Pacific Economic Review, 10: 2 (2005) pp. 167–187

THE ‘THICK MARKET’ EFFECT AND AGGLOMERATION IN HIGH-GROWTH INDUSTRIES

MIKHAIL M. KLIMENKO* *Georgia Institute of Technology*

Abstract. This paper considers a simple model of geographical concentration of new high-technology industries that lack stable design standards. In the model, agglomerative effects result from positive feedback between competitive forces in the upstream and downstream segments of a high-technology industry, rather than as a result of traditional scale economies in the manufacturing of standardized products. The model assumes that firms in the upstream service supply industry have ex ante uncertain costs and compete in Bertrand fashion for the independent demands of downstream firms. This framework explains the mechanism of spatial clustering in industries with a high rate of innovation.

1. INTRODUCTION

One of the most surprising consequences of globalization is the fact that, despite an increasingly liberal trade regime throughout the world and the steady decline of transportation and communication costs, the geographical distribution of production between regions and nations not seem to be losing its relevance. This suggests a paradox of economic geography in an era of global competition, which is summed up in the recent observation by Michael Porter:

> In a global economy – which boasts rapid transportation, high-speed communication, and accessible markets – one would expect location to diminish in importance. But the opposite is true. The enduring competitive advantages in a global economy are often heavily local, arising from concentrations of highly specialized skills and knowledge, institutions, rivals, related businesses, and sophisticated customers. (Porter 1998, p. 90)

One explanation for this paradox can be found in the fact that a nation’s competitive advantage in the modern global economy is determined increasingly by the ability of the nation’s firms to innovate and to adapt to technological change. The main purpose of this paper is to analyze the economic mechanism that determines the geographical concentration of innovative activity and industries characterized by high rates of innovation.

Empirical evidence suggests that variation in the spatial clustering of manufacturing activity does not explain much of the geographic concentration of innovative activity. This fact can be attributed to differences in

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[*] *Address for correspondence*: Mikhail M. Klimenko, School of Economics, Georgia Institute of Technology, 781 Marietta Street NW, Atlanta, GA 30332, USA. Email: mikhail.klimenko@econ.gatech.edu.
I would like to thank two anonymous referees for helpful comments on this paper.

agglomerative mechanisms, leading to geographical concentration in fast-growing industries populated by innovative high-technology firms on the one hand, and mature industries consisting of firms that rarely introduce new products and most of the time routinely produce standardized goods and services on the other.[1]

One of the prominent characteristics of any high-technology industry is a lack of stable industry standards among firms. Leading industry standards typically emerge at the mature stages of industry evolution, when the main concern among competitors becomes cost reduction rather than the acceptance of new products by customers. In contrast, highly innovative firms in fast-growing industries are in the process of continuously seeking the leading standard of the product design. Very often products don't even reach the mature stage before manufacturing costs become a concern, because competition at the early stage of product development results in a constant introduction of new inventions, which alter nascent industry standards.

The highly experimental nature of production and the lack of a leading interface standard explain the close interaction among suppliers of components and assemblers in fast-growing industries. At the early stage of industry evolution, interaction among designers of final assembly processes and intermediate components is often based on the exchange of *tacit knowledge*, which can be transmitted only through frequent face-to-face contacts.[2] Therefore suppliers of components and final assemblers exchanging tacit knowledge need to locate geographically close to each other. In this sense, intermediate inputs and services provided by suppliers are *non-tradable* outside the area of immediate geographical proximity to the assemblers who use these inputs in the manufacture of highly innovative end-products.[3]

Typically, before the leading interface design prevails, upstream suppliers produce intermediate parts to the specifications of downstream assemblers. Since the leading standards have not yet emerged, assemblers have to order expensive tailor-made components instead of picking standardized

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[1] There is empirical work on the geography of innovation which suggests that the propensity for innovative activity to cluster varies across industries even after accounting for the geographic concentration of the production location. Davelaar and Nijkamp (1989) and Goddard and Thwaites (1986) provide empirical evidence linking regional variation in the concentration of innovative activity measured by the introduction of new products and processes to a non-homogeneous geographical spread of *innovative potential* as reflected in the distribution of R&D activity. While the empirical link between geographical concentration of R&D-intensive input suppliers and innovative output producers is illuminating, it doesn't by itself explain why the entire vertically linked industry generating innovative end-products tends to cluster spatially.

[2] Von Hipple (1994) points out that the 'death' of distance as a determinant of the communications cost concerns *information*, which can be easily codified and has singular meaning and interpretation. In contrast, the cost of transmitting tacit or *sticky knowledge*, which is often vague, highly contextual and difficult to codify, has not been affected by recent advances in telecommunications industry. These properties of tacit knowledge determine the high propensity of vertically linked producers to locate near each other during the early stages of industry evolution.

[3] Gaspar and Glaeser (1998) offer a formal model and empirical evidence which shows that under certain conditions contacts by means of electronic technology may either complement face-to-face interactions or be a weak substitute for such interactions.

'off-the-shelf' inputs and using them without alteration as part of their final product.[4]

Systematization and standardization are the key factors that unlock economies of scale and other advantages of large-scale production. Since the objective of this paper is to explain the reasons for geographic concentration in high-growth industries characterized by a lack of stable standards, I have developed a framework in which agglomeration effects arise as a result of intense competition among a multiplicity of alternative suppliers and assemblers, rather than as a result of traditional scale economies in manufacturing of standardized products.[5]

Specifically, Section 2 considers a model that emphasizes the role of *competition* among upstream suppliers of non-tradable inputs (skilled workers, producer service providers) and of downstream assemblers' uncertainty about the costs of these inputs as sources of external economies leading to agglomeration.[6] The model assumes that every firm in the local upstream supplier industry can customize its products for the specifications of all local downstream firms, which are characterized by independent inelastic demands. Therefore, each supplier can produce a variety of assembler-specific intermediate goods or services. Since the supplier's products or services are assembler-specific, all the strategic power in the interaction between upstream and downstream firms is on the side of the latter, and upstream suppliers compete in prices for the inelastic demand of each downstream assembler. To formalize assemblers' uncertainty, I follow Farrell *et al.* (1998) and adopt the order statistics modeling framework of ex post Bertrand competition among input suppliers. Specifically, I assume that suppliers' variable costs of producing customized input for an assembler are independent random draws from a probability distribution.

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[4] Farrell *et al.* (1998) consider the coordination of vertically linked complementary activities in a number of industries and argue that there is a general trend in the evolution of the personal computer industry from closed-form 'hand-in-glove' coordination, towards a more open arm's-length form of coordination. They observe that in the early years of the industry evolution components were typically produced to proprietary interfaces of final assemblers and required hand-in-glove coordination between suppliers and assemblers. After the major computer manufacturers agreed on standardized interfaces, however, the industry began to evolve toward practices that enabled producers of complementary components and services to work at arm's length. At the more mature stage of the industry evolution, end-product manufacturers began to assemble systems from off-the-shelf components provided by competing suppliers.

