Knowledge Complementarity and Innovation

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ABSTRACT. This paper uses an innovation production function to relate the presence of geographically-mediated complementary knowledge resources to the innovative activity of small and large firms. The empirical results suggest that small firm innovation appears to benefit from the presence of external institutions and resources. Although large firm innovative activity benefits from the presence of knowledge resources, location appears to be especially beneficial to small firm innovative activity.

I. Introduction

For most of the past fifty years, economists have believed that large firm size confers an advantage in innovative activity (Schumpeter, 1942; Galbraith, 1952). Large, modern corporations benefit from formal R&D laboratories and the internal specialized business services which provide resources to bring new product innovations to market. These resources are typically beyond the means of small business. The research finding that small businesses are the source of innovation in certain industries (Acs and Audretsch, 1988, 1990; Pavitt, Robson and Townsend, 1987; Rothwell and Zegveld, 1982) poses something of a puzzle. Where do small firms acquire the resources to successfully engage in innovation?

One possible answer is that small firm innovative activity relies on external sources of information as inputs to the innovation process. The increased complexity and uncertainty of engaging in innovative activity suggests that interactions and cooperation among autonomous organizations commanding specialized complementary assets and sources of knowledge may be critical to innovative success (Teece, 1986). Rather than being confined to the organizational boundaries of an individual firm, innovation may be seen as benefitting from a broad geographically defined technological infrastructure to mobilize resources, knowledge, and other innovative inputs essential to the innovation process. In operational terms, key resources to the innovation process may be defined as four classes of institutions and institutional capacities: university R&D, industrial R&D, agglomerations and clusters of firms in related industries, and networks of business service firms. These resources form an integrated and spatially-concentrated network of institutions which provide input to the innovation process. Taken together, these complementary institutions and resources generate positive externalities and spillovers which lower the cost and reduce the risks associated with innovation. The technological infrastructure may enable small firms to engage resources which larger firms may more easily internalize. In this way, location may be especially beneficial to small firm innovative activity.

The purpose of this paper is to identify the degree to which small firm innovation is related to the presence of the complementary resources in the technological infrastructure. Using a knowledge production function approach, the relationship between the location of innovative inputs and innovative output is explored. The remainder of this paper is organized as follows. The next section considers reasons why location matters to small firm innovative activity. Section 3 develops a conceptual model and considers data and estimation issues. Section 4 presents empirical results. Section 5 provides a summary and conclusion. The major finding is that small firm innovative activity appears to benefit from an external technological infrastructure comprised of institutions and resources which provide inputs to the innovation process. The technological infrastructure may

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enable small firms to benefit from complementary resources which are more easily available to their larger counterparts regardless of locations. The empirical results suggest that location may be especially beneficial to small firm innovation.

II. Why location matters for small firm innovative activity

Since Marshall (1949), the importance of agglomeration, a form of external scale economy accruing to geographic location, has been noted. Writing in the late 1960s, Thompson (1962) suggests the existence of a relationship between industrial agglomerations and innovation. More recently, economists have explicitly considered the spatial dimension, highlighting the importance of regional specialization to economic activity (Krugman, 1991a&b), the importance of locational clusters as a source of increasing returns (Arthur, 1988; David and Rosenbloom, 1990) and the productivity effects that stem from co-location of industrial and university research and development (Jaffe, 1989; Acs, Audretsch and Feldman, 1992).

To consider why small firm innovative activity may benefit from location in a technological infrastructure, this section is organized around five "stylized facts" or characteristics of the innovation process from Dosi (1988, pp. 222—223). The stylized facts are: the uncertainty of the innovation process; the reliance on university research; the complexity of the innovation process; the importance of learning by doing; and, the cumulative character of innovative activity. Each of these characteristics is considered in turn.

