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Location, location, location: The geography of innovation and knowledge spillovers

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**Location, Location, Location: The
Geography of Innovation and
Knowledge Spillovers**

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ABSTRACT

Location, Location, Location: The Geography of Innovation and Knowledge Spillovers

by Maryann P. Feldman and David B. Audretsch

The purpose of this paper is to integrate what has recently been learned about the location of innovative activity. There is considerable evidence that R&D spillovers exist, and that they are geographically bounded. The extent to which such knowledge externalities exist as well as the cost of transmitting such spillovers across geographic space is not the same across industries and clearly contributes for the propensity for innovative activity to cluster more in some industries than in others.

ZUSAMMENFASSUNG

Standort, Standort, Standort: Die Geographie von Innovationen und Wissens-Spillovers

Ziel dieses Beitrags ist es, die jüngsten Forschungsergebnisse über den Standort von Innovationsaktivitäten zu integrieren. Es gibt beträchtliche empirische Evidenz darüber, daß F&E-Spillovers existieren und daß sie geographisch begrenzt sind. Der Umfang solcher Wissensexternalitäten als auch die Kosten der Übertragung derartiger Spillovers im geographischen Raum sind nicht für alle Industrien gleich. Dies führt zu einer unterschiedlichen Innovationsneigung, die in einigen Industrien zu einer stärkeren Clusterung führt als in anderen.

1. Introduction

Economics, we tell the students in our introductory classes is about three questions — What to produce? How to produce? And, for whom to produce? The question of *where* to produce, or more generally, the location of economic activity has been relatively neglected for too long. In proposing a new theory of economic geography, Paul Krugman (1991b, p. 5) asks, "What is the most striking feature of the geography of economic activity? The short answer is surely concentration...production is remarkably concentrated in space." Perhaps in response to Krugman's concern, a literature has recently emerged which focuses on the implications of the concentration of economic activity for economic growth. Models posited by Romer (1990), Lucas (1993) and Krugman (1991a and 1991b) link increasing returns to scale yielded by externalities within a geographically bounded region to higher rates of growth.

Along with this literature linking growth to economic geography has come a series of studies examining the relationship between R&D spillovers and the geography of innovation. The purpose of this paper is to integrate what has recently been learned about the geography of innovative activity and how to consider this sheds light on the broader process of technological change.

2. The Knowledge Production Function

The starting point for most theories of innovation is the firm.¹ In such theories the firms are exogenous and their performance in generating technological change is endogenous.² For example, in the most prevalent model found in the literature of technological change, the model of the *knowledge production function*, formalized by Zvi Griliches (1979), firms exist

¹ See for reviews of this literature Baldwin and Scott (1987), Cohen and Levin (1989), and Scherer (1984 and 1991).

² See for example Scherer (1984 and 1991), Cohen and Klepper (1991 and 1992), and Arrow (1962 and 1983).

exogenously and then engage in the pursuit of new economic knowledge as an input into the process of generating innovative activity.

- The most decisive input in the knowledge production function is new economic knowledge. And as Cohen and Klepper conclude (1991 and 1992), the greatest source generating new economic knowledge is generally considered to be R&D. Certainly a large body of empirical work has found a strong and positive relationship between knowledge inputs, such as R&D, on the one hand, and innovative outputs on the other hand.

The empirical link between knowledge inputs with innovative output is apparently stronger as the unit of observation becomes increasingly aggregated. For example, for the unit of observation of countries, the relationship between *R&D* and patents is very strong. The most innovative countries, such as the United States, Japan and Germany, also tend to invest in R&D. By contrast, little patent activity is associated with developing countries, which tend to have very low R&D expenditures.

Similarly, the link between R&D and innovative output, measured in terms of either patents or new product introductions is also very strong when the unit of observation is the industry. The most innovative industries, such as computers, instruments and Pharmaceuticals, also tend to be the most R&D intensive. Thus, Audretsch (1995) finds a simple correlation coefficient of 0.74 between R&D inputs and innovative output at the level of four-digit standard industrial classification (SIC) industries. Moreover, Scherer (1991) notes that the bulk of industrial R&D is undertaken in the largest corporations, however, a series of studies has clearly documented that small firms account for a disproportional share of new product innovations given their low R&D expenditures.

