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Innovative Clusters and the Industry Life Cycle *

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Abstract. The purpose of this paper is to link the propensity for innovative activity to spatially cluster to the stage of the industry life cycle. The theory of knowledge spillovers, based on the knowledge production function for innovative activity, suggests that geographic proximity matters the most where tacit knowledge plays an important role in the generation of innovative activity. According to the emerging literature of the industry life cycle, tacit knowledge plays the most important role during the early stages of the industry life cycle. Based on a data base that identifies innovative activity for individual states and specific industries for the United States, the empirical evidence suggests that the propensity for innovative activity is shaped by the stage of the industry life cycle. While the generation of new economic knowledge tends to result in a greater propensity for innovative activity to cluster during the early stages of the industry life cycle, innovative activity tends to be more highly dispersed during the mature and declining stages of the life cycle, particularly after controlling for the extent to which the location of production is geographically concentrated. This may suggest that the positive agglomeration effects during the early stages of the industry life cycle become replaced by congestion effects during the latter stages of the industry life cycle.

Key words: Innovation, life cycle, geography, clusters.

I. Introduction

In linking together the available evidence concerning the evolution of firms and industries over time into a coherent and compelling theoretical framework, Steven Klepper (1992, p. 2) has concluded that there is, "accumulating evidence supporting the idea of a prototypical life cycle" of industries. Two of the main focal points of this emerging literature is the evolution of *who* innovates and *how much* innovative activity is undertaken. According to Klepper (1992) the answers to both of these questions are very much linked to the stage of the life cycle in which an industry is operating.

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What remains virtually unexplored in the life cycle literature is *where* the innovative activity takes place. The question of the location of innovative activity is important because it reflects the best use of the available knowledge inputs generating that innovative activity.[1] The purpose of this paper is to suggest that the geographic link between knowledge inputs and outputs is shaped by the stage of the industry life cycle. In particular, we examine how the propensity for innovative to spatially cluster is influenced by the industry life cycle.

In the following section we summarise the findings from the literature identifying the role of innovative activity over the industry life cycle and introduce the theory suggesting that the propensity for innovative activity to geographically cluster will tend to be shaped by the stage of the industry life cycle. What emerges from this theory is that the importance of tacit knowledge in generating innovative activity shapes the degree to which innovative activity will cluster. And the relative importance of tacit knowledge in generating innovative activity varies considerably across the various stages of the industry life cycle. In the third section measurement issues are examined, including measuring the extent to which innovative activity in an industry is geographically concentrated or clustered, as well as the stage of the life cycle in which an industry is operating. An empirical model is specified in the fourth section, and the results are presented in the fifth section. Finally, a summary and conclusion are provided in the sixth section. The evidence provides considerable support that the propensity for innovative activity to spatially cluster is shaped by the specific phase of the life cycle within which an industry is operating. While certain types of knowledge sources, such as university research tend to lead to a clustering of innovative activity in the introduction stage of the life cycle but not during the growth stage, other knowledge sources, such as skilled labor, promote innovative clustering throughout the life cycle. Perhaps most striking is the finding that during the mature and declining stages of the life cycle increases in the geographic concentration of production tend to lead to greater and not less dispersion of innovative activity. It may be that *new ideas need new space*, at least during the mature and declining stages of the industry life cycle. In any case, the positive agglomeration effects during the early stages of the industry life cycle apparently are less important during the latter life cycle stages.

[1] The extent to which production and innovative activity is geographically concentrated has important implications across a broad spectrum of fields within economics. For example, one of the most striking implications from the new economic growth theories is that increasing returns to knowledge within a spatially bounded region result in a divergence of growth rates (Lucas, 1993; Romer, 1986 and 1990; and Grossman and Helpman (1991). Perhaps more than most other economic activities, innovation and technological change depend upon new economic knowledge. Thus, Romer (1986 and 1990), Krugman (1991a and 1991b) and Grossman and Helpman (1991), among others, have focused on the role that spillovers of economic knowledge across economic agents and firms play in generating increasing returns and ultimately economic growth.

II. The Theory of the Industry Life Cycle

As Steven Klepper (1992) emphasizes, there have been various renditions of what actually constitutes the industry life cycle.[2] For example, Oliver Williamson (1975, pp. 215–216) has depicted the industry life cycle as, "Three stages in an industry's development are commonly recognized: an early exploratory stage, an intermediate development stage, and a mature stage. The first or early formative stage involves the supply of a new product of relatively primitive design, manufactured on comparatively unspecialized machinery, and marketed through a variety of exploratory techniques. Volume is typically low. A high degree of uncertainty characterizes business experience at this stage. The second stage is the intermediate development state in which manufacturing techniques are more refined and market definition is sharpened, output grows rapidly in response to newly recognized applications and unsatisfied market demands. A high but somewhat lesser degree of uncertainty characterizes market outcomes at this stage. The third stage is that of a mature industry. Management, manufacturing, and marketing techniques all reach a relatively advanced degree of refinement. Markets may continue to grow, but do so at a more regular and predictable rate ... (e)stablished connections, with customers and suppliers (including capital market access) all operate to buffer changes and thereby to limit large shifts in market shares. Significant innovations tend to be fewer and are mainly of an improvement variety."

Seventeen years later Klepper (1992) points out that among the most heavily studied aspects of the life cycle is the evolution of the number of firms. For example, Gort and Klepper (1982) and Klepper and Graddy (1990) examine 46 major new products introduced during the previous century and find that following an initial period of substantial growth in the number of independent producers, a sharp drop, or what they refer to as a *shakeout* occurs. Klepper and Graddy (1990) found that on average the number of firms in the industry was reduced by slightly more than one-half during the shakeout phase. These studies typically find that the entry of new firms is the greatest during the formation stage of a new industry, and then levels off and begins to decline, even before the industry has attained the mature phase. What Klepper and Miller (1995) term as the *shakeout phase*, where the greatest number of exits from the industry occurs, typically takes place well after the number of new entrants into the industry has declined. The combination of the drop in the number of new entrants along with the high number of exiting firms during the shakeout phase leads to a decline in the total number of firms during the mature and declining stage of the life cycle.

Klepper (1992) also emphasizes that an analogous evolution with respect to innovative activity occurs over the course of the industry life cycle.[3] In particular,

[2] Actually, Klepper's (1991 and 1995) own work refers to the life cycle of specific *products* and not necessarily industries.

