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WHY INNOVATIVE ACTIVITY VARIES? THE ROLE OF HIGHER EDUCATION IN LOCAL INNOVATIVE ACTIVITY

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The Role of Higher Education in Local Innovative Activity

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ABSTRACT
Innovation has been the primary source of improvements in the standard of living over since the Industrial Revolution. With the growth of the knowledge economy local economic development officials have sought to foster innovation within their communities. Many have also sponsored efforts to benchmark local levels of innovation in comparison to other places. This paper offers a careful analysis of the characteristics and interrelationships between the most widely used measures of local innovative activity. It proposes and estimates a model of the causes of intercity variation in innovation, and shows that much of this variation be accounted for by differences in the size of the higher education sector. On the other hand, it finds that some aspects of innovation commercialization—especially venture capital investment and Initial Public Offerings—tend to be more concentrated in a few locations than the model would predict, suggesting the presence of economies of scale in these activities.

Introduction

Innovation is widely regarded as one of the chief engines of modern economic growth. Since the Industrial Revolution, the introduction of new products and new, more efficient processes of production has been the key to rising standards of living and economic prosperity in the United States and other developed economies. In past two decades fostering innovation has become an increasingly important element in local economic development strategies of communities throughout the country.

According to Michael Porter, for example, "The central economic goal. . . should be to attain and sustain a high and rising standard of living for. . . citizens. The ability to earn a high and rising standard of living depends on increasing productivity which in turn depends on innovation. The central challenge then in enhancing prosperity is to create the conditions for sustained innovation output" (Massachusetts Technology Collaborative 2003). Inspired by the success of Silicon Valley, the Research Triangle area, the Route 128 complex around Boston, as well as other information technology and life science industry clusters, business leaders and public officials have begun to compete to become the next high-tech industry center.

The attention directed toward innovation as an engine of economic growth has resulted in the production of a growing number of innovation indices that seek to benchmark the innovation performance of a particular city, state or region, relative to national trends.[1] All of these studies rely on similar data to measure aspects of innovation. But their focus has largely been on measurement, and there has been relatively little analysis of the broader characteristics of the data that underlie their measurements. This is unfortunate because a good deal can be learned by looking more closely at the characteristics of the available innovation data. In particular, there are important and striking relationships between the individual indicators that most studies have relied on.

In this paper I carefully evaluate the primary dimensions of recent innovative performance in the 50 largest metropolitan areas in the country. The Census Bureau referst to these areas as Metropolitan Statistical Areas (MSAs). When two or more MSAs are contiguous with one another and have substantial economic interactions the Census Bureau designates the combined unit as a Consolidated Metropolitan Statistical Areas (CMSAs), referring to the entire entity by its primary city name. For brevity, however, I will refer to all of the places in this study

[1] See, for example, Burress, Rosenbloom and Manzoor (2004), Massachusetts Technology Collaborative (2003), Progressive Policy Institute (2001), Maryland Technology Development Corporation (2001), Maine Science and Technology Foundation (2002).

as metropolitan areas, or simply as cities.[2] Together the 50 CMSAs/MSAs in this study account approximately 60 percent of the nation's workforce and economic activity.

Data on innovation can be used to measure two aspects of the innovation economy: the generation of new ideas, and the commercialization of new innovations. Both are essential to sustaining innovation. As I show, much of the variation in idea generation across cities can be explained by differences in the scope of university science and engineering activity across metropolitan areas. Variation in university science and engineering also explains a large part of inter-city differences in innovation commercialization, but it is apparent that venture capital funding and Initial Public Offerings are more highly concentrated than idea generation or university science and engineering. My analysis is begins with a description of the available evidence on innovation at the metropolitan area level and a discussion of the characteristics and distribution of these data. I then propose and estimate a model of the interrelationship of the available indicators and linking them to the size of university science and engineering activities in each metropolitan area. Finally I construct several more aggregated indexes of innovative activity and describe their variation across cities.

Assessing Innovation Performance

[2] The U.S. Census Bureau uses the concept of Metropolitan Statistical Area (MSA) to collect data. Each MSA consists of one or more counties whose economies are closely related to each other. When several MSAs are located close together, forming in effect a single economic entity, the Census Bureau designates a combined unit as a single Consolidated Metropolitan Statistical Area (CMSA). In this paper I consider the 50 larges CMSAs and MSAs. Because of the importance of higher education to some of the analysis I have modified the geographic scope of a five of these metropolitan areas to incorporate data from nearby counties that contain comprehensive research universities. The MSAs that have been adjusted are Indianapolis (joined with Bloomington, with Indiana University), Salt Lake City (joined with Provo, with Brigham Young University), Birmingham (joined with Tuscaloosa, with the University of Alabama), Kansas City (joined with Lawrence, with the University of Kansas), and Grand Rapids (joined with East Lansing, with Michigan State University).

Data Availability

Innovation performance cannot be measured directly or in one single dimension. The production of new ideas and their application in the form of new products or processes is not subject to any simple quantification. Only a limited number of activities associated with the innovation process are subject to measurement, and even those that are measured are not easily expressed in comparable units. Nonetheless, a variety of data sources are available and have been widely used to measure innovative activity across cities and regions. Here I focus on five measures of innovation: university research and development expenditures, patenting, Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) grants, Venture Capital Investments, and Initial Public Offerings (IPOs).