[5] Another example of a high-growth industry without a dominant technical standard is the US automobile industry in the early 1900s. According to industrial historians Thomas (1977) and Rae (1984), the process of standardization of parts and production methods didn't begin until the US auto companies began their race to introduce the first '$1,000 car'. The first vehicles priced under $1,000 appeared on the US market in 1907. This was a result of the significant economies of scale that became possible in the production of supply parts only after the introduction of inter-company technical standards in the assembly industry. However, Detroit had already emerged as a leading center of the US automobile manufacturing before $1,000 cars hit the road and the industry agreed on the dominant technical standards. Therefore, the tendency for agglomeration in the nascent automobile industry has to be explained by reasons other than scale economies.

[6] Elsewhere, we analyze a model that assumes that all firms in the local upstream supplier industry have the same marginal cost and can customize their products to quality specifications of each of the local downstream firms (Klimenko, 2004). Therefore, in that model the main uncertainty is regarding compatibility between the quality characteristics of the inputs offered by suppliers and the quality requirements of assemblers.

In the present model, the location decisions of downstream assemblers are related to the levels of the expected prices for local inputs, which may be very high ex ante if there is not enough competition among the local suppliers. However, the assembler's expected operating costs at a given location continuously decline as a result of the entry of new input suppliers in this location and the intensified competition between them. This attracts assemblers to locations with a relatively larger number of suppliers. On the other hand, the suppliers' ability to compete for several independent demands by tailoring generic intermediate products or services to the specifications of all local assemblers leads to greater expected demand for suppliers' products in locations with a larger assembly industry. The following model demonstrates that this circularity of the relationship between the upstream competition and downstream firms' entry creates an agglomerative force leading to spatial clusters of vertically linked high-technology industries.

An unrealistic feature of the setting considered in Section 2, which could exaggerate the strength of agglomerative forces in vertically linked industries operating without interface standard, is that each assembler is indifferent to the number of other assemblers in the same location. Since in this setting there is no substitution between inputs customized for the specifications of different assemblers, and the suppliers can produce any number of customized input varieties at no additional cost, there is no competition among assemblers for the inputs produced by suppliers. Competition is present only on the suppliers' side, which gives the model the 'many-to-one' structure with prices for assembler-specific input varieties determined in independent rounds of Bertrand competition among local suppliers.

In Section 3, I show that this limitation can be overcome while preserving the general structure of the model. In order to do so, I assume that supply of non-tradable inputs depends on the availability of the local labor force. This allows me to introduce indirect competition among assemblers through the effect of local wage rate on the prices of inputs produced by suppliers. I show that in this setting, too, concentration of all suppliers, assemblers and workers in one location emerges as the equilibrium outcome.

Several strands of literature are related to this study. One of them is the 'new economic geography,' which analyzes how the ability of geographical concentration to increase the local market for goods and services results in finer specialization among local suppliers and in the provision of a wider variety of intermediate inputs. This literature has adopted an approach based on the Dixit–Stiglitz framework of monopolistic competition with iceberg trade costs. However, the approach is not quite suitable for a study of agglomeration effects in innovative activity. Within this framework, geographical concentration emerges as equilibrium only at the intermediate level of final good trade costs.[7]

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[7] High trade costs make it inefficient to service the entire geographical area from one location and lead to the dispersion of industrial activity, while low trade costs reduce the importance of geographical proximity to markets and suppliers. Firms and workers begin to migrate in response to wage differences, and this results in a dispersion across the geographical area. Only at the *intermediate* level of trade costs does a combination of demand and cost linkages generate an agglomerative force, which leads to the emergence of an industrial core.

However, an outstanding feature of high-technology industries' end-products is high value-to-weight ratio, which implies that trade costs are unlikely to be an important factor of such industries' spatial distribution. At the same time, while many specialized inputs and services employed in high-technology industries are non-tradable, they are not necessarily spatially concentrated. Therefore, without a theory accounting for geographical concentration of specialized input suppliers, the model of monopolistic competition with iceberg trade costs would predict that high-technology firms should be more or less spatially dispersed. But this prediction is in disagreement with the geography of high-growth and high-technology industries which demonstrate a strong tendency toward agglomeration.

The agglomeration mechanism presented in this paper is closely related to a Marshallian externality that is associated with *thickness* and *size* of the local input market. In the literature on spatial distribution of economic activity, there are several analytical frameworks explaining how this externality leads to agglomeration. Porter (1990) incorporates the market thickness externality in the concept of a specialized industrial cluster, which he identifies as a critical mass of interconnected companies and institutions in a particular location. The defining characteristics of a cluster, according to Porter (1998), are 'competitive pressure, peer pressure, customer pressure and constant comparison,' which stimulate innovative activity at the cluster.[8] The present paper can be viewed as an attempt to develop the microfoundations for the role that competition and market thickness play in facilitating geographical clustering of industries characterized by the high rate of innovation and technical change.

One of the formal models of market thickness is based on the so-called 'statistical economies of scale,' which Krugman (1991) uses to illustrate that the growth of the number of upstream input suppliers and downstream assemblers creates the effect of co-insurance or 'risk-pooling.' In Krugman's model, the random variations in the aggregate input demand will be lower in locations with more potential assemblers, because fluctuations of individual assemblers' demands at any location are not perfectly correlated even if these firms belong to the same industry. Input suppliers are attracted to locations where it is easier for them to find alternative buyers (i.e. assemblers) experiencing 'good times' if the original buyer has to reduce its demand because of 'bad times.'

To my knowledge, with the exception of Krugman (1991), economists have largely ignored the risk-pooling effect as a source of agglomeration economies. Although Rothschild and Werden (1979) demonstrate in a formal model that

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[8] Porter (1990) presents evidence on regional agglomeration in fast-growing vertically linked industries in different countries around the world and emphasizes the circularity of the relationship between competition in the downstream assembly industry and that in the upstream supply industry. Porter suggests that, if a national industry has a number of domestic assemblers, each with some differences in needs, then upstream suppliers will tend to explore a wider range of technical avenues and to speed up the rate of innovation. Moreover, the existence of a local competitive supplier (subcontractor) industry lowers barriers to entry into the downstream industry by firms that are competing as assemblers. For example, he notes that the presence of many local input suppliers facilitated new entry into the highly innovative pharmaceutical industry in Basel, Switzerland, and into the motorcycle assembly industry in Hamamatsu, Japan (Porter, 1990, p. 120).

random productivity of multiple independent factors of production could be a source of increasing returns to scale with otherwise constant-returns technology, they do not consider the implication of this effect for the spatial distribution of economic activity. In contrast, in a paper on Marshallian externalities operating through the factor markets, David and Rosenbloom (1990) do not explicitly model the mechanism inside the 'black box' of agglomeration economies. Instead, they demonstrate that, had there been scale economies of this nature, they would have led to industrial localization.