[3] Klepper (1992 p. 6) points out that, "Generalizations about innovation are typically based on individual product studies that focus on innovation, a few of which compile counts of innovations

Klepper (1992) has identified three distinct patterns of innovative activity with respect to a product's life cycle. The first is that (product) innovative activity tends to be the greatest during the earliest phases of the life cycle. Second, during the early and growth stages, "the most recent entrants account for a disproportionate share of the major product innovations that are introduced" (Klepper, 1992, p. 6). Finally, as the stage of the life cycle evolves towards maturity, there is a distinct and pronounced shift in the locus of innovative activity, away from new entrants and towards established enterprises.

Thus, an important conclusion drawn by Klepper (1992) is that the industry life cycle can be characterized by a number of different phenomena, including the nature of innovative activity. In particular, during the early stages of the industry life cycle, there is a high amount of innovative activity and new and smaller enterprises tend to have the relative innovative advantage. During the mature stages of the industry life cycle, there tends to be less (product) innovative activity, and established large enterprises tend to have tke innovative activity. Thus, the early stages of the industry life cycle correspond with what Sydney G. Winter (1984, p. 297) characterized as the *entrepreneurial technological regime*, where "An entrepreneurial regime is one that is favorable to innovative entry and unfavorable to innovative activity by established firms." By contrast, the more mature stages of the industry life cycle tend to correspond with what Winter (1984, p. 297) characterized as the *routinized technological regime*, where the established incumbent enterprises tend to have the innovative advantage and the new entrants are confronted by an inherent innovative disadvantage.

1. The Geography of Innovation

While Klepper (1992), Audretsch (1995) and others have focused on *who* innovates and *how much* innovative activity is undertaken, they have generally overlooked another much neglected dimension of innovative activity – where does the innovative activity take place.[4] The location of innovative activity might not matter in the absence of what has become known as *knowledge spillovers*. New economic knowledge is said to spill over when the unit of observation which utilizes that new economic knowledge is distinct from the one that produced it. These knowledge spillovers do not, however, transmit costlessly with respect to geographic distance. Rather, location and proximity matter. That is, while the costs of transmitting *information* may be invariant to distance, presumably the cost of transmitting *knowledge* and especially *tacit knowledge* rises along with distance.[5] Thus, Glaeser, Kallal, Scheinkman, and Schleifer (1991, p. 1127) characterize the

over hme, sometimes broken down into process and product innovations. Not surprisingly, these studies focus on products with rich opportunities for both product and process innovation."

[4] For several studies focusing on the geography of innovative activity see Feldman (1994a and 1994b).

[5] *Fortune* magazine emphasizes the importance of geographic proximity in generating knowledge spillovers because, "business is a social activity and you have to be where the important work is

Marshall-Arrow-Romer model as suggesting that, "intellectual breakthroughs must cross hallways and streets more easily than oceans and continents."

Fortune magazine recently suggested that proximity to sources generating potentially new economic knowledge, such as research universities and the location of R&D laboratories of major corporation may explain the high propensity for knowledge workers to cluster in several geographic regions.[6] For example, a survey of nearly one thousand executives located in America's sixty largest metropolitan areas ranked Raleigh/Durham as the best city for knowledge workers and for innovative activity in the United States.[7] *Fortune* magazine reports, "A lot of brainy types who made their way to Raleigh/Durham were drawn by three top research universities U.S. businesses, especially those whose success depends on staying atop new technologies and processes, increasingly want to be where hot new ideas are percolating. A presence in brain-power centers like Raleigh/Durham pays off in new products and new ways of doing business Dozens of small biotechnology and software operations are starting up each year and growing like[8] *kudzu* in the fertile business climate."

And *Business Week* reports a cluster of innovative activity located in the Seattle region, "These startups clustered in and around Seattle are determined to strike it big in multimedia, a new category of software combining video, sound, and graphics. Why Seattle? First and foremost, there's Microsoft Corp. The $4.5 billion software giant has brought an abundance of programming whiz kids to the area, along with scores of software startups. But these young companies also draw on Seattle's right-brain side: its renowned music scene, acclaimed theater, and a surprising array of creative talent including filmmakers, animators, writers, producers, and artists."[9]

Considerable evidence has been found suggesting that location and proximity clearly matter in exploiting knowledge spillovers. Not only have Jaffe, Trajtenberg and Henderson (1993) found that patent citations tend to occur more frequently within the state in which they were patented than outside of that state, but Audretsch and Feldman (1995) found that the propensity of innovative activity to cluster geographically tends to be greater in industries where new economic knowledge plays

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taking place" (*Fortune*, "The Best Cities for Knowledge Workers November 15 1993, pp. 44–57, p. 46).

[6] Ibid.

[7] The survey was carried out in 193 by the management consulting firm of Moran, Stahl & Boyer (New York City).

[8] *Fortune* magazine reports, "What makes the (triangle) park work so well is a unique nexus of the business community, area universities, and state and local governments.... It is home to more than 34,000 scientists and researchers and over 50 corporate, academic and, government tenants specializing in microelectronics, telecommunications, chemicals, biotechnology, pharmaceuticals, and environmental health sciences", *ibid.*, p. 46.

[9] "Seattle, A Multimedia Kind of Town: Microsoft's Backyard is Home to a Host of CD-ROM Upstarts", *Busines Week*, July 25, 1994, p. 44.

a more important role.[10] In studying the networks in California's Silicon Valley, Anna Lee Saxenian (1990, pp. 96–97) emphasizes that it is the communication between individuals which facilitates the transmission of knowledge across agents, firms, and even industries, and not just the high endowment of workers' knowledge that is conducive to innovative activity: "It is not simply the concentration of skilled labor, suppliers and information that distinguish the region. A variety of regional institutions – including Stanford University, several trade associations and local business organizations, and a myriad of specialized consulting, market research, public relations and venture capital firms – provide technical, financial, and networking services which the region's enterprises often cannot afford individually. These networks defy sectoral barriers: individuals move easily from semiconductor to disk drive firms or from computer to network makers. They move from established firms to startups (or vice versa) and even to market research or consulting firms, and from consulting firms back into startups. And they continue to meet at trade shows, industry conferences, and the scores of seminars, talks, and social activities organized by local business organizations and trade associations. In these forums, relationships are easily formed and maintained, technical and market information is exchanged, business contacts are established, and new enterprises are conceived.... This decentralized and fluid environment also promotes the diffusion of intangible technological capabilities and understandings".[11]

