements of the two plants for the following two cases; (i) the case in which all necessary inputs are available only at A, and B and (ii) the case in which all necessary inputs are ubiquitously available at any point between A and B.

Case 1: All necessary inputs are available only at A and B.

Case 1-1: $ac_1(Q_0) < ac_2(Q_0)$

Solution Two small-scale plants remain isolated from each other with one being located in A and the other in B.

Case 1-2: $ac_1(Q_0) \geqq ac_2(Q_0)$

Case 1-2-1: The distance d (from X to A) can (i) neither simultaneously satisfy inequalities (1) and (2) for $0 \leqq d \leqq h/2$ (ii) nor simultaneously satisfy inequalities (3) and (4) for $h/2 < d \leqq h$.

$$ac_2(Q_0)+r_1 d+r_2 d \leqq ac_1(Q_0) \cdots\cdots (1)$$
$$ac_2(Q_0)+r_1(h-d)+r_2 d \leqq ac_1(Q_0) \cdots\cdots (2)$$

$$ac_2(Q_0)+r_1 d+r_2(h-d) \leqq ac_1(Q_0) \cdots\cdots (3)$$
$$ac_2(Q_0)+r_1(h-d)+r_2(h-d) \leqq ac_1(Q_0) \cdots\cdots (4)$$

Solution Two small-scale plants remain isolated from each other with one being located in A and the other in B.

Case 1-2-2: The distance d that can (i) simultaneously satisfy inequalities (1) and (2) for $0 \leqq d \leqq h/2$ or (ii) simultaneously satisfy inequalities (3) and (4) for $h/2 < d \leqq h$.

Solution The two small-scale plants will agglomerate at point X with distance d from A.

Hence, we obtain from inequalities (1) and (2) the following relationship for Case 1-2:

$$d \leqq \{ac_1(Q_0)-ac_2(Q_0)\}/\{(m+1)r_1\} \cdots\cdots (5)$$
$$(m-1)r_1 d \leqq ac_1(Q_0)-ac_2(Q_0)-r_1 h \cdots\cdots (6)$$

We then get from inequalities (5) and (6) the following ranges of d within which the two small-scale plants will agglomerate.

(i) For $m=0$

$$d > \{ac_2(Q_0)-ac_1(Q_0)\}/r_1+h \cdots\cdots (7)$$

(ii) For $0<m<1$

$$d \geqq \{ac_1(Q_0)-ac_2(Q_0)\}/\{(m-1)r_1\}-h/(m-1) \cdots\cdots (8)$$

(iii) For $m=1$

$$0 \leqq d \leqq h \ [\text{for } r_1 \leqq \{ac_1(Q_0)-ac_2(Q_0)\}/h] \cdots\cdots (9)$$

(iv) For $m>1$

$$d \leqq \{ac_1(Q_0)-ac_2(Q_0)\}/\{(m-1)r_1\}-h/(m-1) \cdots\cdots (10)$$

Similarly, for $h/2 < d \leqq h$, we obtain from inequalities (3) and (4) the following ranges of d within which the two small-scale plants will agglomerate.

(v) For $m=0$

$$d > \{ac_2(Q_0)-ac_1(Q_0)\}/r_1+h \cdots\cdots (11)$$

(vi) For $0<m<1$

$d \geqq \{ac_1(Q_0)-ac_2(Q_0)\}/\{(m-1)r_1\}-h/(m-1)$ ......(12)

(vii) For $m=1$

$0 \leqq d \leqq h$ [for $r_1 \leqq \{ac_1(Q_0)-ac_2(Q_0)\}/h$] ......(13)

(viii) For $m>1$

$d \leqq \{ac_1(Q_0)-ac_2(Q_0)\}/\{(m-1)r_1\}-h/(m-1)$ ......(14)

Employing the results expressed by inequalities (7) through (14), we can construct Figure 1 to show how the basic characteristics of the spatial agglomeration and deglmoeration of movements of the plants would relat to the values of r_1 and m.

Case 2: All necessary inputs are ubiquitously available as any point between A and B.

Case 2-1: For $ac_1(Q_0)<ac_2(Q_0)$

Solution Two small-scale plants remain isolated from each other with one being located in A and the other in B.

Case 2-2: For $ac_1(Q_0) \geqq ac_2(Q_0)$

Solution The same spatial redistribution patterns are observed as for the situation with $m=0$ in Case 1-2.