Innovation can be viewed as highly uncertain; this uncertainty extends beyond the lack of information about anticipated events to include the existence of previously undefined scientific and technical problems. One means for reducing uncertainty in the innovation process is to participate in information exchanges to keep a company at the cutting edge of a technology, and to facilitate problem solving tasks. Innovative networks can be interpreted as the formation of research communities which firms join to exploit new developments in an industry in a timely manner (Nelson, 1990). Griliches (1979) suggests that the commercial value of information decays with time. To the extent that location promotes timely information exchange, innovation will be enhanced. The cost of membership in innovative networks is a reciprocal sharing of information which creates a de facto market for these transactions. The importance of networking for innovation in specific industries within geographic areas has been documented by Saxanien (1990) for Silicon Valley and Powell (1990) for the biotechnology industry. Freeman (1991) provides a review of studies on the importance of networking for innovative activity. The uncertainty involved in using a new technology provides an incentive for firms to locate together (Lundvall, 1988, p. 355). When technology is standardized and reasonably stable, information exchange may be translated into standard codes and long distance transmission of information can take place at low costs. On the other hand, when technology is complex and evolving rapidly, long distance standardized transmission is not possible. Therefore, location close to the source of the technology allows firms to translate information into a useable form, creating an incentive for firms using complex and dynamic technologies to locate near knowledge sources.

A geographic concentration of rival firms may provide knowledge resources to reduce the uncertainty associated with innovative activity. Von Hippel (1988) finds that reciprocal information trading between rival firms provides an important innovative input. Allen (1983) suggests evidence of the geographic nature of information trading among rival firms in the nineteenth century English steel industry. A geographic concentration of rival firms appears to facilitate networking and problem-solving, and advance the state of knowledge in the industry (Porter, 1990). This networking may be especially beneficial to the innovative activity of small firms. As the presence of an industry expands in a given location, firms can specialize in the production of complementary products, and provide corresponding expertise to enhance solution searches and reduce uncertainty. It seems likely that small firms may come into existence to fill product niches.

A second characteristic of innovation is the importance of universities to the innovation process. Universities emphasize the free exchange and flow of information: their existence in an area creates a sort of intellectual commons which implies knowledge spill-overs. In contrast to the common notion that knowledge is a public good easily transferred via publications, gaining commercial control over a new technology requires access to those in possession of knowledge about the technology and how it may be used (Nelson, 1989, p. 23). While information transmission may occur easily, knowledge accumulation is a different activity and benefits from face-to-face interaction. An example of the importance of face-to-face interaction is provided by a survey of biotechnology researchers by Grefsheim et al. (1991). This work uncovered that the most important and timely information comes from personal communications because it contains information far in advance of printed sources. Interviewed researchers also felt that the stylistic limitations of formal papers limited their substantive usefulness. Specifically, "Formal papers do not contain the experimenter's strategies and perspectives, nor can they convey what the experimenter thinks the work means and how it dovetails with or contradicts other work" (Grefsheim et al., 1991, p. 41). It cannot be disputed that academic conferences and long-distance consulting arrangements provide a means for information dissemination, but such contact is less frequent, more costly, and qualitatively different.

A third characteristic is the complexity of innovative activity which increases the scope of activity needed to complete the innovation process. To manage this complexity, innovators must conduct intricate search procedures across a variety of disciplines to find specific information. Within each discipline searched, the source of information will be highly specialized. The limited usefulness of this information on a day-to-day basis favors external transactions, especially for small firms.

The increased scope of innovative activity is suggested by the increased prominence of business services. These services provide information about consumer demand and help shepherd new product innovation through a maze of regulations and product specifications. The specialized services of patent attorneys, market research and feasibility studies, and commercial testing labs are beyond the means of all except the largest corporations to internalize. Survey work by MacPherson (1991) found that the intensity of the usage of external producer services correlates highly with realized product innovations in medical and chemical firms. Most importantly, since producer services exist solely to supply information, these firms tend to locate near their clients (Coffey and Polese, 1987).

