Maximizing Minnesota's Competitiveness through Technological Innovation

A Plan B Paper

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Abstract

With the advent of new economies, knowledge or intellectual capital has been regarded as a key factor in economic growth. In particular, knowledge is privatized in the form of intellectual property such as patents. It enables businesses to invest in R&D by offering incentives for invention and to stimulate entrepreneurship by capitalizing breakthroughs and promoting industry advancement. This paper analyzes economic and technological competitiveness of states to which Big Ten Universities belong with a focus on biotech sector, and asks whether the relationship between their economic and technological competitiveness is positive, and how much universities' R&D expenditure influences states' technological competitiveness. To evaluate economic and technological competitiveness in given regions, both location quotient and activity index methods were used. Their main data sources were employment data from the U.S. Bureau of Labor Statistics and patent data from the U.S. Patent and Trademark Office. First, through a comparative analysis, the correlation between economic and technological competitiveness turned out positive and Minnesota's current position was understood. Second, based on Jaffe's theory which examined the spillover effect of universities' R&D on states' technological competitiveness, the maximal value of patent output from the University of Minnesota to strengthen Minnesota's technological and further economic competitiveness was determined within limited resources such as university's R&D budget.

1. Introduction

1.1. Patent, innovation, and economic development

With the advent of new economies, knowledge or intellectual capital has been regarded as a key factor in economic growth. In particular, knowledge is privatized in the form of intellectual property (IP) such as patents. It enables businesses to invest R&D, offering an incentive for invention and to stimulate entrepreneurship capitalizing breakthroughs and promote industry advancement. In this context IP has been recognized to contribute greatly to technology advancement and economic development. Several studies (Kitch, Arora, Merges, and Nelson et al.) have supported the viewpoint that IP has played an affirmative role in a market and contributed to commercializing universities' findings (Murray and Stern 2007). Yet scholars do not focus on only the bright side of IP, and some have started to examine the negative effects of the IP system. Some studies (Heller, Eisenberg, David, and Lessig et al.) argue that IP rights might privatize science too much, put the barrier against the scientific commons, and thus restrict scientific progress (Murray and Stern 2007). Furthermore, the recent advent of so-called *patent trolls*, patent owners who do not intend to use a patent but enforce their patent rights against purported infringers, exposes the weakness of the IP system.

Despite considerable controversy about the link between IP and innovation, many scholars have started to pay attention to using patent information in innovation analysis, and many studies suggested that patent statistics are very useful in describing economic development through technological change (Griliches 1990) or innovative activities (Pavitt 1985). Especially, Jaffe (1989) utilized patent counts to measure technological change, arguing that a patent is "a proxy for new economically useful knowledge." A fundamental issue regarding the identification and measurement of R&D spillovers, however, still remains unresolved in the economics of technology (Acs et al 1991), which stemmed from Kuznets (1962)'s observation that the greatest obstacle to understanding the economic role of technological change was a clear inability of scholars to measure it. Despite such difficulties many scholars have tried to contrive a way to measure it. Several methods have been developed. Acs et al (2002) classified measures of technological change into three ways: (1) a measure of the inputs into the innovation process, such as R&D expenditure; (2) and intermediate output, such as the number of patents; or (3) a direct measure of innovative output. The first measure is difficult to separate the budgeted resources used for only innovation from total resources. And the last measure has a fatal shortcoming in accessibility because the innovations were recorded just one time in 1982 by the Small Business Administration. In this context, patent data can be a good indicator since they are readily available over time, i.e. they are more accessible measures.

There are only a few studies that examine the link between technological innovation and regional economic growth using patent data. Nunn and Worgan (2002) compared innovation capacity of Indiana's metropolitan statistical areas (MSAs) with that of other MSAs using patent productivity, i.e. patents per 10,000 employees. Acs et al (2002) examined the validity of patent data as measures of innovation through comparison of the innovation count data and patent counts data in studying regional innovation systems. Mukherji and Silberman (2009) measured the performance of U.S. states 1997 – 2007 using shift-share and location quotient analysis and patent trend analysis. All these studies found the positive correlation between technological innovation and regional economic growth in MSA and state level. But, these studies used rough technical areas and their data, and focused on the absolute value of patents.

1.2. Role of universities in innovation

There are ten top states that account for 64 percent of state R&D expenditures. They have common characteristics such as a high tech corridor and locations near large universities (NSF 2010). Universities have been a source for innovation and for regional economic development. Stanford University and University of California at Berkeley of Silicon Valley, and Massachusetts Institute of Technology and Harvard University of Route 128, and Duke University, University of North Carolina at Chapel Hill and North Carolina State University of Research Triangle Park are most famous examples. These universities were the incubators for scientific and technical information networks in which communities of innovators, and increasingly firms, were embedded (Crow and Tucker 1999). University research spilled over into the generation of inventions and innovations by private firms (Acs et al 1991).

From the viewpoint of economic historians, the strength of the American university system was essential for the rise of American technological and economic leadership in the postwar era (Sampat 2006). What drew out universities into the main stage of R&D and innovation was somewhat due to the Bayh-Dole Act of 1980. Dating back to the 1970s and 80s, the U.S. confronted severe competition with Japan and the newly industrializing countries and U.S. needed to maintain its technological leadership. It prompted the U.S. to try to enhance America's competitiveness. These efforts were made to incentivize the transfer of new technologies from research institutions to industry, such as the Bayh-Dole Act of 1980. The Act allowed universities to patent inventions resulting from federally-sponsored research, and to license these patents to industry (Crow and Tucker 1999). By the Act, the academic sector such as universities became a major R&D performer next to the business sector. Especially, the R&D growth rate of universities in 1990s was around 7% which was faster than any other sector, although recent growth rate became a little slower (NSF 2010).

1.3. The hypothesis and differentiation of this study

Like many findings which studied the relationship between economic development and technological innovation, this study is based on the hypothesis that the relationship is positive. Yet, unlike prior studies, this study explores the relationship using relative values of patent activity index and location quotients rather than only focusing on the absolute value of patent productivity. Also, through the comparison with 2004 and 2008 this study observes a time shift of the relationship.

The study area is mainly focused on Minnesota and the University of Minnesota, but it includes seven other US states – Illinois, Indiana, Iowa, Michigan, Ohio, Pennsylvania, and Wisconsin – which all have the Big Ten Universities – University of Illinois, Northwestern University, Indiana University, Purdue University, University of Iowa, University of Michigan, Michigan State University, Ohio State University, Pennsylvania State University, and University of Wisconsin. The reason these states and their universities were selected is that they have relatively high geographic homogeneity being located in the Midwest. Although the analysis of fifty states and their universities might be more statistically significant, it also has a risk of including heterogeneity in geographic factors.

This study is centered on biotechnology and its industries, specifically pharmaceutical and medicine technology industries, rather than enumerating all kinds of technologies and industry sectors. Biotechnology is an overarching technology prominent in the federal R&D portfolio and also in Minnesota's, and there are many bio-related businesses such as Medtronic and St. Jude in Minnesota. Another reason for selecting the biotech sector is due to the relative ease of data processing. For this study, the employment data and patent data, which each have their own classification systems, are collected and then matched classified codes to each other's. While the biotech sector is relatively clear in matching jobs, other sectors such as information technology and mechanical technology are not. It means that inaccurate matching job might bring about noise and, in turn, harm the reliability of this study.

Another hypothesis of this study is that the maximum value of innovation can be drawn out within limited resources by the mathematical optimization technique. In this study, the optimum output of patents, as a proxy of technological innovation, for Minnesota's economic development is computed with the aid of GAMS (General Algebraic Modeling System) programming. Primary dependent variables are the university R&D and industry R&D, in particular the university R&D in the biotech sector is mainly tested.

The following sections first describe the methodology used for the quantitative analysis, then interpret the results and finally discuss their significance in the context of linkage among university R&D, patents and economic development.

2. Methodology

2.1. Framework and Data

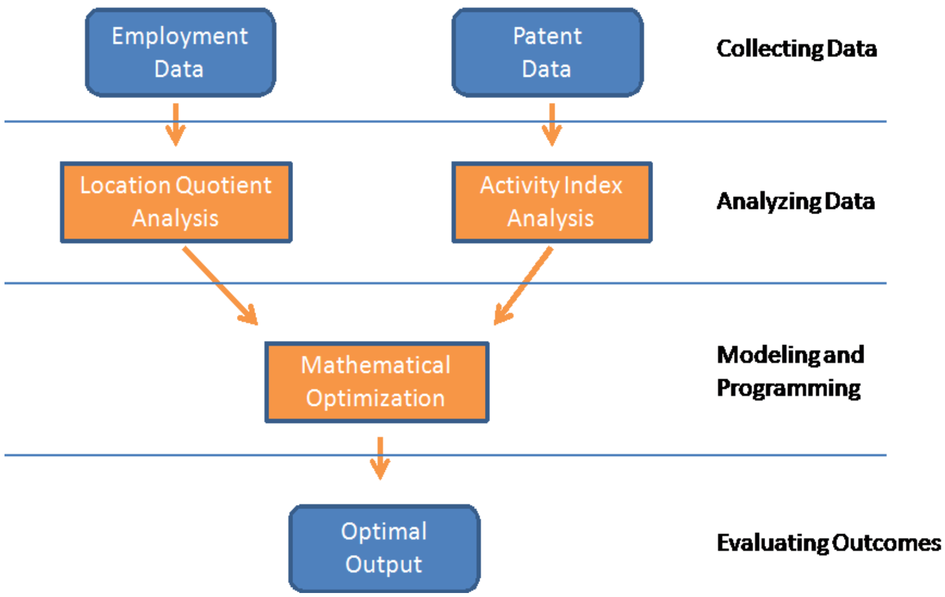
This paper will explore the relationship between Big Ten Universities and economic/technological competitiveness. To evaluate economic and technological competitiveness in given regions, location quotient (LQ) and activity index (AI) methods are adopted, respectively. Their main data sources are employment data and patent data from online websites of U.S. government statistics. Secondly, this paper draws out the maximal value of technological output of the University of Minnesota (UMN) to strengthen Minnesota's economic competitiveness within limited resources such as financial and human resources. To this end, mathematical optimization method will be employed, that is, an optimization model will be constructed, and programmed and run with the aid of GAMS application.

As shown in [Figure 1], this analysis consists of four stages: collecting data, analyzing data, modeling and programming, and evaluating outcomes. At the first stage, employment data for LQ analysis and patent data for AI analysis were gathered from the U.S. Census Bureau and the Bureau of Labor Statistics of U.S. Department of Labor, and the U.S. Patent and Trademark Office (USPTO), respectively. Employment data used comes from the County Business Pattern (CBP) data, which contains employment and earnings by North American Industry Classification System (NAICS[1]) by state and county, metropolitan statistical area and ZIP code. Patent data used comes from the Patent Technology Monitoring Team (PTMT) reports, which contain patent counts by type of patent document, geographic origin, patenting organization, patented technology, i.e. International Patent Classification (IPC) or U.S. Patent Classification (UPC), and inventor by state and year. There exists inconsistency between NAICS and IPC or UPC because NAICS focuses on employment by industry while IPC or UPC focuses on patent by technology. A correspondence between the two classification systems in order

[1] Before 1997 CBP data has been processed by 4-digit Standard Industrial Classification (SIC), but since 1997 it has been done by NAICS.

to compare with outcomes of two analyses, i.e. economic and technological competitiveness, was generated.

