Title

Role of Science and Engineering Education and R&D in U.S. State Growth and Innovation

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Role of Science and Engineering Education and R&D in U.S. State Growth and Innovation.*

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Abstract
Our research explores the feasibility and challenges of using composite indicators (defined as indicators that combine answers to several questions) based on National Center for Science and Engineering Statistics data and multivariate statistical methods to explain the redistribution of innovation and economic performance across the states in the US. Composite indicators examine a number of relevant factors as a way to capture a more detailed picture of the growth strategy of the states and the diversity of regional economic performance than a single indicator such as the proportion of the labor force in science and engineering or the R&D intensity of the state. Composite indicators address several broad issues characterizing economic performance such as: (a) R&D trends; (b) Science and Engineering composition of the labor force; (c) Science and Engineering education; (d) Sources of R&D funding. Those are items for which there exist appropriate indicators published and we combine. The conclusion of our analysis is that pockets of innovation notwithstanding, states can be in a wide spectrum of R&D performance, R&D funding, Science and Engineering education efforts, and economic growth. This suggests that focusing on pockets of innovation as models for regional economic development may not be the best strategy to guarantee economic growth.

Key Words: Composite Indicators, K-means clustering, ANOVA, Regional Development, R&D, Innovation, trend.

1. Introduction

There is variation in regional economic performance in the United States (US) [3]. In particular, innovation exhibits a pronounced tendency to cluster both spatially and temporally [5], [21], [11], [23], [9]. There are numerous economic theories, and accompanying empirical evidence, to explain that variation. Tecu [22] attributes the regional variability in innovative activities in large manufacturing firms in the US to production in the geographic location of the activity, that is to the internal environment of the firm; manufacturing tends to pull the development of new products to factory locations. By this explanation, clusters of innovation would be found in areas with lots of manufacturing. On the other hand, a growing literature on knowledge spillovers suggests that location endowments and agglomeration economies, the external environment of the firm, for example access to information, is the predominant factor for the location of industrial innovation in research hubs [10]. The fostering of local innovation by publicly-funded research institutions is considered an external factor [8]. A third set of studies argues that the locations of innovative activity and other activities of the firm are explained both by the internal and the external environment

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together [1] and that external and internal drivers may be magnet to some activities but not others.

The regional determinants of innovation are of enormous interest for regional economic development. Innovation has long been recognized as an important driver of economic growth [13] [14] although the question of how technology and innovation influence economic development is a controversial issue, and has been so for a long time [4]. In the last decade, evidence that areas with strong clusters of innovation perform better economically than areas without those clusters; they have higher job growth, higher wage growth, more businesses, and a higher rate of patenting have contributed to the serious interest in cluster-based development [23], [9] and reconsideration of traditional economic development theories and policy. Highlighting successful examples and best practices of state high tech economic development, the Federal Government, in 2004, declared an inherent interest in promoting innovation based on regional strengths [18], thus coining the term innovation-based regional economic development.

Innovation activity in the US has traditionally been represented by Research and Development expenditures (R&D) and that is how it is measured in this paper and most of the literature cited. Innovation activity measured that way is the one carried out by highly educated labor in research and development intensive companies, being large or small, with strong ties to leading centers of excellence in the scientific world, what Fagerberg et al. [4] call first world activity or new to the world innovations. The associated inputs and capabilities to do R&D associated with them (such as Science and Technology (S&T)education) can be viewed as a long-term investment in innovation but they are not part of R&D.

The public and private sectors in the US play a complementary role in R&D. Thus innovation-based regional economic development is almost synonymous with more federal R&D policy and funds. The allocation of these funds is problematic, however, given the empirical findings of the economic literature mentioned above. Firm-external and -internal factors, as well as university innovation together may explain the geographic distribution of R&D more comprehensively [22]. The relative importance of each of those factors may determine how to allocate R&D. Should R&D be allocated to R&D clusters of firms? Or should it be allocated to large existing production sites, or both? The consensus seems to exist about the fact that an innovation ecosystem is nurtured by R&D, education and the ability to build (manufacture), implement technology and commercialize it [13]. To address the later, scholars have coined the term “capabilities“ to represent the combined effect of several factors surrounding technology on innovation [12]. Many of these are difficult to operationalize and overlap [4].