Thickness and size of the local market also affect the search behavior of buyers. Fischer and Harrington (1996) base their analysis of agglomeration on an analytical framework in which sellers compete in prices and buyers search over prices and quality characteristics of the products offered by sellers. However, in their model each seller can supply to the market only one brand of differentiated products. In contrast, the present analytical framework considers the possibility that a seller (supplier) can sell multiple varieties by customizing its products to the specific needs of individual assemblers. This possibility is important to the present analysis because I am focusing on a vertically linked industry in which suppliers and assemblers interact without a stable interface standard, rather than on comparison-shopping in consumer goods markets. In the latter, consumers search for the best bargain among the goods offered by several retail stores. In contrast, the process of matching buyers and sellers in the markets for specialized intermediate inputs and producer services often involves a bilateral search which is subject to economies of scope on the sides of both buyers and sellers. Therefore, thickness and size of the local market can affect the search behavior of firms on both sides of the market. Although in our framework only assemblers search over the price offers of suppliers, the fact that each supplier can compete for the independent demands of all of the assemblers implies that essentially we are considering a bilateral search mechanism.

The models of Greif and Rodriguez-Clare (1995) and Rotemberg and Saloner (2000) emphasize another aspect of market thickness closely related to the firms' motivation for geographical clustering in our analytical framework. Greif and Rodriguez-Clare (1995) point out that the hold-up problem could arise if the downstream industry consists of only one assembler in a particular region, since in that case suppliers' location-specific investments become essentially assembler-specific. However, if the downstream industry in a particular location is populated by many competing assemblers, suppliers' investments acquire a general-purpose nature and they are more willing to make such investments. Rotemberg and Saloner (2000) show how agglomeration can arise out of competition between firms for the services provided by skilled workers. In their model the workers invest in the acquisition of industry-specific skills only if there is competition among potential employers.

In the spirit of the models of Rotemberg and Saloner (2000) and Greif and Rodriguez-Clare (1995), this paper analyzes the framework in which availability of alternative assemblers at a location mitigates the problem of the location specificity of assets of non-tradable input suppliers. In the model considered here, suppliers are attracted to locations with a higher number of assemblers because then each supplier has a greater probability of making a sale. At the same time, each assembler's expected input cost declines as a result of ex post competition among an increasing number of suppliers; therefore, assemblers are attracted to locations with more intense competition among input suppliers.

As with all models formalizing market thickness as a source of agglomeration, this paper predicts that the location decisions of assemblers and suppliers are interdependent. Assemblers prefer to locate where they have several potential upstream suppliers, because competition in the upstream market leads to lower prices for the intermediate goods; however, suppliers like to have multiple alternative customers with uncorrelated individual demands. On average, this tends to increase the demand for intermediate inputs, resulting in higher expected profits for the suppliers.

The rest of this paper is organized as follows. Section 2 presents the basic stochastic model, which is motivated by the preceding discussion of the effects of competition on the geography of innovative activity. Section 3 considers a model that extends the value chain of innovative assemblers and service suppliers to incorporate labor as an input used by the suppliers. Concluding remarks follow in Section 4.

2. AN ORDER-STATISTICS MODEL OF BERTRAND COMPETITION WITH STOCHASTIC COSTS AND AGGLOMERATION

In the simple partial equilibrium model presented in this section, the external economies of agglomeration arise from the non-tradability of inputs produced by competing suppliers and assemblers' uncertainty about the prices at which they will be able to acquire non-tradable inputs from suppliers at a new location. Given this ex ante uncertainty over input prices, assemblers benefit from locating their production facilities in areas with a higher concentration of potential input suppliers. Competition between the suppliers drives down the input prices, thereby benefiting the assemblers. Suppliers have higher ex ante expected revenues and profits at locations with a larger concentration of assemblers. Therefore, suppliers tend to establish production in areas where there is a larger number of prospective buyers of their products.

Consider a group of risk-neutral assembler firms j ($j = 1, \ldots, N$) which produce tradable outputs X_j at some location. There is inelastic unit demand and some exogenously determined reservation price P_j for each output j.[9] Assembler j's technology converts (at no cost) one unit of a non-tradable input variety x_j into one unit of output X_j.

There are n identical risk-neutral suppliers of non-tradable input ($i = 1, \ldots, n$) at the location, and each supplier can customize its product at no cost to the specifications of any of the local assemblers (i.e., it can produce any of the N varieties of input). Thus, suppliers have diversified production, and once their

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[9] An example of such a market is that of assemblers producing a supercomputer or particle accelerator for which there is unit demand.

production facilities are established at a certain location there is no extra fixed cost of producing an additional variety of inputs, although varieties may have different variable costs.[10]

Following Farrell *et al.* (1998), I adopt the framework of ex post Bertrand competition and assume that suppliers' variable costs of producing inputs for assembler j, x_{ji} $(i = 1, \ldots, n)$, are n independent random draws from the distribution F_j, such that $F_j(0) = 0$. Specifically, we consider the following sequence of events. First, a supplier sets up a production facility at a certain location where it can supply up to N varieties of input (i.e., it can customize its product to the specifications of up to N local assemblers). Then the supplier calculates its unit cost of producing (customizing) each of these varieties and the costs of other $n - 1$ suppliers at the given location. In each of N assembler-specific markets, the same group of n suppliers competes in prices for the unit demand of one assembler. Therefore, the equilibrium unit cost of production of the input variety j will be the smallest of n draws from the distribution $F_j(\cdot)$. Using the notation of order statistics and omitting assembler's subscript, this smallest draw is denoted by $x_{(1)}^{(n)}$. The equilibrium price of an input variety will be the second-smallest of n draws, $x_{(2)}^{(n)}$. Given the inelastic demand for the assembled goods the assembler's profit is $P - x_{(2)}^{(n)}$; and the operating profit of the supplier with the smallest unit cost is $x_{(2)}^{(n)} - x_{(1)}^{(n)}$.[11]

Assuming for simplicity that $F_j(x) = F(x)$ for all j, $(j = 1, \ldots, N)$, and writing $G(x) = 1 - F(x)$, the expected value of $x_{(1)}^{(n)}$ can be expressed as

$$E[x_{(1)}^{(n)}] = \int_0^\infty x d(1 - G(x)^n) = \int_0^\infty G(x)^n dx \tag{1}$$

This expression is clearly decreasing in n, because $0 \leq G(x) \leq 1$ for all x.

Using a well known result in the theory of order statistics (see Arnold *et al.*, 1992), we can calculate the expected operating profit of an input producer that could become a supplier to N assemblers as[12]

$$\begin{aligned}\pi &= \frac{N}{n} E[x_{(2)}^{(n)} - x_{(1)}^{(n)}] = NE[x_{(1)}^{(n-1)} - x_{(1)}^{(n)}] \\ &= N\int_0^\infty G(x)^{n-1}(1 - G(x))dx.\end{aligned} \tag{2}$$

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[10] The industries I have in mind are information technology (IT) consulting or software development. IT companies sustain large sunk costs to establish local offices, which then offer customized versions of the core product or service to clients in the area. The client-specific cost of customization is typically small compared with the fixed cost of opening a local office and stuffing it with IT consultants.

