Knowledge Creation and Innovation in the Hoosier State

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Like it or not, the global economy is increasingly knowledge-based. And, in the future, knowledge will become even more important. This article looks at the role that knowledge-producing institutions may play in creating a competitive region and enhancing economic performance.

Does knowledge production at institutions like universities or research and development (R&D) facilities lead to innovation? Does it lead to more innovative activities the closer one is to those knowledge anchor institutions?

It is often suggested that the intensity of knowledge production and its related innovative activities depends upon the geographic proximity of knowledge and information sources. On the other hand, with the rapid development of communication technologies, the importance of geographic proximity on innovative outcomes would be greatly reduced.

Does distance matter? This article proposes a measure for the importance of proximity to knowledge creation and explains how it may be useful for business and macroeconomic policies that relate to technological innovations. We use this measure to see if there is a geographic link between knowledge creation and innovation for Hoosiers.

Review on Knowledge and Proximity

Laboratories and universities that produce knowledge are tangible: One can count the number of scientists in white lab coats, the number of microscopes or length of a linear accelerator. One cannot see, much less count, the flow of knowledge. That said, the diffusion of knowledge is important for creating new products or services. Thus, academic researchers have been interested in measuring knowledge production and diffusion. Many of these researchers have used the number or rate of patents as a metric for knowledge creation (for example, Bontazzi & Peri, 2003; Jaffe, 1986; Jaffe et al., 1993).

According to Krugman (1991), knowledge flows are invisible: "They leave no paper trail by which they may be measured and tracked, and there is nothing to prevent theorists from assuming anything about them that she likes…" Tracking these invisible knowledge flows was pioneered by Jaffe (1986). Patent citations are something of a paper trail for knowledge spillovers. But using patent citations as a gauge to measure the spillover from creating knowledge and innovation is not perfect: "Only a small fraction of research output is ever patented. In particular, much of the results of very basic research cannot be patented" (Jaffe et al., 1993).

Proximity is also critical to the notion of knowledge spillovers. Many researchers explicitly incorporate geographic proximity into measuring the impact of knowledge creation sources. Knowledge is embedded in people and, as a result, the face-to-face interaction of people is needed in the exchange and diffusion of knowledge, for example, within professional associations and communities (Bontazzi & Peri, 2003; Pond et al., 2009).

There are several ways universities as knowledge producers can measure their potential or actual effect on innovation.

1. The number of STEM degrees an institution graduates. While many, if not most, of the graduates would get jobs far removed from the degree-granting university, the number of STEM graduates would reflect the STEM programs and faculty that would diffuse knowledge locally.
2. The number of patents that the university itself files.
3. The number of technology startups by faculty or students that can be attributed to the university. Many large universities support innovation centers and technology parks.
4. The level of research and development funding a university receives to conduct scientific exploration. University R&D expenditures may also help to develop collateral businesses, collaborative networks and supply chains in the surrounding area.

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Given that we are attempting to determine knowledge spillovers, university R&D expenditures may be the most direct and comprehensive metric for determining the level of innovative activities in a locale. The question then becomes, how far away are the effects of R&D expenditures felt? University knowledge creation may also spill over to neighboring counties or regions. Many researchers attempted to quantify such

Table 1: Data Sources and Summary Statistics

Description	Source	Mean	Std. Dev.	Min.	Max.
Output Measure					
Number of patents per 1,000 workers	3	0.30	0.31	0	1.92
Input Measures					
Knowledge Spillovers					
Has university R&D spending (0 or 1)	7	0.17	0.38	0	1
Knowledge spillovers with 50-mile cutoff	7, 11	34.85	28.47	0.00	188.00
Knowledge spillovers with 100-mile cutoff	7, 11	109.95	48.47	23.70	239.60
Knowledge spillovers with 250-mile cutoff	7, 11	293.42	57.70	174.10	410.20
Human Capital					
Population share of age 25 and older with bachelor's and above degrees	4, 8	0.11	0.05	0.05	0.35
Has STEM programs (0 or 1)	4	0.29	0.46	0	1
STEM graduates, share of population	4, 8	0.00	0.00	0.00	0.02
High-Tech Index					
Employment share in high-tech industries	2	0.05	0.03	0.00	0.19
Employment share in technology-related occupations	1	0.08	0.02	0.04	0.18
Has large high-tech firms (0 or 1)	9	0.23	0.42	0	1
Number of large high-tech establishments per 1,000 workers	2, 9	0.01	0.02	0	0.13
Number of small high-tech establishments per 1,000 workers	2, 9	1.50	0.67	0.00	4.84
Small high-tech establishment quotient	2, 9	0.99	0.15	0.00	1.18
Establishment Formation					
Share of establishment births	10	0.07	0.01	0.04	0.12
Share of employment from establishment births	10	0.03	0.01	0.01	0.06
Proprietorship					
Share of proprietorship relative to total employment	6	0.21	0.08	0.07	0.50
Venture Capital					
Has venture capital investment (0 or 1)	5	0.14	0.35	0	1
Venture capital per $1,000 GDP	5, 6	0.05	0.20	0	1.09
Population Density					
Population density (per square miles)	8	177.70	281.59	21.80	2279.60