Of particular importance in providing a source of innovating-generating knowledge are research scientists at universities. Jaffe (1989) and Acs, Audretsch, and Feldman (1992 and 1994), for example, find that the knowledge created in university laboratories *spills over* to contribute to the generation of commercial innovations in the private sector. Acs, Audretsch and Feldman (1994) and Feldman (1994a and 1994b) find persuasive evidence that spillovers from university research contribute substantially to the innovative activity of private corporations. Similarly, Link and Rees (1990) find that private corporations are able to exploit their university-based associations to generate innovations. And Zucker, Darby and Brewer (1994, p. 1) provide considerable evidence suggesting that the timing and location of new biotechnology firms is "primarily explained by the presence at a particular time and place of scientists who are actively contributing to the basic science."

Studies identifying the extent of knowledge spillovers are based on the knowledge production function. As introduced by Zvi Griliches (1979), the knowledge production function links inputs in the innovation process to innovative outputs. Griliches pointed out that the most decisive innovative input is new economic knowledge, and the greatest source that generates new economic knowledge is

[10] Audretsch and Stephan (1995) and Zucker, Darby and Brewer (1994) have found that the propensity to cluster spatially in the biotechnology industry is high.

[11] Saxenian (1990, pp. 97–98) claims that even the language and vocabulary used by technical specialists is specific to a region, "... a distinct language has evolved in the region and certain technical terms used by semiconductor production engineers in Silicon Valley would not even be understood by their counterparts in Boston's Route 128."

generally considered to be R&D. Jaffe (1989), and Acs, Audretsch and Feldman (1992 and 1994), and Feldman (1994a and 1994b) modified the knowledge production function approach to a model specified for spatial and product dimensions:

$$I_{si} = IRD^{\beta_1} * UR_{si}^{\beta_2} * (UR_{si} * GC_{si}^{\beta_3}) * \varepsilon_{si} \qquad (1)$$

where I is innovative output, IRD is private corporate expenditures on R&D, UR is the research expenditures undertaken at universities, and GC measures the geographic coincidence of university and corporate research.[12] The unit of observation for estimation was at the spatial level, s, a state, and industry level, i.

While there is considerable evidence supporting the existence of knowledge spillovers, neither Jaffe (1989), Jaffe, Trajtenberg and Henderson (1993), nor Acs, Audretsch and Feldman (1992 and 1994), and Feldman (1994a and 1994b) actually examined the propensity for innovative activity to cluster spatially. But implicitly contained within the knowledge production function model is the assumption that innovative activity should take place in those regions, s, where the direct knowledge-generating inputs are the greatest, and (2) where knowledge spillovers are the most prevalent.

During the early stages of the industry life cycle, tacit knowledge should play a relatively more important role in generating innovative activity. There are no widely accepted standards with respect to product specifications, so that obtaining information about what consumers want and how it can be produced demands proximity to the knowledge sources. By contrast, during the latter stages of the industry life cycle, tacit knowledge plays a much less important role. In the mature stage most of the technical aspects of the product have become standardized, and the nature of demand is well known. At this point the cost of transmitting information over geographic space becomes trivial. Thus, the propensity for innovative activity to geographically cluster would be expected to be relatively high during the early stages of the product life cycle and then decline as the industry evolves over the life cycle towards maturity.

III. Measurement

In linking the industry life cycle to the propensity for innovative activity to cluster a number of measurement issues must be addressed. The most general issue is how to measure innovative activity. The second issue is how to measure the geographic concentration and dispersion of that innovative activity. And the third issue is how to measure the industry life cycle.

[12] Jaffe (1989) argued that the proximity of university research to corporate laboratories should raise the potency of spillovers from university laboratories. While Jaffe (1989) was not able to provide evidence supporting this hypothesis, Acs, Audretsch and Feldman (1992) did find evidence.

1. Innovative Activity

Paul Krugman (1991a, p. 53) has surrendered the possibility of directly measuring innovative activity because, "knowledge flows are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes." But Jaffe, Trajtenberg and Henderson (1993, p. 578) point out that, "knowledge flows do sometimes leave a paper trail" – in particular, in the form of innovation citations. To measure the spatial distribution of innovative activity we rely on the most recent and most ambitious data base that provides a direct measure of innovative activity. The United States Small Business Administration (the Small Business Administration's Innovation Data Base or the SBIDB) compiled a data base of 8,074 commercial innovations introduced in the United States in 1982. A private firm, The Futures Group, compiled the data and performed quality control analyses for the United States Small Business Administration. A data base consisting of innovations by four-digit standard industrial classification (SIC) industries was formed from the new product announcement sections in over one hundred technology, engineering and trade journals that span every industry. The SBIDB contains a total of 4,476 innovations in manufacturing industries. Of these, there are 276 innovations which can not be used because they were introduced by establishments outside of the United States or did not have complete locational information.

2. The Geographic Concentration of Innovative Activity

We adapt the state as the spatial unit of observation. While this is clearly at best a crude proxy of the relevant economic market,[13] it does have one obvious appeal other than that it conforms to a number of data sources – the most relevant unit of policy making is at the level of the state. As *Business Week* recently pointed out, "States are still the important engines in domestic policy."[14]

Using the citation data base described above an innovation is attributed to the state in which the establishment responsible for the development of the innovation is located. Some innovations are, in fact, developed by subsidiaries or divisions of companies with headquarters in other states. Since headquarters may announce new product innovations, the data base discriminates between the location of the innovating establishment and the location of the larger, innovating entity (Edwards and Gordon, 1984). For our purposes, the state identifier of the establishment is used to investigate the spatial distribution of innovation. Of the total number of innovations recorded in the data base, 4,200 were manufacturing innovations with information specifying the location.

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[13] As Paul Krugman (1991, p. 57) emphasizes, "States aren't really the right geographical units," because of disparities in population and lack of concordance between economic markets and political units.

[14] "America's Heartland: The Midwest's New Role in the Global Economy," *Business Week*, July 25, 1995, p. 35.