[11] For the sake of analytical tractability, it is assumed that assemblers do not behave strategically in the price determination game. Without such an assumption, the equilibrium price would be determined by the midpoint $(x_{(2)}^{(n)} - x_{(1)}^{(n)})/2$ if the assembler and the supplier with the lowest cost had the same bargaining power. The equilibrium price $x_{(2)}^{(n)}$ can be also justified by assuming that, although the assembler behaves strategically, its bargaining power vis-à-vis the lowest cost supplier is very small.

[12] The second equality in equation (2) is based on the so-called 'triangle rule' from the theory of order statistics (see Arnold *et al.*, 1992, theorem 5.3.1, pp. 111–12). According to that rule,

$$E[x_{(2)}^{(n)} - x_{(1)}^{(n)}] = nE[x_{(1)}^{(n-1)} - x_{(1)}^{(n)}].$$

Since suppliers compete in Bertrand fashion, the profit of each supplier is equal to its contribution to lowering social costs. Therefore the *expected profit* of the nth supplier in a given location is equal to the expected reduction in input costs owing to the addition of one more draw, i.e. one more supplier in this location: $E[x_{(1)}^{(n-1)} - x_{(1)}^{(n)}]$.

The factor N/n on the left-hand side indicates that the unit cost of an input supplier can be drawn in N independent draws[13] from samples of size n and that in each of these draws it can have the lowest cost with probability $1/n$. From (2) it is immediately apparent that the expected profit of an input producer is larger at those locations where it could sell its products to a larger number of assemblers and where it could compete with a smaller number of other input producers.

Each assembler at the location has an expected profit, given by

$$\begin{aligned}\Pi &= P - E[x_{(2)}^{(n)}] = P - nE[x_{(1)}^{(n-1)} - x_{(1)}^{(n)}] - E[x_{(1)}^{(n)}] \\ &= P - \int_0^{\infty} G(x)^{n-1}(n(1 - G(x)) + G(x))dx.\end{aligned} \tag{3}$$

Since the expected value of the second-order statistic from a sample of size n, $E[x_{(2)}^{(n)}]$, is decreasing in the size of the sample, the assembler's expected profit (3) increases with the number of competing suppliers at the location.

Assemblers are attracted to places where the density of suppliers is high because the expected input prices there are lower; and they are indifferent to the presence of the other assemblers because in this framework each assembler uses its own variety of input and does not affect the interaction between input suppliers and other assemblers. Suppliers are attracted to places where the density of assemblers is high because expected sales there are greater; and they are repulsed by places where the supplier density is high because of the stronger competition among suppliers there. Hence the spatial distribution of both classes of firms affects the equilibrium prices and profits in this economy.

The geographical area under consideration consists of two locations, A and B. N_j and n_j ($j = A, B$) denote respectively the number of assemblers and suppliers in location j at a given period of time. The total number of assemblers (suppliers) in both locations is defined by $N_A + N_B = N(n_A + n_B = n)$. The location choice game unfolds through time, period by period, with cost parameters of all suppliers randomly drawn every period at both locations. Therefore, the identity of suppliers that win the price competition at a given location may change every period. Since the expected assembler and supplier profits defined by equations (2) and (3) are for one period only, all firms are confronted with the location decision every period of the location choice game.

The possibility of multiple equilibria in the model can be presented graphically. The sides of the rectangle on Figure 1 represent the shares of assemblers

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[13] It would be more realistic to assume that draws are correlated, reflecting the notion that firms that have lower costs of supplying inputs to some assemblers tend to have lower costs of supplying to the other assemblers as well. But I ignore this issue here.

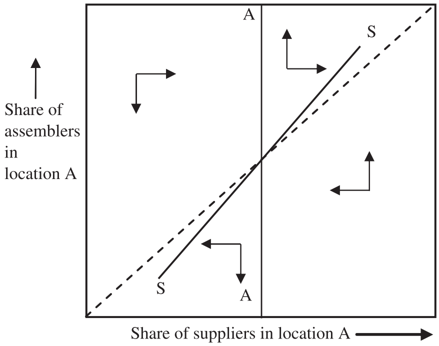

Figure 1. Dynamics of a spatial distribution of suppliers and assemblers

and suppliers in location A. The center of the rectangle represents an even split of both types of firm between the two locations which makes them equally attractive for any firm. Points on the curves AA and SS represent the distributions of assemblers and suppliers, which make the typical assembler and supplier indifferent between the two locations. The curves intersect at the center of the rectangle: if firms are evenly divided between the two locations, they earn the same profits in either location. Since the assembler's expected profit (3) is independent of the number of other assemblers in the location, the locus of assembler indifference AA is a vertical line.

The supplier indifference line SS is positively sloped and steeper than the 45° line. This is apparent from the right-hand side of the supplier expected profit equation (2). If we move away from the point of even split of suppliers and assemblers between the two locations by increasing the number of both types of firms in location A, then the number of assemblers N_A should grow faster than the number of suppliers n_A to compensate for the exponential decline of the term $G(x)^{n_A-1}$ with the increase of n_A and maintain the level of expected profit.

The arrows on Figure 1 indicate the dynamics of firms' locational decisions. Three equilibria are possible. One of them corresponds to even distribution of economic activity between the two locations (i.e. at the intersection of the loci SS and AA). The other two correspond to a concentration of all assemblers and suppliers in either location A or location B.

One method of equilibrium selection in cases of multiple equilibria that is popular in the international trade literature is the Marshallian adjustment process (see e.g. Neary, 1978; Krugman, 1991). This method assumes that there is an initial distribution of suppliers and assemblers between the two locations: $(N_A^0, N_B^0, n_A^0, n_B^0)$. Both types of firm are assumed to move toward the location that offers the higher expected profit. The process is self-reinforcing, because suppliers and assemblers are forward-looking and base their location decisions on the expectations about the behavior of all other suppliers and assemblers. Therefore, the equilibria that survive in the long run are determined by the initial spatial distribution of firms and the evolution of the expectations, which at any point of history can be interpreted as the state of the system. Intuitively, behind the Marshallian adjustment process is an adaptive learning process in which each firm's expectations concerning the strategy that other firms will play are based on the success of their past strategies. If other firms are expected to follow the same strategy in the future as they did in the past, then it makes sense for any firm taking other firms' strategies as given to follow the Marshallian adjustment rule.[14]

Applying the logic of the Marshallian adjustment dynamics to the present model, we can see that the intersection of the loci SS and AA at the center, which corresponds to an even distribution of economic activity between the two locations, is an unstable equilibrium. We are unlikely to observe it if there is even an infinitesimal amount of noise in the system. Therefore, we should observe the eventual convergence to the stable equilibrium, which corresponds to concentration of both assemblers and suppliers either in location A or location B, depending on initial conditions.

Another way to address the issue of the equilibrium selection in games with multiple equilibria is to employ the concept of evolutionary stability. The evolutionary approach assumes that a strategy that does well is imitated, while a strategy that does badly is rejected. Therefore, evolution can be taken as a metaphor for learning. In the context of the present model, we can assume that in every period a fraction of firms with a lower payoff change their current strategies to the more profitable strategy: the greater the payoff difference, the greater the incentive to change the strategy. The fraction of firms using the better performing strategy (i.e. choosing the more profitable location) will increase relative to those using the lower payoff strategy. If there is inertia in firm behavior owing to costs associated with switching locations, then the proportion of firms at each location changes smoothly. Therefore, the proportion of suppliers and assemblers choosing a given location is subject to evolutionary pressure over time. This eventually leads to a convergence to the evolutionary equilibrium.