3. Knowledge Spillovers

The recent wave of studies revealing small enterprises to be the engine of innovative activity in certain industries, despite an obvious lack of form R&D activities, raises the question,

Where do new and small firms get the innovation producing inputs, that is the knowledge? One answer is from other, third-party, firms or research institutions, such as universities. Economic knowledge may spill over from the R&D conducting firm or research institution creating it for application by other firms.

The existence of knowledge spillovers challenges an assumption implicit to the knowledge production function -- that firms exist *exogenously* and then *endogenously* seek out and apply knowledge inputs to generate innovative output. Although this may be valid some, if not most of the time, Audretsch (1995) finds empirical evidence to suggest that it is knowledge in the possession of economic agents that is *exogenous*, and in an effort to appropriate the returns from that knowledge, the spillover of knowledge from its producing entity involves endogenously creating a new firm. Certainly the view that knowledge is exogenous and the new firms are endogenous is consistent with the findings of Audretsch and Stephan (1996) that virtually all new firms in the U.S. biotechnology industry are formed around, and typically by, scientists at universities or research institutions.

Thus, the model of the knowledge production function may still be valid, but the implicitly assumed unit of observation — at the level of the firm — may be less valid. Krugman (1991a and 1991b) is among the most recent to argue that the relevant unit of observation may actually be a constellation of complementary firms within a geographic unit, so that knowledge can *spill over* from one firm within the region to another. Theoretical models posited by Romer (1990), Lucas (1993) and Krugman (1991a and 1991b) link increasing returns to scale yielded by externalities within a geographically bounded region to higher rates of growth. And the empirical evidence clearly suggests that R&D and other sources of knowledge not only generate externalities, but studies by Audretsch and Feldman (1996), Jaffe (1989), Audretsch and Stephan (1996), Feldman (1994a and 1994b), and Jaffe, Trajtenberg and Henderson (1993) suggest that such knowledge spillovers tend to be geographically bounded within the region where the new economic knowledge was created. That is, new economic knowledge may spill-over but the geographic extent of such knowledge spillovers is limited.

In particular, the locational choice for economic activity should be profoundly effected in a world where the cost of communications has become trivial: "The death of distance will mean that any activity that relies on a screen or a telephone can be carried out anywhere in the world."³

4. Location, Location, Location

The importance of geographic location to knowledge spillovers and innovative activity in a world increasingly dominated by E-mail, fax machines and electronic communications super-highways may seem surprising and even paradoxical. After all, the new tele-communications technologies have triggered a virtual spatial revolution in terms of the geography of production. According to *The Economist*, "The death of distance as a determinant of the cost of communications will probably be the single most important economic force shaping society in the first half of the next century. It will alter, in ways that are only dimly imaginable, decisions about where people live and work; concepts of national borders; patterns of international trade."⁴

The resolution to the paradox posed by the localization of knowledge spillovers in an era where telecommunications has dramatically reduced the cost of communication lies in a distinction between knowledge and information. While the marginal cost of transmitting *information* may be invariant to distance, presumably the marginal cost of transmitting *knowledge*, and especially *tacit knowledge*, rises with distance.

Von Hippie (1994) persuasively demonstrates that high context, uncertain knowledge, or what he terms as sticky knowledge, is best transmitted via face-to-face interaction and through frequent contact. Proximity matters in transmitting knowledge because as Kenneth Arrow (1962) pointed out some three decades ago, such tacit knowledge is inherently non-rival in nature, and knowledge developed for any particular application can easily spill over and be applied for different purposes. Similarly, Zvi Griliches (1992, p. 29-47) has defined knowledge

³ "The Death of Distance," *The Economist*, 30 September, 1995.

⁴ *Ibid.*, P. 39.

spillovers as "working on similar things and hence benefiting much from each others research." Glaeser, Kallal, Scheinkman and Shleifer (1992, p. 1126-1152) have observed that "intellectual breakthroughs must cross hallways and streets more easily than oceans and continents."

That knowledge spillovers tend to be geographically localized is consistent with frequent observations made by the popular press, business community and policy makers. For example, *Fortune* magazine points out that, "business is a social activity, and you have to be where important work is taking place."⁵ 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.⁶ *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 at top 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 *kudzu* in the fertile business climate."⁷

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,

⁵ "The Best Cities for Knowledge Workers," *Fortune*, 15 November, 1993, p. 44-57.

⁶ The survey was carried out in 1993 by the management consulting firm of Moran, Stahl & Boyer of New York City.