Figure 1 Analysis Framework



At the second stage, LQ and AI analyses were examined to compare various outcomes by universities and states. LQ and AI analysis methods are introduced in detail in the next section. At the third stage, mathematical optimization technique, specifically linear or non-linear programming, was used to extract optimal outputs for more efficient and effective technological advancement and economic development of UMN and the State of Minnesota.

To examine optimal outputs, we use the GAMS application with the aid of a computer. Mathematical optimization technique is briefly introduced in the next section, and its mathematical background and GAMS programming code is described in Appendix. The most reliable and feasible model was chosen among a variety of models to explain the mechanism of regional economic development with input and output factors, so as to run GAMS. For example, Jaffe (1989) presented a modified knowledge production function as follows:

$$log(P_{ik}) = \beta_{1k}\, log(I_{ik}) + \beta_{2k}\, log(U_{ik}) + \beta_{3k}[log(U_{ik}) \times log(C_{ik})] + e_{ik}$$

where *P* is number of patented inventions, *I* represents the private corporate expenditures on R&D, *U* represents the research expenditures undertaken at universities, *C* is a measure of the geographic coincidence of university and corporate research, and *e* represents stochastic disturbance. The unit of observation is at the level of the state, *i*, and the industrial sector, *k*.

At the final stage, the outcomes of GAMS are evaluated, and a sensitivity analysis was conducted. For sensitivity analysis, some input factors with constraints such as Minnesota's and UMN's financial and human resources, which are essential for maintaining technological and economic competitiveness, are adjusted.

2.2. Location Quotient, Activity Index and Concordance Table

Location quotient (LQ)

Many regard the "economic base model" as a useful starting point for any economic analysis. According to Klosterman (1990), "the economic base technique is the oldest, simplest, and most widely used technique for regional economic analysis and projection." The economic base model begins by dividing the regional economy into two sectors: basic (non-local) and non-basic (local). "The basic sector consists of firms and parts of firms whose economy is dependent on factors external to the local economy (Klosterman 1990)." Examples of economic activity included in the basic sector would be: federal and state governmental employment and purchases, firms servicing tourists (hotels, convention centers, restaurants, etc), and any other business whose product or service supports demand outside the regional economy. Conversely, the non-basic sector is made up of industries relying upon local demand.

The metrics used in the economic base model are: employment, sales, payroll, and income. Due to limitations on data availability, employment is often the most useful unit of measure. The economic base model focuses on employment in the basic sector. Basic employment generates economic activity in the non-basic sector and is therefore pertinent in doing analysis. “A basic sector activity, such as the sale of exports, brings additional money into the local economy. Some of this money remains in the local economy, increasing the demand for local goods and services supplied by the non-basic sector (Klosterman 1990).” With this rationale, the economic base model’s ability to estimate basic employment is pertinent in this analysis of the eight states’ economy.

Despite being the most widely criticized model of economic analysis, the location quotient approach is the most commonly used method of regional economic analysis. The location quotient approach is useful in determining the extent to which the regional economy is specialized in a particular industry. The limitations portion of this paper will identify the various assumptions contained within the location quotient method. Nevertheless, by identifying the industries each state is specialized in, industries whose production exceeds local demand were targeted, thus generating basic employment. The formula for basic employment using the location quotient method can be written as follows:

$$LQ_i^t = \frac{e_i^t / E_i^t}{e_T^t / E_T^t} \quad \text{this is equivalent to} \quad LQ_i^t = \frac{e_i^t / e_T^t}{E_i^t / E_T^t}$$

where e_i^t is employment in industry *i* at time *t* in study area, E_i^t is employment in industry *i* at time *t* in parent area, e_T^t is total employment in all industries at time *t* in study area, and E_T^t is total employment in all industries at time *t* in parent area[2].

[2] For example, suppose US total employment in all areas = 10, US total employment in biotech industry = 3, Minnesota total employment in all areas = 2, and Minnesota total employment in biotech industry = 1. So, LQ = (1/2)/(3/10) = (1/3)/(2/10) = 1.67, that is, Minnesota specializes in biotech industry.

Activity index (AI)

The concept of AI is similar to that of LQ except for the change from employment data to patent data. The sectoral structure of states' or universities' patenting activity can be investigated using a measure of specialization relative to other states or universities. The most frequently used indicator is called the "Activity Index" or "Specialization Index (SI)" or "Revealed Technological Advantage (RTA)," and is defined as the share of a nation (or state) *i* in patents in a given field of technology *j* filed with a given state (or institution), divided by the nation (or state)'s share of all patents in that state (or institution)[3].

$$AI = \frac{P_{ij} / \sum P_{ij}}{\sum P_{ij} / \sum\sum P_{ij}}$$

Concordance between Employment (Industry) Data and Technology (Patent) Data

As mentioned before, industry classification such as SIC and NAICS does not correspond with patent classification such as IPC and UPC. So, specifically when studies define relationships between economic data and patent data, and more broadly, economic growth and technological activity, structural problems are encountered. To close this gap, this paper uses the concordance table between SIC and UPC presented by the USPTO[4] rather than other concordance tables of the NBER[5], Yale University[6] or Silverman[7].

[3] For example, suppose US total patents in all areas = 10, US total patents in bio technology = 3, Minnesota total patents in all areas = 2, and Minnesota total patents in bio technology = 1. So, AI = (1/2)/(3/10) = (1/3)/(2/10) = 1.67, that is, Minnesota specializes in bio technology.

[4] According to Hirabayashi (1999), the USPTO has maintained and updated a concordance between the UPC and SIC systems since 1974, when it was created. This concordance, often referred to as the "OTAF Concordance," was developed

2.3. Mathematical Optimization and GAMS

Mathematical Optimization

The basic problem of economics, economizing, is that of allocating scarce resources among competing ends. Because of the scarcity of resources, choices must be made, and rational choices are those attaining certain objectives within the limitation of resource scarcity. From this perspective, Morgan and Henrion (1992) pointed out maximizing a multi-attribute utility function as one of criteria for decision-making. Multi-attribute utility involves specifying a utility function that evaluates outcomes in terms of all their important attributes including uncertainties and risks. The alternative with maximum utility is selected. Such economizing problem can be considered in the application to economics through the mathematical optimization problem, defined as the choice of value of certain variables so as to maximize a function subject to constraints. If expressed mathematically, the economizing problem is that of selecting instruments from the opportunity set so as to maximize the objective function (Intriligator 2002).

Mathematical optimization is often divided into two categories: static optimization and dynamic optimization. In turn, static optimization is based on classical, linear and non-linear programming, while dynamic optimization is based on control problems, calculus of variations and dynamic programming. In terms of mathematics, mathematical optimization is based on the Weierstrass Theorem and the Local-

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by manually reviewing classification categories in the UPC and associating them with a limited set of industry-based product fields based on the 1972 SIC.

[5] Hirabayashi (1999) also introduced UPC-SIC Concordance which is a high level concordance from UPC to two-digit SIC. It, however, may not be sufficiently detailed to accurately reflect associated industry categories since some classes contain different subclass areas that match to different industry categories.

[6] The Yale Technology Concordance and a concordance developed by Professor Silverman of the University of Toronto are two examples of an IPC-based concordance.

[7] He has constructed a concordance that links the IPC system to the SIC system at the four-digit level. This concordance has been used by various scholars to assess the specific industries in which firms have technological strength (Silverman 1999); patenting activity through the industry life cycle (McGahan and Silverman 2001); industry-specific technological uncertainty (Luque 2000); and industry-specific effects in university-industry technology transfer (Mowery and Ziedonis 2001). (http://www.rotman.utoronto.ca/~silverman/research.htm)

Global Theorem and approached by the Method of Lagrange Multiplier and the Kuhn-Tucker Conditions. These mathematical theories are discussed in Appendix.

GAMS

The General Algebraic Modeling System (GAMS) software is specifically designed for modeling linear, nonlinear and mixed integer optimization problems. The system is especially useful with large, complex problems. GAMS allows the user to concentrate on the modeling problem by making the setup simple. The system takes care of the time-consuming details of the specific machine and system software implementation. GAMS is especially useful for handling large, complex, one-of-a-kind problems which may require many revisions to establish an accurate model. The system models problems in a highly compact and natural way. The user can change the formulation quickly and easily, can change from one solver to another, and can even convert from linear to nonlinear with little trouble[8].

[8] GAMS home page (http://www.gams.com)

3. Comparative Analysis of Economic and Technological Competitiveness in Biotech Sector

3.1. Comparative analysis of location quotients of eight states in biotech industry

To analyze biotech industry, NAICS code 3254 (Pharmaceutical and medicine manufacturing) and its subclasses[9], and NAICS code 3345 (Electronic instrument manufacturing) and its subclasses[10], and NAICS code 3391 (Medical equipment and supplies manufacturing) and its subclasses[11] were targeted. For more detailed analysis, biotech industry was divided into two groups: (1) Pharmaceutical and Medicine (NAICS 3254), and (2) Medical Device (NAICS 3345 and 3391). To compute location quotients of eight states, *Location Quotient Calculator* offered by the Bureau of Labor Statistics was used and the number of employees (NOEs) as well as LQs of each state was acquired.

[Table 1], [Table 2] and [Table 3] show NOEs and LQs of eight states in biotech industries – including pharmaceutical and medicine, and medical device – in 2004 and 2008. In the overall biotech industry, Pennsylvania, Indiana, Minnesota and Illinois have more than 50,000 employees while other states have less than 40,000. In particular, Indiana and Minnesota highly specialize in the biotech industry, with the LQs larger than two and the high increase of NOEs, while Iowa, Ohio and Wisconsin are less specialized in it. In pharmaceutical and medicine sub-area, Indiana, Pennsylvania and Illinois have relatively large NOEs and LQs, and thus specialize in this area. Although Minnesota has relatively small NOE and LQ in this area, two indices have climbed up in contrast with other states whose indices have slightly decreased. In the medical device sub-area, Minnesota and Indiana have the largest NOEs and LQs. Specifically, Minnesota highly specializes in this area. On the whole, Minnesota and Indiana

[9] NAICS 32541 Pharmaceutical and medicine manufacturing, 325411 Medicinal and botanical manufacturing, 325412 Pharmaceutical preparation manufacturing, 325413 In-vitro diagnostic substance manufacturing, and 325414 Other biological product manufacturing

[10] NAICS 334510 Electromedical apparatus manufacturing, and 334517 Irradiation apparatus manufacturing

[11] NAICS 33911 Medical equipment and supplies manufacturing, 339111 Laboratory apparatus and furniture manufacturing, 339112 Surgical and medical instrument manufacturing, 339113 Surgical appliance and supplies manufacturing, 339114 Dental equipment and supplies manufacturing, 339115 Ophthalmic goods manufacturing, and 339116 Dental Laboratories

are leaders in biotech industry, while Pennsylvania, Illinois and Michigan have high NOEs by absolute numbers.