The evolutionary approach to equilibrium selection in this model can be illustrated using 'replicator dynamics,' which is routinely employed in evolutionary game theory. Again, let us suppose initially that there is some distribution of shares of firms across the locations $S_A^0, S_B^0, s_A^0, s_B^0$ $(S_A + S_B = 1,\ s_A + s_B = 1)$. At any given time, the state of the system (S_A, S_B, s_A, s_B) determines the equilibrium supplier and assembler profits in the two locations: Π_A, Π_B, π_A, and π_B. Let us define the average supplier and assembler profits in the economy as

$$\bar{\Pi} = S_A \cdot \Pi_A + S_B \cdot \Pi_B$$

and

$$\bar{\pi} = s_A \cdot \pi_A + s_B \cdot \pi_B$$

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[14] In general, I ought to give a more explicit characterization of the Marshallian dynamic process of spatial adjustment. To do so, however, would raise mathematical and computational difficulties that I prefer not to deal with. Instead, I adopt an informal approach and use phase diagrams to support the intuition. An explicit formal model employing Marshallian adjustment dynamics can be found in Neary (1978).

When $\Pi_A > \bar{\Pi}$ ($\pi_A > \bar{\pi}$) some assemblers (suppliers) will find it profitable to change the location, and S_A (s_A) will increase. The profit difference exerts evolutionary pressure on the spatial distribution of firms. Under replicator dynamics, the location's share of suppliers (assemblers) grows proportionally to the difference between the location's assembler (supplier) profit and the average assembler (supplier) profit in the economy:

$$\dot{S}_j = \phi S_j(\Pi_j - \bar{\Pi}), \quad j = A, B,$$

$$\dot{s}_j = \phi s_j(\pi_j - \bar{\pi}), \quad j = A, B,$$

where $\dot{S}_j$ and $\dot{s}_j$ are the time derivatives of S_j and s_j, and ϕ is a constant. Given the shares S_A, S_B, s_A, s_B and the total numbers of suppliers and assemblers in the economy, N and n, (3) and (2) define the profits (Π_A, Π_B) and (π_A, π_B), that feed back into the dynamics of S_A, S_B, s_A and s_B.

Friedman and Fung (1996) describe several relevant concepts of the long-run evolutionary equilibrium. A state $\boldsymbol{S^*} = (S_A^*, S_B^*, s_A^*, s_B^*)$ is a fixed point or a steady state if it has no tendency to change over time, that is if in this state $\dot{S}_j = 0$ and $\dot{s}_j = 0$. A fixed point $\boldsymbol{S^*}$ is an evolutionary equilibrium if it is locally asymptotically stable. The basin of attraction of an evolutionary equilibrium $\boldsymbol{S^*}$ is the set of all such initial conditions that eventually evolve to $\boldsymbol{S^*}$.

When applied to the present model, the logic of the evolutionary adjustment dynamics leads to the same outcome as the Marshallian adjustment rule.[15] Although the even distribution of economic activity between the two locations is a fixed point (i.e. a Nash equilibrium), it is not an evolutionary equilibrium.[16] The two possible evolutionary equilibria correspond to full concentration of all assemblers at a single location.

The mechanism leading to agglomeration in this model can be illustrated using Porter's (1990) case study of the industrial cluster around the town of Sassuolo, which is located between the provinces of Modena and Reggio Emilia in northern Italy. The area is famous for its high concentration of world-class producers of ceramic materials for interior design. Production of ceramic tiles

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[15] In fact, the standard replicator dynamics can be derived from different models of adaptive learning behavior, which underlies the Marshallian adjustment rule (e.g. Crawford, 1991).

[16] Again, I omit the detailed formal examination of location choice dynamics among suppliers and assemblers. However, it should be emphasized that the analysis of spatial evolutionary dynamics in the context of the present model can be made fully rigorous by building on the approach contained in Friedman and Fung (1996). Those authors consider a model in which the firms in two countries choose between the two alternative modes of internal organization. The dynamics of the organizational choice by firms in the two countries, which trade with each other, is structurally very similar to the present model's dynamics of locational choice by suppliers and assemblers. Although the exact mechanisms generating instantaneous payoffs in my own and Friedman and Fung's models are very different, in terms of its influence on the evolution of the game their 'network effect' is similar to my agglomeration effect and their 'glut effect' is similar to the effect of competition, which pushes the suppliers away from each other in the present model. For example, proposition 3 in Friedman and Fung (1996) shows that, when barriers to trade in inputs and outputs are reduced, the only evolutionary equilibrium is the adoption of the same organizational mode by all firms in both countries. With appropriate modification, this result can be applied to the present framework to show that the only evolutionary equilibrium is a full concentration of all suppliers and assemblers at a single location.

is a highly innovative and fast-changing industry which is partly due to the rapidly evolving fashions in interior design. Here is how M. Porter describes the effect of the linkage between the entry of new independent input suppliers and assemblers in the cluster:

> As the industry grew and concentrated around Sassuolo, a pool of specialized workers and technicians developed, including engineers, production specialists, maintenance workers, service technicians, and design personnel. New firms found it easy to hire the requisite expertise locally. A Sassuolo manufacturer also had a whole array of knowledgeable specialists in the area on whom he could call to solve production design problems.
>
> The geographic concentration of the Italian industry encouraged the formation of other Italian firms around Sassuolo that supplied other inputs and services such as molds, glazes, packaging materials, and transportation. An array of small, specialized consulting firms emerged to give advice to tile producers on plant design, logistics, commercial, advertising, and fiscal matters. Third-party service firms were able to operate at peak efficiency due to the geographic concentration of their customer base. (Porter, 1990, p. 213)

From 1960 to 1997 the total number of firms in the Italian ceramic tile industry grew from 55 to 379. Over the same period, the total number of workers employed in the industry increased from 8,906 to 31,487 (see Porter, 1990, p. 219; Assopiastrelle, 1998, p. 5). By 1997, 305 companies were concentrated in the 'ceramic belt' of the provinces of Modena and Reggio Emilia, where ceramic tile production constitutes 81% of the overall Italian total and 25% of world production. This is a large increase from the region's 60% share of the national output in the 1980s.

3. AN ORDER-STATISTICS AGGLOMERATION MODEL WITH LABOR MARKET

This section extends the baseline framework considered in Section 2 by adding labor as another segment to the vertical value chain consisting of assemblers and suppliers.[17] In this extended version of the model, an increase in the assemblers' demand for inputs translates into increased suppliers' demand for labor, which raises the local wage. Since the higher local wage raises the costs of all local input suppliers, prices for inputs also rise. This reduces the profits of the assemblers, who are no longer indifferent to the presence of other assemblers in the same location. In this setting, to determine whether competitive forces still lead to a concentration of the entire vertically linked industry in one location, we need to take into account the interaction of location decisions made by the actors in all three segments of the industry, i.e. workers, suppliers and assemblers.