N=92
Source: 1) IBRC Occupational Statistics, 2) IBRC QCEW-Complete Employment Estimates, 3) U.S. Patent and Trademark Office, 4) U.S. Department of Education (IPEDS), 5) ThompsonOne, 6) U.S. Bureau of Economic Analysis, 7) National Science Foundation, 8) American Community Survey (U.S. Census Bureau), 9) County Business Patterns (U.S. Census Bureau), 10) Business Dynamics Statistics (U.S. Census Bureau), 11) IBRC distance decay function

knowledge spillovers by constructing different measures that attenuate the R&D effects as the distance from the research university and its neighborhoods increases (Anselin et al., 1997, 2000; Audretsch et al., 2005; Fischer & Varga, 2003; Woodward et al., 2006).

Anselin and colleagues (1997) find that university R&D spillovers positively affect patent and innovation creation in the regions within the university's proximity extending over 50 miles. Woodward and colleagues (2006) suggest that the optimum radius for the effect of university R&D on new plant formation is 60 miles. The effect of distance, however, may also depend on the type of industry.

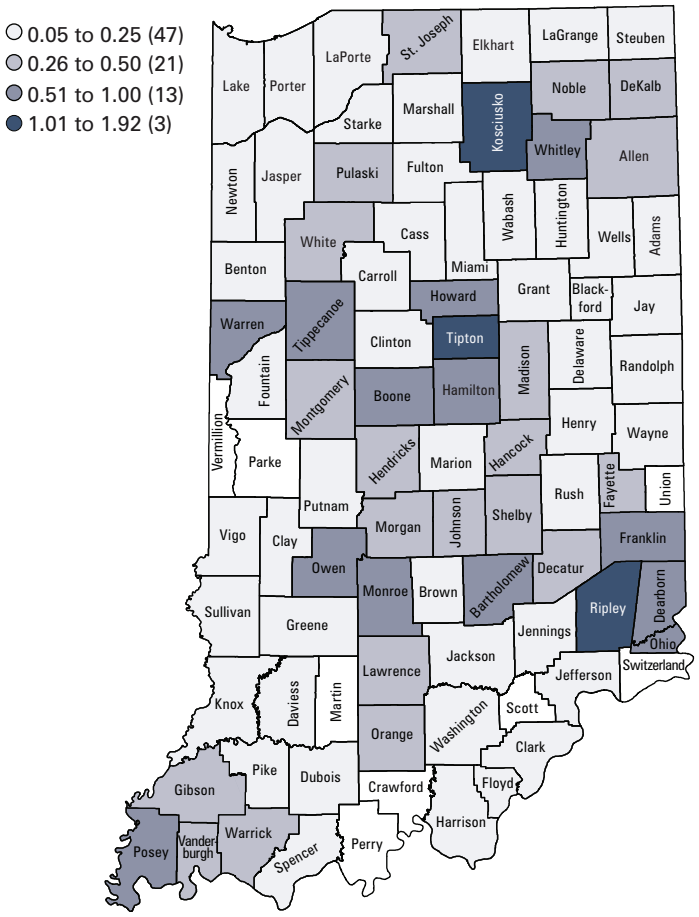
Empirical Analysis and Findings

The critical core assumption of the causal relationship is that R&D produces knowledge and knowledge promotes innovation and that innovative activities culminate in creating patents.

Thus, in our exploration of knowledge spillovers in Indiana, we use university R&D expenditures as the foundation for our metric of knowledge spillovers and use a decay function to reflect the diminishing influence of those expenditures—and, thus, the university—as the distance from the university increases. In other words, university-based knowledge has a positive spillover effect on innovation, which is measured by patenting activities.