The research we describe in this paper differs from the above mentioned research. The latter is microeconomic research, focused on models of firm location choices, and proposing policy recommendations based on those choices. Our research touches on a subject which has not been studied much, namely the distribution of R&D across US states and how that is related to the economic growth of the state, the human capital and highly skilled labor employed by the state, and the relative allocations of private and public R&D to that state. The diversity of theories that explain the choice of R&D allocation and its impact mentioned earlier in this paper makes us expect a complex relation between the state macroeconomic factors that we study. And indeed, that is the case. For this reason, we classify states using composite indicators. Then from this classification, we propose to dig deeper into the microeconomic characteristics of the state that have lead to that macro picture.

The contribution of our paper to the literature is as follows. Our research explores the feasibility and challenges of using composite indicators (defined as indicators that combine answers to several questions) based on National Center for Science and Engineering Statistics (NCSES) data [14] and multivariate statistical methods. Composite indicators examine a number of relevant factors as a way to capture a more detailed picture of the growth strategy of the states and the diversity of regional economic performance than a single indicator such as the proportion of the labor force in science and engineering or the R&D intensity of the state. Composite indicators address several broad issues characterizing economic performance such as: (a) R&D trends; (b) Science and Engineering composition of the labor force; (c) Science and Engineering education; (d) Composition of R&D. Those are items for which there exist appropriate indicators published. Once states are characterized according to composite indicators comprising those measurements, we propose further work that could be done to study which microeconomic theory best applies to groups of states, the role the business infrastructure, the financial system and the capability for commercial exploitation of technology, among other factors.

The organization of this paper is as follows. Section 2 describes R&D performed, economic growth and education trends by state. Section 3 adds the sources of R&D funding and classifies states using k-means cluster analysis based on R&D performed, economic growth, technical education and sources of R&D funding. Section 4 concludes with recommendations for future research. Description of all the variables used in this paper and the sources of the data used can be found in [20]. We put all the detailed sources of data and descriptions of variables in that web site because of space limitations and to avoid losing the continuity of the discussion in the paper.

2. Innovation and economic performance of US states.

The United States Census Bureau and the NCSES collect and analyze data on the geographic distribution of R&D expenditures in the United States among the 50 states, the District of Columbia, and Puerto Rico [17], [15]. The data are categorized by type of performer (industry, Federal Government, academia, FFRDCs, and other nonprofit organizations) and by source of funds (industry and Federal Government, and for university performers only, state government, academia and other nonprofit organizations) [16]. The amounts of R&D funding from specific Federal agencies also are provided. NCSES‘ state profiles also offers detailed Science and Engineering profiles for all 50 states [13] [14].

That data reveal that R&D (in absolute terms) is concentrated in only a few states. In 2008, the 10 states with the largest R&D expenditure levels accounted for about 62% of U.S. state-based R&D expenditures: California, New Jersey, Texas, Massachusetts, Washington, Maryland, New York, Michigan, Pennsylvania, and Illinois. California alone accounted for 22% of the U.S. total, exceeding each of the next three highest states by about a factor of four [2]. Those states also have the highest regional concentration of scientists and engineers, with Illinois, Virginia and Florida at about the same level (about 3% of total) as most of them [11].These indicators, however, taken in isolation, do not shed light on states growth strategies.

States vary significantly in the size of their economies, owing to differences in population, land area, infrastructure, natural resources, and history. Consequently, variations in the R&D levels of states may simply reflect differences in economic size or the nature of their R&D efforts. An easy way of controlling for the size effect is to measure each state's R&D level as a proportion of its Gross State Product (GSP). That proportion is referred to as R&D intensity or concentration [2].