Broadly speaking these data can be interpreted as indicators of two distinct aspects of the innovation process. The first two data series reflect aspects of idea generation—while university R&D expenditures reflect the level of resource investment into basic research, rates of patenting are one measurable index of the results of these efforts.The first of which reflects idea generation, while the second category encompasses a variety of measures of the scope of efforts to commercialize new ideas. Not all innovations are patented of course, and not all patents lead to commercially viable products. Nonetheless, patents are one of the most frequently used quantitative measures of innovative activity.

The remaining three data series measure different aspects of the flow of resources devoted to the commercialization of innovations. Transforming ideas into commercial products is a crucial step in the innovation process, and one that requires large investments of resources. Applied research and development account for much of total research and development spending in the United States and without these activities many new ideas would not find useful applications.

The SBIR program, administered by the Small Business Administration, is reputed to be the largest seed capital fund for development of new products and processes in the world. It provided competitive grants to entrepreneurs seeking to conduct "proof-of-concept" research (Phase I) and prototype development (Phase II). The STTR program makes competitive awards to small business and public sector partners to promote technology transfer activities. SBIR and STTR grant awards to businesses are thus an indicator of the level of innovative activity of small businesses in each city.

Venture capital investments provide a second indicator of the extent of commercialization activity in a city. Venture capital is a small but crucial part of the financial market, providing capital infusions in the early stages of business development. Because venture capitalists generally provide close supervision to the ventures in which they invest the location of venture capital funds may play an important role in promoting the geographic concentration of emerging industries.

During the Information Technology boom of the 1990s Initial Public Offerings (IPOs) of stock in which privately held companies were taken public boomed as a means of financing the expansion of technology companies. The number of companies going public headquartered in a city provides a third measure of the extent of commercialization efforts in the community. companies whose headquarters are located in metropolitan area.

Characteristics of the Data

Table 1 lists the values of these five indicators of innovative performance for the largest 50 MSAs/CMSAs in the United States, along with each city's population in 2002. Overall, one would expect that larger metropolitan areas would generate more innovations than smaller ones. This conjecture is confirmed in Table 2, which contains a matrix of correlation coefficients between the different innovation measures and metropolitan population. All of the innovation measures display a high degree of correlation with metropolitan population, and with each other. Nonetheless, there are important differences in the extent of correlation: university R&D expenditures and rates of patenting have a much higher correlation with population than does venture capital funding.

Figure 1 looks at the distribution of innovative activity from a somewhat different perspective, plotting the Lorenz curves for each measure of innovation and comparing their distribution to the distribution of population across metropolitan areas.[3] The further below the diagonal line the Lorenz curve lies, the more unequally the distribution of the variable in question. This divergence can also be summarized quantitatively in the Gini coefficient, which measures the ratio of the area under the Lorenz curve to the area under the diagonal line. The Gini coefficient ranges from zero (complete inequality) to one (perfect equality).

As Figure 1 makes clear, all of the measures of innovation are more concentrated than population, but the two measures of idea generation are only marginally more concentrated than is population. All of the commercialization measures tend to be more concentrated than either

[3] Lorenz curves are commonly used in studies of wealth or income distribution. In this case households are ordered from lowest to highest income and their cumulative share of total income is plotted as a function of their cumulative share of households. Here the unit of analysis is a metropolitan area, so I plot the cumulative share of each measure of innovation as a function of the cumulative share of metropolitan areas.

population or the idea generation indicators, with venture capital funding being the most concentrated.

The correlation between individual the different innovation indicators partly reflects their common association with city size, but even after adjusting them to remove these effects by expressing them in per capita terms it is evident that the different measures of innovation are correlated across cities. Table 3 reports the matrix of correlation coefficients between per capita measures of innovative activity. Per capita university R&D expenditures and patenting show little relationship to city size, but there remains a pronounced correlation between measures of commercialization and population, suggesting that there are important scale effects for commercialization that help to explain the inequality of the distribution of these measures. It is also apparent that there are important correlations between the different innovation indicators even after the common effects of city size are accounted for.

A model of the determinants of innovative activity

Many observers believe that research universities have played an important role in creating dynamic, innovative local economies. The Progressive Policy Institute (2001) states, for example that in "the New Economy, the key engines of growth - technology and research-based companies and industries - are fueled by a large and high-caliber scientific and engineering workforce….So growing a high-quality, scientific workforce is critical to boosting innovation and productivity."

Casual observation suggests that the presence of one or several universities has played an important role in stimulating many of the most dynamic regional economies to emerge in the past quarter century. Stanford University is commonly credited with playing a central role in stimulating the growth of the computer industry in Silicon Valley while spin-offs from MIT, Harvard, and other universities in the Boston area are depicted as the genesis of the cluster of high-tech industry along the Route 128 corridor outside Boston. Similarly, accounts of the growth of the Research Triangle area in North Carolina, the recent expansion of biotechnology firms in San Diego, and the computer industry around Austin, Texas all give prominence to the role of university's in generating much of the intellectual property that has promoted the growth of these places.