⁷ *Fortune* magazine reports, "What makes the Triangle Park 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.

and a surprising array of creative talent including film makers, animators, writers, producers, and artists."⁸

Considerable empirical 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 (1996) found that the propensity of innovative activity to cluster geographically tends to be greater in industries where new economic knowledge plays a more important role.

5. Linking Knowledge Spillovers to Innovation

Studies identifying the extent of knowledge spillovers are based on extend the knowledge production function introduced by Griliches (1979). Griliches pointed out that the most decisive innovative input is new economic knowledge, and the greatest source that generates new economic knowledge is generally considered to be R&D. Jaffe (1989), Feldman (1994a and 1994b) and Audretsch and Feldman (1996) modified the knowledge production function approach to a model specified for spatial and product dimensions:

$$I_{st} = IRD^{\beta_1} * (UR_{st})^{\beta_2} * [UR_{st} * (GC_{st})^{\beta_3}] * \epsilon_{st}$$

where I_{st} 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. The unit of observation for estimation was at the spatial level, s , a state, and industry level, t . Estimation of equation (1) essentially shifted the knowledge production function from the unit of observation of a firm to that of a geographic unit.

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

6. The Geography of Innovation

Krugman [1991a, p. 53] has argued that economists should abandon any attempts at measuring knowledge spillovers because "...knowledge flows are invisible, they leave no paper trail by which they may be measured and tracked." But as Jaffe, Trajtenberg and Henderson [1991, p. 578] point out, "knowledge flows do sometimes leave a paper trail" — in particular in the form of patented inventions and new product introductions.

In this paper we rely upon a direct measure of innovative output, rather than on a measure of intermediate output, such as patented inventions. This United States Small Business Administration's Innovation Data Base (SBIDB) is the primary source of data for this paper. The database consists of new product introductions compiled from the new product announcement sections of over one-hundred technology, engineering and trade journals spanning every industry in manufacturing. From the sections in each trade journal listing innovations and new products, a data base consisting of the innovations by four-digit standard industrial classification (SIC) industries was formed. An innovation is defined in the database as "a process that begins with an invention, proceeds with the development of the invention, and results in introduction of a new product, process or service to the marketplace" [Edwards and Gordon, 1984, p. 1]. These innovation data have been implemented by Audretsch [1995] to analyze the relationship between industry dynamics and technological change, and by Audretsch and Feldman [1996], Feldman [1994] and Feldman and Florida [1994] to examine the spatial distribution of innovation.

There are several important qualifications that should be made concerning the SBIDB. The trade journals report relatively few process, service and management innovations and tend to capture mainly product innovations. The most likely effect of this bias is to underestimate the number of innovations emanating from large firms, since larger enterprises tend to produce more process innovations than do their smaller counterparts. However, because it was found that the large-firm innovations are more likely to be reported in the trade journals than are small-firm innovations, the biases are perhaps somewhat offsetting.

Another potential concern might be that the significance and "quality" of the innovations vary considerably. In fact, each innovation was classified according to one of the following levels of significance: (1) the innovation established an entirely new category of product; (2) the innovation is the first of its type on the market in a product category already in existence; (3) the innovation represents a significant improvement in existing technology; and (4) the innovation is a modest improvement designed to update an existing product. Audretsch (1995) shows that about 87 percent of the innovations were in this fourth category and most of the remaining innovations were classified in the third category.

An important strength of the database is that the innovating *establishment* is identified as well as the innovating *enterprise*. While this distinction is trivial for single-plant manufacturing firms, it becomes important in multi-plant firms. This is because some innovations are made by subsidiaries or divisions of companies with headquarters in other states. Even though the headquarters may announce new product innovations made by the company, the database still identifies the individual establishment actually making the innovation.

Table 1 indicates that California is the state in which the greatest number of innovations was registered, followed by New York, New Jersey, and Massachusetts. A particularly striking feature shown in Table 1 is that the bulk of innovative activity in the United States occurs on the coasts, and especially in California and in New England. By contrast, no innovative activity is registered in certain Midwestern states such as North Dakota, South Dakota and Wyoming. Of course, simply comparing the absolute amount of innovative activity across states ignores the fact that the manufacturing base of some states is larger than others. Thus, the number of innovations generated per billions of dollars of value added in manufacturing is also compared in order to control for the size of the geographic region. After controlling for the size of the manufacturing base, Massachusetts emerges as the most innovative state, registering more than 22 innovations per billion dollars of value added, while New Jersey is the second most innovative state with more than 18 innovations per billion dollars of value added. Even after controlling for the size of the geographic region, the result is that the bulk of the innovative activity in the United States occurs on the coasts and not in the Midwest.