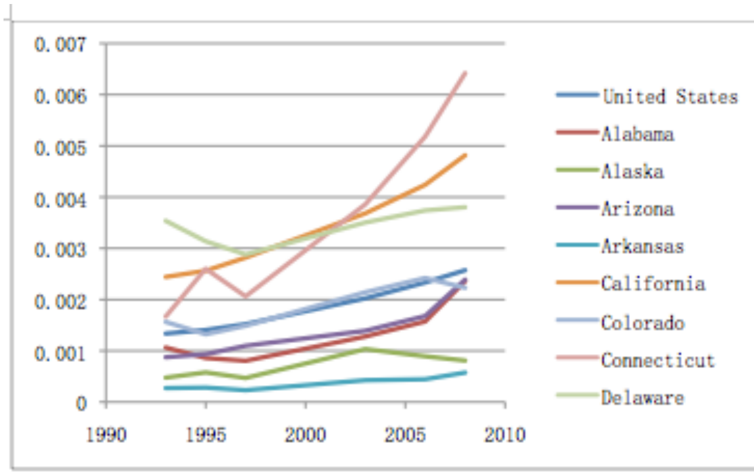

Figure 1: Examples of states with trends of R&D intensity above, around or below the average USA trend.

An alternative way to look at the R&D effort by state is to look at R&D relative to the size of the science and engineering labor force in the state. This is the metric we use in this paper to represent R&D intensity.

R&D intensity thus defined has been increasing during the last 10 years in all states, at different rates in each state. However, some states have trends above the national average, some states have trends around the national average, and other states have trends below the national average. For example, in Figure 1 we can see that California, Connecticut and Delaware, while growing at different rates in the last decade, have trends above the national trend for the United States throughout the whole period; R&D intensity in Colorado has been growing at the same rate and level as the national trend; and Arkansas, Arizona, Alabama and Alaska are below the national trend. The classification of the states according to the trend in their R&D intensity in the last decade is:

R&D intensity below the national average (low): Alabama, Alaska, Arizona, Arkansas, Florida, Georgia, Hawaii, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Mississippi, Missouri, Montana, Nebraska, Nevada, New York, North Carolina, North Dakota ,Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, West Virginia, Wisconsin, Wyoming, Puerto Rico.

R&D intensity around the national average (mid): Colorado, Idaho, Illinois, Minnesota, New Hampshire, Oregon, Virginia.

R&D intensity above the national average (high): California , New Jersey, Massachusetts, Washington, Maryland, Connecticut, Delaware, District of Columbia, Michigan, New Mexico, Rhode Island.

We can see from the list above that three states: New York, Pennsylvania and Illinois have trends below or at the national trend level, even thought they are among the top 10 R&D spenders in absolute value in 2008.

Table 1: ANOVA of Gross State Product, proportion of PhD in labor force, proportion of science and engineering labor force and proportion of bachelors in the 2008 population against trend group. Except for p-value row, numbers in the table are averages of those variables in each group.

R&D Trend	GSP	PhD	S&E labor	R&D	Bachelors
Low	0.09114965	0.003341007	0.5678636	0.001274049	53.15129
Mid	0.09282734	0.004500136	0.5820331	0.002495315	56.88121
High	0.124843	0.009972643	0.567276	0.006187585	65.48651
F test P-value	0.0146	0.00144	0.919	0.00000	0.17
National trend	0.09850	0.004900	0.5693	0.0025015	56.26

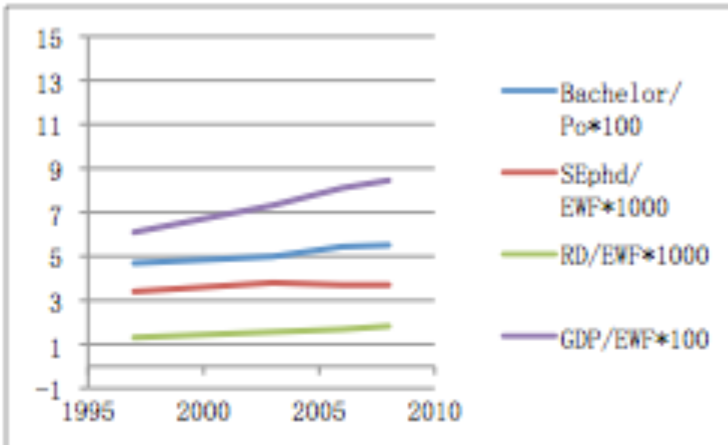

Figure 2: Representative trends of GSP, PhD and Bachelors for states with low R&D trend. The case of Ohio.