3. Agglomeration and Deglomeration Processes

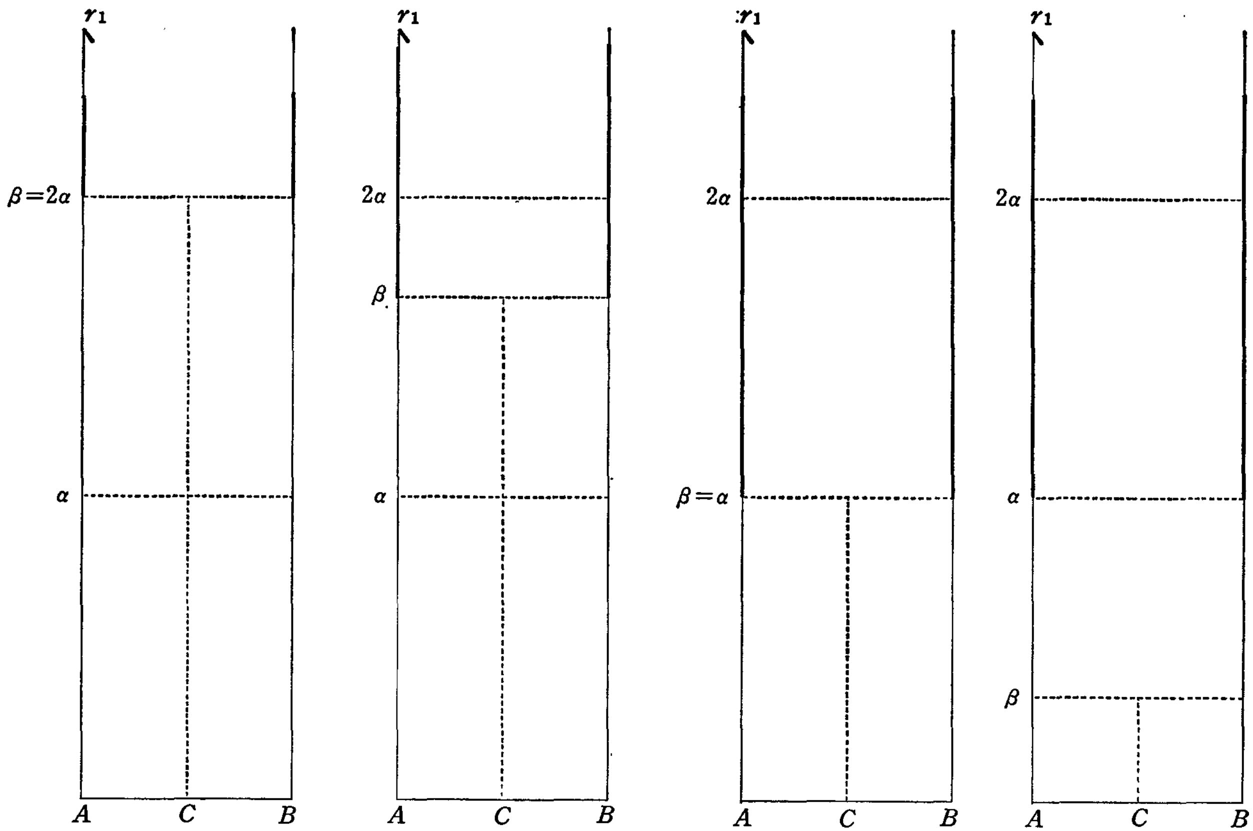
Focusing our attention upon Figures 1a through 1d, let us examine for Case 1-2 how the locational patterns of the two small-scale plants both of which produce commodity z_1 would change as the vaules of m and r_1 vary. It is to be kept in mind here that the reduction of the value of r_1 would usually result from the performance of transport technological innovation.