To actually measure the extent to which innovative activity in a specific four-digit SIC (standard industrial classification) industry is concentrated within a geographic region, we follow Paul Krugman's (1992) example and calculate gini coefficients for the geographic concentration of innovative activity. The gini coefficients are weighted by the relative share of economic activity located in each state. Computation of weighted gini coefficients enables us to control for size differences across states. The gini coefficients are based on the share of activity in a state and industry relative to the state share of the national activity for the industry. Cases in which state or industry data have been suppressed have been omitted from the analysis. Table I ranks the gini coefficients of the number of innovations across the 48 continental states (excluding Hawaii and Alaska) for those four-digit SIC industries exhibiting the highest propensity to cluster spatially, as well as the corresponding values of the gini coefficients based on manufacturing value added and employment. Thus, innovative activity in the electronic components industry tended to be the most geographically concentrated, followed closely by switchgear apparatus and telephones.

Of course, as Jaffe, Trajtenberg and Henderson (1993) point out, one obvious explanation why innovative activity in some industries tends to cluster geographically more than in other industries is that the location of production is more concentrated spatially. Thus, in explaining why the propensity for innovative activity to cluster geographically varies across industries, we need first to explain, and then control for, the geographic concentration of the location of production. Corresponding gini coefficients for the location of manufacturing (value added) are also included in Table I.

There are three important tendencies emerging in Table I. first, there is no obvious simple relationship between the gini coefficients for production and innovation. Second, the gini coefficient of the number of innovations exceeds that of value added and employment in those industries exhibiting the greatest propensity for innovative activity to cluster spatially. By contrast, the gini coefficients of innovative activity for most industries is less than that for value added and employment.

Third, those industries exhibiting the greatest propensity for innovative activity to cluster are high-technology industries. There are, however, several notable exceptions. For example, in motor vehicle bodies, which is certainly not considered to be a high-technology industry, the geographic concentration of production of innovative activity is the seventh greatest in Table I. One reason may be the high degree of geographic concentration of production, as evidenced by gini coefficients for value added (0.9241) and employment (0.8089) that actually exceed that of innovative activity (0.6923). This points to the importance of controlling for the geographic concentration of production in explaining the propensity for innovative activity to spatially cluster. And finally, the gini coefficient for value added exceeds that for employment in virtually every industry.

TABLE I. Geographic concentration of production for industries with highest propensity for innovative activity to cluster

		Gini coefficients		
		Innovation	Value-added	Employment
3679	Electronic components	0.7740	0.5889	0.5854
3613	Switchboard apparatus	0.7420	0.7791	0.4951
3661	Telephones	0.7242	0.7576	0.6076
3621	Motors & generators	0.7143	0.6480	0.4468
3651	Radio & TV receiving sets	0.7088	0.8495	0.4339
2511	Wood household furniture	0.7085	0.6288	0.5588
3711	Motor vehicle bodies	0.6923	0.9241	0.8089
2834	Pharmaceuticals	0.6916	0.7816	0.6771
3537	Industrial trucks	0.6862	0.6384	0.4459
2824	Organic fibers	0.6856	0.7617	0.7086
3612	Transformers	0.6376	0.7362	0.3841
2614	Paper coating	0.6374	0.6023	0.2847
3563	Air & gas compressors	0.6349	0.6010	0.3937
3824	Fluid meters & devices	0.6295	0.7463	0.5463
3648	Lighting equipment	0.6282	05828	0.6793
3576	Scales & balances	0.6256	0.6591	0.6950
2038	Frozen specialities	0.6231	0.6236	0.7076
3822	Environmental controls	0.5904	0.7447	0.4423
2751	Commercial printing	0.5822	0.5585	0.5621
2821	Plastics materials & resins	0.5792	0.8368	0.7645
3569	General industrial machines	0.5736	0.4869	0.6446
3494	Valves & pipe fitting	0.5685	0.4831	0.5062
2522	Metal office furniture	0.5569	0.6993	0.7785
2648	Stationery products	0.5443	0.6829	0.5712
2851	Paints	0.5434	0.5433	0.3414
3469	Metal stampings	0.5431	0.5970	0.4238
3356	Nonferrous rolling & drawing	0.5420	0.6661	0.7281

3. The Industry Life Cycle

Klepper and Gort (1982), Klepper and Graddy (1990) and Klepper and Miller (1995) all measure the stage of the industry life cycle by tracking the evolution of an industry starting with its incipiency, based on a wave of product innovations. But the measures of geographic concentration and dispersion, for both innovation and the location of production, documented in the previous section, are available only for one point of time. That is, these measures provide a snapshot at a single point in time for each industry. Thus, the life cycle stage of each industry at this point in

TABLE I. Continued

		Gini coefficients		
		Innovation	Value-added	Employment
2086	Bottled & canned soft drinks	0.5385	0.6454	0.6465
3535	Conveyors & related equipment	0.5366	0.5727	0.5702
3585	Refrigeration equipment	0.5363	0.5928	0.5941
2521	Wood office furniture	0.5347	0.7641	0.4293
3728	Aircraft equipment	0.5333	0.8654	0.7384
3629	Electrical apparatus	0.5328	0.5712	0.6708
3442	Metal doors	0.5318	0.3131	0.2653
2542	Metal partitions	0.5309	0.3576	0.3636
3799	Transportation equipment	0.5290	0.6417	0.5419
3732	Boat building	0.5268	0.7241	0.5252
3552	Textile machinery	0.5219	0.7217	0.5769
2992	Lubricating oils	0.5196	0.8637	0.5495
3589	Service industry machinery	0.5107	0.6376	07307
3079	Plastic product	0.5107	0.4298	0.3703
2865	Cyclic crudes & intermediates	0.5041	0.8355	0.8256
3069	Fabricated rubber products	0.5012	0.6910	0.6472
3851	Ophthalmic goods	0.5004	0.8221	0.5660
3499	Fabricated metal products	0.4902	0.4426	0.4070
3549	Metalworking machines	0.4893	0.5834	0.6148
2034	Dehydrated fruits	0.4878	0.8282	0.7784
3312	Blast furnaces	0.4848	0.8167	0.7032
3559	Special industry machinery	0.4770	0.4873	0.6147
3674	Semiconductors/related	0.4731	0.8527	0.7134

time needs to be measured.[15] As discussed in the second section of this paper, the life cycle framework proposed by Klepper (1992) suggests that the degree of (product) innovative activity combined with the type of firm generating the innovative activity sheds corresponds to the stage of the industry life cycle. More specifically, industries which are highly innovative and where that innovative activity tends to come from small firms are better characterized as being in the introduction stage of the life cycle. Industries which are highly innovative and where the large firms tend to generate that innovative activity are better characterized by the growth stage of the life cycle. Industries which are low innovative and where large firms have a higher propensity to innovate are better characterized by the mature stage of the life cycle. And finally, industries which are low innovative and where small firms have a higher propensity to innovate are best characterized by the declining stage of the life cycle. The higher propensity to innovate of small enterprises vis-à-vis their