Table 1: Innovative Activity in States

State	Number of Innovations	Value Added (\$ millions)	Innovations per Value Added (\$ Billions)
Massachusetts	360	16,349	22.02
New Jersey	426	22,853	18.64
California	974	54,862	17.75
New Hampshire	33	2,175	15.17
Arizona	41	3,333	12.30
Connecticut	132	10,934	12.07
Minnesota	110	9,605	11.45
New York	456	44,290	10.30
Delaware	15	1,596	9.40
Colorado	42	4,472	9.39
Rhode Island	24	2,737	8.77
United States	4,200	585,166	7.18
Florida	66	9,255	7.13
Pennsylvania	245	36,017	6.80
Illinois	231	40,279	5.73
Vermont	6	1,050	5.71
Washington	48	8,955	5.36
Oregon	32	6,138	5.21
Wisconsin	86	16,606	5.18
Texas	169	33,150	5.10
Ohio	188	43,055	4.37
Oklahoma	20	4,662	4.29
Georgia	53	12,549	4.22
Idaho	6	1,430	4.20
New Mexico	3	734	4.09
Maryland	28	7,116	3.93
Virginia	38	10,882	3.49
Utah	11	3,333	3.30
D.C.	2	610	3.28

Table 1: Innovative Activity in States

State	Number of Innovations	Value Added (\$ millions)	Innovations per Value Added (\$ Billions)
Nebraska	9	2,867	3.14
Michigan	112	37,566	2.98
Kansas	15	5,338	2.81
Missouri	36	13,042	2.76
Iowa	20	8,684	2.30
South Carolina	18	8,186	2.20
Indiana	49	22,718	2.16
North Carolina	38	18,231	2.08
Nevada	1	495	2.02
Maine	4	2,343	1.71
Tennessee	20	12,663	1.58
Hawaii	1	786	1.27
West Virginia	4	3,880	1.03
Arkansas	5	4,882	1.02
Kentucky	9	9,546	0.94
Mississippi	4	5,619	0.71
Alabama	5	8,406	0.59
Louisiana	5	9,418	0.53

source: Feldman (1994)

While Table 1 indicates the geographic distribution of innovative activity in the United States, it obscures the propensity for innovative activity to spatially cluster by aggregating innovative activity across all industries. Thus, the distribution of innovative activity for the seven most innovative four-digit SIC industries is shown in Table 2. A striking result is that the spatial concentration of innovative activity in particular industries is considerably greater than for all of manufacturing. For example, in the computer industry, 342 of the 821 innovations recorded, or 41.7 percent, are in California. And an additional ten percent are recorded in Massachusetts. Thus, two states alone for over one-half of all of the innovations in the computer industry. At the same time, the last column indicates that innovations in the computer industry accounted for slightly more than one-third of all of the innovations in California and a little more than one-fifth of all innovations in Massachusetts.

Similarly, nearly 40 percents of the 127 innovations in the pharmaceutical industry were recorded in New Jersey, while an additional 14 percents were made in New York. Thus, over one-half of pharmaceutical innovations were recorded in the New Jersey - New York area. At the same time, pharmaceutical innovations accounted for over one-tenth of all innovations registered in New Jersey.

7. Innovative Clusters

While there is considerable evidence supporting the existence of knowledge spillovers, neither Jaffe (1989), Jaffe, Trajtenberg and Henderson (1993), nor 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 where knowledge spillovers are the most prevalent. In our 1996 paper we link the propensity for innovative activity to cluster together to industry specific characteristics, most notably the relative importance of knowledge spillovers.