These observations suggest a theoretical framework that can be used to disentangle the interrelationship between the different measures of metropolitan innovation. Figure 2 provides a schematic illustration of this model. In this model, the higher education sector in each city is taken as predetermined, or exogenous. The other key assumption embedded in the model is that the size of local idea generation activity is exogenous from the perspective of local efforts at commercialization. In other words, while a larger idea generating sector stimulates more commercialization activity, there is no feedback through which commercialization stimulates increased university R&D expenditures or patenting.

In the diagram the potential channels of influence between different activities are represented with arrows. A larger higher education sector contributes to idea generation through higher levels of university R&D and the production of more patentable innovations. University R&D expenditures are also assumed to influence rates of patenting, on the assumption that the greater the R&D effort, the more potentially patentable ideas will be generated.

Turning to commercialization, I assume that all three measures are positively influenced by the size of the university sector (through spin-offs and collaborative ventures), and by variations in the level of idea generation activities in the community. In addition to these influences, the model allows for the possibility of positive feedbacks between different commercialization activities to allow for synergistic interactions.

Estimation

The linkage between higher education and innovative activity largely involves interactions between university scientists and engineers on the one hand and the private sector on the other. To measure the size of these interactions I use data on the number of science and engineering (S&E) doctorates awarded by universities in each city in 1994.[4] The number of such graduates is both an indirect reflection of the number of scientific and technical research faculty employed by these universities and a direct measure of the potential supply of new labor market entrants.

As with the measures of innovative activity discussed earlier, the number of S&E doctorates awarded is highly correlated with city size. To remove this effect I first estimate the relationship between S&E doctorates and city size, regressing the number of doctorates awarded on a quadratic function of city population. The results of this regression are reported in Table 4, which shows that nearly three quarters of the variation in S&E doctorates can be explained by differences in city size.

Using the estimated relationship in Table 4 to predict the number of S&E doctorates that would be expected based on city size, I then calculate the difference between the actual number of doctorates and this predicted number to use in the subsequent analysis. These deviations of the actual number of doctorates from the predicted number (referred to as PhD-Deviation) are a measure of exogenous differences in the size of the higher education sector across cities. If the

[4] Using data on doctorates from 1994 insures that this variable can be treated as exogenous in the subsequent analysis.

conjecture that a larger higher education system contributes to innovative activity is true, then this variable should exert a positive influence on levels of innovation.

Table 5 reports estimates of the determinants of the two dimensions of idea generation measured by the data. The top panel of the table focuses on university R&D expenditures, while the bottom panel explores the determinants of patenting. In each case I begin by estimating the effects of city size by regressing the innovation measure on population and population squared. I then add additional explanatory variables. In the case of university R&D the only additional explanatory variable is the difference between the actual number of S&E Doctorates awarded and the predicted number based on city size, PhD-Deviation. PhD-Deviation exerts a positive and highly statistically significant effect on the level of university R&D. With the addition of this variable the model is able to explain more than 90 percent of the intercity variation in levels of university R&D expenditures.

The bottom panel of Table 5 repeats the analysis, this time considering levels of patenting across cities. As in the case of university R&D expenditures, exogenous variations in the size of the higher education sector (PhD-Deviation) exert a positive and statistically significant effect on patenting, as shown in the second column of results. The third column of the table allows for the possibility that variations in the level of university R&D expenditures exert an independent effect on levels of patenting. To capture this effect I use the estimated coefficients from the regression in the top panel of the table to first predict the level of university R&D that would be expected based on city size and PhD-Deviation, and then calculate the deviations of university R&D expenditures from this predicted level to use as a regressor (R&D-Deviation) in the patenting equation. Comparing the second and third columns it is apparent that after controlling for city size and variations in higher education, there is no independent effect of university R&D expenditures.

Table 6 examines the determinants of innovation commercialization. Each panel of the table reports regressions for one of the measures of commercialization. In each panel the first column reports estimates of the relationship between city size and commercialization. The second column adds PhD-Deviation along with deviations of university R&D expenditures and patenting from their predicted values. I use the estimated coefficients from these regressions to calculate the predicted level of each measure of commercialization. In the third column I explore interactions between the different aspects of innovation commercialization by including deviations from their predicted values as additional explanatory variables.

As in Table 5, there is a strong and consistent positive relationship between the PhD-Deviation variable and all three measures of innovation commercialization. Cities with larger than predicted higher education sectors have higher levels of innovation commercialization than similarly sized cities with smaller higher education sectors. After accounting for this effect none of the other variables help to predict the level of SBIR grants in a city. On the other hand, both venture capital funding and IPO activity are higher in cities with higher than expected levels of patenting. In addition there appears to be an extremely high correlation between venture capital funding levels and IPO activity. Thus cities with concentrations of venture capital funding reap the benefits when some of these ventures eventually go public.

Discussion

A large part of the aggregate variation in innovative activity across cities is simply a reflection of differences in city size. Larger cities produce more innovations. But this is not the whole story. Even expressed in per capita terms there are significant correlations between different measures of innovation. Untangling the cause and effect relationships between these different measures requires a theoretical framework in which to analyze them. The assumptions of this model are, of course, not directly testable within the framework of the empirical analysis. With that caveat, the data are consistent with the widely held view that the strength of science and engineering activities within a city play an important role in encouraging innovative activity.