[15] See Audretsch (1987) for a study measuring the stage of the industry life cycle within a cross-section framework.

larger counterparts may reflect the seeds of the introductory phase of the life cycle of new products emerging in what would otherwise be a declining industry.

This framework was used to classify 210 four-digit SIC industries into these four stages of the life cycle. High innovative industries were rather arbitrarily defined as those industries exhibiting innovative activity in excess of the mean. Low innovative industries were similarly defined as those industries with innovative rates less than the mean. The innovation rate is defined as the number of innovations divided by the number of employees in the industry (measured in thousands). The innovation rate is used rather than the absolute number of innovations in order to control for the size of the industry. That is if two industries exhibit the same number of innovations but one industry is twice as large as the other, it will have an innovation rate one-half as large as the other industry. To measure the relative innovative advantage of large and small firms, the small-firm innovation rate is compared to the large-firm innovation rate, where the small-firm innovation rate is defined as the number of innovations made by firms with fewer than 500 employees divided by small-firm employment and the large-firm innovation rate is defined as the number of innovations made by firms with at least 500 employees divided by large-firm employment.

Using this classification system, 62 of the industries were classified as being in the introductory stage of the life cycle (defined as highly innovative and the small firms have the innovative advantage), 32 industries were classified as being in the growth stage of the life cycle (defined as highly innovative and the large firms have the innovative advantage), 64 industries were defined in the mature stage of the life cycle (defined as low innovative and the large firms have the innovative advantage), and 52 were defined in the declining stage of the life cycle (defined as low innovative and the small firms have the innovative advantage).

IV. Model

1. Clustering of Production

In addressing the question, "Why should innovations tend to cluster spatially more in some industries than in other industries," one obvious answer is simply that the location of production is more geographically concentrated in some industries than in others. As Jaffe, Trajtenberg and Henderson (1993, p. 579) point out, "The most difficult problem confronted by the effort to test for spillover localization is the difficulty of separating spillovers from correlations that may be due to a pre-existing pattern of geographic concentration of technology related activities. That is, if a large fraction of citations to Stanford patents comes from the Silicon Valley, we would like to attribute this to localization of spillovers. A slightly different interpretation is that a lot of Stanford patents relate to semiconductors, and a disproportionate fraction of the people interested in semiconductors happen to be in the Silicon Valley, suggesting that we would observe localization of citations even if proximity offers no advantage in receiving spillovers. Of course, the ability to receive spillovers is probably one reason for this pre-existing concentration of activity."

Thus, Jaffe, Trajtenberg and Henderson (1993) identify two critical issues which must be considered in trying to identify why the propensity for innovative activity to cluster spatially varies across industries. First, the extent to which the location of production is geographically concentrated must be controlled for, so that the relevant question becomes, "Even after accounting for the geographic concentration of the location of production, why does the propensity for innovative activity to cluster vary across industries?" And second, in trying to account for the degree to which the location of production is geographically concentrated, an important factor is the extent to which knowledge spillovers play a role in the industry. The impact that new economic knowledge plays in concentrating production has been pointed out by Browne (1980, p. 6), who observed that, "Industries which are undergoing rapid change and innovation and which produce speciality products tend to cluster together because of the need for specialised resources, particularly skilled labor, not available elsewhere." Similarly, Markusen, Hall and Glasmeier (1986) argue that the new firms and potential competitors strategically locate within close geographic proximity of the information sources in new and highly innovative industries.

Of course, while knowledge externalities may be important in influencing the degree to which the location of production is spatially concentrated, they are certainly not the only factor. Krugman (1991a) points out that the extent to which the location of production is geographically concentrated will be shaped by transportation costs. Similarly, industries which are highly dependent upon natural resource inputs are also going to tend to be geographically concentrated – presumably close to the source of those inputs. In addition, Shelburne and Bednarzik (1993) argue that industries which are more capital-intensive will tend to be geographically concentrated, since production will tend to be concentrated among fewer enterprises. That is, as capital intensity and the importance of scale economies rises, a fewer number of larger establishments will be able to exist at a level of output in excess of the minimum efficient scale (MES) level of output. At the same time, the larger the size of the market, the more spatially dispersed production location will be, since presumably more firms will be able to produce at an optimal scale of production.

We incorporate these forces that shape the degree to which the location of production tends to be geographically concentrated, as measured by the gini coefficient for value-added of the four-digit SIC industry, by including as exogenous variables:

• Transportation costs, as measured by the radius of the mean distance shipped. This measured was taken from Leonard Weiss (1991) and is constructed from the *Commodity Transport Survey of the United States Census of Transportation*, 1967.[16] Transportation costs are inversely related to the mean distance shipped, that

[16] A more recent year is not available. We assume that the structure of transportation costs across industries is relatively invariant over time.

higher values of transportation costs should be associated with a greater geographic concentration of production.

• The dependence upon natural resources, as measured by the share of total industry inputs that are purchased from mining and agriculture, 1967. This measure was derived from Input-Output data.[17] Loesch (1954) and Fuchs (1962) argue that firms in industries with a high dependency on natural resource inputs will tend to locate in close proximity to those resources. Therefore, a higher content of natural resource inputs in an industry should result in a greater geographic concentration of the location of production.

• The extent of scale economies, as measured by the mean establishment size of the largest one-half of establishments in the industry, divided by value-of-shipments in the industry. After controlling for the size of the market, a higher degree of scale economies is expected to result in fewer enterprises of efficient scale and ultimately a greater degree of geographic concentration of production.