Table 1 Location Quotients of Eight States in Total Biotech Industry in 2004 and 2008

State	2004		2008	
	No of employees	LQ	No of employees2	LQ2
Minnesota	55,650	2.15	65,232	2.49
Illinois	55,060	0.97	55,625	0.97
Indiana	68,713	2.42	78,462	2.80
Iowa	7,010	0.51	7,110	0.50
Michigan	37,352	0.88	39,906	1.01
Ohio	39,492	0.75	35,537	0.70
Pennsylvania	77,451	1.40	72,970	1.30
Wisconsin	26,399	0.97	23,883	0.88
US	1,258,457	1.00	1,289,406	1.00

Table 2 Location Quotients of Eight States in Pharmaceutical and Medicine sub-area in 2004 and 2008

State	2004		2008	
	No of employees	LQ	No of employees2	LQ2
Minnesota	2,477	0.42	3,498	0.59
Illinois	20,597	1.59	18,534	1.44
Indiana	20,057	3.09	18,822	2.99
Iowa	2,589	0.82	2,793	0.87
Michigan	10,057	1.04	8,209	0.93
Ohio	4,746	0.40	5,105	0.44
Pennsylvania	23,308	1.84	22,294	1.77
Wisconsin	2,716	0.44	3,490	0.57
US	287,199	1.00	289,586	1.00

Table 3 Location Quotients of Eight States in Medical Device sub-area in 2004 and 2008

	2004		2008	
State	No of employees	LQ	No of employees2	LQ2
Minnesota	53,173	2.66	61,734	3.03
Illinois	**34,463**	**0.79**	**37,091**	**0.84**
Indiana	48,656	2.22	59,640	2.74
Iowa	**4,421**	**0.41**	**4,317**	**0.39**
Michigan	27,295	0.83	31,697	1.04
Ohio	**34,746**	**0.86**	**30,432**	**0.77**
Pennsylvania	54,143	1.26	50,676	1.16
Wisconsin	**23,683**	**1.13**	**20,393**	**0.97**
US	971,258	1.00	999,820	1.00

[Figure 2], [Figure 3] and [Figure 4] show location quotient transitions in biotech industry – including pharmaceutical and medicine, and medical device – between 2004 and 2008. To distinguish LQs of each state, graduated colors are classified into five groups: (1) 0 – 0.50, (2) 0.51 – 1.00, (3) 1.01 – 1.50, (4) 1.51 – 2.00, and (5) 2.00 and above. These figures provide an easier access than above tables. In the overall biotech industry, Minnesota and Indiana maintain a lead and Michigan moves to the upper level. In pharmaceutical and medicine sub-area, Indiana leads other states and Minnesota and Wisconsin go up while Michigan and Illinois go down. In medical device sub-area, the transition between 2004 and 2008 is similar to overall biotech industry.

Figure 2 Location Quotient Transition in Biotech Industry between 2004 and 2008

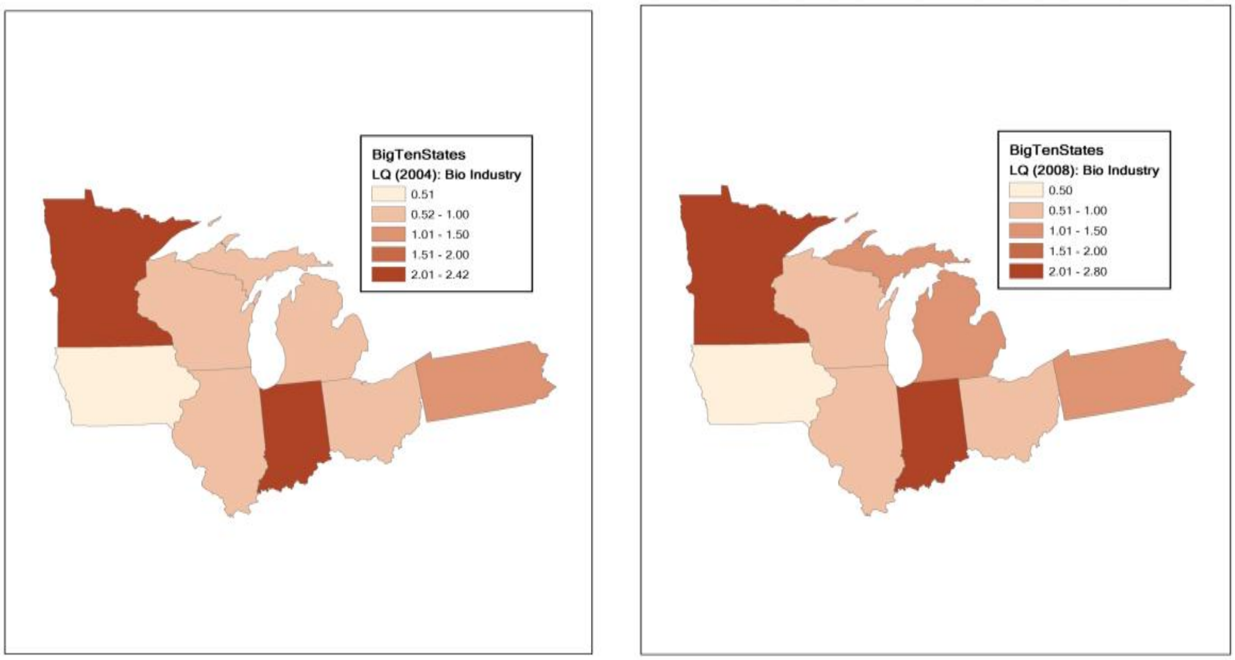


Figure 3 Location Quotient Transition in Pharmaceutical and Medicine sub-area between 2004 and 2008

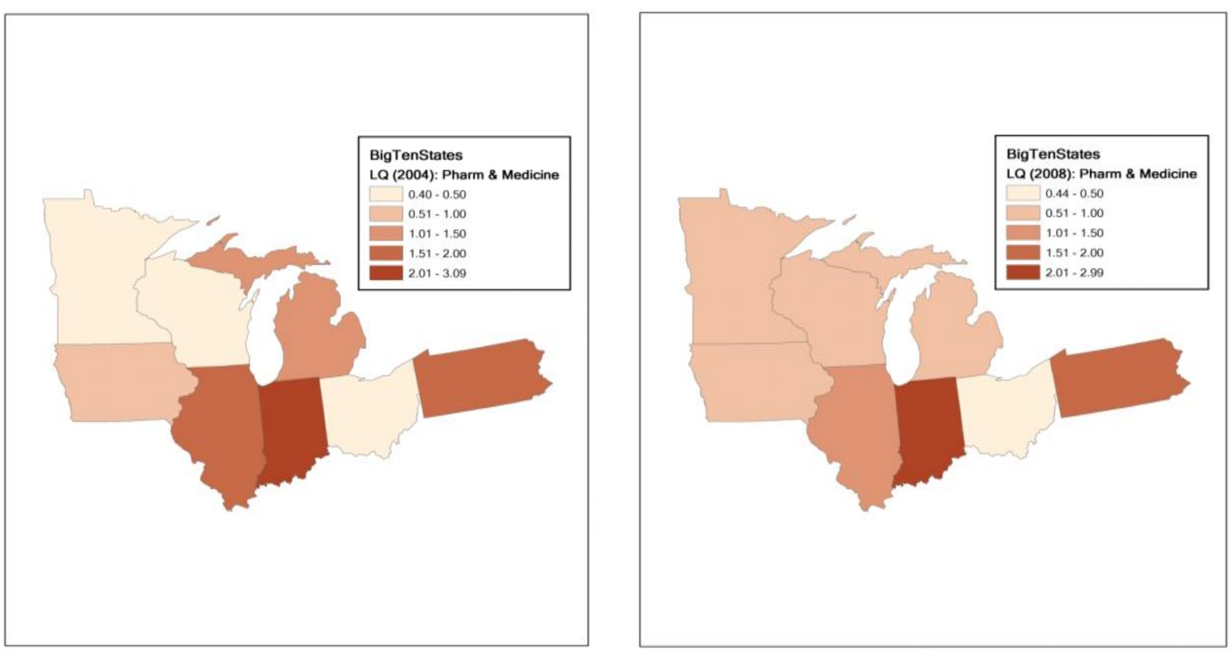
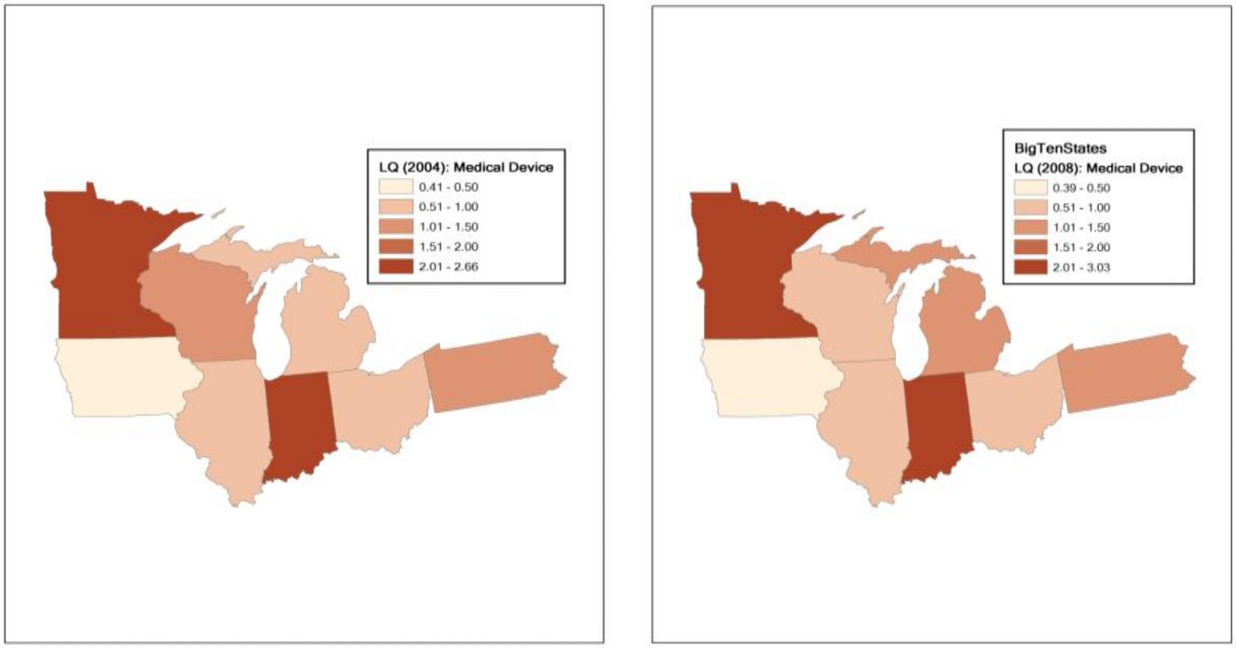


Figure 4 Location Quotient Transition in Medical Device sub-area between 2004 and 2008



[Table 4] and [Table 5] show LQs of eight states in more detailed levels of biotech industry in 2004 and 2008. On the whole, Indiana excels in both areas of pharmaceutical and medicine – particularly, *Pharmaceutical preparation manufacturing* (NAICS 325412), and medical device – particularly, *Surgical and medical instrument manufacturing* (NAICS 339112). Minnesota follows Indiana, but Minnesota concentrates on the area of medical device – particularly, *Electromedical apparatus manufacturing* (NAICS 334510) and *In-vitro diagnostic substance manufacturing* (NAICS 325413). In addition to Indiana and Minnesota, Pennsylvania also specializes in bio industry, in particular *Other biological product manufacturing* (NAICS 325414) in which Iowa and Wisconsin highly specialize. Wisconsin dominates other states in *Irradiation apparatus manufacturing* (NAICS 334517).