Cities whose universities produce more S&E graduates perform better on all measures of innovative activity than those with below average levels of S&E graduates. Adding this one variable accounts for a large fraction of the inter-city variation in innovative activity that is observed in the data. While these associations may not hold in the future, they provide strong support for the view that investments in higher education are an important channel to boost metropolitan innovation performance.

An Index of Innovative Activity

Having considered the characteristics of the individual innovation indicators it is also illuminating to look at more aggregated measures of innovation performance across cities. Because we are interested primarily in the intensity of innovative activity across cities, rather than in measuring differences in overall size, I begin by expressing each innovation indicator in per capita terms. To make the different indicators comparable I then convert them to index values by expressing the level in each city as a percentage of the level that indicator in the city with the highest per capita value. The maximum score for each indicator is 100, and theoretically the minimum is zero.

The final step in constructing the Innovation Index is to aggregate the indicators. I do this in two stages. In the first step I combine individual indicators into two sub-indexes reflecting idea creation and commercialization, respectively. Each sub-index is an unweighted average of the individual indicators for that category. In the second step I combine the two sub-indexes to arrive at an aggregate Innovation Index.

Table 6 reports the values of aggregate index along with the values of the two sub-indexes for each metropolitan area arranged in order of declining magnitude of the aggregate innovation index. Figure 3 plots the pairs of values of the two sub-indexes for each city. At the top of the list are San Francisco and Boston, two large metropolitan areas that combine high values of both idea creation and commercialization. The remainder of the top five cities consists of three smaller metropolitan areas: Raleigh, Austin, and Rochester; all of which score especially highly in idea creation, and all but Rochester score well in terms of commercialization. After these cities come a group of mostly mid-sized metropolitan areas—San Diego, Denver, Washington, DC, Minneapolis and Seattle—which rank highly in terms of both idea creation and commercialization, but fall well below the leaders in each of these individual categories.

Conclusions

Innovation is widely seen as the key to regional economic development, and cities around the country are seeking to identify economic development strategies that will encourage increased innovation in their area. A crucial foundation for developing such strategies is an understanding of the current state of innovative activity across metropolitan areas. In the last few years a large number of communities have undertaken the construction of so-called Innovation Indexes that compare local performance with some set of other perceived competitor communities. While the specific analytical approach of these indexes varies somewhat, virtually all reflect performance on a core set of innovation indicators reflecting idea creation and commercialization activities.

Benchmarking local performance is useful, but it is important to step back from such "horse-race" comparisons to examine the characteristics of the underlying data in greater detail. In this paper I have undertaken such an analysis. As I show, there are significant regularities in the available innovation indicators. In part these reflect differences in metropolitan size which are largely removed by focusing on per capita measures of innovation intensity. But even in per capita terms measures of innovation are highly correlated.

Based on a simple model of the likely interaction between different dimensions of innovation I have estimated an empirical model that suggests that the primary source of these correlations arises because of differences in the level of university science and engineering activities across cities. These differences account for a large fraction of the variation in innovation activity across cities. Thus investments in expanding higher education infrastructure and faculty appear to be one potential avenue for cities seeking to improve their rankings in terms of innovative activity.

In addition, the model also confirms that there are important synergies between several dimensions of innovation commercialization. In particular places with high levels of venture capital investment other things equal, tend also to be places with higher than expected numbers of IPOs. And both venture capital and IPOs tend to cluster in places with unusually high rates of patenting.

Acknowledgements

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Table 1: Selected Innovation Indicators for CMSAs/MSAs