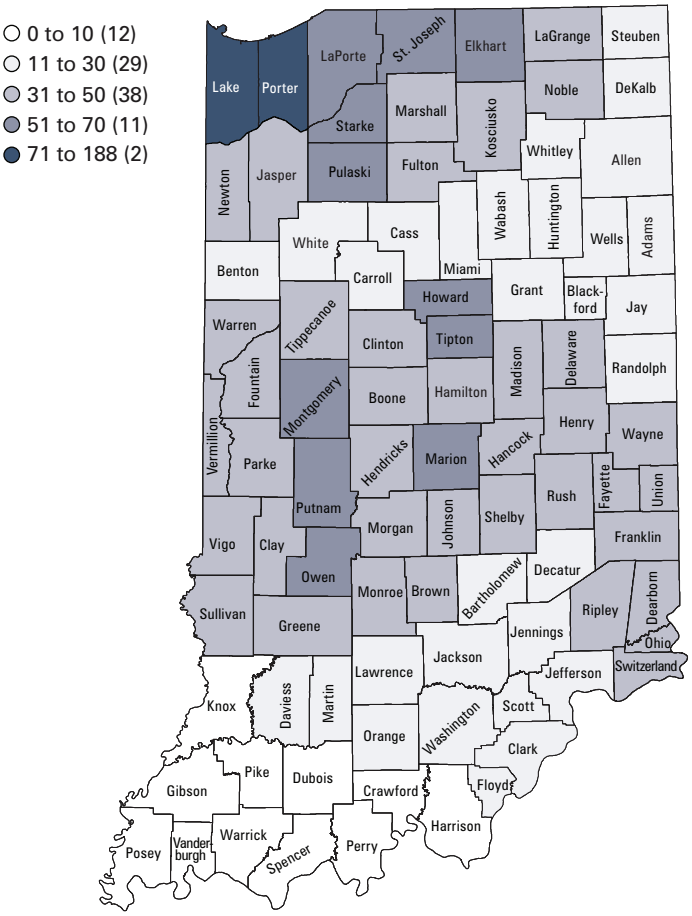
University-based knowledge spillovers are calculated using university R&D spending, weighted by the distance between the university and the center of the county selected. We incorporated R&D spending in the following

Figure 1: Number of Patents per 1,000 Workers, 2010-2011 Average



Source: IBRC, using U.S. Patent and Trademark Office data and IBRC QCEW-complete employment estimates

Figure 2: University-Based Knowledge Spillovers, 50-Mile Radius, 2011-2013 Average



Source: IBRC, using National Science Foundation data

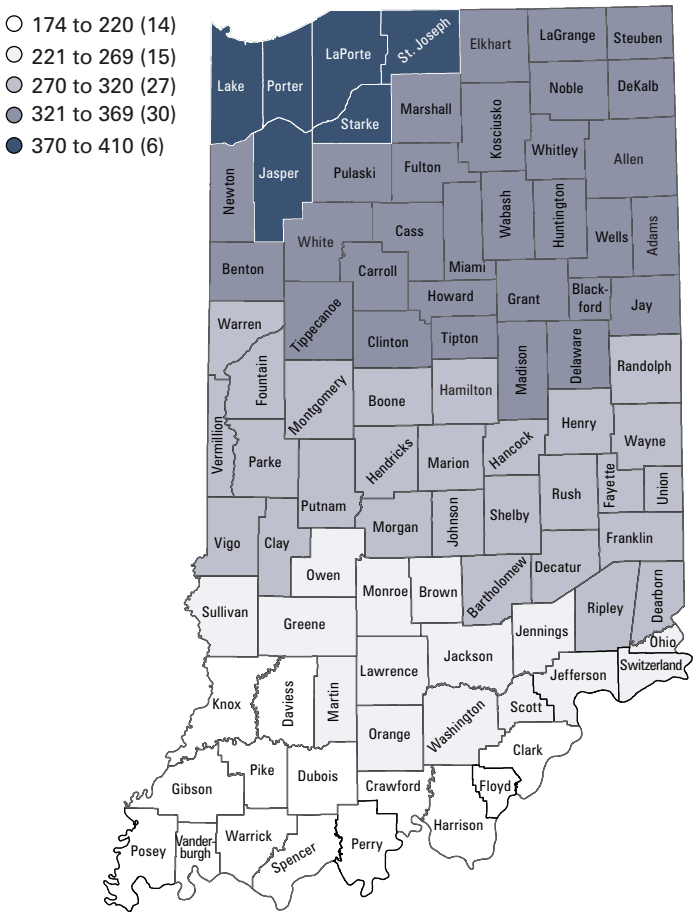
fields: engineering, geosciences, life sciences, math and computer science, and physical science. Higher scores represent regions close to universities with high R&D spending in the science and engineering fields. We tested for the effect of distance by using three distance thresholds for our knowledge spillover variable: within a 50-, 100- and 250-mile radius of the county with the university.