There is a certain element of serendipity in the search for relevant information. Shimshoni (1966) argues that the larger the number of skills and interests represented in a given geographical area, the greater the probability of encounters which may lead to fruitful information exchanges. Firms located in areas with the range of information sources to enhance the innovation process, will realize lower search costs in obtaining relevant information.

A fourth characteristic of innovation is the increased role of experimentation in the form of learning by doing and learning by using. Some aspects of knowledge have a tacit nature which cannot be completely codified and transferred through blueprints and instructions. This knowledge is learned through practice and practical example (Nelson and Winter, 1982). This expertise can come from a variety of sources in related industries. It may be generated by buyers of the product as they provide information about their needs and requirements which are relevant to product design and development (Von Hippel, 1988). This expertise may be facilitated by input suppliers who disseminate technical information which, in turn, facilitates new product innovation (Cohen, Levin and Mowery, 1987). In addition, competitors, who face the same obstacles and bottlenecks can be an important source of tacit information (Von Hippel, 1988; Porter, 1990).

Recent work by Carlson and Jacobsson (1991) suggests that the market for new technologies is primarily regional. The development of technologically complex products requires close collaboration between suppliers and customers. Until a product becomes standardized, constant specification and design changes make it very costly for suppliers to get involved with distant customers.

A fifth and final characteristic is that innovation has a cumulative character which builds on existing expertise. Early in the literature, Machlup (1962, pp. 161—163) pointed out that the process of solving a technical problem often raises new research questions and positions existing innovators to continue to innovate. An area with innovative activity will develop a set of specialized resources which provide comparative advantage for the next round of innovation. This process is defined by Arthur (1990) as self-reinforcing expertise and gives rise to the geographic clustering of innovative activity.

In sum, the five characteristics presented here characterize innovation as a process reliant on timely flows of external information. The risk inherent in the innovation process suggests that one way in which firms, especially small firms, can reduce uncertainty is by engaging in reciprocal sharing of information or networking with related firms. The prominence of university research argues for proximity to this innovative input to stay at the cutting edge of technology. The increased complexity of innovation suggests that other sources of information such as related industry presence and specialized business services are key to innovative success. These specialized information sources tend to locate near their client markets. Finally, the cumulative nature of innovative activity suggests that areas with demonstrated innovative success have assembled information to facilitate the next round of innovation. Firms located in areas with limited access to information inputs must rely on their own internal efforts, and will face higher costs in acquiring information (Davelaar and Nijkamp, 1989; Brody and Florida, 1991). Large firms may attempt to internalize these knowledge sources by hiring skilled individuals with relevant expertise. Lacking the resources of their larger counterparts, small firm innovative activity may rely more on external transactions. Therefore, location in a technological infrastructure may provide the resources that enable small firms to innovate.

III. Model and data

Following Griliches (1979), innovation is analyzed in a modified production function approach; innovative output depends on the amount of innovative inputs. For this abstraction, innovative inputs are suggested by disaggregating the innovation process into interdependent stages of basic research, applied research and commercial manufacturing and marketing (Kline and Rosenberg, 1987). While this model has been applied to individual firms, a technological infrastructure perspective suggests that institutions and institutional resources may provide outside sources of innovative inputs.

Innovative output, INN_{is}, the number of innovations for an industry i, in a geographic area, s, is modeled as a function of four innovative inputs:

$$INN_{is} = UNIV_{Is}^{B_1}\, IND_{Is}^{B_2}\, RELPRES_{Is}^{B_3}\, BSERV_{Is}^{B_4}. \tag{1}$$

IND_{Is} is industrial R&D expenditures in the geographic area, s, for the related, larger industry group, I. The more encompassing industry group, I, measures the technological area across which spill-overs would be expected to occur. $UNIV_{Is}$ is university research expenditures measured at the level of the academic department and allocated to the relevant industry group. $RELPRES_{Is}$ is the presence of related industry, including the presence of firms in industries using related technologies as well as downstream users of a technology who may disseminate information about the technology. $BSERV_{Is}$ is the presence of specialized business services related to innovative activity within the industry.