	Total Population (1000s), 2000	University R&D Expenditures ($1000s), 2001	Average Annual Number of Patents Issued, 1990-2000	Average Annual Value of SBIR and STTR Awards ($1000s), 1996-2000	Average Annual Value of Venture Capital Investments ($1000s), 1996-2002	Number of IPOs, 1996-2003
New York[a]	21,200	$2,289,579	5,212	$35,166	$547,790	143
Los Angeles[a]	16,374	$1,648,279	3,585	$51,362	$322,504	74
Chicago[a]	9,158	$839,621	2,575	$7,214	$116,416	38
Washington, DC[a]	7,608	$1,884,116	1,498	$56,081	$276,877	54
San Francisco[a]	7,039	$1,568,494	5,468	$42,348	$1,872,733	211
Philadelphia[a]	6,188	$790,932	1,979	$16,809	$123,114	35
Boston[a]	5,819	$1,482,786	2,776	$96,918	$608,997	77
Detroit[a]	5,456	$798,951	2,054	$10,402	$19,442	16
Dallas[a]	5,222	$303,452	1,388	$3,331	$140,303	32
Houston[a]	4,670	$953,444	1,426	$4,733	$61,446	41
Atlanta[b]	4,112	$648,583	711	$6,903	$115,737	25
Miami[a]	3,876	$202,937	514	$1,093	$54,413	21
Seattle[a]	3,555	$596,819	945	$13,622	$158,602	30
Phoenix[b]	3,252	$121,337	821	$4,318	$37,273	11
Minneapolis[b]	2,969	$456,194	1,582	$7,245	$69,091	21
Cleveland[a]	2,946	$252,515	920	$7,023	$17,015	5
San Diego[b]	2,814	$625,380	1,158	$26,546	$169,726	32
St. Louis[b]	2,604	$455,557	577	$2,372	$41,304	8
Denver[a]	2,582	$408,129	814	$26,664	$196,445	31
Tampa[b]	2,396	$173,499	295	$1,058	$16,926	11
Pittsburgh[b]	2,359	$501,874	678	$4,739	$36,479	10
Portland[a]	2,265	$38,666	635	$3,023	$48,858	8
Cincinnati[a]	1,979	$209,267	736	$3,661	$11,276	4
Kansas City[c]	1,876	$178,433	217	$1,170	$16,620	11
Sacramento[a]	1,797	$437,686	273	$1,742	$16,869	2
Indianapolis[c]	1,728	$262,852	470	$634	$9,079	9
Salt Lake City[c]	1,702	$219,231	430	$6,237	$33,879	10
Milwaukee[a]	1,690	$118,028	519	$667	$3,425	3
Orlando[b]	1,645	$80,188	187	$3,629	$22,576	3
San Antonio[c]	1,592	$129,544	154	$2,168	$4,141	2
Norfolk[b]	1,570	$101,015	132	$2,169	$1,814	2
Las Vegas[b]	1,563	$42,332	102	$174	$336	1
Grand Rapids[c]	1,541	$19,068	404	$433	$917	3
Columbus[b]	1,540	$395,738	290	$3,136	$17,110	3
Charlotte[b]	1,499	$8,192	207	$742	$19,540	8
New Orleans[b]	1,338	$107,106	123	$617	$11,410	3
Greensboro[b]	1,252	$126,152	200	$1,100	$4,645	4

Austin[b]	1,250	$307,442	873	$7,151	$115,206	12
Nashville[b]	1,231	$215,505	113	$982	$23,822	7
Providence[b]	1,189	$144,184	195	$1,550	$4,675	1
Raleigh[b]	1,188	$993,313	538	$5,843	$68,679	10
Hartford[b]	1,183	$174,510	440	$3,977	$18,891	5
Buffalo[b]	1,170	$190,522	287	$3,064	$5,593	4
Memphis[b]	1,136	$31,062	121	$288	$6,499	2
West Palm Beach[b]	1,131	$25,396	320	$381	$24,244	13
Jacksonville[b]	1,100	$1,236	92	$0	$5,139	3
Rochester[b]	1,098	$249,850	1,346	$1,400	$14,971	3
Birmingham[c]	1,086	$267,845	67	$1,044	$6,781	3
Oklahoma City[b]	1,083	$154,084	125	$627	$4,283	2
Louisville[b]	1,026	$74,752	125	$874	$6,374	5
Mean	3272.92	446113.60	934	9886.30	110605.76	21.44
STD	3756.99	521738.85	1187.27	18207.56	283704.67	37.21
Max	21,200	2,289,579	5,468	96,918	1,872,733	211
Min	1,026	1,236	67	174	336	1

[a] CMSA
[b] MSA
[c] Expanded MSA, see text for explanation of criteria used.

Notes and Sources: Population-U.S., Bureau of the Census <factfinder.census.gov> ; University Research and Development Expenditures-National Science Foundation, Division of Science Resources Statistics, *Academic Research and Development Expenditures: Fiscal Year 2001*, NSF 03-316, Project Officer, M. Marge Machen (Arlington, VA 2003) http://www.nsf.gov/sbe/srs/nsf03316/, Table B-32; Average annual number of patents awarded-special tabulation provided by Harvard University, Cluster Mapping Project; Average Annual Value of SBIR/STTR grants-computed from Small Business Administration award data http://tech-net.sba.gov/tech-net/search.html; Venture Capital Investments-Special tabulations provided by Thompson Investment Analytics Report; Number of Initial Public Offerings-tabulated by Policy Research Institute, University of Kansas based on reports on Hoover’s Online http://www.hoovers.com/global/ipoc/index.xhtml.

Table 2: Correlation Coefficients between Innovation Indicators

	University R&D Expenditures	Patents	SBIR/STTR Grants	Venture Capital	IPOs	Population
University R&D	1.0000					
Patents	0.8476	1.0000				
SBIR/STTR Grants	0.7862	0.6705	1.0000			
Venture Capital	0.6330	0.7966	0.6188	1.0000		
IPOs	0.8028	0.9231	0.6707	0.9357	1.0000	
Population	0.8386	0.8459	0.5813	0.4610	0.7205	1.0000

Table 3: Correlation Coefficients between Per Capita Innovation Indicators

	University R&D Expenditures	Patents	SBIR/STTR Grants	Venture Capital	IPOs	Population
University R&D	1.0000					
Patents	0.3466	1.0000				
SBIR/STTR Grants	0.3975	0.3559	1.0000			
Venture Capital	0.3256	0.5090	0.6050	1.0000		
IPOs	0.2791	0.4581	0.5678	0.9261	1.0000	
Population	-0.0366	0.0594	0.1642	0.1988	0.2411	1.0000

Table 4: Estimates of Number of Science and Engineering Doctoral Degrees Awarded in 2001 as a Function of City Population

	Coef.	Std. Err.	P>|t|
population	0.1307	0.0254	0.000
population squared	0.0000	0.0000	0.126
Intercept	-43.7827	63.2201	0.492
R-squared	0.743		

Sources and Notes: National Science Foundation, *Selected Data on Science and Engineering Doctorate Awards: 1994*, NSF 95-337 (Arlington, VA, 1995). http://www.nsf.gov/sbe/srs/s4094/tables.htm, Table 6; see notes to Table 1 for population data.