Table 2: Geographic Distribution of Innovative Activity for Most Innovative Industries

Sic	Industry	State	Number of Innovations	State Share of Industry Innovations	Industry Share of State Innovations
3573	Computers (n=821)	California	342	41.7	35.1
		Massachusetts	78	9.5	21.7
		New York	58	7.1	12.7
		Texas	39	4.8	23.1
		New Jersey	38	4.6	8.9
		Illinois	28	3.4	12.1
3823	Process Control Instruments (n=464)	California	80	17.2	8.2
		Massachusetts	61	13.1	16.9
		New York	45	9.7	9.9
		Pennsylvania	40	8.6	16.5
		Illinois	32	6.9	13.9
3662	Radio and TV Communication Equipment (n=339)	California	105	31.0	10.8
		New York	40	11.8	8.8
		Massachusetts	32	9.4	8.9
3674	Semiconductors (n=172)	California	84	48.8	8.6
		Massachusetts	17	9.9	4.7
		Texas	13	7.6	7.7
3842	Surgical Appliances (152)	New Jersey	43	28.3	10.1
		California	17	11.2	1.7
		Pennsylvania	10	7.9	4.1
2834	Pharmaceuticals (127)	New Jersey	50	39.4	11.7
		New York	18	14.2	3.9
		Pennsylvania	10	7.9	4.1
		Michigan	8	6.3	7.1
3825	Measuring Instruments for Electricity (115)	California	37	32.2	3.8
		Massachusetts	22	19.1	16.9
		New York	13	11.3	2.9

Source: Feldman (1994)

Table 3: 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	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
2641	Paper Coating	0.6374	0.6023	0.3847
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	0.5828	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	0.5790	0.4238

Table 3: Geographic Concentration of Production for Industries with Highest Propensity for Innovative Activity to Cluster

		Gini Coefficients		
		Innovation	Value-Added	Employment
3356	Nonferrous Rolling & Drawing	0.5420	0.6661	0.7281
2086	Bottled & Canned Soft Drinks	0.5385	0.6454	0.6465
3535	Conveyors & Related Equipments	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	0.7307
3079	Plastics 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

Source: Audretsch & Feldman (1996a)

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 (1991b) 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 3 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 3.

There are three important tendencies emerging in Table 3. 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 3. 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.

In our 1996 paper we measure three different types of new economic knowledge — industry R&D, university R&D, and skilled labor. A key assumption we make in examining the link between knowledge spillovers in an industry and the propensity for innovative activity to cluster is that knowledge externalities are more prevalent in industries where new economic knowledge plays a greater role.

One obvious complication in testing for this link is that innovative activity will be more geographically concentrated in industries where production is also geographically concentrated, simply because the bulk of firms are located within close proximity. Even more problematic, though, is the hypothesis that new economic knowledge will tend to shape the spatial distribution of production as well as that of innovation. Indeed, we found 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 geographic concentration of production, the results suggest that industries in which knowledge spillovers are more pervasive — that is where industry R&D, university research and skilled labor are the most important — have a greater propensity for innovative activity to cluster than industries where knowledge externalities are less important.

8. The Industry Life Cycle

A growing literature, crafted into a compelling theoretical framework by Steven Klepper (1996) suggests that *who* innovates and *how much* innovative activity is undertaken is closely linked to the phase of the industry life cycle. In our 1996b 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.

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 time needs to be measured.⁹ In the life cycle framework proposed by Klepper (1996) suggests that the degree of (product) innovative activity combined with the type of firm generating the innovative activity corresponds to the stage of the industry life cycle (Audretsch & Feldman 1996b). 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

⁹ See Audretsch (1987) for a study measuring the stage of the industry life cycle within a cross-section framework.

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-a-vis their 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).

The results provide 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 hand, 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 an innovative cluster to spatially cluster is certainly shaped by the stage of the industry life cycle.

9. The Black Box of Geographic Space and the Structure of Economic Activity

Despite the general consensus that has now emerged in the literature that knowledge spillovers within a given location stimulate technological advance, there is little consensus as to exactly how this occurs. The contribution of the knowledge production function approach was simply to shift the unit of observation away from firms to a geographic region. But does it make a difference how economic activity is organized within the black box of geographic space? Political scientists and sociologists have long argued that the differences in the culture of a region may contribute to differences in innovative performance across regions, even holding

knowledge inputs such as R&D and human capital constant. For example, Saxenian (1994) argues that a culture of greater interdependence and exchange among individuals in the Silicon Valley region has contributed to a superior innovative performance than is found around Boston's Route 128, where firms and individuals tend to be more isolated less interdependent.