2.1 Relation of trends in R&D intensity to GSP, technical labor force and education

Looking only at the year 2008 and the three trend groups mentioned above, we conducted an analysis of variance (ANOVA) to determine whether the three groups differ significantly in GSP, in the proportion of PhDs in the science and engineering (S&E) labor force, in the proportion of the labor force in S&E, and in the proportion of the population with a Bachelors degree.

As indicated in Table 1, the S&E proportion of the labor force is not significantly different across the three trend groups. Similarly, the proportion of bachelors in the population is not significantly different between the low and mid groups, but it is significantly higher in the high trend states. Higher proportion of PhDs in the S&E labor force and higher GSP are significantly and directly related to trend in R&D intensity. Thus, states are not high, low or mid R&D trend because they differ in technical labor force. They are in a given R&D trend category because of their GSP, the proportion of PhDs in their labor force and the proportion of their population that has had tertiary education. We could deduce from this that efforts states make to develope a highly technical labor force do not pay equally across the states when the pay is represented by innovation (as represented by R&D performed).

Recognizing the limitations of looking at a single year‘s data, as we did above, we sought distinctive patterns in the trends of GSP, PhD, and bachelors for the three R&D intensity

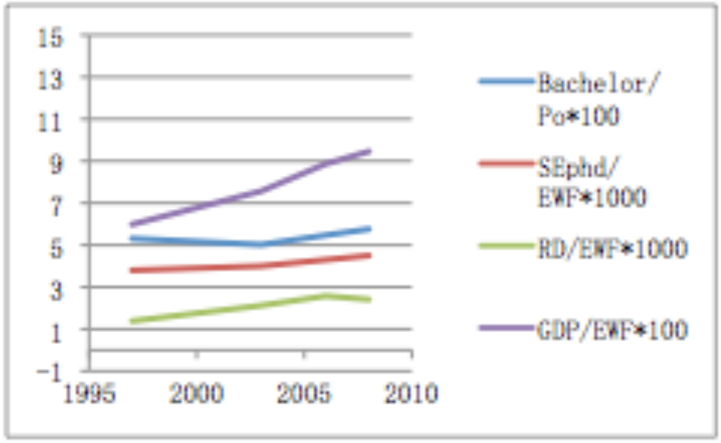

Figure 3: Representative trends of GSP, PhD and Bachelors for states with mid R&D trend. The case of Minnesota.

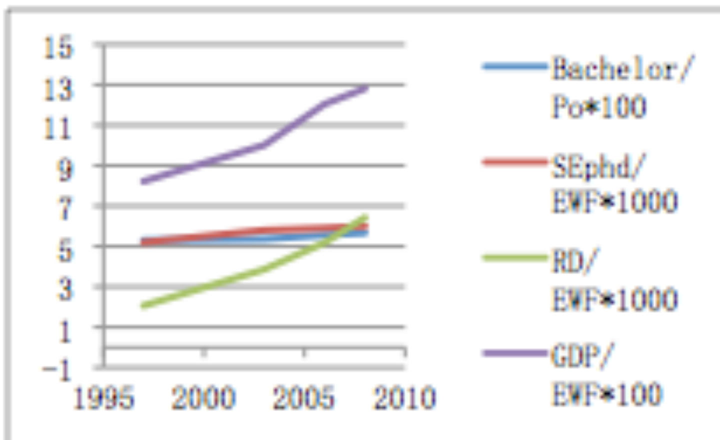

Figure 4: Representative trends of GSP, PhD and Bachelors for states with high R&D trend. The case of Connecticut.

trend groups. Figures 2, 3 and 4 illustrate the distinctive patterns found. Those figures show the typical pattern in the low, mid and high groups, respectively as represented by a typical state in that group. As we can see, GSP and R&D are growing in all states, albeit at different rates each. However, bachelors and PhD trends are not growing with those variables in all the states. Overall, the data show the following:

Low R&D trend : moderate GSP growth rate but almost stagnant R&D growth rate.