Another way to conceptualize the path from R&D to patents is a knowledge production function (KPF). A production function in economics is something like a recipe: Add inputs, like eggs and cheese, and you get an output, like an omelet. The KPF output is the number of patents generated in each Indiana county expressed as a linear combination of several input measures, one of which is university-based knowledge spillovers (KSPL). Other inputs include educational attainment of a county's population, the occupational mix, the number of (and the employment in) high-tech firms, and venture capital investment in the area. **Table 1** reports the complete list of inputs, data sources and summary statistics.

Figures 1 through **5** present key data for the state. **Figure 1** shows patent creation in the state, scaling the number of patents by the number of workers in the county. We see that the counties with the higher tech industries—medical devices, in particular—are the patenting hot spots. We also see that more rural counties with relatively few workers outshine many larger cities in the state. While university towns are well represented, it appears that patent rates are more strongly driven by industry, not academia.

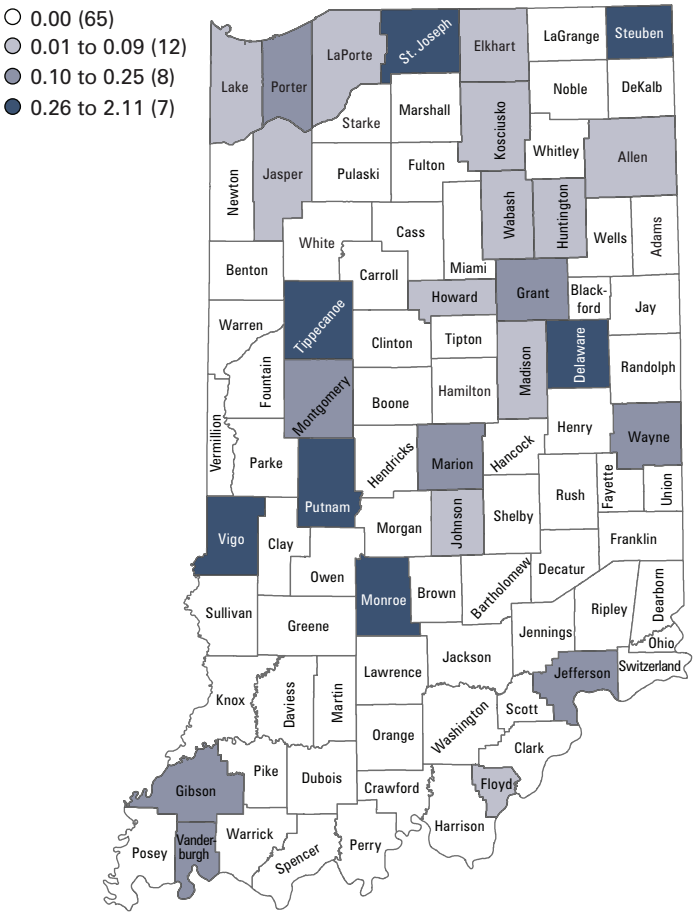
Figures 2 and **3** show two of the three distance threshold measures for university knowledge spillovers. For the 50-mile radius, we see that counties close to Chicago would be the region that, if proximity matters greatly, would benefit the most from the R&D and innovation activities in Chicagoland. Somewhat surprisingly, the two large state research

Figure 3: University-Based Knowledge Spillovers, 250-Mile Radius, 2011-2013 Average



Source: IBRC, using National Science Foundation data

Figure 4: STEM Degrees Awarded as a Percent of Total Population, 2010-2012 Average



Source: IBRC, using U.S. Department of Education (IPEDS) and U.S. Census Bureau (American Community Survey) data