Using state level data to model a more local phenomenon may bias the parameter estimates. For estimation, two additional variables are added to control for aggregation bias:

$$\begin{aligned} Log(INN_{is}) = {} & \beta_1 \log(UNIV_{Is}) + \beta_2 \log(IND_{Is}) + \\ & \beta_3 log(RELPRES_{Is}) + \beta_4(BSERV_{.s}) \\ & + \beta_5 CONC_{.s} + \beta_6(POP_{.s}) + \\ & \beta_7 \log(SALES_{i.}) + \varepsilon_{is}. \end{aligned} \tag{2}$$

State population $POP_{.s}$, is included as a control for state size and to facilitate cross state comparisons. The variable $CONC_{.s}$ provides a measure of the concentration of manufacturing activity within the state and accommodates within state variation. Industry sales, $SALES_{i.}$ are included as a control for product demand which may affect the quantity of innovations generated within an industry.

The dependent variable in the model is the number of innovations for an industry, i which originated in state, s. The data are the product of a census of innovation citations from over 100 scientific and trade journals conducted by the U.S. Small Business Administration (SBA) in 1982 (Edwards and Gordon, 1984). The SBA data captures innovation which, by nature of the citation, added new economically useful knowledge to a product category. In contrast to patent data, which marks the certification of a new invention, innovation citations announce the market introduction of a commercially viable product.[1] The SBA data contains a total of 4,200 product innovations with information on the location of the enterprise which introduce the innovation.

The innovation data contains a total of 95 three digit industries with at least one innovation citation. When the data are stratified by state, a large number of zero cells result. In order to proceed with the estimation, it is necessary to limit the sample. Table I presents the sample of industries used in the estimation. These industries contain a minimum of fifty innovation citations. These thirteen industries account for 80% of the total innovations in 1982.

The independent variables in the model are defined as follows. University R&D is measured at the academic department level using data from the National Science Foundation's Survey of Science Resources. Related industry is measured as value added for the major industry group related to the industry under consideration from the Census of Manufacturers. The SIC code classification scheme is designed to accommodate this type of relationship. A three digit industry is related to other industries within its two digit major industrial group. As an example, SIC 283, drugs, would benefit from the presence of related activity in the industrial group SIC 28, Chemicals and Allied Products. Related industry is measured as manufacturing value added for the corresponding two digit industry. Implicit in the innovation process is a time lag involved in translating an invention into a commercial product innovation. The exact time lapse between discovery and subsequent commercial product innovation is highly variable and difficult to specify. For example, Mansfield (1991) estimated that the average time lag between an academic research finding and the first related commercial introduction of a new product was, on average, seven years with a standard deviation of two years. To model the expenditures on the innovative inputs, we use the average annual expenditures in the ten year period prior to the introduction of the innovation. This measure attempts to capture the stock of knowledge embodied in a geographic area and provides a more appropriate measure of regional capacity than the flow of a single year's expenditures.

There are a variety of business services which provide knowledge of the market and the commercialization process. For example, the services of patent attorneys may be a critical input to the innovative process. Unfortunately, data on the

TABLE I
Distribution of innovations by three digit industry for small and large firms: Ranked by number of total innovations