Table 4 Location Quotients of Eight States in 2004

Class Title	Minnesota	Illinois	Indiana	Iowa	Michigan	Ohio	Pennsylvania	Wisconsin
Bio Industry	2.15	0.97	2.42	0.51	0.88	0.75	1.40	0.97
Pharmaceutical and medicine	0.42	1.59	3.09	0.82	1.04	0.4	1.84	0.44
NAICS 3254 Pharmaceutical and medicine manufacturing	0.42	1.59	3.09	0.82	1.04	0.4	1.84	0.44
NAICS 32541 Pharmaceutical and medicine manufacturing	**0.42**	**1.59**	**3.09**	**0.82**	**1.04**	**0.4**	**1.84**	**0.44**
NAICS 325411 Medicinal and botanical manufacturing	ND	0.53	ND	ND	0.27	0.2	ND	0.17
NAICS 325412 Pharmaceutical preparation manufacturing	**0.29**	**1.87**	**3.88**	**0.36**	**1.23**	**0.46**	**1.89**	**0.17**
NAICS 325413 In-vitro diagnostic substance manufacturing	3.05	0.16	0.47	ND	ND	0.07	ND	1.27
NAICS 325414 Other biological product manufacturing	**ND**	**0.85**	**ND**	**3.97**	**ND**	**0.17**	**3.96**	**2.73**
Medical Device	2.66	0.79	2.22	0.41	0.83	0.86	1.26	1.13
NAICS 3345 Electronic instrument manufacturing								
NAICS 33451 Electronic instrument manufacturing								
NAICS 334510 Electromedical apparatus manufacturing	**10.23**	**0.31**	**ND**	**0.43**	**0.16**	**0.25**	**0.49**	**1.58**
NAICS 334517 Irradiation apparatus manufacturing	ND	1.19	0.12	ND	ND	0.75	0.16	18.54
NAICS 3391 Medical equipment and supplies manufacturing	**2.24**	**0.81**	**2.38**	**0.47**	**0.88**	**0.89**	**1.33**	**0.89**
NAICS 33911 Medical equipment and supplies manufacturing	2.24	0.81	2.38	0.47	0.88	0.89	1.33	0.89
NAICS 339111 Laboratory apparatus and furniture mfg.	**1.15**	**1.12**	**2.49**	**ND**	**1.7**	**2.42**	**0.89**	**4.94**
NAICS 339112 Surgical and medical instrument manufacturing	3.18	0.94	2.97	0.21	0.34	0.42	1.58	0.44
NAICS 339113 Surgical appliance and supplies manufacturing	**1.92**	**0.49**	**3.2**	**0.27**	**1.52**	**1.3**	**1.54**	**0.55**
NAICS 339114 Dental equipment and supplies manufacturing	0.76	1.77	0.73	ND	0.61	0.7	2.02	1.07
NAICS 339115 Ophthalmic goods manufacturing	**2.39**	**0.56**	**0.72**	**ND**	**0.49**	**0.94**	**0.83**	**0.6**
NAICS 339116 Dental Laboratories	1.51	0.87	1.23	0.93	1.03	0.76	0.64	1.36

Note: ND (Not Disclosable)

Table 5 Location Quotients of Eight States in 2008

Class Title	Minnesota	Illinois	Indiana	Iowa	Michigan	Ohio	Pennsylvania	Wisconsin
Bio Industry	**2.49**	**0.97**	**2.80**	**0.50**	**1.01**	**0.70**	**1.30**	**0.88**
Pharmaceutical and medicine	**0.59**	**1.44**	**2.99**	**0.87**	**0.93**	**0.44**	**1.77**	**0.57**
NAICS 3254 Pharmaceutical and medicine manufacturing	0.59	1.44	2.99	0.87	0.93	0.44	1.77	0.57
NAICS 32541 Pharmaceutical and medicine manufacturing	**0.59**	**1.44**	**2.99**	**0.87**	**0.93**	**0.44**	**1.77**	**0.57**
NAICS 325411 Medicinal and botanical manufacturing	0.08	0.56	ND	ND	0.54	ND	0.17	0.62
NAICS 325412 Pharmaceutical preparation manufacturing	**0.32**	**1.74**	**3.82**	**0.38**	**1.08**	**0.52**	**1.82**	**0.29**
NAICS 325413 In-vitro diagnostic substance manufacturing	4.54	0.15	0.62	ND	ND	0.48	0.33	1.09
NAICS 325414 Other biological product manufacturing	**0.48**	**0.62**	**ND**	**3.78**	**ND**	**ND**	**3.81**	**2.55**
Medical Device	**3.03**	**0.84**	**2.74**	**0.39**	**1.04**	**0.77**	**1.16**	**0.97**
NAICS 3345 Electronic instrument manufacturing								
NAICS 33451 Electronic instrument manufacturing								
NAICS 334510 Electromedical apparatus manufacturing	**10.38**	**0.47**	**ND**	**ND**	**0.21**	**0.28**	**0.85**	**0.95**
NAICS 334517 Irradiation apparatus manufacturing	ND	1.07	ND	ND	ND	0.75	0.2	19.34
NAICS 3391 Medical equipment and supplies manufacturing	**2.58**	**0.86**	**2.96**	**0.42**	**1.11**	**0.85**	**1.2**	**0.72**
NAICS 33911 Medical equipment and supplies manufacturing	2.58	0.86	2.96	0.42	1.11	0.85	1.2	0.72
NAICS 339111 Laboratory apparatus and furniture mfg.	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**
NAICS 339112 Surgical and medical instrument manufacturing	3.94	0.99	3.61	0.19	0.54	0.46	1.46	0.52
NAICS 339113 Surgical appliance and supplies manufacturing	**1.86**	**0.6**	**4.12**	**0.48**	**1.94**	**1.25**	**1.22**	**0.6**
NAICS 339114 Dental equipment and supplies manufacturing	0.82	2.14	0.59	NC	1.38	ND	1.64	1.25
NAICS 339115 Ophthalmic goods manufacturing	**2.78**	**0.46**	**0.91**	**0.48**	**0.45**	**1.31**	**0.78**	**0.65**
NAICS 339116 Dental Laboratories	1.34	0.89	1.19	0.95	1.06	ND	0.65	1.27

Note: ND (Not Disclosable)

3.2. Analysis of location quotient of Minnesota in biotech industry

To analyze the LQ of Minnesota in more detail, four categories[12] were introduced: *Stars* (LQ is larger than 1.00 and increasing), *Cash Cows* (LQ is larger than 1.00 and decreasing), *Rising Stars* (LQ is smaller than 1.00 and increasing), and *Dogs* (LQ is smaller than 1.00 and decreasing). [Table 6] shows these categories – in the last column of table – according to each subclass of biotech industry as well as LQs.

Looking at LQs, on the whole Minnesota is said to specialize in biotech industry although weak at pharmaceutical and medicine sub-area. It is due to the strength of medical device sub-area of Minnesota. Most LQs have increased from 2004 to 2008, that is, Minnesota has concentrated on biotech industry compared to other industries. Applying four categories, overall Minnesota's bio industry belongs to *Stars* because the LQ is larger than one and has increased from 2.15 in 2004 to 2.49 in 2008. In more detail, pharmaceutical and medicine sub-area belongs to *Rising Stars* while medical device sub-area belongs to *Stars*, in particular *Electromedical apparatus manufacturing* is the main focus of *Stars*.

[12] This method is the instrument devised by the Boston Consulting Group (1970), known as the Growth Rate-Market Share Matrix or the Boston Matrix, in short BCG Matrix. According to Flamholtz and Randle (1998), Businesses in quadrant 1 are termed "Dogs" because they have low market share and growth potential. Businesses in quadrant 2 are called "Cash Cows" because they have high market shares but low growth potential. The connotation of a Cash Cow was that the business would be "milked" or used as a source of funding for more promising investment opportunities. Businesses in quadrant 3 are "Stars" because they have relatively high market shares and high profit growth potential, while those in quadrant 4 are termed "Rising Stars" because they have low market shares but high growth potential.

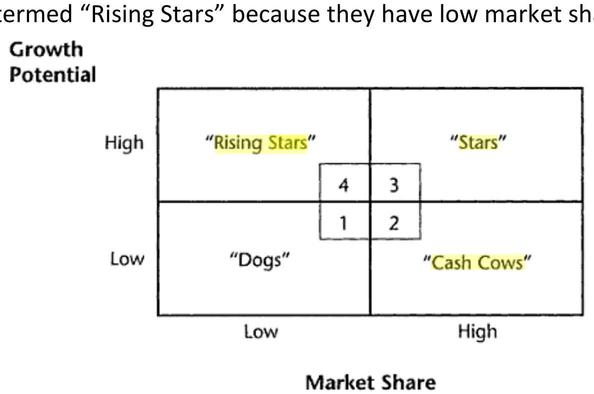


Table 6 Location Quotients of Minnesota in Biotech Industry

Industry	2004	2008	Category
Bio Industry	**2.15**	**2.49**	**Stars**
Pharmaceutical and medicine	**0.42**	**0.59**	**Rising Stars**
NAICS 3254 Pharmaceutical and medicine manufacturing	0.42	0.59	Rising Stars
NAICS 32541 Pharmaceutical and medicine manufacturing	**0.42**	**0.59**	**Rising Stars**
NAICS 325411 Medicinal and botanical manufacturing	ND	0.08	Undefined
NAICS 325412 Pharmaceutical preparation manufacturing	**0.29**	**0.32**	**Rising Stars**
NAICS 325413 In-vitro diagnostic substance manufacturing	3.05	4.54	Stars
NAICS 325414 Other biological product manufacturing	**ND**	**0.48**	**Undefined**
Medical Device	**2.66**	**3.03**	**Stars**
NAICS 3345 Electronic instrument manufacturing	**.**	**.**	**.**
NAICS 33451 Electronic instrument manufacturing	.	.	.
NAICS 334510 Electromedical apparatus manufacturing	**10.23**	**10.38**	**Stars**
NAICS 334517 Irradiation apparatus manufacturing	ND	ND	Undefined
NAICS 3391 Medical equipment and supplies manufacturing	**2.24**	**2.58**	**Stars**
NAICS 33911 Medical equipment and supplies manufacturing	2.24	2.58	Stars
NAICS 339111 Laboratory apparatus and furniture mfg.	**1.15**	**NC**	**Undefined**
NAICS 339112 Surgical and medical instrument manufacturing	3.18	3.94	Stars
NAICS 339113 Surgical appliance and supplies manufacturing	**1.92**	**1.86**	**Cash Cows**
NAICS 339114 Dental equipment and supplies manufacturing	0.76	0.82	Rising Stars
NAICS 339115 Ophthalmic goods manufacturing	**2.39**	**2.78**	**Stars**
NAICS 339116 Dental Laboratories	1.51	1.34	Cash Cows

Note: 1) ND (Not Disclosable)

2) Whether LQs in 2004 and 2008 are same or different, that is, whether LQ is increasing or not was not tested statistically. For example, in case of NAICS 325412 the increase of LQ from 0.29 to 0.32 might not be statistically significant.