As in the previous sections, I analyze an economy that has two possible locations A and B. There is a total of N assemblers and n input suppliers, which can locate at either of these two locations. Again, I denote this by using self-explanatory notation: $N = N_A + N_B$ and $n = n_A + n_B$. Each assembler i is represented by the following revenue function: $R_i = \beta \ln q_i$. Input q_i is non-tradable and can be produced at location A (B) by any of n_A (n_B) suppliers.

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[17] Like firms, workers are assumed to be risk-neutral.

As in the previous framework, I assume that each of the suppliers can produce inputs customized for any of the assemblers at the location. The suppliers of input q_i (i.e. the input used by assembler i) use identical technologies which require x_i units of labor to produce one unit of q_i; thus, at the location where the wage is w, the marginal cost of supplier i is $x_i w$. There are no fixed costs. However, the unit labor requirement x_i is not known with certainty before the suppliers choose the location. The coefficients x_i have ex post (that is, after firms choose the location) realizations as independent draws from the distribution $F_i(\cdot)$, such that $F_i(0) = 0$. Thus, at location A, n_A suppliers compete in a Bertrand fashion in N_A markets, defined by the demands for assembler-specific input varieties. Each of the suppliers has some probability of having the lowest marginal cost in the production of all N_A varieties of input and becoming the actual supplier to all of the assemblers at the location.

Ex ante, the unit cost of the most efficient supplier of the input variety i at location A is the product of the equilibrium wage at the location and the smallest of the n_A independent draws from the distribution $F_i(\cdot)$, i.e. $x_{(1)i}^{(n_A)} w_A$. Then the price will be equal to the second-smallest unit cost, i.e $x_{(2)i}^{(n_A)} w_A$, and the operating profit of the most cost-efficient supplier is $(x_{(2)i}^{(n_A)} - x_{(1)i}^{(n_A)}) w_A$.

The assemblers choose the amount of input in order to maximize their profits; i.e., they set marginal revenue product of the input equal to its price:[18]

$$\frac{\beta}{q_i} = x_{(2)i}^{(n_A)} w_A, \quad i = 1, \dots, N_A \tag{4}$$

Since the unit labor requirement of lowest-cost supplier is $x_{(1)i}^{(n_A)}$, the ex post labor demand at location A is the sum of labor demands L^i generated by the suppliers of input varieties $q_i (i = 1, \dots, N_A)$:

$$\sum_{i=1}^{N_A} L^i = \sum_{i=1}^{N_A} q_i x_{(1)i}^{(n_A)} = \sum_{i=1}^{N_A} \frac{\beta x_{(1)}^{(n_A)}}{w_A x_{(2)i}^{(n_A)}} = \frac{\beta}{w_A} \sum_{i=1}^{N_A} \frac{x_{(1)}^{(n_A)}}{x_{(2)i}^{(n_A)}} \tag{5}$$

I denote the number of workers concentrated at location A by L_A and assume that within the location the labor market clears:

$$L_A = \sum_{i=1}^{N_A} L^i. \tag{6}$$

Therefore, the equilibrium wage at location A is determined ex post by

$$w_A = \frac{\beta}{L_A} \sum_{i=1}^{N_A} \frac{x_{(1)i}^{(n_A)}}{x_{(2)i}^{(n_A)}} \tag{7}$$

The equilibrium wage at location B, w_B, can be determined in a similar fashion by assuming labor market clearance and appropriately changing the location

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[18] In Section 2 the assemblers do not have to choose the quantity of the input, since they have inelastic demand for one unit of the input. This is because in that section the assembler needs exactly one unit of the input to produce one unit of the output and faces inelastic unit demand for the output. By contrast, in the present section the assembler is characterized by the revenue function $R_i = \beta \ln q_i$.

subscripts of the variables denoting the numbers of suppliers, assemblers and workers and the equilibrium input quantities.

Combining equations and (4) and (7), we obtain the ex post equilibrium quantities of inputs acquired by assemblers at location A:

$$q_i = \frac{L_A}{x_{(2)i}^{(n_A)}}\left(\sum\nolimits_{k=1}^{N_A}\frac{x_{(1)k}^{(n_A)}}{x_{(2)k}^{(n_A)}}\right)^{-1}, \quad i = 1, \ldots, N_A. \tag{8}$$

The similar expression represents the ex post equilibrium quantities of inputs acquired by assemblers at location B.

For simplicity, I further assume that unit labor requirements for all input varieties, x_i, ex ante have the same standard uniform distribution: $F_i(\cdot) = \text{Uniform}\,[0, 1]$ $(i = 1, \ldots, N_A)$. Then, using a well known result in the order-statistics theory that the ratio of the first and the second-order statistics in a random sample from the standard uniform population is a random variable with the standard uniform density (see Arnold *et al.*, 1992), I obtain the ex ante expected equilibrium wage at location A:[19]

$$E(w_A) = \frac{\beta}{L_A}N_A E\left(\frac{x_{(1)}^{(n_A)}}{x_{(2)}^{(n_A)}}\right) = \frac{\beta N_A}{2L_A}, \tag{9}$$

where we omit the assembler's subscript.

From (9), it is apparent that the size of the supplier industry has two effects on the expected wage at the given location. On the one hand, the greater is n_A, the lower is the second-smallest unit cost parameter $x_{(2)}^{(n_A)}$. This effect lowers the local input price $x_{(2)}^{(n_A)}w_A$ and translates into greater demand for inputs, and therefore greater derived demand for labor and an increased wage. On the other hand, the greater is n_A, the lower is the unit expected cost parameter of the most efficient supplier, $x_{(1)}^{(n_A)}$, which defines the realized unit labor requirement in the local supplier industry. This effect reduces the demand for labor and therefore depresses the wage. These two effects of the size of the supplier industry on the local labor demand offset each other, making the expected wage (9) independent of the number of suppliers.

The ex ante expected profit of a supplier at location A is defined by

$$\begin{aligned} E(\pi_A) &= \frac{N_A}{n_A}E\left[\left(x_{(2)}^{(n_A)} - x_{(1)}^{(n_A)}\right)w_A q_A\right] = \frac{\beta N_A}{n_A}E\left[\frac{\left(x_{(2)}^{(n_A)} - x_{(1)}^{(n_A)}\right)}{x_{(2)}^{(n_A)}}\right] \\ &= \frac{\beta N_A}{n_A}\left[1 - E\left(\frac{x_{(1)}^{(n_A)}}{x_{(2)}^{(n_A)}}\right)\right] = \frac{\beta N_A}{2n_A}, \end{aligned} \tag{10}$$

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[19] The results presented in this section are more than an exercise based on the special case of the order statistics from the standard uniform distribution. It is well known that, if U is a Uniform [0, 1] random variable, then, for *any* distribution with *continuous* cumulative distribution function $F(x)$, the transformed random variable $F^{-1}(U)$ has distribution function F. Moreover, the order statistics $X_{(1)}^{n}, X_{(2)}^{(n)}, \ldots, X_{(n)}^{(n)}$ in a sample from *any continuous* distribution with cumulative distribution function $F(x)$ can be transformed by the *order-preserving* probability integral transformation $U = F(x)$ into the order statistics $U_{(1)}^{(n)}, U_{(2)}^{(n)}, \ldots, U_{(n)}^{(n)}$ from the standard uniform distribution (see Arnold *et al.*, 1992).

where q_A denotes the input demand of a typical assembler at location A. The second equality in (10) is obtained using (4),[20] and the fourth again uses the property that the ratio of the first and the second-order statistics in a random sample from the Uniform [0, 1] population is a random variable with the Uniform [0, 1] density.