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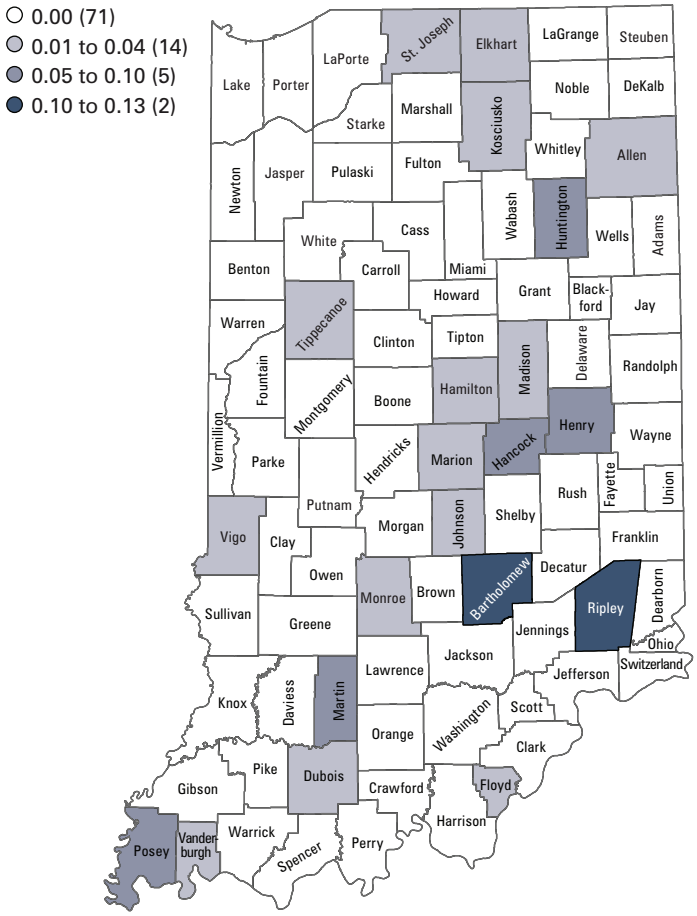
universities (Indiana University in Monroe County and Purdue University in Tippecanoe County) did not produce high scores in their respective home counties but rather seemed to "heat up" the counties where their expected spillover effects would overlap.

In **Figure 3,** we see what happens as we expand the expected scope of spillover effects. With a much larger radius, the effects of Chicago universities are felt in many more northern counties in Indiana, which get much higher spillover scores. Moreover, the effects of Chicago's university R&D overwhelm the effects of R&D at Indiana's universities, thus creating a gradual diminishing of the spillover score as one moves south through the state.

Figure 4 presents something of a proxy value for the science and technology activities in a county. The number of STEM degrees awarded as a proportion of the local population is a measure for the concentration of people who can create knowledge and, as a result, measures the potential or capacity to innovate new products, services and production processes. Not surprising, and in contrast to the knowledge spillover scores and patenting rates, the home counties of the universities in the state are the STEM graduate hot spots.

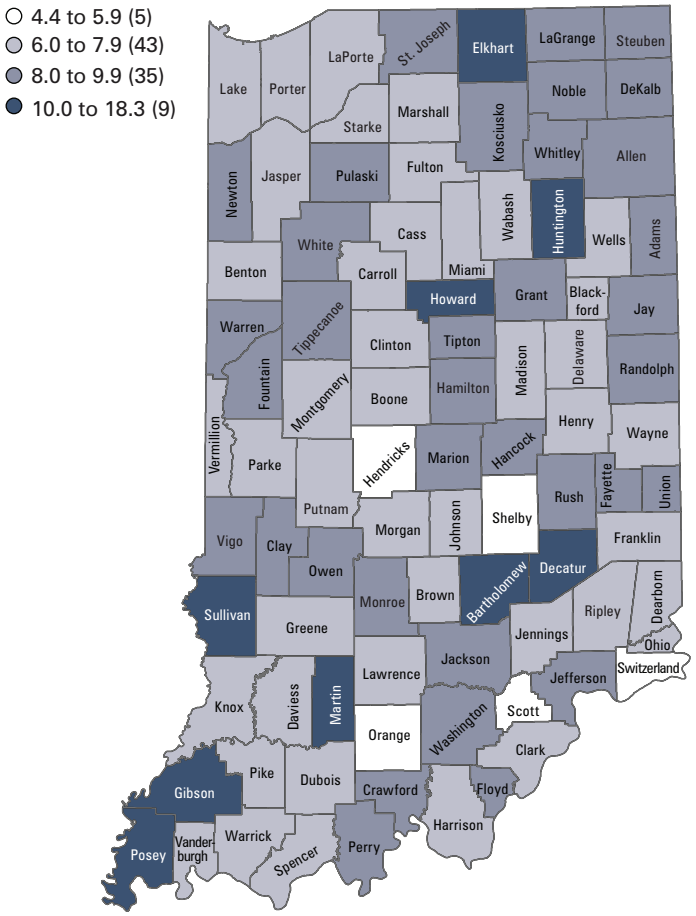
Figure 5 presents the relative concentration of high-tech firms employing over 500 people. Bartholomew and Ripley counties are dominated by Cummins and Hill-Rom, respectively. While Kosciusko County, also a high-tech

Figure 5: Number of Large High-Tech Establishments per 1,000 Workers, 2012-2013 Average