• While it is not possible to directly measure the extent to which tacit knowledge plays in the industry, as Arrow (1962) and Krugman (1991a) point out, it is possible to identify industries in which new economic knowledge plays a relatively more important role. Presumably in such industries tacit knowledge also plays a more important role. This is done by including the R&D-sales ratio, which is taken from the 1977 *Line of Business Survey* undertaken by the United States Federal Trade Commission.[18] The crucial assumption we make here is Arrow's 1962 argument that knowledge externalities are more important in, and reflected at least to some degree by, highly R&D intensive industries. By contrast, the role of tacit knowledge, while perhaps still present, presumably plays a less important role where the creation of new economic knowledge, as reflected by R&D intensity, is negligible. Thus, the location of production would be expected to be more concentrated in those industries where the externalities of tacit knowledge are prevalent, that is in industries which are R&D intensive.

• The degree of human capital, as measured by the share of 1970 employment accounted for by professional and kindred workers, plus managers and administrators (except farm), plus craftsmen and kindred workers.[19] The greater the extent to which the industry work force is comprised of skilled workers, the more important knowledge spillovers are likely to be. Thus, industries which rely on a higher com-

[17] The source of the measure of natural resource dependence is the *United States International Trade Commission Data Bank.*

[18] Edwards and Gordon (1982) found that the 1982 innovations resulted from inventions made on average 4.2 years earlier. Thus, it seems reasonable that innovations correspond to R&D inputs made around 1977, which allows for an appropriate time lag to transmit knowledge into commercial products.

[19] This measure is at the three-digit SIC level and has been repeated across four-digit SIC industries common to each three-digit industry. While the variable is taken from the data bank of the United States International Trade Commission, the original source is the United States Department of Commerce, Bureau of the Census, Census of Population, Subject Report PC (2)-7C, *Occupations by Industry*, Washington D.C., 1972.

ponent of skilled workers should tend to exhibit a greater tendency towards spatial concentration of industrial location.

2. CLUSTERING OF INNOVATIVE ACTIVITY

As was previously emphasized, it is only after the extent to which the geographic concentration of production has been controlled for that the degree to which innovative activity spatially clusters can be addressed. Thus, the starting point of explaining the propensity for innovative activity to cluster spatially is the extent to which production is geographically concentrated. In addition, the main hypothesis of this paper suggests that innovative activity will tend to cluster in industries where new economic knowledge plays an especially important role – and particularly during the early stages of the industry life cycle.

We include three sources of economic knowledge in estimating the gini coefficient of innovative activity – industry R&D, the share of the labor force accounted for by skilled labor, and the amount of university research devoted to each industry.[20] The amount of university research devoted to each industry, academic department were assigned to industries using a survey of industrial R&D managers by Levin et al. (1982 and 1987).[21] For example, basic scientific research in medicine, biology, chemistry and chemical engineering is found to be relevant for product innovation in drugs (SIC 2834). University research expenditures are taken from the National Science Foundation's (NSF) *Survey of Science Resources*.

V. Results

Based on the classification system described in Section III of this paper, Table II presents the regression results estimating the gini coefficient of manufacturing value added across states and Table III presents the regression results estimating the gini coefficient of innovative activity across states. These regressions are estimated in comparable pairs, using the three-stage least squares (3SLS) estimation technique. The estimates of the coefficients of the (3SLS) equations for the geographic concentration of production exhibit remarkable stability and consistency across the four stages of the industry life cycle. For example, the positive and statistically significant coefficients of *Transportation Costs* in each for each of the phases of the industry life cycle suggest that production tends to be more geographically concentrated as transportation costs increase, regardless of the stage of the life

[20] There are great differences in the scope and commercial applicability of university research undertaken in different fields. Academic research will not necessarily result in useful knowledge fore every industry; however, scientific knowledge from certain academic departments is expected to be more important for certain industries than for others.

[21] To measure the relevance of a discipline to an industry the question was asked, ">How relevant were the basic sciences to technical progress in this line of business over the past 10–15 years?" The survey uses a Linkert scale of 1 to 7 to assess relevance. The variable we construct is the sum of university research expenditures for any department which is rated with a relevance greater than a value of 5 on the Linkert scale.

TABLE II. Regression results estimating geographic concentration of production across states (*t*-values in parentheses)

	Birth	Growth	Maturity	Decline
Transportation	20.442	32.310	6.299	12.322
	(3.488)	(3.960)	(1.775)	(1.758)
Natural resources	0.399	0.266	0.408	0.288
	(3.942)	(2.001)	(1.831)	(2.859)
Scale economies	−0.020	−0.016	−0.020	−0.029
	(−2.001)	(−3.863)	(−2.148)	(−2.278)
R&D	4.816	4.165	5.829	4.954
	(3.947)	(4.075)	(3.694)	(4.605)
Skilled labor	0.859	0.679	1.263	1.063
	(4.811)	(3.824)	(3.694)	(8.101)
Sample Size	62	32	64	52
R^2	0.952	0.970	0.922	0.971

TABLE III. Regression results estimating geographic concentration of innovation across states (*t*-values in parentheses)

	Birth	Growth	Maturity	Decline
Production gini	0.104	−0.273	−0.200	−0.237
	(0.512)	(−1.279)	(−2.008)	(−1.633)
University research	4.981	4.361	1.791	1.514
	(1.895)	(1.113)	(7.373)	(4.539)
R&D	26.090	83.630	0.024	7.970
	(0.968)	(1.588)	(0.041)	(3.186)
Skilled labor	0.618	1.076	0.611	0.64
	(1.770)	(2.997)	(3.068)	(2.751)
Sample size	62	32	64	52
R^2	0.795	0.833	0.755	0.751

cycle. Similarly, the positive and statistically significant coefficients of *Natural Resources* suggest that a high dependence on natural resources tends to result in a greater geographic concentration of production in all four of the life cycle phases. The negative coefficient of *Scale Economies* is the opposite of the expected positive coefficient, and suggests that *ceteris paribus*, production tends to be more dispersed rather than more concentrated in industries where scale economies play an important role. One explanation for this surprisingly coefficient may be that this measure implicitly assumes that the size of the market is restricted to the United States. However, to the extent that many manufacturing industries are global in scale, this measure will tend to be overstated.