Mid R&D trend: moderate GSP growth rate but GSP grows faster than R&D.

High R&D trend : both GSP and R&D are growing at very fast rate and at the same rate.

As we saw earlier in this paper, the S&E Ph.D. variable helps explain the differences among the three trend groups in 2008. As indicated in Figures 2, 3 and 4, we find, when looking at trends in that variable, that its slow growth is not correlated with R&D and GSP growth in any of the groups. Similar conclusion can be reached about bachelors in the population.

The above analysis indicates that a fraction of the economic growth in the states is not related to growth in their highly technical labor force or education. It transpires from all this trend analysis that economic growth may be explained by R&D performance growth, but also by other factors not included in our study so far. All states seem to be making similar efforts in growing their educated population and their technical composition of the labor force, and yet their economic growth rates and innovation rates are not following suit. In the next section, we try to determine whether there is a distinct pattern in the sources of funding of R&D that could help explain, albeit partially, these conclusions.

3. R&D funding sources. Composite indicators.

Sources of funding of R&D include investments by the Federal Government, states, colleges and universities, and the business and non-profit sectors. In this section we study the mixture of R&D investment in the states that are high, mid and low trend. We find that there is no clear cut characterization of R&D sources of funding in the three trend groups. We clustered the states according to the amount of R&D funding received from the different sources of R&D and the S&E proportion of graduates in the state. Five clusters were obtained. Then we observed which of the R&D trend groups found in Section 2 fell in each of the clusters. In 4 of the five clusters, we could observe low, mid and high R&D intensity trends.

Table 2 shows the five clusters (colors) and the R&D trend group, the quartiles of the industrial, academic and federal sources of R&D funding distribution within which that cluster falls on average, and the science and engineering graduates in the states. Q1, for example, represents the lowest quartile, 25% of states have a value lower than that. States that are underlined have pockets of innovation [21], and states that are boldface are among the top ten R&D performer, in absolute value, in 2008 (see Section 1 in this paper). The classification by the k-means clustering algorithm [7] gives the following groups (in color):

Low R&D performance with second and first quartile R&D funding, second quartile S&E and pockets of innovation (black color cluster).

Georgia, which is among those states, has a technology development plan around traditional strengths of its universities, the Georgia Research Alliance and is in the top 10 in absolute value in 2008. Oklahoma has industry pockets focused on life sciences, telecommunications, weather related industries and aerospace. Missouri, Texas and West Virginia also have pockets of innovation. Texas and New York are in the top 10 in 2008, in absolute value.

Low R&D performers with third quartile R&D funding, second quartile S&E and pockets of innovation (blue cluster, low).

In this group, North Carolina presents the Research Triangle Park, Pennsylvania and Delaware have Innovation Partnerships and Pennsylvania is in the top 10 absolute performers in 2008.

Low R&D performers with third quartile R&D funding, fourth quartile S&E degrees and pockets of innovation (red cluster, low).

Ohio presents pockets of innovation and is also an absolute top 10 performer in 2008.

Mid R&D performers with third quartile R&D funding, second quartile S&E and pockets of innovation (blue cluster, mid).

Table 2: K-means clustering of states combined with R&D trends. Components of the composite indicators of states. Quartiles of R&D funding and technical labor force indicated by Q1 (less than 25%), Q2 (between 25% and 50%), Q3 (between 50% and 75%) and Q4 (between 75% and 100%).

States	R&Dtrend	Industry R&D	Academic R&D	Federal R&D	Technical LF
AK, AR, FL, **GA**, WY HI, KY, LA, ME, MS, MO, MT, NE, NV, **NY**, OK SC, SD, TN, **TX**, WV	Low	Q1	Q2	Q2	Q2
AL, AZ, NC, **PA**, VT, WI	Low	Q3	Q3	Q3	Q2
ID, **IL**, NH, OR, VA	Mid	Q3	Q3	Q3	Q2
DE	High	Q3	Q3	Q3	Q2
IN, IA, KS, ND, **OH**, UT	Low	Q3	Q3	Q3	Q4
CO, MN	Mid	Q3	Q3	Q3	Q4
RI	High	Q3	Q3	Q3	Q4
CA, CT MI, **NJ**, **WA**	High	Q4	Q2	Q4	Q2
MD, **MA**, NM	High	Q4	Q4	Q4	Q4

In this group, Illinois has nanotechnology pockets of innovation and is in the top 10 of absolute performers in 2008.