In studying the networks in California's Silicon Valley, Saxenian (1990, p. 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 a high endowment of human capital and knowledge in the region: "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."¹⁰

While economists tend to avoid attributing differences in economic performance to cultural differences, there has been a series of theoretical arguments suggesting that differences in the underlying structure between regions may account for differences in rates of growth and technological change. In fact, a heated debate has emerged in the literature about the manner in

¹⁰ Saxenian (1990, p. 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."

which the underlying economic structure within a geographic unit of observation might effect economic performance. One view, which Glaeser, Kallal, Scheinkman and Shleifer [1992] attribute to the *Marshall-Arrow-Romer* externality, suggests that an increased concentration of a particular industry within a specific geographic region facilitates knowledge spillovers across firms. This model formalizes the insight that the concentration of an industry within a city promotes knowledge spillovers between firms and therefore facilitates innovative activity. An important assumption of the model is that knowledge externalities with respect to firms exist, but only for firms within the same industry. Thus, the relevant unit of observation is extended from the firm to the region in the tradition of the Marshall-Arrow model, and in subsequent empirical studies, but spillovers are limited to occur within the relevant industry.

By contrast, restricting knowledge externalities to occur only within the industry may ignore an important source of new economic knowledge — inter-industry knowledge spillovers. Jacobs [1969] argues that the most important source of knowledge spillovers are external to the industry in which the firm operates and that cities are the source of considerable innovation because the diversity of these knowledge sources is greatest in cities. According to Jacobs, it is the exchange of complementary knowledge across diverse firms and economic agents which yields a greater return on new economic knowledge. She develops a theory that emphasizes that the variety of industries within a geographic region promotes knowledge externalities and ultimately innovative activity and economic growth.

The extent of regional specialization versus regional diversity in promoting knowledge spillovers is not the only dimension over which there has been a theoretical debate. A second controversy involves the degree of competition prevalent in the region, or the extent of local monopoly. The Marshall-Arrow-Romer model predicts that local monopoly is superior to local competition because it maximizes the ability of firms to appropriate the economic value accruing from their innovative activity. By contrast, Jacobs [1969] and Porter [1990] argue that

competition is more conducive to knowledge externalities than is local monopoly.¹¹ It should be emphasized that by local competition Jacobs does not mean competition within product markets as has traditionally been envisioned within the industrial organization literature. Rather, Jacobs is referring to the competition for the new ideas embodied in economic agents. Not only does an increased number of firms provide greater competition for new ideas, but in addition, greater competition across firms facilitates the entry of a new firm specializing in some particular and new product niche. This is because the necessary complementary inputs and services are likely to be available from small specialist niche firms but not necessarily from large, vertically integrated producers.

The first important test of the specialization versus diversity theories to date has focused not on the gains in terms of innovative activity, but rather in terms of employment growth. Glaeser, Kallal, Scheinkman and Schleifer [1992] employ a data set on the growth of large industries in 170 cities between 1956 and 1987 in order to identify the relative importance of the degree of regional specialization, diversity and local competition in influencing industry growth rates. The authors find evidence that contradicts the Marshall-Arrow-Romer model but is consistent with the theories of Jacobs. However, their study provided no direct evidence as to whether diversity is more important than specialization in generating innovation.

Feldman and Audretsch (1995) identify the extent to which the organization of economic activity is either concentrated, or alternatively consists of diverse but complementary economic activities, and how this composition influences innovative output. We ask the question, *Does the specific type of economic activity undertaken within any particular geographic concentration matter?* To consider this question we link the innovative output of product categories within a specific city to the extent to which the economic activity of that city is concentrated in that industry, or conversely, diversified in terms of complementary industries sharing a common science base.

¹¹ Porter (1990) provides examples of Italian ceramics and gold jewelry industries in which numerous firms are located within a bounded geographic region and compete intensively in terms of product innovation rather than focusing on simple price competition.

To systematically identify the degree to which specific industries share a common underlying science and technology base, we rely upon a deductive approach that links products estimated from their closeness in technological space. We use the responses of industrial R&D managers to a survey by Levin et al. (1987). To measure the significance of a scientific 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 Likert scale of 1 to 7, from least important to most important, to assess the relevance of basic scientific research in biology, chemistry, computer science, physics, math, medicine, geology, mechanical engineering and electrical engineering. Any academic discipline with a rating greater than 5 is assumed to be relevant for a product category. For example, basic scientific research in medicine, chemistry and chemical engineering is found to be relevant for product innovation in drugs (SIC 2834).