The coefficient of industry R&D is positive and clearly statistically significant for all four phases of the life cycle. Similarly, the positive and statistically significant coefficient of the extent of skilled labor suggests that the location of production tends to be more geographically concentrated in industries where new economic knowledge plays an important role, regardless of the phase of the life cycle.

While the results for the geographic concentration of production do not appear to be sensitive to the stage of the industry life cycle, Table III shows that the same cannot be said for the propensity for innovative activity to cluster. Using the 3SLS method of estimation, the extent to which production is geographically concentrated is found to significantly influence the propensity for innovative activity to cluster during the mature and declining stages of the life cycle but not during the introduction and growth stages. What is perhaps more surprising is the negative coefficient of the gini coefficient of value added in the mature and declining stages. This suggests that innovative activity tends to exhibit a lower propensity to cluster spatially as the geographic concentration of production rises during the mature and declining stages of the industry life cycle. While this negative coefficient of the gini of value added is at first glance perplexing, we will come back to it after considering all of the results in a fuller context to provide at least some resolution.

The coefficient of *University Research* is positive and statistically significant in the introduction phase of the life cycle, as well as in the mature and declining phases, but not during the growth phase. By contrast, the propensity for innovative activity to cluster tends to be systematically higher in industries which are R&D intensive during the declining phase of the life cycle, but not during the first three phases. Innovative activity exhibits a greater propensity to cluster in industries where skilled labor accounts for a greater share of the labor force during each of the four phases of the industry life cycle. This may suggest that skilled labor is a more decisive mechanism for the transmission of tacit knowledge than is either university research or industry research.

The rather perplexing negative coefficients of the gini of value added in the mature and declining stages of the industry life cycle can perhaps be reconciled by recalling the point made by Jaffe, Trajtenberg, and Henderson (1993) that a high degree of geographic concentration of production will also tend to exhibit a high propensity for innovative activity to cluster, simply because the bulk of firms are already located close to each other. However, after taking into account the extent to which new economic knowledge is crated from the three different sources, the resulting negative coefficient suggests that innovative activity will actually tend to have a lower propensity to cluster as the concentration of production rises, than would otherwise be predicted by the relative importance of the three knowledge sources.

Remembering the positive impact of new economic knowledge on the geographic of production from Table II, this may indicate that the relative importance of knowledge spillovers where new economic knowledge plays an important role will tend to promote a clustering of innovative activity. At the same time there is at least some tendency for that innovative activity to take place outside of the location where the bulk of production is located. The may reflect, at least to some extent, an inherent tension between the propensity for innovative activity to cluster in order to exploit the value of such knowledge spillovers, but at the same time to seek out new economic space because, *new ideas need new space*, at least during the mature and declining stages of the life cycle. This is consistent with the gini coefficients for value added of 0.8167 and employment of 0.7032 in the steel industry (blast furnaces) in Table I, which are considerably greater than the gini coefficient for innovative activity of 0.4848. This greater dispersion of innovative activity than of production in the steel industry may reflect the shift in new economic activity away from the vertically integrated steel mills in the midwest and towards the emergence of the mini-mills located in the south of the United States.[22] The steel industry (blast furnaces) is classified as a declining industry according to our analysis. In any case, industries where tacit knowledge plays a decisive role also tend to exhibit a greater geographic concentration of production. It appears that the propensity for innovative activity to cluster spatially is more attributable to the influence of spillovers of tacit knowledge and not merely the geographic concentration of production.

VI. Conclusions

A growing literature, crafted into a compelling theoretical framework by Steven Klepper (1992), suggests that *who* innovates and*how much* innovative activity is undertaken is closely linked to the phase of the industry life cycle. In this paper we suggest an additional key aspect to the evolution of innovative activity over the industry life cycle – *where* that innovative activity takes place. The theory of knowledge spillovers, derived from the knowledge production function, suggests that the propensity for innovative activity to cluster spatially will tend to be the greatest in industries where *tacit knowledge* plays an important role. Because it is tacit knowledge, as opposed to *information*, which can only be transmitted informally, and typically demands direct and repeated contact. The role of tacit knowledge in generating innovative activity is presumably the greatest during the early stages of the industry life cycle, before product standards have been established and before a dominant design has emerged.

One obvious complication in testing for the existence of the link between the industry life cycle and the propensity for innovative activity to cluster is that not only will innovative activity presumably be more geographically concentrated in

[22] The innovative contribution of the minimills in the steel industry, located in a different geographic region, vis-à-vis their established, larger counterparts has been noted by the *Wall Street Journal* (May 10, 1991, p. 1), "Wall Street has been in love with Nucor Corp.", which has become the seventh largest steel company in the United States through its fifteen *minimill* plants. Nucor has pursued a strategy not only of "... declaring war on corporate hierarchy", but also by being "... terribly efficient, aggressively non-union and quite profitable. Most of its 15 minimills and steel fabrication operations are situated in small towns, where they have trained all sorts of people who never through they'd make so much money. And Nucor has developed a revolutionary new plant that spins gleaming sheet steel out of scrapped cars and refrigerators."

industries where production is also geographically concentrated, simply because the bulk of firms are located within close proximity, but even more problematic is the hypothesis that the role of new economic knowledge in the industry will tend to shape the spatial distribution of production as well as innovation. Indeed, we find that a key determinant of the extent to which the location of production is geographically concentrated is the relative importance of new economic knowledge in the industry.

But even after controlling for the extent of the geographic concentration of production, we find considerable evidence suggesting that the propensity for innovative activity to spatially cluster is shaped by the stage of the industry life cycle. On the one hand, new economic knowledge embodied in skilled workers tends to raise the propensity for innovative activity to spatially cluster throughout all phases of the industry life cycle. On the other had, certain other sources of new economic knowledge, such as university research tend to elevate the propensity for innovative activity to cluster during the introduction stage of the life cycle but not during the growth stage, but then again during the stage of decline.

Perhaps most striking is the finding that greater geographic concentration of production actually leads to more, and not less, dispersion of innovative activity. Apparently innovative activity is promoted by knowledge spillovers that occur within a distinct geographic region, particularly in the early stages of the industry life cycle, but as the industry evolves towards maturity and decline may be dispersed by additional increases in concentration of production that have been built up within that same region. That is, the evidence suggests that what may serve as an *agglomerating influence* in triggering innovative activity to spatially cluster during the introduction and growth stages of the industry life cycle, may later result in a *congestion effect*, leading to greater dispersion in innovative activity. In any case, the results of this paper suggest that the propensity for innovative cluster to spatially cluster is certainly shaped by the stage of the industry life cycle.