Table 5: Estimates of Determinants of University R&D Expenditures and Patenting

	Coef.	Std. Err.	P>|t|	Coef.	Std. Err.	P>|t|	Coef.	Std. Err.	P>|t|
Panel A: University Research and Development Expenditures, 2001 (in $1,000)									
Population	193.5323	31.5566	0.000	189.7958	19.2848	0.000			
Population-squared	-0.0042	0.0016	0.013	-0.0040	0.0010	0.000			
PhD-Deviation				1028.4110	113.0828	0.000			
Intercept	-84781.6000	77156.1200	0.277	-69684.8200	47957.6700	0.153			
R-Squared	0.742			0.909					
Panel B: Average Number of Patents Granted Per Year, 1990-2000									
Population	0.4462	0.0698	0.000	0.4432	0.0528	0.000	0.4432	0.0497	0.000
Population-squared	0.0000	0.0000	0.009	0.0000	0.0000	0.001	0.0000	0.0000	0.000
PHD-Deviation				1.9540	0.3098	0.000	1.9540	0.2912	0.000
RD-Deviation							-0.0010	0.0004	0.012
Intercept	-288.6178	170.7209	0.098	-276.4131	131.3822	0.041	-276.4131	123.4919	0.030
R-Squared	0.756			0.870			0.887		

Table 6: Estimates of the Determinants of SBIR/STTR Grants, Venture Capital Investment, and Initial Public Offerings

	Coef.	Std. Err.	P>|t|	Coef.	Std. Err.	P>|t|	Coef.	Std. Err.	P>|t|
				Panel A: SBIR/STTR Grants (in $1,000s)					
Population	1.4420	0.3216	0.000	1.4402	0.2421	0.000	1.4402	0.2368	0.000
Population-Squared	0.0000	0.0000	0.006	0.0000	0.0000	0.000	0.0000	0.0000	0.000
PhD-Deviation				8.8420	1.4197	0.000	8.8420	1.3888	0.000
RD-Deviation				0.0024	0.0019	0.220	0.0024	0.0019	0.211
Patent-Deviation				-0.1059	0.0676	0.125	-0.1059	0.0661	0.117
VC-Deviation							0.0097	0.0066	0.149
IPO-Deviation							-59.1653	64.6627	0.366
Intercept	-1609.0930	786.3503	0.046	1660.2280	602.0711	0.011	1600.2280	588.9729	0.010
R-Squared	0.441			0.720			0.745		
				Panel B: Average Annual Value of Venture Capital Investments (in $1,000s)					
Population	93.3445	28.5250	0.002	93.7341	15.7877	0.000	93.7341	5.5502	93.7341
Population-Squared	-0.0032	0.0015	0.036	-0.0032	0.0008	0.000	-0.0032	0.0003	-0.0032
PhD-Deviation				742.3127	92.5764	0.000	742.3127	32.5453	742.3127
RD-Deviation				-0.1600	0.1234	0.202	-0.1600	0.0434	-0.1600
Patent-Deviation				30.8201	4.4075	0.000	30.8201	1.5495	30.8201
SBIR-Deviation							5.3111	3.6089	5.3111
IPO-Deviation							9050.4020	544.5633	9050.4020
Intercept	-117122.0000	69743.9400	0.1000	118579.7000	39261.0400	0.004	-118579.7000	13802.2400	-118579.7000
R-Squared	0.286			0.808			0.977		
				Panel C: Number of Initial Public Offerings 1996-2003					
Population	0.0124	0.0030	0.000	0.0124	0.0016	0.000	0.0124	0.0006	0.000
Population-Squared	0.0000	0.0000	0.068	0.0000	0.0000	0.001	0.0000	0.0000	0.000
PhD-Deviation				0.0750	0.0094	0.000	0.0750	0.0034	0.000
RD-Deviation				0.0000	0.0000	0.667	0.0000	0.0000	0.233
Patent-Deviation				0.0034	0.0004	0.000	0.0034	0.0002	0.000
SBIR-Deviation							-0.0003	0.0004	0.366
VC-Deviation							0.0001	0.0000	0.000
Intercept	-12.0990	7.2240	0.101	-12.2971	3.9900	0.004	-12.2971	1.4253	0.000
R-Squared	0.555			0.884			0.986		

Notes: All dollar values (university R&D, SBIR/STTR grants, and venture capital investments) are measured in 1,000s.