The profit of a representative assembler in location A is given by

$$\Pi_A = \beta \ln q_A - x_{(2)}^{(n_A)} w_A q_A = \beta\left(\ln L_A - \ln x_{(2)}^{(n_A)} - \ln \sum_{i=1}^{N_A} \frac{x_{(1)i}^{(n_A)}}{x_{(2)i}^{(n_A)}} - 1\right). \tag{11}$$

Then the expected profit is defined by

$$E(\Pi_A) = E(\beta \ln q_A - x_{(2)}^{(n_A)} w_A q_A) = \beta\left(\ln L_A - E(\ln x_{(2)}^{(n_A)}) - E\left(\ln \sum_{i=1}^{N_A} \frac{x_{(1)i}^{(n_A)}}{x_{(2)i}^{(n_A)}}\right) - 1\right). \tag{12}$$

As I show in the Appendix, the assembler's expected profit (12) increases in the number of suppliers n_A and decreases in the number of assemblers N_A concentrated in the location. Therefore, the introduction of the labor market into the model creates a negative congestion externality from the assemblers' location decisions. Unlike the models considered in the previous sections, in the present setting assemblers are repulsed by places with a high overall density of assemblers.

Figures 2 and 3 show the loci for which assemblers, suppliers and workers are indifferent between locations A and B. At the center of a rectangle with the *shares* of suppliers and assemblers at location A on, respectively, the horizontal and vertical axes, the firms of both types are indifferent between the two locations because each location has the same number of them: $S_A/s_A = 0.5/0.5 = 1$. From (10) it is apparent that the locus of supplier indifference between the locations, SS in Figure 2, is characterized by the slope $S_A/s_A = 1$.[21] Moving away from the rectangle's center by increasing the number of suppliers requires an equal proportional increase in the number of assemblers to keep the suppliers indifferent between the locations.

From (12), it follows that the location indifference line of an assembler, AA in Figure 2, will be positively sloped and steeper than the indifference line of a supplier,[22] implying that equal division of suppliers and assemblers between the two locations is not a stable equilibrium. The dynamics of the model are indicated by the arrows. Even a very small amount of noise can destabilize the whole system and force it to converge to one of the two

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[20] It follows from the equation (4) that $q_A w_A = \beta / x_{(2)}^{(n_A)}$.

[21] This corresponds to a line with slope $0.5N/0.5n = N/n$ if SS is plotted on a rectangle whose sides are the absolute numbers of suppliers and assemblers at location A.

[22] This is due to the concavity of the logarithmic function and the fact that $0 < x_{(2)}^{(n_A)} < 1$. It can be shown that a more than proportional increase in the number of assemblers is needed to compensate for an increase in the number of suppliers and to preserve the assembler's expected profit at the same level. See the Appendix for further discussion.

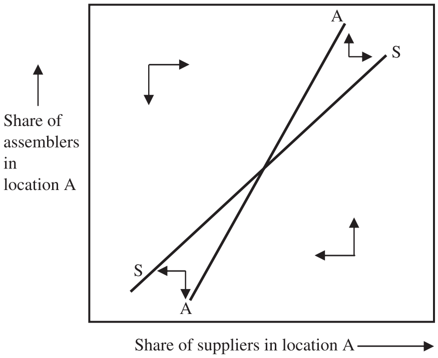

Figure 2. Dynamics of a spatial distribution of suppliers and assemblers in a *framework with the labor market*

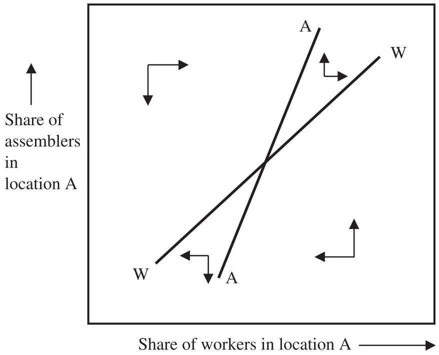

Figure 3. Dynamics of a spatial distribution of workers and assemblers

equilibria where all suppliers and assemblers concentrate either at location A or location B.

The dynamics of worker–assembler locational interaction are very similar to the supplier–assembler locational dynamics. The lines WW and AA in Figure 3 show which distributions of assemblers and workers will leave the typical assembler and worker, respectively, indifferent between locations A and B. Since the expected wage (9) depends only on the ratio of assemblers to workers, the locus of worker indifference between the two locations, WW, is a line with the slope equal to 1.[23]

The center of the rectangle in Figure 3 represents an equal distribution of assemblers and labor force between the two locations. The Appendix shows that to leave assemblers indifferent between locations A and B when the number of workers in location A increases at the expense of the number in location B, it would be necessary to offset the increase in the A's number of workers by a more than proportional increase in A's number of assemblers. Thus, the line AA in Figure 3 is steeper than WW. It is immediately apparent from the dynamics indicated by the arrows that the equilibrium in the middle is unstable, and therefore the assembler industry and the labor force end up concentrating either in location A or in location B.

Therefore despite the congestion effect due to the competition among suppliers for labor at each location, agglomeration still emerges as the stable equilibrium outcome in this framework; all three segments of the vertically linked industry (i.e. workers, upstream suppliers and downstream assemblers) end up concentrating in the same location.[24] Although the discrete nature of

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[23] This corresponds to a line with slope $0.5N/0.5L = N/L$ if WW is plotted on a rectangle whose sides are absolute numbers of workers and assemblers at location A.