References

Acs, Z. J., Audretsch, D. B., and Feldman, J. P. (1992) 'Real effects of academic research: Comment', *American Economic Review*, **82**(1), 363–367.

Acs, Z. J., Audretsch, D. B., and Feldman, M. P. (1994) "R&D spillovers and recipient firm size', *Review of Economics and Statistics*, **100**(2), May.

Arrow, K. J. (1962) 'Economic welfare and the allocation of resources for invention', in R. R. Nelson (ed.), *The Rate and Direction of Inventive Activity*, Princeton University Press, Princeton, pp. 609–626.

Audretsch, D. B. (1987) 'An empirical test of the industry life cycle', *Weltwirtschaftliches Archiv*, **123**(2), 297–308.

Audretsch, D. B. (1995) *Innovation and Industry Evolution*, MIT Press, Cambridge MA.

Audretsch, D. B. and Feldman, M. P. (1996) 'R&D spillovers and the geography of innovation and production', *American Economic Review*, 86 (1).

Audretsch, D. B. and Stephen P. (1996). 'Company-Scientist Locational Links: The Case of Biotechnology', *American Economic Review*, 86 (3).

Browne, L. E. (1984) 'High technology and regional economic development', *Economic Indicator*, Federal Reserve Bank of Boston.

Edwards, K. L. and Gordon, T. J. (1984) 'Characterization of innovations introduced on the U.S. market in 1982', The Futures Group, prepared for the United States Small Business Administration under Contract No. SBA-6050-0A-82, March.

Feldman, M. P. and Florida, R. 1994, 'The geographic sources of innovation: Technological infrastructure and product innovation in the United States', *Annals of the Association of American Geographers*, **84**(2), 210–229.

Feldman, M. P. (1994a) 'Knowledge Complementarity and Innovation', *Small Business Economics*, **6**(5), 363–372.

Feldman, M. P. (1994b) *The Geography of Innovation*, Kluwer Academic Publishers, Boston.

Fuchs, V. R. (1962) *Change in the Location of Manufacturing in the United States Since 1929*, Yale University Press, New Haven.

Glaeser, E. L, Kallal, H. D., Scheinkman, J. A., and Shleifer, A. (1992) 'Growth of cities', *Journal of Political Economy*, **100**, 1126–1152.

Gort, M. and Klepper, S. (1982) 'Time paths in the diffusion of product innovations', *Economic Journal*, **92**, 630–653.

Griliches, Z. (1979) 'Issues in assessing the contribution of R&D to productivity growth', *Bell Journal of Economics*, **10**(1), 92–116.

Grossman, G. and Helpman, E. (1991) *Innovation and Growth in the Global Economy*, MIT Press, Cambridge MA.

Jaffe, A. B. (1986) 'Technological opportunity and spillovers of R&D: Evidence from firms, patents, profits and market value', *American Economic Review*, **76**(5), 984–1001.

Jaffe, A. B. (1989) 'Real effects of academic research', *American Economic Review*, **79**(5), 957–970.

Jaffe, A. B., Trajtenberg, M., and Henderson, R. (1993) 'Geographic localization of knowledge spillovers as evidenced by patent citations', *Quarterly Journal of Economics*, **63**(3), 577–598.

Jovanovic, B. and MacDonald, G. M. (1994) 'The life cycle of a competitive industry', *Journal of Political Economy*, **104**(2), 322–347.

Klepper, S. and Graddy, E. (1990) 'The evolution of new industries and the determinants of market structure', *Rand Journal of Economics*, **21**, 27–44.

Klepper, S. and Miller, J. H. (1995) 'Entry, exit and shakeouts in the United States in new manufactured products', *International Journal of Industrial Organization*, **13**(4), 567–591.

Klepper, S. and Simons, K. L. (1993) 'Technological change and industry shakeouts', Unpublished paper presented at the Annual Association of the American Economic Association, Boston.

Klepper, S. (1992) 'Entry, exit, growth, and innovation over the product life cycle', Unpublished paper presented at the 1992 Conference of the International Joseph A. Schumpeter Society, Kyoto.

Krugman, P. (1991a) 'Increasing returns and economic geography', *Journal of Political Economy*, **99**(3), 483–499.

Krugman, P. (1991b) *Geography and Trade*, MIT Press, Cambridge MA.

Krugman, Paul, (1991c) 'History and industry location: The case of the manufacturing belt', *American Economic Review*, **81**(2), 80–83.

Loesch, A. (1954) *The Economics of Location*, Yale University Press, New Haven.

Lucas, R. E. Jr. (1993), 'Making a miracle', *Econometrica*, **61**(2), 251–272.

Markusen, A., Hall, P., and Glasmeier, A. (1986) *High Tech America: The What, How, Where and Why of Sunrise Industries*, Allen & Unwin, Boston.

Romer, P. (1986) 'Increasing returns and long-run growth', *Journal of Political Economy*, **64**, 1002–1037.

Romer, P. (1990) 'Endogenous technological change', *Journal of Political Economy*, **64**, 1002–1037.

Shelburne, R. C. and Bednarzik, R. W. (1993) 'Geographic concentration of trade-sensitive employment', *Monthly Labor Review*, 3–13.

Thompson, W. R. (1962) 'Locational differences in inventive effort and their determinants', in R. R. Nelson, (ed.), *The Rate and Direction of Inventive Activity*, Princeton University Press, Princeton, pp. 253–272.

Vernon, R. (1966) 'International investment and international trade in the product life cycle', *Quarterly Journal of Economics*, **80**, 190–207.

Weiss, L. W. (1991) 'The Geographic Size of Markets in Manufacturing', in D. B. Audretsch and H. Yamawaki (eds.), *Structure Conduct, and Performance*, New York University Press, New York, pp. 64–91.

Williamson, O. E. (1975) *Markets and Hierarchies: Analysis and Antitrust Implications*, The Free Press, New York.

Winter, S. G. (1984) 'Schumpeterian competition in alternative technological regimes', *Journal of Economic Behavior and Organization*, 5, 137–158.