Table 7: Innovation Index Rankings,

CMSA/MSA	Idea Generation	Commercialization	Innovation Index
San Francisco[a]	45.0	78.7	61.9
Boston[a]	34.7	61.2	47.9
Raleigh[b]	68.5	26.4	47.5
Austin[b]	43.2	33.7	38.4
Rochester[b]	63.6	7.3	35.5
San Diego[b]	30.1	39.1	34.6
Denver[a]	22.3	43.6	32.9
Washington, DC[a]	22.8	27.2	25.0
Minneapolis[b]	30.9	15.7	23.3
Seattle[a]	20.9	22.6	21.8
Houston[a]	24.7	13.4	19.1
Hartford[b]	24.0	13.4	18.7
Pittsburgh[b]	24.4	10.7	17.6
Philadelphia[a]	20.7	14.2	17.5
Salt Lake City[c]	18.0	16.4	17.2
Detroit[a]	24.1	7.5	15.8
Columbus[b]	23.0	7.6	15.3
New York[a]	16.5	14.1	15.3
Atlanta[b]	16.5	13.6	15.1
Buffalo[b]	19.7	9.6	14.7
West Palm Beach[b]	12.9	16.1	14.5
Los Angeles[a]	14.9	13.8	14.4
Cincinnati[a]	21.5	6.7	14.1
Indianapolis[c]	20.2	7.2	13.7
St. Louis[b]	19.5	7.2	13.4
Dallas[a]	14.3	11.5	12.9
Cleveland[a]	17.9	7.4	12.6
Sacramento[a]	20.8	4.4	12.6
Chicago[a]	16.9	7.8	12.4
Nashville[b]	14.2	10.3	12.3
Birmingham[c]	17.3	5.8	11.5
Portland[a]	12.4	9.3	10.9
Phoenix[b]	12.5	7.9	10.2
Milwaukee[a]	16.7	3.0	9.9
Kansas City[c]	10.4	8.9	9.6
Greensboro[b]	12.5	5.8	9.2
Providence[b]	14.0	4.0	9.0
Louisville[b]	9.3	7.9	8.6
Oklahoma City[b]	13.2	3.7	8.5
Miami[a]	8.5	8.3	8.4
Tampa[b]	9.4	6.9	8.1

Orlando[b]	7.5	8.2	7.9
Charlotte[b]	6.0	8.6	7.3
Grand Rapids[c]	11.4	2.8	7.1
San Antonio[c]	8.8	4.4	6.6
New Orleans[b]	8.5	4.5	6.5
Norfolk[b]	7.3	4.3	5.8
Memphis[b]	6.0	3.2	4.6
Jacksonville[b]	3.5	3.6	3.5
Las Vegas[b]	4.3	1.0	2.6

Source: See text.