Mid R&D performers with third quartile R&D funding, fourth quartile S&E degrees and pockets of innovation(red cluster, mid).

Colorado and Minnesota present pockets of innovation.

High R&D performers with third quartile R&D funding, second quartile S&E and pockets of innovation (blue cluster, high).

Delaware presents pockets of innovation.

High R&D performers with third quartile R&D funding, fourth quartile S&E and pockets of innovation (red cluster, high).

Rhode Island presents pockets of innovation.

High R&D performers with fourth quartile R&D funding, second quartile S&E and pockets of innovation (cyan cluster, high).

California, New Jersey and Washington present pockets of innovation (the Information Technology and Aerospace pocket of innovation in Washington state and Silicon Valley in California) and are also top 10 absolute performers in 2008.

High R&D performers with fourth quartile federal and private R&D funding, fourth quartile S&E, and pockets of innovation (green cluster)

Massachussetts and Maryland in this group presents pockets of innovation (Boston's Route 128) and are also in the top 10 absolute performers in 2008.

As we can see from this classification of the states, pockets of innovation notwithstanding, states can be in a wide spectrum of R&D intensity trends, R&D funding and S&E education efforts, and the corresponding GSP growth trends found in Section 2 of this paper. This suggests that focusing on pockets of innovation as models for regional economic development as we discussed in the Introduction to this paper may not be the best strategy for economic development at the state level.

4. Conclusions and suggestions for future research

As we predicted in the Introduction to this paper, there is a complex relation between the state-level macroeconomic factors that we study. We found in Section 2 that states have managed to have similar S&E composition of their labor force but have obtained mixed effect on their innovative performance. In Section 3, we find that the efforts in educating that S&E labor force vary widely across the states. The intense labor mobility present in the United States may help explain those contradictory results.

We also found in Section 3 that the groups of states we classified have pockets of innovation despite the groups‘ average innovative activity. Pockets of innovation are claimed to have been successful because of entrepreneurship and venture capital [6]. Researchers, capital and modern infrastructure are not the sole factors. Venture capital is needed. But we saw that pockets of innovation and the venture capital that may be behind them do not make a state innovative or enhances the economic performance of that state relative to other states. Perhaps the nature of the pockets of innovation makes a difference in discriminating innovation in the states.

The analysis conducted in Section 3 also reveals that the strength and sources of R&D funding do not help much in discriminating R&D performance among the states. High and varied R&D funding is found in low, mid and high performance states, suggesting that perhaps investment in R&D is not the only factor that affects the rate and capacity for innovation. Public policy, and innovation not based on R&D as well as other factors not included in this paper may possibly help discriminate among states better.

We are aware that it is firms that innovate, not countries or industries (or states). Aggregate analysis by state hides a lot of heterogeneity in firms behavior. But it is important for states to see where they stand in the big picture of innovative activities compared to their efforts in educating the technical labor force and the impact of those efforts on their economy. There is a very unequal distribution of growth and innovation across the states, as we see in this paper. This calls for further confirmatory analysis to try to explain that inequality.

We have overcome statistical problems due to using cross-sectional data alone in this paper by including time series data and looking at trends and growth rates. But we were still cautions in drawing too much inference from the data and have presented our results mostly at descriptive level. We also had to exclude the district of Columbia from all of our analysis because it has such an outlying effect that all results are distorted with it present. Further work needs to be conducted with longitudinal data sets and more years of data to confirm the statistical significance of the findings here. In addition to that, further analysis needs to be conducted to try to understand what is behind the classification of states according to the composite indicators we obtained in Section 3. The main message arising from the results of this paper, namely that for some of states the effort put in having more S&E grads does not translate in higher R&D per worker even if clusters of innovation and the share of Federal and private R&D is the same as that of higher trend states, needs explaining [19].

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