Source: IBRC, using U.S. Census Bureau (County Business Patterns) data and IBRC QCEW-complete employment estimates

Figure 6: Employment Share (Percent) in Technology Occupations, 2013



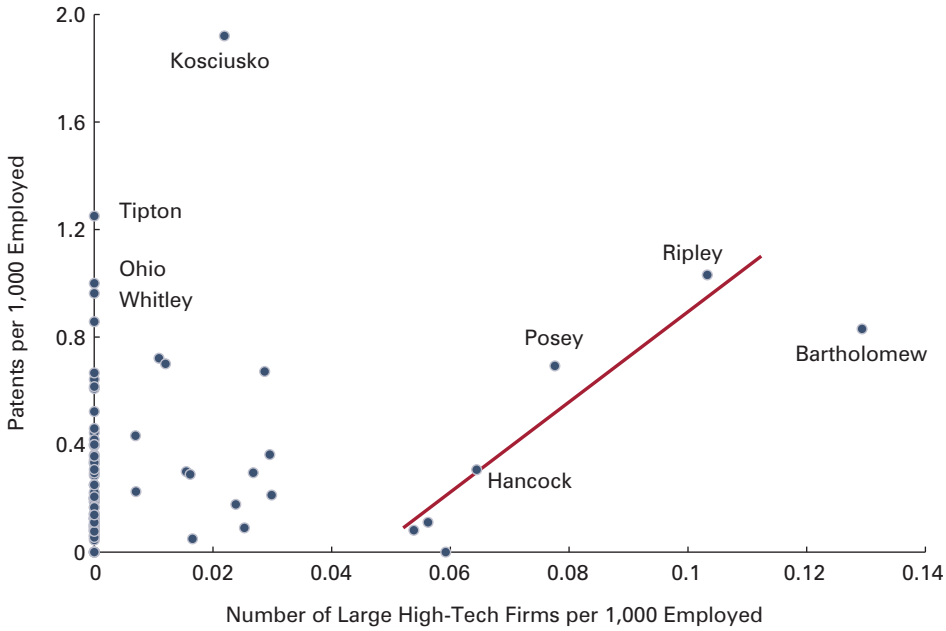
Source: IBRC, using U.S. Census Bureau (County Business Patterns) data and IBRC QCEW-complete employment estimates

heavyweight, has a wide array of firms of many different sizes, it is about three times the size of Ripley County, thus lowering the overall value for this measure. **Figure 6** shows the concentration of high-tech employment. It may be akin to the employment of STEM occupations. We see that Martin County, home to the Naval Surface Warfare Center (NSWC) Crane Division and its associated research labs, is a high-tech occupation hot spot. Next door, Orange County, a tourist destination, has a low concentration of STEM-type occupations. We may also see that many counties are home to "advanced manufacturing" facilities (which include many automobile manufacturers) that employ an assortment of technicians and engineers.

Our KPF analysis is exploratory. By all appearances, several Indiana counties are special cases that cloud the investigation. After several iterations of analysis, we excluded four counties from the analysis: Kosciusko, Lake, Porter and Martin. These counties are outliers for our statistical analysis, but they rather make the case that R&D and proximity to concentrations of scientific activities drive innovation (more on this later).

For several of the KPF inputs in the statistical model, we used both binary (i.e., either one or zero) and level variables. For example, if an institution in a county awarded any STEM degrees, it would be coded with a one (1) and a zero (0) if not. The level variable for STEM graduates would be the number of degrees awarded. The use of the binary measure is due to most of the counties in the state not having tertiary educational institutions awarding STEM degrees. The level measure is used to see if there is "power in numbers," to put it colloquially. The level measure shows the strength of the variation in STEM degrees awarded and whether it explains any variation in the number of patents within the distance thresholds.

Figure 7: Relationship between Large High-Tech Establishments and Patent Rates in Indiana Counties



Note: Patent data are 2010-2011 averages and large high-tech firm data are 2012-2013 averages.
Source: IBRC, using IBRC QCEW-complete employment estimates and U.S. Patent and Trademark Office data

Table 2: How Distance Affects the University-Based Knowledge Spillovers on Patents in Indiana

Knowledge Spillover	Knowledge Spillover Impact Factor
50-mile cutoff	0.00277
100-mile cutoff	0.00027
250-mile cutoff	0.00020

N = 88
Source: Indiana Business Research Center

Table 2 summarizes the empirical results. Our main hypothesized driver of innovation—university-based knowledge spillovers—does appear to have a positive effect on patents, although its impact is marginal. Distance also seems to matter. Consistent with previous research, the spillover score measured using the smallest radius (50 miles) has the greatest and the most significant effect on patents. As distance increases to 100 and 250 miles, the effect diminishes. We see this phenomenon graphically in **Figures 2** and **3**. The 50-mile spillover scores in **Figure 2** show a few counties with strong proximity values, while the 250-mile spillover scores show a smoother and more intense dispersion. (One could attribute the fact that these effects cannot be statistically confirmed using the standards of academic practice to the fact that our data set was limited to only Indiana counties. That said, the results of the strength of the knowledge spillover score's impact based on distance is encouraging.)