3.3. Comparative analysis of activity indices of eight states in biotechnology

To analyze biotech patent, US Patent Classification (UPC) codes ranging from 128 to 800 were examined. Similar to the LQ analysis, for more detailed analysis, biotechnology was divided into two groups: (1) Pharmaceutical and Medicine (UPC 424, 435 and 800)[13], and (2) Medical Device (UPC 128, 351, 433, 601, 604, 606, 607 and 623)[14]. To compute activity indices of eight states, the USPTO website was visited and the number of patents (NOPs) as well as AIs of each state was acquired.

[13] UPC 424 Drug, Bio-Affecting and Body Treating Compositions (includes Class 514), 435 Chemistry: Molecular Biology and Microbiology, and 800 Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes

[14] UPC 128 Surgery (includes Class 600), 351 Optics: Eye Examining, Vision Testing and Correcting, 433 Dentistry, 601 Surgery: Kinesitherapy, 604 Surgery (Medicators and Receptors), 606 Surgery (instruments), 607 Surgery: Light, Thermal,

[Table 7], [Table 8] and [Table 9] show NOPs and AIs of eight states in biotechnology - including pharmaceutical and medicine, and medical device - in 2004 and 2008. In the overall biotechnology, Minnesota and Pennsylvania have NOPs more than 300 while most other states have NOPs less than 200. In particular, Minnesota has the highest NOP of 555 in 2004 and 469 in 2008, and Iowa has the highest AI of 1.90 in 2004 and 2.90 in 2008. In pharmaceutical and medicine sub-area, Pennsylvania dominates other states in NOP and Iowa does in AI. These two states highly specialize in this area and are followed by Indiana. In the medical device sub-area, Minnesota dominates other states in both NOE and AI, and is followed by Indiana and Wisconsin.

Table 7 Activity Indices of Eight States in Total Biotechnology in 2004 and 2008

State	2004		2008	
	No of patents	AI	No of patents2	AI2
Minnesota	555	1.79	469	1.81
Illinois	**253**	**0.71**	**209**	**0.75**
Indiana	179	1.24	155	1.54
Iowa	**141**	**1.90**	**166**	**2.90**
Michigan	193	0.46	152	0.50
Ohio	**251**	**0.77**	**192**	**0.85**
Pennsylvania	409	1.26	367	1.49
Wisconsin	**188**	**1.00**	**185**	**1.34**
US	9,509	1.00	7,904	1.00

and Electrical Application, and 623 Prosthesis (i.e., Artificial Body Members), Parts Thereof, or Aids and Accessories Therefor

Table 8 Activity Indices of Eight States in Pharmaceutical and Medicine sub-area in 2004 and 2008

State	2004		2008	
	No of patents	AI	No of patents2	AI2
Minnesota	138	0.82	105	0.67
Illinois	**154**	**0.80**	**150**	**0.89**
Indiana	95	1.22	85	1.40
Iowa	**131**	**3.27**	**162**	**4.68**
Michigan	136	0.60	100	0.54
Ohio	**101**	**0.57**	**87**	**0.63**
Pennsylvania	275	1.57	269	1.81
Wisconsin	**77**	**0.76**	**104**	**1.25**
US	5,124	1.00	4,783	1.00

Table 9 Activity Indices of Eight States in Medical Device sub-area in 2004 and 2008

State	2004		2008	
	No of patents	AI	No of patents2	AI2
Minnesota	417	2.91	364	3.57
Illinois	**99**	**0.60**	**59**	**0.53**
Indiana	84	1.26	70	1.76
Iowa	**10**	**0.29**	**4**	**0.18**
Michigan	57	0.29	52	0.43
Ohio	**150**	**1.00**	**105**	**1.17**
Pennsylvania	134	0.89	98	1.01
Wisconsin	**111**	**1.29**	**81**	**1.49**
US	4,385	1.00	3,121	1.00

[Figure 5], [Figure 6] and [Figure 7] show activity index transitions in biotechnology – including pharmaceutical and medicine, and medical device – between 2004 and 2008. To distinguish LQs of each state, graduated colors are classified into five groups: (1) 0 – 0.50, (2) 0.51 – 1.00, (3) 1.01 – 1.50, (4) 1.51 – 2.00, and (5) 2.00 and above. These figures enable us to understand the AI transitions more easily than above tables. In the overall biotechnology, Iowa maintains a lead and is followed by Minnesota, and Indiana moves to the upper level. In pharmaceutical and medicine sub-area, Iowa leads other states and is followed by Pennsylvania, and Wisconsin and Ohio go up while Michigan goes down. In medical device sub-area, Minnesota dominates other states, and Indiana, Ohio and Pennsylvania move to the upper level.

Figure 5 Activity Index Transitions of Eight States in Biotechnology in 2004 and 2008

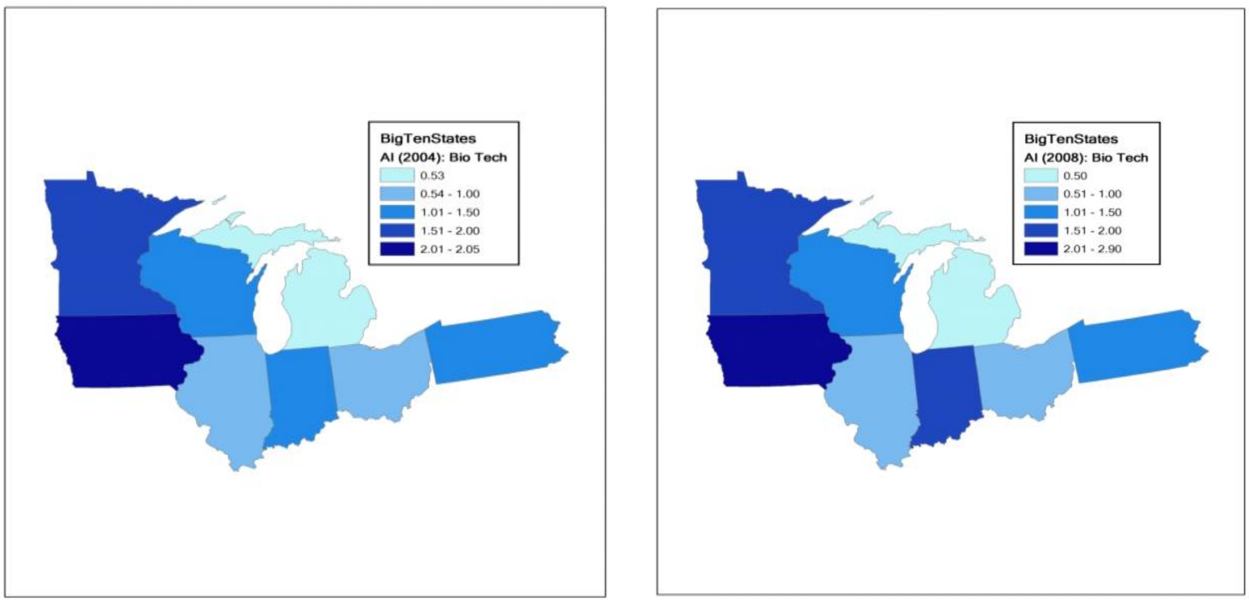


Figure 6 Activity Index Transitions of Eight States in Pharmaceutical and Medicine sub-area in 2004 and 2008

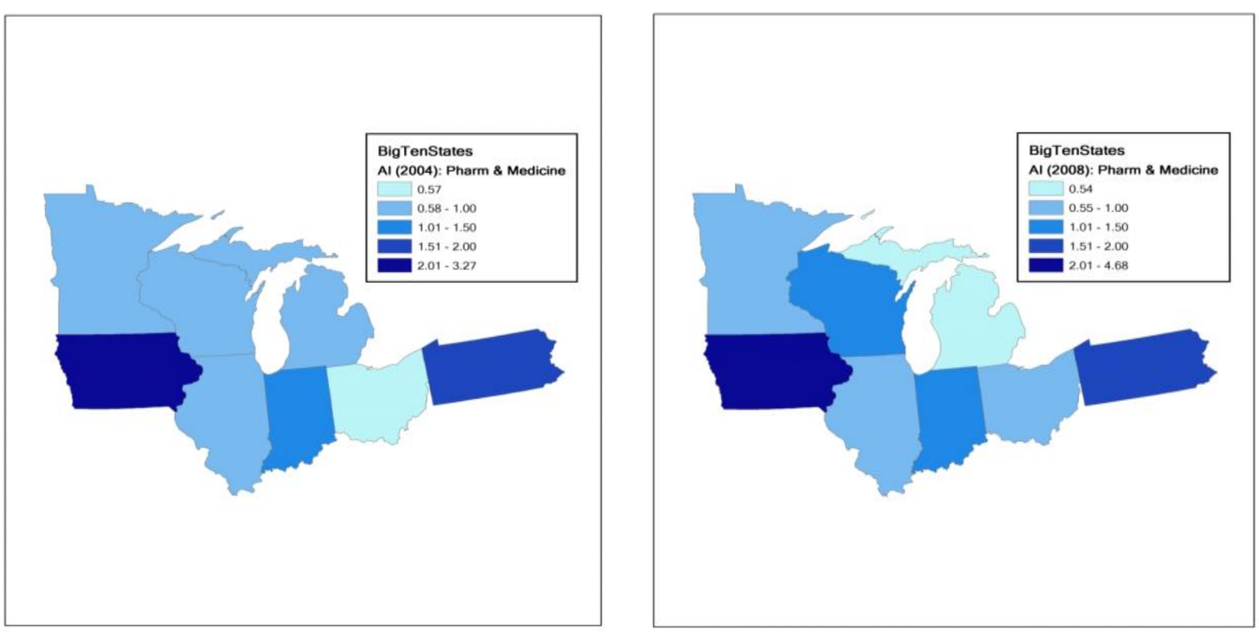
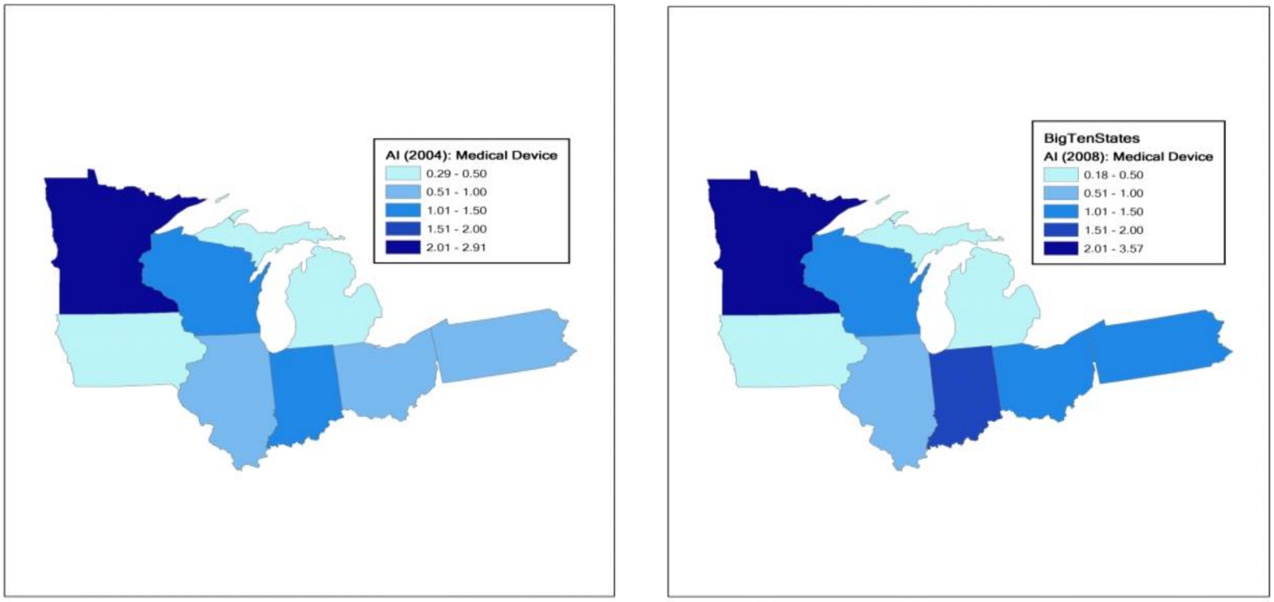


Figure 7 Activity Index Transitions of Eight States in Medical Device sub-area in 2004 and 2008



[Table 10] and [Table 11] show AIs of eight states in more detailed levels of biotechnology in 2004 and 2008. On the whole, Iowa make a lead specializing in pharmaceutical and medicine – particularly, *Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes* (UPC 800)[15], and Minnesota holds the second specializing in medical devices – particularly, *Surgery: Light, Thermal and Electrical Application* (UPC 607). Indiana specializes in both pharmaceutical and medicine, and medical device – particularly, *Prosthesis, Parts Thereof, or Aids and Accessories Therefor* (UPC 623).