Figure 1: Distribution of Population and Innovation Measures

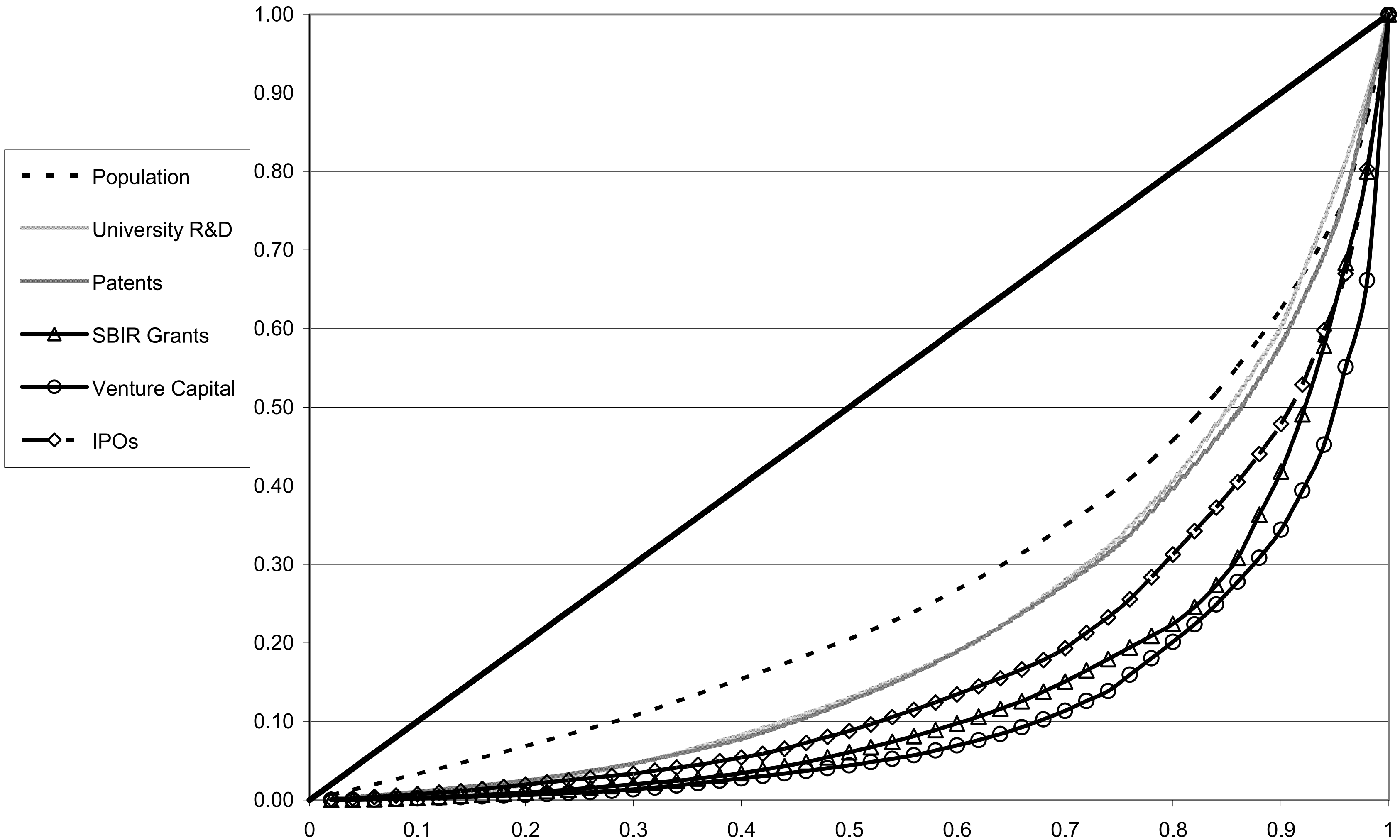

Figure 2: Schematic Model of the Determinants of Innovative Activity

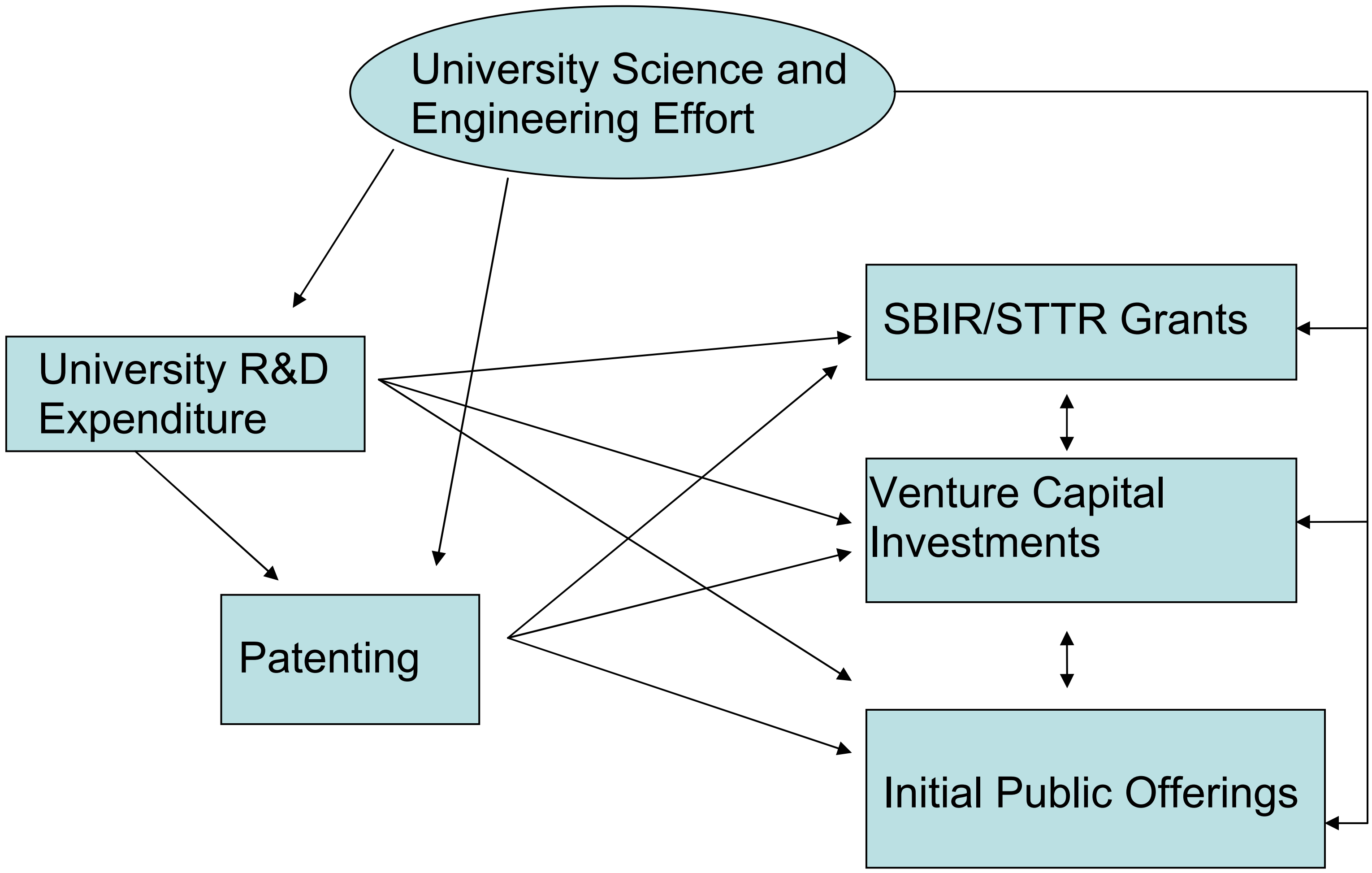

Figure 3: Relationship Between Idea Generation and Innovation Commercialization