We then used cluster analysis to identify six groups of industries which rely on similar rankings for the importance of different academic disciplines. These six groups reflect distinct underlying common scientific bases. Table 4 lists these six science-based groupings, along with the number of four-digit industries included in each cluster, the mean number of innovations per industry, the critical underlying scientific discipline, along with the mean rating for the importance of that scientific discipline, and the most innovative industries included in the cluster.

It should be emphasized that Table 4 identifies innovative groups in terms of clustering around the same underlying scientific bases, but not in terms of geographic space or even product space. For example, there are 15 distinct industries included in what we term the biomedical cluster. On average, each industry contributed 3.22 innovations. Their shared underlying knowledge base consists of chemistry (with a mean ranking on the Likert scale of 5.53), medical sciences, computer sciences and material sciences. Surgical Appliances (SIC 3842), Surgical and Medical Instruments (SIC 3841), and Pharmaceuticals (SIC 2834) are three of the fifteen industries heavily dependent on this common underlying scientific knowledge base. There are 21 industries included in the Agra-Business group, 34 industries included in the Chemical Engineering group, 7 industries in the Office Machinery group and 11 industries included in the

Industrial Machinery group. The largest science-based group is what we term High-Tech Computing, which includes 80 industries.

Table 5 presents the prominent cities within each science-based industrial cluster. Again, the listing of prominent cities recalls the well known association between cities and industries. For example, Atlanta was a prominent center for innovation which used the common science base of agra-business. While the national innovation rate was 20.34 innovations per 100,000 manufacturing workers, agra-business in Atlanta was almost five times as innovative. A Chi-Squared test of the independence of location of city and science-based industrial activity reveals that neither the distribution of employment nor the distribution of innovation is random. Industries which rely on a common science base exhibit a tendency to cluster together geographically with regard to the location of employment and the location of innovation. We conclude that the distribution of innovation within science-based clusters and cities appears to reflect the existence of science-related expertise.

To test the hypothesis that the degree of specialization, or alternatively diversity, as well as the extent of local competition within a city shapes the innovative output of an industry, we estimate a model where the dependent variable is the number of innovations attributed to a specific four-digit SIC industry in a particular city. To reflect the extent to which economic activity within a city is specialized, we include as an explanatory variable a measure of industry specialization which was used by Glaeser, Kallal, Scheinkman and Shleifer (1992) and is defined as the 1982 share of total employment in the city accounted for by industry employment in the city, divided by the share of United States employment accounted for by that particular industry. This variable reflects the degree to which a city is specialized in a particular industry relative to the degree of economic activity in that industry that would occur if employment in the industry were randomly distributed across the United States. A higher value of this measure indicates a greater degree of specialization of the industry in that particular city. Thus, a positive coefficient would indicate that increased specialization within a city is conducive to greater innovative output and would support the *Marshall-Arrow-Romer* thesis. A negative coefficient would indicate that greater specialization within a city impedes innovative output and would support

Table 4: The Common Science Bases of Industry Clusters

Cluster	<u>Critical Academic Departments</u>	Most Innovative Industries
Agra-Business	Chemistry (6.06) Agricultural Science (4.65) Computer Science (4.18) Biology (4.09)	SIC 2013: Sausages SIC 2038: Frozen Specialities SIC 2087: Flavoring Extracts SIC 2092: Packaged Foods
Chemical Engineering	Material Science (5.32) Chemistry (4.80) Computer Science (4.50) Physics (4.12)	SIC 3861: Photographic Equipment SIC 3443: Fabricated Plate Work SIC 2821: Plastic Materials SIC 3559: Special Ind Machinery
Office Machinery	Computer Science (6.75) Medical Science (5.75) Math (5.49) Applied Math (4.64)	SIC 3576: Scales and Balances SIC 3579: Office Machinery SIC 3535: Conveyors SIC 2751: Commercial Printing
Industrial Machinery	Material Science (5.03) Computer Science (4.76) Physics (3.94) Chemistry (3.88)	SIC 3551: Food Processing Equipment SIC 3523: Machinery SIC 3546: Hand Tools SIC 3629: Industrial Apparatus
High-Tech Computing	Material Science (5.92) Computer Science (5.63) Physics (5.45) Math (4.76)	SIC 3573: Computing Machinery SIC 3662: Radio/TV Equipment SIC 3832: Process Control Instruments SIC 3674: Semiconductors
Biomedical	Chemistry (5.53) Medical Science (5.47) Computer Science (5.32) Material Science (5.02)	SIC 3842: Surgical SIC 3841: Medical Instruments SIC 2834: Pharmaceuticals SIC 3811: Scientific Instruments