As noted above, we tested other potential drivers of innovation in a county (or region). The variable that has the most statistically confirmed positive effect on patents is the number of large high-tech firms (technically, high-tech establishments). For counties that have large high-tech establishments, our model estimated that the number of patents created would increase by five for every 1,000 employees in those large high-tech firms. STEM graduates and educational attainment (i.e., the share of bachelor's degrees and above) both have

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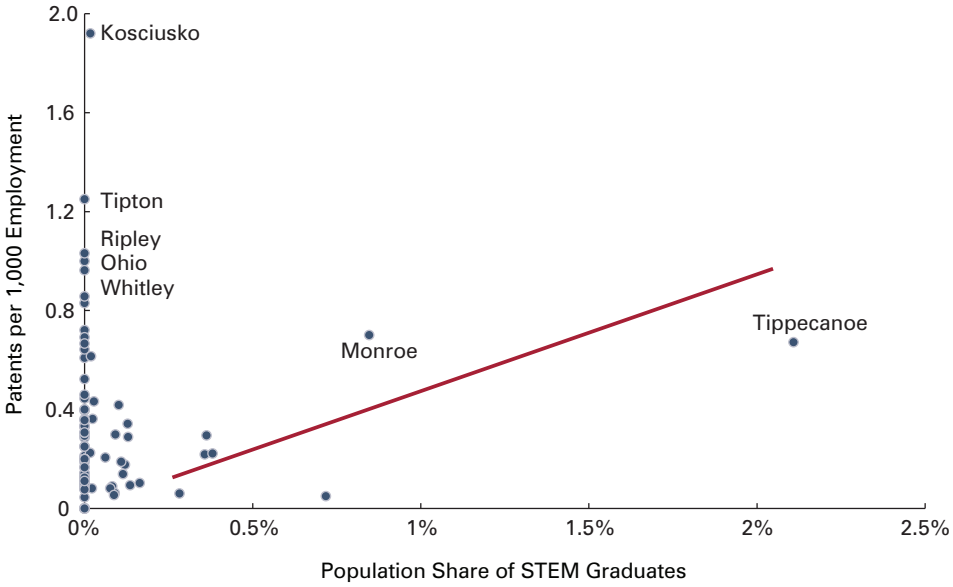
significantly positive effects on patent creation.

One input that has significantly negative impacts on patents is proprietorship. Upon reflection, that general proprietorship has negative effects is not surprising given that we control for the concentration of small high-tech establishments. Another measure, the relative strength of a county in terms of its small businesses in high-tech sectors, which is shown to have a positive effect on patents, picks up the positive influence of proprietorship—albeit for a subset of proprietors. Other negative, statistically relevant variables also include the binary measures, such as producing STEM graduates, having university R&D spending and the presence of large high-tech firms, as well as population density. But while these variables may pass statistical relevance, the size of the negative effects are much smaller than the size of the positive effects associated with high-tech firm size and STEM graduates. For those interested in the statistical details, please see the online appendix at www.ibrc.indiana.edu/ibr/2016/spring/appendix.html.