SIC	Industry	Number of innovations		
		Total count of innovation	Small firm $\mu(\sigma)$	Large firm $\mu(\sigma)$
357	Computer and office machinery	954	18.41 (47.61)	10.52 (21.53)
382	Measuring and controlling instruments	668	13.31 (21.64)	7.24 (11.25)
366	Communications equipment	376	7.66 (15.09)	3.86 (7.58)
367	Electronic components	261	4.07 (12.53)	4.10 (12.53)
384	Surgical, medical and dental instruments and supplies	228	5.72 (11.11)	1.59 (3.22)
356	General industrial machinery and equipment	164	3.14 (4.56)	2.24 (2.73)
283	Drugs	133	1.10 (1.97)	3.41 (8.60)
355	Special industrial machinery	116	2.45 (3.51)	1.14 (1.85)
349	Miscellaneous fabricated metal products	105	1.83 (3.23)	1.38 (1.99)
362	Electronic industrial machinery	74	1.17 (2.02)	1.24 (1.86)
386	Photographic equipment and supplies	61	0.97 (1.92)	1.14 (2.29)
282	Plastic materials and synthetic resins	51	0.38 (0.78)	0.76 (1.94)
284	Soap, detergents and cleaning preparations	50	0.83 (1.58)	0.69 (1.79)

presence of this input do not exist because all legal services are grouped together in SIC 8111 without any finer detail. Of all the producer services available to support innovative activity, the only category which is specifically and solely targeted to the introduction of new innovations is Commercial Testing Laboratories, SIC 7397. This is used as a rough proxy measure for business services related to innovative activity. To measure $BERV_{.s}$, the annual average receipts of Commercial Testing Laboratories are used.

A geographic concentration variable $CONC_{.s}$ is added to control for potential sources of aggregation bias. This variable is used to measure the degree to which manufacturing activity is concentrated within states. This variable is added to the equation to compensate for the use of states as the unit of observation. The geographic concentration variable measures the amount of manufacturing activity in the largest Standard Metropolitan Statistical Area (SMSA) relative to total manufacturing activity in the state. Manufacturing activity is measured as the value of manufacturing shipments from the 1977 Census of Manufacturers. The numerator of the concentration index is the value of manufacturing shipments for the largest SMSA in the state and the denominator is the value of manufacturing shipments for the entire state.[2]

Industrial R&D is measured as expenditures for industrial R&D performed within companies as reported by the National Science Foundation's Science Resources Survey. These data do not include that cost of R&D contracted to outside organizations such as universities and colleges, nonprofit organizations, research institutions and other companies. The data represent the ten year average for R&D expenditures. NSF confidentiality requirements mean that data is unavailable for some locations. Industrial R&D expenditures are available for twenty nine states. The available state data contain over 92% of the total innovations introduced in the U.S. in 1982. The sample for estimation accounts for 78% of the U.S. population and 81% of the university research expenditures in 1982. Conversely, states for which R&D data is unavailable account for 325 innovations or 7.7% of the total innovations. The estimation uses the resulting combination of 29 states and 13 industries which yields 377 observations.

TABLE II
Correlation matrix for innovative inputs

	IND_s	$UNIV_{is}$	$RELPRES_{is}$	$BSER_s$
IND_s	1.00	–	–	–
$UNIV_{is}$	0.68	1.00	–	–
$RELPRES_{is}$	0.63	0.39	1.00	–
$BSERV_s$	0.73	0.56	0.53	1.00

Note: Reported correlations are for the log values of each of the variables.

There are several estimation issues to consider. The dependent variable, number of innovations by state and industry, is a censored dependent variable: the number of innovation will either be zero or some positive integer. Cases with no innovation provide information about how innovative locations differ from non-innovative locations[3] and results in unbiased estimates. For these reasons, the Tobit model is used. An additional econometric concern always suspect with geographic cross-sectional data is multicollinearity. With state data, it is highly likely that the independent variables may be affected by some common trend or underlying state characteristics. Table II presents the correlation matrix for the innovative inputs. There is evidence of some degree of multicollinearity which may result in parameter estimates exhibiting higher estimated variances and, as a result, the coefficients may be less statistically significant than expected.[4]

A summary of the data used in the empirical estimation is presented in Table III. Innovations are measured as the count of innovations in a state and three digit industry. University research expenditures, industrial R&D expenditures, related industry value added, receipts from specialized business services, and total industry sales are in millions of 1972 dollars. State population is measured as the resident population, in thousands, in 1977. Industry sales are measured as the 1977 value of shipments for the three digit industry.