Figure 1a is for the condition of $m=0$ which implies that no freight charge is required for transporting input-baskets (or that all necessary inputs are ubiquitously available between A and B). From this figure it can be seen that no agglomeration of r_1 is greater than β where

$$\beta=2\{ac_1(Q_0)-ac_2(Q_0)\}/\{(m+1)h\}$$
$$=2\{ac_1(Q_0)-ac_2(Q_0)\}/h \qquad (\text{for } m=0).$$

The two plants, however, would suddenly agglomerate at point C halfway between A and B as soon as the value of r_1 reduces down to β. Then, as the value of r_1 continues to decrease from β, the feasible region for the agglomeration of the two plants would gradually expand from C in both directions towards A and B until r_1 becomes equal to α where

$$\alpha=\{ac_1(Q_0)-ac_2(Q_0)\}/h.$$



$m=0$ $(0=r_2<r_1)$ [1a]

$0<m<1$ $(r_2<r_1)$ [1b]

$m=1$ $(r_2<r_1)$ [1c]

$m>1$ $(r_2<r_1)$ [1d]

(Note) $\alpha=\{ac_1(Q_0)-ac_2(Q_0)\}/h$
$\beta=2\{ac_1(Q_0)-ac_2(Q_0)\}/\{(m+1)h\}$

Figure 1 Spatial Agglomeration and Deglomeration: Feasible Region for Industrial Location

When the value of r_1 is equal to or less than α, the two plants would agglomerate at any point between A and B.

Now assume that there exist the demand not only for commodity z_1 but also for commodities z_2, z_3, ..., and z_n in both cities A and B, and that for each commodity z_i (for $i=2$, 3, ..., n) there exist as for commodity z_i one small-scale plant to produce commodity z_i in A and another in B at the initial point of time t_0 (This pair of plants shall be called companion plants.). Also introduce for each commodity z_i (for $i=2$, 3, ..., n) a set of assumptions that are similar to the set of Assumptions 1 through 6 as have already been introduced for commodity z_1. Furthermore, over our n commodities there are assumed;

(i) the same difference between "the average production cost at production level Q_0 for the non-aggregated production cost function" and "the average production cost at production level Q_0 for the spatially aggregated production cost function,"
(ii) the same transport rate for a unit of commodity, and
(iii) the same transport rate for a unit of input-basket.

Under these new assumptions, Figure 1a suggests that for various values of r_1 the following steps of the spatial agglomeration and deglomeration phenomena can be observed as described by Table 1.

(i) For $r_1>\beta$
A set of n small-scale plants each of which produces one of the n commodities z_1, z_2, ..., and z_n in a mutually exclusive and collectly exhaustive manner, would be located in A and another set of their companion plants would be located in B.
This phase shall be referred to as the stage of two-point isolation since for every commodity the companion plants are isolatedly (or separately) located from each other, one in A and the other in B.

(ii) For $r_1=\beta$
Every pair of the companion plants would agglomerate at point C.
This phase shall be referred to as the stage of one-point concentration (or the stage of complete agglomeration) since all of the 2n plants are concentedly located at C.

(iii) For $\alpha<r_1<\beta$
The n pairs of the companion plants spatially spread themselves evenly (in a probabilistic sense), with each pair of companion plants sticking together, over the feasible agglomeration region which gradually enlarges as the value of r_1 reduces.
This phase shall be referred to as the deglomerating stage since the spatial

Table 1 Agglomeration and Deglomeration Cycles (For Case 1-2-2)

stage \ value of m				
stage	$A \rightarrow$	$B \rightarrow$	$C \rightarrow$	D
value of m	F	$\leftarrow B$	$\leftarrow E$	$\leftarrow D$
$m=0$	$r_1>2\alpha(=\beta)$	$r_1=2\alpha(=\beta)$	$\alpha<r_1<2\alpha(=\beta)$	$r_1\leqq\alpha(=\beta/2)$
$0<m<1$	$r_1>\beta$	$r_1=\beta$	$\alpha<r_1<\beta$	$r_1\leqq\alpha$
$m=0$	$r_1>\alpha(=\beta)$	$r_1=\alpha(=\beta)$	$[r_1=\alpha(=\beta)]$	$r_1<\alpha(=\beta)$
stage	$A \rightarrow$	$B' \rightarrow$	$C' \rightarrow$	D
value of m	F	$\leftarrow B'$	$\leftarrow E'$	$\leftarrow D$
$m>1$	$r_1>\alpha$	$r_1=\alpha$	$\beta<r_1<\alpha$	$r_1\leqq\beta$

(Note)

A: stage of two-point isolation
B: stage of one-point concentration
B′: stage of two-point concentration
C: deglomerating stage
C′: two-sided deglomerating stage
D: stage of even distribution
E: agglomeration stage
E′: two-sided agglomerating stage
F: stage of two-point deconcentration
$\alpha=\{ac_1(Q_0)-ac_2(Q_0)\}/h$
$\beta=2\{ac_1(Q_0)-ac_2(Q_0)\}/\{(m+1)h\}$

distribution of the n pairs of the companion plants is being deconcentrated from point C into its neighborhood areas.