[15] This UPC code includes not only pharmaceutical and medicine area such as nonhuman animal for human disease but also biofuels and plant breeding and mutating, so there might be an anomaly.

Table 10 Activity Indices of Eight States in Biotechnology in 2004

Class	Class Title	Minnesota	Illinois	Indiana	Iowa	Michigan	Ohio	Pennsylvania	Wisconsin
	Bio Technology	1.79	0.71	1.24	1.90	0.46	0.77	1.26	1.00
	Pharmaceutical and medicine	0.82	0.80	1.22	3.27	0.60	0.57	1.57	0.76
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	0.73	0.69	1.85	0.74	0.80	0.87	2.06	0.62
435	Chemistry: Molecular Biology and Microbiology	0.35	0.80	0.41	1.51	0.56	0.38	1.51	1.09
800	Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes	3.59	2.26	3.15	33.16	0.39	0.61	0.16	1.72
	Medical device	**2.91**	**0.60**	**1.26**	**0.29**	**0.29**	**1.00**	**0.89**	**1.29**
128	Surgery (includes Class 600)	2.33	0.67	0.64	0.51	0.50	1.16	1.09	1.96
351	Optics: Eye Examining, Vision Testing and Correcting	0.20	0.74	0.00	0.91	0.17	1.14	1.06	0.38
433	Dentistry	0.56	1.91	2.90	0.00	0.32	0.43	1.58	0.35
601	Surgery: Kinesitherapy	2.25	1.25	1.16	0.00	0.38	0.51	0.00	0.84
604	Surgery (Medicators and Receptors)	2.63	1.04	1.84	0.34	0.38	1.62	1.18	3.67
606	Surgery (instruments)	2.39	0.26	1.93	0.16	0.18	1.34	1.16	0.27
607	Surgery: Light, Thermal, and Electrical Application	7.83	0.13	0.18	0.00	0.06	0.47	0.15	0.52
623	Prosthesis (i.e., Artificial Body Members), Parts Thereof, or Aids and Accessories Therefor	3.11	0.47	3.64	0.26	0.38	1.29	0.71	0.21

Table 11 Activity Indices of Eight States in Biotechnology in 2008

Class	Class Title	Minnesota	Illinois	Indiana	Iowa	Michigan	Ohio	Pennsylvania	Wisconsin
	Bio Technology	**1.81**	**0.75**	**1.54**	**2.90**	**0.50**	**0.85**	**1.49**	**1.34**
	Pharmaceutical and medicine	**0.67**	**0.89**	**1.40**	**4.68**	**0.54**	**0.63**	**1.81**	**1.25**
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	0.29	0.77	1.29	0.83	0.65	0.65	2.22	0.62
435	Chemistry: Molecular Biology and Microbiology	0.46	0.64	0.50	1.83	0.49	0.55	1.62	2.00
800	Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes	3.27	2.22	4.66	33.02	0.15	0.80	0.25	2.20
	Medical device	**3.57**	**0.53**	**1.76**	**0.18**	**0.43**	**1.17**	**1.01**	**1.49**
128	Surgery (includes Class 600)	2.59	0.69	1.56	0.61	0.40	1.07	0.92	2.34
351	Optics: Eye Examining, Vision Testing and Correcting	0.56	0.39	1.43	0.00	0.35	0.63	0.73	1.04
433	Dentistry	1.11	0.51	0.00	0.00	0.71	0.63	1.17	1.04
601	Surgery: Kinesitherapy	2.38	1.47	0.00	0.00	1.68	0.00	0.42	0.75
604	Surgery (Medicators and Receptors)	2.49	0.47	0.66	0.00	0.54	2.11	1.68	2.88
606	Surgery (instruments)	2.45	0.38	2.89	0.00	0.61	1.45	1.13	0.48
607	Surgery: Light, Thermal, and Electrical Application	12.10	0.22	0.00	0.00	0.07	0.55	0.51	1.06
623	Prosthesis (i.e., Artificial Body Members), Parts Thereof, or Aids and Accessories Therefor	3.14	0.72	4.93	0.00	0.15	1.09	0.91	0.16

3.4. Analysis of activity index of Minnesota

[Table 12] shows AIs of Minnesota in 2004 and 2008, along with four categories. Looking at AIs on the whole, because the AIs in both 2004 and 2008 are larger than one, it can be said that Minnesota specializes in overall biotechnology. All Surgery areas (Class 128, 601, 604, 606 and 607), Class 623 and 800 are highly specialized, which have the AIs larger than 2.00. In particular, *Surgery: Light, Thermal, and Electrical Application* (Class 607) has the AIs of 7.83 in 2004 and 12.10 in 2008, which are not only very high but also increasing fast.

Using four categories for more meaningful analysis, overall Minnesota's biotechnology belongs to *Stars* because the AI is larger than 1.00 and has increased from 1.78 in 2004 to 1.81 in 2008. In more detail, pharmaceutical and medicine sub-area is regarded as *Dogs* while medical device sub-area is *Stars*. Technologies marked *as Stars* include most Surgery areas and Class 623, specifically Class 607 can be called the star of *Stars*, which are essential technologies for Minnesota's competitiveness. Technologies marked as Rising Stars include Class 351, 433 and 435, which are important for Minnesota's future competitiveness because their AIs are increasing, although they are smaller than 1.00. Technologies marked as Cash Cows is Class 604, which already contributed to Minnesota's competitiveness but now is declining because it entered mature market. Technologies marked as Dogs are Class 424, which is the weakest technology in Minnesota.

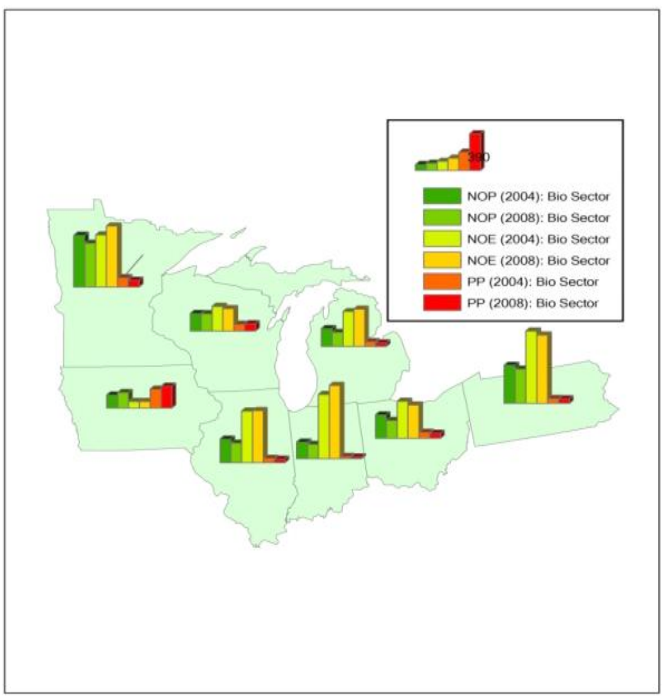
Table 12 Activity Indices in Minnesota

Class	Class Title	2004	2008	Category
	Bio Technology	**1.79**	**1.81**	**Stars**
	Pharmaceutical and medicine	**0.82**	**0.67**	**Dogs**
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	0.73	0.29	Dogs
435	**Chemistry: Molecular Biology and Microbiology**	**0.35**	**0.46**	**Rising Stars**
800	Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes	3.59	3.27	Cash Cows
	Medical device	**2.91**	**3.57**	**Stars**
128	Surgery (includes Class 600)	2.33	2.59	Stars
351	**Optics: Eye Examining, Vision Testing and Correcting**	**0.20**	**0.56**	**Rising Stars**
433	Dentistry	0.56	1.11	Rising Stars
601	**Surgery: Kinesitherapy**	**2.25**	**2.38**	**Stars**
604	Surgery (Medicators and Receptors)	2.63	2.49	Cash Cows
606	**Surgery (instruments)**	**2.39**	**2.45**	**Stars**
607	Surgery: Light, Thermal, and Electrical Application	7.83	12.10	Stars
623	**Prosthesis (i.e., Artificial Body Members), Parts Thereof, or Aids and Accessories Therefor**	**3.11**	**3.14**	**Stars**

3.5. Analysis of patent productivity in biotech sector

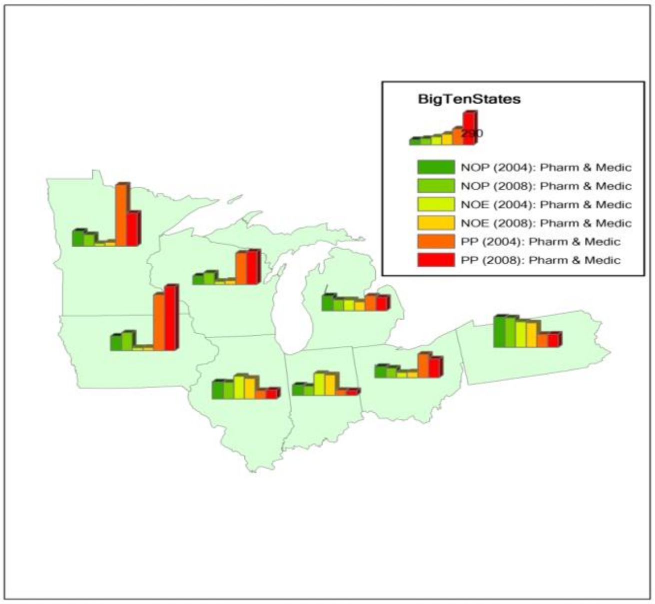
To complement the analysis using only relative values of LQ and AI, the absolute value of patent productivity is employed, which represents the number of patents per one hundred employees. [Figure 8], [Figure 9], and [Figure 10] show patent productivity in biotech sector – including pharmaceutical and medicine, and medical device – with NOPs and NOEs in 2004 and 2008. In the overall biotech sector, Minnesota, Pennsylvania, Indiana, and Illinois are relative leaders. Of leading states, Minnesota dominates other states, specifically in patent count (NOP) and patent productivity (PP), with a similar NOE. Other leading states have large NOEs, but relatively small PPs. Of following states, Iowa is a little distinctive with the largest PP due to the smallest NOE, although it has relatively small NOP. In pharmaceutical and medicine sub-area, Pennsylvania dominates other states in NOP and NOE while Minnesota and Iowa do in PP. Specifically, the group of Minnesota, Iowa and Wisconsin, and another group of Illinois, Indiana, Michigan, Ohio, have the similar features. In medical device sub-area, Minnesota dominates other states in all NOE, NOP and PP.