IV. Empirical results

The relative importance of inputs for different firm sizes can be ascertained by estimating the innovation equation separately for the innovation

TABLE III
Summary statistics

Variable	Mean	St. dev.	Min	Max
Innovations (INN_{is})	7.72	24.49	0	365
University Research ($UNIV_{ls}$)	32.52	59.41	0.3	380.60
Industry R&D (IND_{s})	582.90	818.51	9.0	3883.00
Industry R&D (IND_{ls})	50.87	91.87	0.09	580.80
Related Industry Presence ($RELPRES_{ls}$)	903.06	1062.60	4.04	4404.00
Business Services ($BSERV_{s}$)	13.88	17.02	0.50	89.52
Geographic Concentration Index ($CONC_{s}$)	0.41	0.23	1.10	0.94
State Population (POP_{s})	5919.07	4905.33	955.00	22350.00

Innovation is measured as integer count of innovations. University research expenditures, industrial R&D expenditures, related industry value added, receipts from specialized business services and total industry sales are in millions of 1972 dollars. Population is measured in thousands.

activity of small and large firms and comparing the resulting coefficients. The SBA innovation data identify innovations emanating from large firms and from small enterprises. Large firms are defined as having 500 or more employees. Small firms are defined as having fewer than 500 employees.

TABLE IV
Tobit estimation results by firm size
(Standard errors in parenthesis)

Dependent variable: Log(INN_{is})			
Variable	All firms	Large firms	Small firms
Log($IND_{.s}$)	0.190[a]	0.146[a]	0.140[a]
	(0.054)	(0.040)	(0.057)
Log($UNIV_{ls}$)	0.123[a]	0.068[a]	0.145[a]
	(0.044)	(0.037)	(0.046)
Log($RELPRES_{ls}$)	0.296[a]	0.245[a]	0.214[a]
	(0.047)	(0.044)	(0.050)
Log($BSERV_{.s}$)	0.118[a]	0.071[b]	0.149[a]
	(0.057)	(0.047)	(0.059)
Log($POP_{.s}$)	0.103[a]	0.085[a]	0.126[a]
	(0.030)	(0.028)	(0.032)
Log($SALES_{i.}$)	−0.230	−0.086	−0.198
	(0.117)	(0.106)	(0.120)
$CONC_{.s}$	1.020[a]	0.810[a]	0.895[a]
	(0.197)	(0.178)	(0.202)
$\hat{\sigma}$	0.850	0.743	0.841
Log-likelihood	−473.46	−402.24	−444.83

Standard errors in parenthesis. Number of observations is 377.
[a] indicates significance at 0.95. [b] indicates significance at 0.90.

Table IV compares the results of the model estimation for alternatively all firms, large firms and small firms in the respective columns. The four innovation inputs from the geography of innovation model, including university R&D; industrial R&D; and related industry presence are statistically significant at 0.95. The presence of specialized business services is statistically significant at 0.95 for small firms and 0.90 for large firms. Regardless of firm size, the geography of innovation production function for innovative output holds. A Chow test of the equality of coefficients in the two regressions rejects the hypothesis that the two models are equivalent at 0.01 level of significance. The innovative activity of small and large firms reflect different usage of the innovative inputs.

There are several differences between small and large firms in the importance of the inputs in generating innovative output. Innovative small firms make greater use of university research than do their larger counterparts.[5] The elasticity of innovative output with respect to university research is more than twice as great for small firms than for large firms. One potential explanation for this finding is that small firms have a less well-developed internal R&D capability than their larger counterparts and thus rely more heavily on external R&D from universities. Link and Rees (1990) reach a similar conclusion in survey work on the usage of university research. The lack of internal resources to support in-house specialized business services may also account for the finding that innovative activity of small firms benefits more from the presence of specialized business services in the state.[6] The elasticity of innovative output with respect to business services was twice as great for small firms than for their larger counterparts.