[24] Since location choices of workers and suppliers do not affect each other's payoffs (i.e. wages (9) and supplier profits (10)), their respective location decisions in a $L_A \times n_A$ diagram will mimic the decisions of assemblers.

location decisions by agents in this setting precludes the comparative-statics analysis of the equilibrium size of geographical clusters of industries, the present model demonstrates that competition for scarce resources and congestion temper the centripetal forces of agglomeration economies. The results presented in this section, therefore, are broadly consistent with the existing empirical evidence that congestion externalities deter the continuous concentration of industries in urban areas.[25]

4. CONCLUSION

Spatial localization of the automobile industry in Michigan around the turn of the century, and more recent clustering of the electronics hardware and software industry in Silicon Valley, California, and of general aviation aircraft producers in Wichita, Kansas, are just a few of the examples pointing to the presence of agglomeration economies in high-growth industries with a high rate of innovation. The main goal of this paper is to suggest that the economic mechanism of agglomeration in young and highly innovative industries is different from the mechanism leading to a geographical concentration of mature manufacturing activity. This difference can be explained by the specifics of the relationship between vertically linked suppliers and assemblers in industries at early stages of their evolution. High labor intensity and the non-tradability of upstream products and services make the suppliers' investments site-specific. At the same time, the lack of stable interface standards between vertically linked segments of the high-growth industry implies that supplier products are customized to the specifications of individual assemblers rather than mass-produced to satisfy standardized assembler demand.[26]

The non-tradability of suppliers' products creates incentives for the suppliers to locate in areas where there is a large concentration of assembly firms, enabling the generic product or service to be easily customized to fit the needs of a number of local downstream assemblers. This is especially important given

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[25] Mano and Otsuka (2000) use the data on manufacturing employment growth in postwar Japan to analyze the relative importance of the 'pull' factors associated with the agglomeration economies and the 'push' factors associated with the congestion and increased factor prices in urban areas in the determination of industrial location. After examining the evolution of the impacts of these factors over time, they conclude that congestion and rising competition associated with urbanization are the strong built-in forces that lead to periods of reversal of concentration of manufacturing industries in urban areas.

[26] The geographic concentration of economic activity in mature industries is driven primarily by the mechanism that is based on economies of scale and arises in large-scale standardized production. Such a mechanism has been extensively studied in the 'new economic geography' literature (see Fujita *et al.*, 1999). In formal models employed in this literature, agglomerative forces are generated by the imperfectly competitive behavior of upstream supplier firms, which produce a continuum of differentiated intermediate goods and incur 'iceberg' trade costs, and the downstream firms' 'love of variety' of intermediate inputs. The latter is typically described by the Dixit–Stiglitz preferences and creates a 'forward linkage' force pushing the downstream firms to locations in which there is a greater concentration of upstream suppliers of differentiated intermediate goods. At the same time, demand generated by the downstream industry creates a 'backward linkage' force, since sites with a large concentration of downstream firms are preferred locations for the production of intermediate goods subject to economies of scale.

the uncertainty about the outcome of cost competition among the suppliers. At the same time, the entry of additional suppliers results in lower prices for inputs, which make locations with a higher supplier density more attractive to assemblers. The main message from the models considered above is that this circularity of the relationship between upstream and downstream location decisions creates an agglomerative force leading to spatial clusters of high-technology industries. This force is sufficiently strong to ensure that a concentration of the vertically linked suppliers and assemblers in one location will emerge as the equilibrium outcome even when the co-location of assemblers creates a negative externality owing to the limited supply of local labor.

Although the main focus of the model is the spatial distribution of highly innovative firms, the stochastic mechanism of agglomeration described in this paper could be applied with some modifications to the study of the geography of more mature industries, in which firms often base their location decisions on considerations of scale economies and proximity to markets. Increasing returns to scale in the models of trade in differentiated goods and agglomerative forces based on statistical economies of scale associated with risk-pooling effects are not mutually exclusive. It is a matter of further research to create an analytical framework encompassing increasing returns, love of variety and risk diversification.

The models analyzed in this paper have important policy implications. Because of the powerful role of geographical concentration in stimulating innovation and technical change, government policy can be essential in cluster formation. There are a number of examples of successful government policies aimed at reinforcing and widening the existing industrial clusters as well as creating the new ones. In Korea the government has established a special region for electronics companies in the Kumi area of Kyongsang-do Province. Massive government investments into specialized infrastructure and technical facilities in the region have been able to attract a variety of companies for which geographic concentration has eventually become self-reinforcing. Now the region is characterized by the presence of a diverse spectrum of vigorously competing electronics firms. As this experience suggests, the key to success in the policy aimed at the formation of regional industrial clusters lies in matching the core of the industry's needs with the local resources of the region, and in creating favorable conditions for competitive entry of specialized input suppliers.

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APPENDIX

PROPOSITION. *The assembler's expected profit (12) increases in the number of suppliers n_A and decreases in the number of assemblers N_A concentrated in location A.*

Proof: For the Uniform [0, 1] distribution of the unit labor requirement parameter x_i, the ratio of the first and the second-order statistics, $x_{(1)i}^{(n_A)}/x_{(2)i}^{(n_A)}$, is a Uniform [0, 1] random variable for any n_A (Arnold *et al.*, 1992). Therefore, $E(\ln \sum_{i=1}^{N_A}(x_{(1)i}^{(n_A)}/x_{(2)i}^{(n_A)}))$ is the expectation of the increasing logarithmic function of a sum of N_A independent non-negative random variables. Hence it should be increasing in N_A and invariant to changes in n_A, because

$$\ln \sum_{i=1}^{N_A''} \frac{x_{(1)i}^{(n_A)}}{x_{(2)i}^{(n_A)}} \geq \ln \sum_{i=1}^{N_A'} \frac{x_{(1)i}^{(n_A)}}{x_{(2)i}^{(n_A)}} \tag{A1}$$

whenever $N_A'' > N_A'$ and for $\forall n_A$. However,

$$E(\ln x_{(2)}^{(n_A)}) = \int_0^1 \ln(x) n_A(n_A-1)x(1-x)^{n_A-2}dx = n_A(n_A-1)\int_0^1 \ln(x)x(1-x)^{n_A-2}dx$$
$$= n_A(n_A-1)\left[\frac{1}{n_A^2} - \frac{1}{n_A(n_A-1)}\sum_{k=1}^{n_A-1}\frac{1}{k}\right] = 1 - \sum_{k=1}^{n_A}\frac{1}{k}, \tag{A2}$$

which clearly decreases in n_A.

Therefore, the assembler expected profit (12) increases in the number of suppliers n_A and decreases in number of assemblers N_A concentrated at location A. □

Finally, I demonstrate that the locus of assembler indifference between locations A and B is steeper than the 45° line. Using (12), and applying the Jensen inequality to concave logarithmic function, we have

$$\begin{aligned} E(\Pi_A) &= \beta\left(\ln L_A - E(\ln x_{(2)}^{(n_A)}) - E\left(\ln \sum_{i=1}^{N_A}\frac{x_{(1)i}^{(n_A)}}{x_{(2)i}^{(n_A)}}\right) - 1\right) \\ &\geq \beta(\ln L_A - E(\ln x_{(2)}^{(n_A)}) - \ln N_A - \ln \bar{U} - 1) \\ &= \beta\left(\ln\frac{L_A}{N_A} - E(\ln x_{(2)}^{(n_A)}) - \ln \bar{U} - 1\right), \end{aligned} \tag{A3}$$

where $\bar{U}$ is the mean of the standard uniform random variable. From (A3), it is apparent that an equal proportional increase in the number of assemblers would be insufficient to offset an increase in the number of workers in location A. In order to leave a representative assembler indifferent between the two locations, it would be necessary to increase A's share of workers more than proportionally to the increase in A's share of assemblers. Thus, the line AA is steeper than the line WW, which has a 45° slope.