Figure 8 Patent Productivity in Biotech Sector



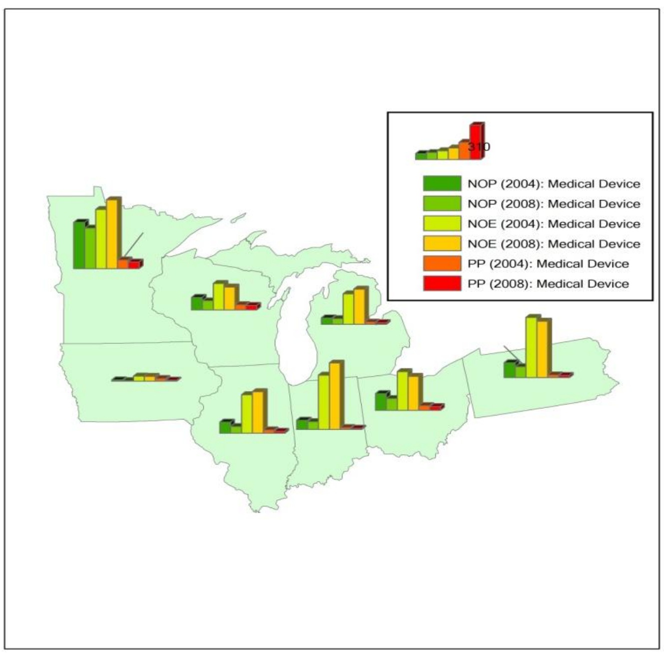
Note: NOE (Number of Employees * 100), PP (Patent Productivity per 100 employees)

Figure 9 Patent Productivity in Pharmaceutical and Medicine sub-area



Note: NOE (Number of Employees * 100), PP (Patent Productivity per 100 employees)

Figure 10 Patent Productivity in Medical Device sub-area



Note: NOE (Number of Employees * 100), PP (Patent Productivity per 100 employees)

3.6. Matching LQ and AI

To justify the positive relationship between technologies innovation and economic development, LQ and AI are matched using concordance between them. [Table 13] shows there are close relationship between LQ and AI, although there exists a little difference in specific values. Looking at Categories, there is a striking similarity in outcomes between LQ and AI analysis.

Table 13 Comparison between LQ and AI of Minnesota

Industry	LQ	Category		Technology	AI	Category
Bio Industry	**2.32**	**Stars**		**Bio Technology**	**1.80**	**Stars**
Pharmaceutical and medicine	**0.51**	**Rising Stars**		**Pharmaceutical and medicine**	**0.75**	**Dogs**
NAICS 3254 Pharmaceutical and medicine manufacturing	0.51	Rising Stars				
NAICS 32541 Pharmaceutical and medicine manufacturing	0.51	Rising Stars				
NAICS 325411 Medicinal and botanical manufacturing	ND	Undefined		UPC 424 Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	0.51	Dogs
NAICS 325412 Pharmaceutical preparation manufacturing	0.31	Rising Stars		UPC 435 Chemistry: Molecular Biology and Microbiology	0.41	Rising Stars
NAICS 325413 In-vitro diagnostic substance manufacturing	3.80	Stars				
NAICS 325414 Other biological product manufacturing	ND	Undefined		UPC 800 Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes	3.43	Cash Cows
Medical Device	**2.85**	**Stars**		**Medical device**	**3.24**	**Stars**
NAICS 3345 Electronic instrument manufacturing	.	.				
NAICS 33451 Electronic instrument manufacturing	.	.				
NAICS 334510 Electromedical apparatus manufacturing	10.31	Stars		UPC 607 Surgery: Light, Thermal, and Electrical Application	9.97	Stars
NAICS 334517 Irradiation apparatus manufacturing	ND	Undefined				
NAICS 3391 Medical equipment and supplies manufacturing	2.41	Stars				
NAICS 33911 Medical equipment and supplies manufacturing	2.41	Stars				
NAICS 339111 Laboratory apparatus and furniture manufacturing	ND	Undefined				
NAICS 339112 Surgical and medical instrument manufacturing	3.56	Stars		UPC 128 Surgery (includes Class 600)	2.46	Stars
				UPC 606 Surgery (instruments)	2.42	Stars
NAICS 339113 Surgical appliance and supplies manufacturing	1.89	Cash Cows		UPC 601 Surgery: Kinesitherapy	2.32	Stars
				UPC 604 Surgery (Medicators and Receptors)	2.56	Cash Cows
				UPC 623 Prosthesis (i.e., Artificial Body Members), Parts Thereof, or Aids and Accessories Therefor	3.12	Stars
NAICS 339114 Dental equipment and supplies manufacturing	0.79	Rising Stars		UPC 433 Dentistry	0.84	Rising Stars
NAICS 339115 Ophthalmic goods manufacturing	2.59	Stars		UPC 351 Optics: Eye Examining, Vision Testing and Correcting	0.38	Rising Stars
NAICS 339116 Dental Laboratories	1.43	Cash Cows				

Note: 1. LQ = Average of LQs in 2004 and 2008, AI = Average of AIs in 2004 and 2008

2. ND: Not Disclosable

4. Maximization of Competitiveness of Minnesota and UMN

4.1. Spillovers of academic research

As shown in the previous chapter, LQ is related to AI, and there seems to be a positive correlation between economic competitiveness and technological one, even though this is not statistically tested in this paper due to the small sampling of states to focus on those with Big Ten Universities. Lots of scholarly literatures have examined the correlation and elicited positive outcomes, and further tried to find out the causes of the positive correlation. Location or "agglomerations or geographic concentrations of knowledge that provide a means to facilitate information searches, increase search intensity, and, in general, ease task coordination (Feldman 1999, 5)" has been recognized as one of important sources for the positive relationship. In these studies, some scholars have paid attention to the production function with a measure of innovation as the dependent variable and a set of geographic units as the explanatory variables.

Griliches (1979) introduced the knowledge production function to examine geographically mediated knowledge spillovers:

$$\boldsymbol{I_{si} = IRD^{\beta 1} * UR_{si}^{\beta 2} * \varepsilon_{si}}$$

where *I* is the measure of innovative output, *IRD* is private corporate expenditures on R&D and *UR* is the research expenditures undertaken at universities. This conceptualization changed the observation from the traditional unit of the firm to the geographic level, *s*, for an industry, *i*.

Jaffe (1989) modified the knowledge production function presented by Griliches as follows:

$$\boldsymbol{log(P_{ikt}) = \beta_{1k}\, log(I_{ikt}) + \beta_{2k}\, log(U_{ikt}) + \beta_{3k}[log(U_{ikt}) \times log(C_{ikt})] + \varepsilon_{ikt}}$$

where *P* is number of patented inventions, *I* represents the private corporate expenditures on R&D, *U* represents the research expenditures undertaken at universities, *C* is a measure of the geographic coincidence[16] of university and corporate research, and ε represents stochastic disturbance. The unit of observation is at the level of the state, *i*, the technological areas, *k*, and time, *t*. Jaffe also modeled a simultaneous system to capture the potential effect of university research on industry R&D location (Anselin et al 2000):

$$\boldsymbol{log(I_{ikt}) = \beta_{4k}\, log(U_{ikt}) + \beta_{5k} Z_2 + \mu_{ikt}}$$

where Z_2 is instrumental variables for normalization between states such as state population (POP) and manufacturing value added (VA), and μ represents stochastic disturbance.

For the breakdown of industrial R&D into technical areas, Jaffe finally drew out the following model:

$$\boldsymbol{log(P_{ikt}) = \beta 1k log I it + (\beta 2k + \beta 1k\gamma) log U ikt + \beta 3k[log U ikt \times log C ikt] - \beta 1k\gamma log U it + \varepsilon ikt}$$ ... *[Formula 1]*

$$\boldsymbol{log(I_{it}) = \beta_{5k} Z_2 + (\beta_{4k} - \gamma)\, log(U_{ikt}) + \gamma\, log(U_{it}) + \mu_{ikt}}$$ ... *[Formula 2]*

To determine the coefficients of these two formulas, Jaffe used state-level data from 29 states ([Table 14] shows eight states' data extracted from Jaffe's full data), conducted three-stage least squares (3SLS) and obtained estimated values as shown in [Table 15] and [Table 16].

[16] Jaffe estimated total professional employees by multiplying total labs times the average number of professional employees per lab. He used the following formula to calculate the geographic coincidence index *Ci*:

$$C_i = \frac{\sum_s U_{is} TP_{is}}{[\sum_s U_{is}^2]^{1/2} [\sum_s TP_{is}^2]^{1/2}}$$

Table 14 Variable Means by State

STATE	URD_BIO	URD_TOT	IRD_TOT	GC	POP_TOT	PAT_BIO	PAT_TOT
MINN	29.7	55.7	399	1	3958	55	628
ILLI	45.5	254.9	894	0.96	11345	161	2451
INDI	16.1	51.3	398	0.06	2891	117	784
IOWA	16.3	46.4	135	0.03	2891	10	243
MICH	34.1	103.2	1815	0.23	9131	148	1725
OHIO	32.8	76.2	926	0.94	10772	92	1999
PENN	51.9	139.2	1293	0.85	11884	208	2329
WISC	25	65	224	0.48	4590	34	634

Note: 1) All dollar figures are in millions of 1972 dollars. Population is in thousands.

2) URD: University R&D, IRD: Industry R&D, GC: Geographic Coincidence, POP: Population, PAT: Patent, _TOT: Total Area, _BIO: Bio sector

Source: Jaffe (1989)

Table 15 3SLS Results of Full Patent Model in Drugs Area (Formula 1)

Variable (Parameters)	$Log(I_{it})$ (β_1)	$Log(U_{ikt})$ ($\beta_2 + \beta_1\gamma$)	$Log(U_{ikt})Log(C_i)$ (β_3)	$Log(U_{it})$ ($-\beta_2 \gamma$)
Coefficients	0.989	0.385	0.152	-0.194

Source: Jaffe (1989)

Table 16 3SLS Results for the Industry R&D Equation in Drugs Area (Formula 2)

Variable (Parameters)	$Log(U_{ikt})$ ($\beta_{4k} - \gamma$)	$Log(U_{it})$ (γ)	Log(VA)	Log(POP)
Coefficients	-0.730	1.078	0.787	0.421

Source: Jaffe (1989)

As a result of Jaffe's 3SLS, the following formulas were finally obtained:

$$\boldsymbol{log(P_{ikt})} = (\mathbf{0.989})\boldsymbol{log(I_{it})} + (\mathbf{0.385})\,\boldsymbol{log(U_{ikt})} + (\mathbf{0.152})[\boldsymbol{log(U_{ikt})} \times \boldsymbol{log(C_{ikt})}] - (\mathbf{0.194})\,\boldsymbol{log(U_{it})} \quad \ldots \textit{[Formula 3]}$$

$$\boldsymbol{log(I_{it})} = (\mathbf{0.787})\log(\boldsymbol{VA}) + (\mathbf{0.421})\log(\boldsymbol{POP}) - (\mathbf{0.730})\log(\boldsymbol{U_{ikt}}) + (\mathbf{1.078})\log(\boldsymbol{U_{it}}) \ldots \textit{[Formula 4]}$$

These formulas and coefficients are used in the following section to test the effects of biotech sector funding in universities on patent production.