V. Summary and conclusion

Where do small firms acquire the resources to successfully engage in innovation? The results presented here suggest that small firms rely more on external sources of input to the innovation process. Small firms appear able to generate innovative output while undertaking negligible amounts of investment in R&D by capturing spill-overs from university research. Large firms are more adept at exploiting knowledge created in their own laboratories, while smaller firms exhibit a comparative advantage at exploiting spill-overs from university laboratories. One potential explanation for this is that small businesses have a less well developed internal R&D capability than their larger counterparts and thus rely more heavily on external R&D from universities. Link and Rees (1990) reach a similar conclusion in survey work on the usage of university research. While large firms are likely to have formal university research relationships, small firms tend to receive greater benefit. Another possible explanation of this result is that knowledge which may be otherwise difficult to appropriate results in the start-up of new, small firms. The findings further indicate that small firms' innovative activity benefits more from the presence of specialized business services than their larger counterparts. Small firms' lack of internal resources to support in-house specialized business service may account for this finding. This finding is consistent with MacPherson's (1988) survey findings that the intensity of use of external producer services correlates highly with small firm realized product innovations.

Larger firms are able to internalize innovative inputs and provide complementary assets to facilitate innovation. Lacking these resources, small firm innovative activity appears to benefit from an external technological infrastructure, an integrated and spatially-concentrated network of complementary institutions and resources which provide input to the innovation process. This technological infrastructure may enable small firms to engage resources only available to larger firms in other locations. In this way, location may be especially beneficial to small firm innovation.

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Notes

[1] There are some limitations to these data and potential sources of bias to note. The data are only available as a cross-section for the year 1982. Innovation citations which appear in publications may be biased towards unusual or specific items which the editors consider to be of special interest. Some product innovations may not be reported because they were not of interest to the editors. Large firms with public relations departments may have greater rapport with journal editors resulting in an over representation of innovative activity from large firms. This is perhaps offset by the fact that small firms view these announcements as inexpensive advertising and aggressively pursue these contacts. Innovations are attributed to the state in which the establishment responsible for the development of the innovation was located. It was anticipated that some innovations would be developed by subsidiaries or divisions of companies with headquarters in other states. Since headquarters may announce new product innovations, the SBA data discriminates between the location of the innovating establishment and the location of the innovating entity. The subsidiary or division responsible for the major development of the innovation is known as the establishment. The parent company or headquarters is known as the entity. For example, Intel Corporation introduced a 16-Bit Micro-Controller (Model Number 8096). The major development was done by a division of Intel in Arizona. Intel is headquartered in California. In this case, the state of the establishment is Arizona and the state of the entity is California: the innovation was attributed to the state of Arizona. The state identifier of the establishment is used to investigate the spatial patterns of innovation. Finally, states are not an entirely satisfactory unit of observation to use in this analysis. Ideally, we would like data at a sub-state level of aggregation, however, no such data existed at the time of the analysis. Information as to the economic significance or the revenue generated by each innovations is not available.

[2] For the estimation of the innovation equation the log of the geographic concentration variable is not taken. There is no

strong a priori functional specification and the estimation of the innovation equation with a log transformation of this variable yields similar results.

[3] In the sample used for estimation, there are 140 state and industry observations, or 37 percent, with zero innovations.

[4] In addition, no conclusive presence of spatial-correlation was found and no correction was made. Additionally, Breusch-Pagan tests revealed no heteroscedasticity in the innovation equation specification.

[5] There is a statistically discernable difference in the coefficients of university research expenditures for small and large firms at the 95 percent level of confidence using a two-tailed test.

[6] There is a statistically discernable difference in the coefficients of business services for small and large firms at the 90 percent level of confidence using a two-tailed test.

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