Source: Feldman & Audretsch (1995)

Table 5: Innovation in Science-Based Industry Clusters

Cluster	Prominent Cities	Mean Industry Innovations per 100,00 workers
Agra-Business	Atlanta	92.40
	Dallas	41.15
	Chicago	33.03
	St. Louis	91.74
Chemical Engineering	Dallas	38.09
	Minneapolis	66.67
	San Francisco	43.89
	Wilmington	85.47
Office Machinery	Anaheim-Santa Ana	92.59
	Minneapolis	31.86
	Rochester Stamford	72.20
		68.40
Industrial Machinery	Anaheim-Santa Ana	54395
	Cincinnati Cleveland	66.01
	Passaic, N.J.	141.51
		90.90
High-Tech Computing	Boston	73.89
	Houston San	62.08
	Jose	44.88
	Minneapolis	181.74
Biomedical	Boston	38.71
	Cleveland	68.76
	Dallas New	35.22
	York	188.07

Source: Feldman & Audretsch (1995)

Jacobs' theory that diversity of economic activity is more conducive to innovation than is specialization of economic activity.

To identify the impact of an increased presence of economic activity in complementary industries sharing a common science base on the innovative activity of a particular industry within a specific city, a measure of the presence of science-based related industries is included. This measure is constructed analogously to the index of industry specialization, and is defined as the share of total city employment accounted for by employment in the city in industries sharing the science base, divided by the share of total United States employment accounted for by employment in that same science base. This variable measures the presence of complementary industries relative to what the presence would be if those related industries were distributed across the United States. A positive coefficient of the presence of science-based related industries would indicate that a greater presence of complementary industries is conducive to greater innovative output and would lend support for the diversity thesis. By contrast, a negative coefficient would suggest that a greater presence of related industries sharing the same science base impedes innovation and would argue against Jacobs' diversity thesis.

The usual concept of product market competition in the industrial organization literature is typically measured in terms of the size-distribution of firms. By contrast, Jacobs' concept of *localized competition* emphasizes instead the extent of competition for the ideas embodied in individuals. The greater the degree of competition among firms, the greater will be the extent of specialization among those firms and the easier it will be for individuals to pursue and implement new ideas. Thus the metric relevant to reflect the degree of localized competition is not the size of the firms in the region relative to their number (because, after all, many if not most manufacturing product markets are national or at least inter-regional in nature) but rather the number of firms relative to the number of workers. In measuring the extent of localized competition we again adopt a measure used by Glaeser, Kallal, Scheinkman and Shleifer (1992), which is defined as the number of firms per worker in the industry in the city relative to the number of firms per worker in the same industry in the United States. A higher value of this index of localized competition suggests that the industry has a greater number of firms per

worker relative to its size in the particular city than it does elsewhere in the United States. Thus, if the index of localized competition exceeds one then the city is locally less competitive than in other American cities.

In Feldman and Audretsch (1995) the regression model is estimated based on the 5,946 city-industry observations for which data could be collected. The poisson regression estimation method is used because the dependent variable is a limited dependent variable with a highly skewed distribution. By focusing on innovative activity for particular industries at specific locations, we find compelling evidence that specialization of economic activity does not promote innovative output. Rather, the results indicate that diversity across complementary economic activities sharing a common science base is more conducive to innovation than is specialization. In addition, the results indicate that the degree of local competition for new ideas within a city is more conducive to innovative activity than is local monopoly.

10. Conclusions

This is considerable evidence that, first, R&D spillovers exist, and second, that they are geographically bounded. The extent to which such knowledge externalities exist as well as the cost of transmitting such spillovers across geographic space is not the same across industries and clearly contributes for the propensity for innovative activity to cluster more in some industries than in others. Apparently the stage of the industry life cycle, which presumably reflects the relative importance of tacit knowledge versus information, plays an important role in determining the importance of both R&D spillovers as well as their spatial dimension.

Increasingly scholars of technological change realize that external sources of knowledge are critical to innovation. The new learning on R&D spillovers and the geography of innovation suggests that the boundaries of the firm are but one means to organize and harness knowledge. An analogous means of organizing economic activity are spatially defined boundaries. Geographic location may provide another useful set of boundaries within which to organize knowledge and innovation.

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