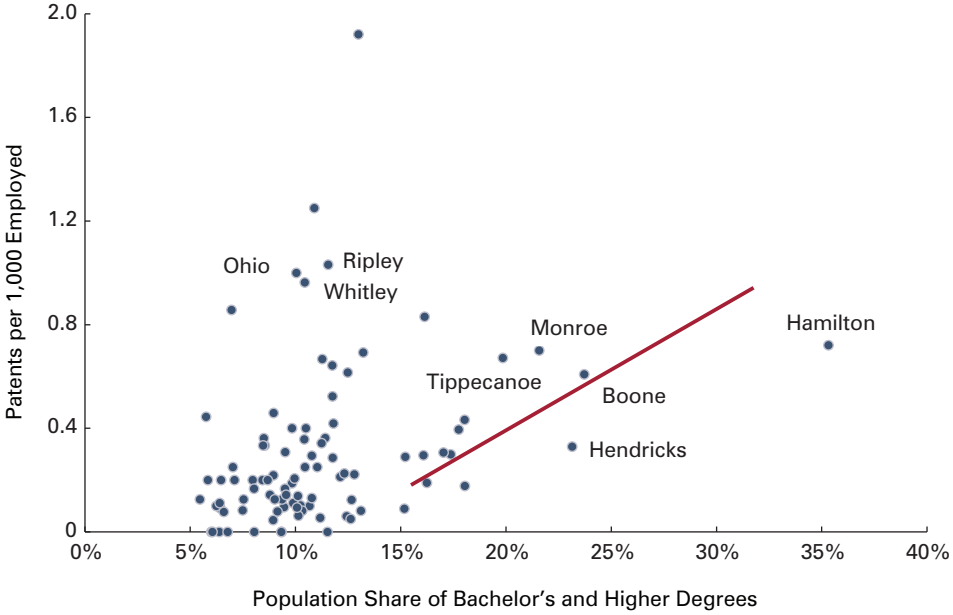
Figures 7 through **9** present selected results from the analysis. Several researchers have hypothesized that large firms would be relatively more innovative because deeper pockets give them the resources to commit to R&D. Our

Figure 8: Relationship between STEM Graduates and Patents in Indiana Counties



Note: Patent data are 2010-2011 averages and STEM graduates are 2010-2012 averages.
Source: IBRC, using IBRC QCEW-complete employment estimates, U.S. Patent and Trademark Office and U.S. Department of Education (IPEDS) data

Figure 9: Relationship between Educational Attainment (Bachelor's Degree and Above) and Patents in Indiana Counties



Note: Patent data are 2010-2011 averages and educational attainment data are for 2013.
Source: IBRC, using IBRC QCEW-complete employment estimates, U.S. Patent and Trademark Office and U.S. Census Bureau (American Community Survey) data

results seem to bear this out. **Figure 7** shows that the association between patents and large high-tech firms is clearer for counties that have relatively higher numbers of large high-tech firms. But the relationship between large high-tech firms and patents isn't hard and fast. Understanding how Ohio County does relatively well in terms of patent rates warrants further investigation.

Figure 8 shows that counties that produce STEM graduates don't necessarily produce the most patents. In general, no clear association exists between patents and the share of STEM graduates. However, a positive linear relationship can be seen for a few counties that have STEM programs—mainly Tippecanoe and Monroe counties. The takeaway here is that our STEM graduate hypothesis cannot be supported.

Figure 9 shows no obvious association between patents and the share of college degrees in general. That said, there is a positive linear relationship for a subset of counties that have relatively higher shares of college degrees and higher patenting rates.

Discussion and Conclusion

Our results are tempered by the fact that our analysis is restricted to Indiana, a relatively small, and perhaps unrepresentative, data set. Because our data set is small, the influence of standout counties is even more strongly felt. Kosciusko, Lake, Porter and Martin counties were standouts. Lake and Porter are close enough to Chicago and its endowment of top-shelf universities which, added to its proximity to Notre Dame, resulted in particularly high knowledge spillover scores. Kosciusko County is home to a high concentration of medical device manufacturing and all of the collateral R&D and patenting. Kosciusko is off the charts, as the array of maps indicate. Martin County, home to NSWC Crane, is an engineering hot spot and as a result, is off the charts in terms of STEM occupations. Crane is not, however, a patenting hot spot—or so it may appear. Patented technology developed at Crane is attributed and filed under the Secretary of the Navy. In other words, the link between patents and the location of the technology development is broken. (With more effort, one could

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re-establish this link with a deeper dive into the patent filings.)

It has been said that cities (as in large cities) are places where ideas (and hence creativity and innovation) go to procreate. If one were to roughly equate innovation with patents (and not all do), we see that the state is something of a curious outlier. Relatively low population density regions in the state are the locations that have high patent rates: Bartholomew, Kosciusko, Martin, Monroe, Riley and Tippecanoe counties. The policy implications are uncertain. Hoosiers, however, can feel pretty good that STEM density trumps population density. Maintaining this advantage should be on the screen of policymakers in the state.

In conclusion, innovation in Indiana, as measured by patenting activities, benefits from university-based knowledge spillovers. That said, innovation in Indiana is largely driven by counties like Bartholomew and Ripley that have large high-tech establishments. Counties such as Tippecanoe and Monroe, home to the state's flagship public universities that produce numerous STEM graduates, also benefit from high concentrations of human capital. ❑

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View the complete regression results at www.ibrc.indiana.edu/ibr/2016/spring/appendix.html.