(iv) For $r_1\leqq\alpha$

The n pairs of the companion plants are evenly distributed between the two points A and B.

This phase shall be referred to as the stage of even distribution (or the stage of complete deglomerations).

Within the framework of the Weberian isodapane approach, among the primary factors to facilitate spatial agglomeration of economic activities are not only technological innovation in transport activities which reduces the transport cost but also technological innovation which reduces the average production cost for the level of relatively large amount of production and the realization of localization economies which reduces the average production cost in the spatially aggregated production cost function for each pair of companion plants. Therefore, if we can expect the continuously successful performances as to the above three primary factors which facilitate the spatial agglomeration of each companion plants, then the four steps of the spatial agglomeration and deglomeration phenomena te be followed by the n pairs of the companion plants as the value of r_1 reduces would be proceeded at much faster speed than in the case we consider only the technological innovation in transport services as agglomeration factors. However, if we can reasonably expect that there would come the time (i) when, for each commodities, the technological innovation in the small-scale production which reduces the average production cost for the relatively small amount of production is more successfully carried out as compared with the technological innovation in the large-scale production, and (ii) when, for each pairs of companion plants, the urbanization economies as defined as the external economies consequent upon a spatial juxtaposition of a large number of plants in different industries is larger in magnitude as compared with the localization economies, then as described by Table 1 the following reverse steps of the spatial agglomeration and deglomeration phenomena can be observe as the time goes on.

(v) Stage of even distribution (with the momentum of reverse direction)
The agglomeration of any pairs of companion plants is feasible at any point between A and B.

(vi) Agglomerating stage
The feasible region for the agglomeration of any pairs of companion plants gradually shrinks towards the direction of point C.

(vii) Stage of one-point concentration (with the momentum of reverse direction)
The agglomeration of any pairs of companion plants is feasible only at point C.

(viii) Stage of two-point deconcentration
For any commodities the companion plants are separately located, one in A and the other in B.

Meanwhile, for the conditions of $0<m<1$, $m=1$, and $m>1$, we have Figures 1b, 1c, and 1d respectively. In Figure 1b, the stage of two-point concentration would take place at the lower value of r_1 than Figure 1a. In Figure 1c, the stage of one-point concentration and the deglomerating stage are combined into one stage in such a way that, when r_1 happens to become equal to α (or β), the stage of two-point isolation suddenly jumps into the stage of even distribution (or, the stage of even distribution with the momentum of reverse direction suddenly jumps into the stage of two-point deconcentration).

In Figure 1d, the deglomeration process starts with the two agglomeration centers A and B as compared with Figures 1a and 1b where the deglomeration process starts with one agglomeration center C, and therefore we have the stage of two-point concentration for $r_1=\alpha$, and the two-sided deglomerating stage for $\beta<r_1<\alpha$ as shown in Table 1. Concerning the reverse steps of the spatial agglomeration and deglomeration phenomena in Figure 1d, we have the two-sided agglomerating stage for $\beta<r_1<\alpha$ and the stage of two-point concentration (with the momentum of reverse direction) for $r_1 = \alpha$ as also shown in Table 1.

4. Conclusion

This analysis has not dealt with any concepts of (i) profit maximization, (ii) input substitution, or (iii) price elasticity of demand, and it carries a set of significantly severe assumptions. It has nevertheless explored and probed into the basic dynamic characteristics observed for the relationships between (i) the spatial agglomeration and deglomeration process of economic activities and (ii) the technological innovation in the sphere of transportation and production activities as well as the external agglomeration economies.

Among the findings which we can find interesting are as follows:

(i) Even though the innovation of thet ransport technology gets progressed, if the technological innovation for the production processes is not so significantly favorable for the large-scale production activities, then it is possible that the reverse steps of the spatial agglomeration and deglomeration processes would take place.

(ii) Figures 1b and 1d would be combied together to construct a series of agglomeration and deglomeration steps including both non-reverse direction steps and reverse direction steps.

Notes

1) In this connection, Weber (1909, p. 128) indicates "that the local aggregation of several plants simply carries farther the advantages of the large plants, and hence that the factors of agglomeration which creates this higher stage of social agglomeration" (*i. e.*, localization economies) "will be the same as those which created the large-scale plant."

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