4.2. Maximization of patent output

On the basis of the causal model describing the relationship among patent output, technological competitiveness and economic competitiveness, maximization of patent output is conducted.

Figure 11 Causal Model of Patent Output

To obtain the maximal value of patent output (for technological competitiveness and further for economic competitiveness), [Formula 3] and [Formula 4] are employed. For the clear description of mathematical optimization problem, the objective function and constraints are presented as follows:

- Objective Function: ***maximize*** $\boldsymbol{log(P_{ikt})}$ or

  $$\textbf{maximize } (0.989)\log(I_{it}) + (0.385)\log(U_{ikt}) + (0.152)[\log(U_{ikt}) \times \log(C_{ikt})] - (0.194)\log(U_{it})$$

- Constraints: $\log(I_{it}) = (0.787)\log(VA) + (0.421)\log(POP) - (0.730)\log(U_{ikt}) + (1.078)\log(U_{it})$; $U_{ikt} \leq U_{it}$; $I_{it} \leq (I_{it})_{endow}$; $U_{it} \leq (U_{it})_{endow}$; $U_{ikt} \leq (U_{ikt})_{endow}$

The objective function means that patent output in biotech sector (P_{ikt}), which is affected by industrial R&D expenditure (I_{it}), university R&D expenditure in total area (U_{it}) and in biotech area (U_{ikt}), and geographic coincidence (C_{ikt}), is maximized. Two constraints are satisfied in conducting the maximization: (1) industrial R&D expenditure (I_{it}) is calculated by subtracting university R&D expenditure in total area (U_{it}) and in biotech area (U_{ikt}) and adding instrumental variables such as population (*POP*) and manufacturing value added (*VA*); and (2) R&D expenditure in industry and the university cannot be greater than its endowments such as those for R&D budgets.

Because the objective function has a (log-) linear form, it is coded[17] in the form of linear programming with data – U_{it}, U_{ikt}, $(I_{it})_{endow}$, $(U_{it})_{endow}$, $(U_{ikt})_{endow}$, *POP*, and *VA* – and run by GAMS software with a log form of data ([Table 17]).

Table 17 Log Form of Data

STATE	URD_BIO	URD_TOT	IRD_TOT	GC	POP_TOT	PAT_BIO	PAT_TOT
MINN	3.391	4.020	5.989	0.000	8.283	4.007	6.443

Note: Refer to [Table 14]

In addition to constraints above, other constraints are introduced in order to observe the change of maximal patent output according to the change of the proportion of university R&D in biotech sector:

- Additional Constraints: $U_{ikt} \geq U_{it} / 4$

For example, $U_{ikt} \geq U_{it} / 4$ means that the proportion of university R&D in biotech sector should be greater than 25% of university R&D in total area (Case 2).

[Table 18] shows the outcomes[18] of GAMS programming to maximize biotech patent output with various conditions. This examines two factors influencing biotech patent output: changes in university total R&D expenditure (U_{it}) and changes in the university R&D biotech portfolio (U_{ikt} / U_{it}). For

[17] *See* Appendix C.
[18] *See* Appendix D.

example, what if the university R&D budget is cut by 10 million dollars by the state (Case 1), or what if incentives in R&D investment in the biotech sector cause the sector to grow to 25% of total R&D amount at university (Case 2). GAMS programming was used to explore these scenarios.

The results of Case 1 show that the budget cut on R&D leads to the significant decrease of biotech patent output in both conditions (with and without incentives): from 161 to 135 (-26) and from 115 to 98 (-17), respectively. The effect of changing the university R&D biotech portfolio to 25% combined with university cuts was also considerable in both stages (with and without budget cut): from 161 to 115 (-46) and from 135 to 98 (-37), respectively. The more detailed results are given in [Table 19]. In the case of no portfolio changes, as the university's total R&D expenditure decreases by one million dollars, the number of biotech patents declines, on average, by six or five. Even in the case with increased university biotech portfolio, as the university's total R&D expenditure decreases by one million dollars, the number of biotech patents declines, on average, by three or four. In both cases the more the university's total R&D expenditure decreases, the more the number of biotech patents decreases.

Table 18 Outcomes of GAMS programming

GAMS output	Stage 1		Stage 2		Change	
	Condition 1	Condition 2	Condition 1	Condition 2	Condition 1	Condition 2
Maximized Values	5.0815 (161)	4.7429 (115)	4.9088 (135)	4.5869 (98)	16.1% (-26/161)	14.7% (-17/115)

Note: 1) Stage 1 and Condition 1: Input data is the same to [Table 17] and there is no biotech portfolio change.

2) Stage 1 and Condition 2: Input data is the same to [Table 17] and there is a biotech portfolio change such that URD_BIO ≥ URD_TOT / 4.

3) Stage 2 and Condition 1: URD_TOT decreases by 10 million dollars and there is no biotech portfolio change.

4) Stage 2 and Condition 2: URD_TOT decreases by 10 million dollars and there is a biotech portfolio change such that URD_BIO ≥ URD_TOT / 4.

Table 19 More Detailed Outcomes of GAMS programming

Case 1: No biotech portfolio change and decrease in university total R&D expenditure

Maximal value	No minus	minus $2mil	minus $4mil	minus $6mil	minus $8mil	minus $10mil
log values	5.0815	5.0493	5.0161	4.9821	4.9463	4.9088
no. of patents	161	156	151	146	141	135
decreasing rate		**-3.17%**	**-3.27%**	**-3.34%**	**-3.52%**	**-3.68%**

Case 2: With biotech portfolio change and decreasing university total R&D expenditure

Maximal value	No minus	minus $2mil	minus $4mil	minus $6mil	minus $8mil	minus $10mil
log values	4.7429	4.7137	4.6838	4.653	4.6207	4.5869
no. of patents	115	111	108	105	102	98
decreasing rate		**-2.88%**	**-2.95%**	**-3.03%**	**-3.18%**	**-3.32%**

Note: Biotech portfolio change means that URD_BIO ≥ URD_TOT / 4.

Yet, both [Table 18] and [Table 19] show a contradictory result. If incentives to increase university R&D in the biotech sector are provided, patent output in biotech sector should increase, that is, values of Case 2 should be greater than those of Case 1 in [Table 19]. But, the result is on the opposite direction. Why this result came out? Instead of detailed discussions, which are left to the future study, a brief explanation is presented in this paper. An ostensible reason is that, looking at [Formula 3] and [Formula 4], the coefficients of *log(Uikt)* have the opposite signs and the difference in size: (+) 0.385 vs. (-) 0.730. Thinking of more fundamental reasons, there are some other possibilities. One possibility is that basically, increase in R&D expenditures at university does not necessarily lead to increase in patent output in a particular sector because industry funding decreases according to the model [Table 16]. Especially, universities R&D tend to focus on purer and more basic areas, which are not eligible for patent granting, whereas industry tends to focus on more applied areas. And professors prefer publishing their research to journals to filing patents. Another possibility is that there exist more complex patent application processes and patent thickets in biotech sector. It means that filing patents in biotech area has more uncertainty, and is tougher than other technology areas such information and communication technology. Thus it can deter university researchers from filing patents in biotech. Also, increasing the university biotech R&D to 25% comes at the expense of other university R&D which may contribute even more to the biotech sector patents outside of university. For example, basic university research on electronics might lead to its collaboration with medical devices companies that in turn get biotech patents. Thus decreasing support for these university R&D areas may ultimately decrease patents in biotech.

4.3. Limitations

The most fundamental criticism of this analysis will be tendency to identify patents with innovation (Worgan and Nunn 2002). They are different in that "not all patented inventions prove to be innovations, and many innovations are never patented" (Acs and Audretsch 1989). It is supported by the fact that only ten percent of patents are commercialized and considerable portion of innovations are kept secrets according to the strategy of firms. Worgan and Nunn (2002) also indicated that in most cases how or even whether patents are actually used is unknown and some patentees strategically use patents for the defense of their businesses rather than commercialization of patents.

Also, Jaffe's knowledge production function has lots of limitations. First, he introduced only university and industry R&D expenditures to his model for the purpose of explaining the spillover effect of university. But, there could be other factors having effect on patent output, for example, internal factors such as the cost of filing patents and the goal of obtaining patents, and external factors such as pro-patent policy by the government. Secondly, Jaffe's two formulas used for maximization are based on several assumptions such that there exists a correlation between the proportion of industry R&D portfolio and university's. However, it is admitted that universities focus their research on basic and fundamental areas, while industry focuses on applied and marketable areas. Finally, because the model's coefficients were estimated through state-level data from 29 states with heterogeneous characteristics, they might not fit well with Minnesota. Because Minnesota has an edge in the biotech sector, Jaffe's model might underestimate the patent output of Minnesota, while overestimating other states which do not specialize in the biotech sector.

5. Conclusion

5.1. Summary

Summary from LQ and AI analyses

This paper explored the ties between technological development and regional economic growth through LQ and AI analysis, focusing on the biotech sector including pharmaceutical and medicine, and medical device areas. For more specific qualitative analysis for Minnesota of eight states in the Midwest, the BCG matrix with four categories was employed, which has been used for analyzing competitiveness according to market share and market growth.

On the whole, it seems that Minnesota maintains its competitiveness in biotechnology and its industries, which is verified not only by relative values such as high LQ and AI but also by absolute values such as relatively large employments and patents. In particular, Minnesota dominates other states in medical device sub-area and overall patent productivity in biotech. But, some concerns arise in that its competitiveness is unbalanced. In other words, it is concentrated in only medical device sub-area with the pharmaceutical and medicine sub-area suffering. This situation is contrasted with other states – in particular, Pennsylvania and Indiana – which keep a balance between the two sub-areas.

Looking at the BCG matrix, most sub-areas belong to either *Stars* or *Rising Stars* with rare *Dogs*. Specifically, most surgery-related industries and technologies under medical device are placed in *Stars*. It gives a positive signal for Minnesota to grow biotech industries and to develop biotechnologies because it shows that the biotech market in Minnesota is still growing up and has a potential for higher growth.

Comparing the outcomes of LQ analysis with the ones of AI analysis, it seems that there exists a positive correlation between the two. Specifically, qualitatively there exists a correlation between categories in two BCG matrices when each industry and technology matched by concordance table corresponds with similar BCG categories.

Summary from mathematical optimization

On the basis of the positive correlation between economic competitiveness and technological competitiveness, mathematical optimization technique was employed to maximize the patent output which is a proxy for technological competitiveness of Minnesota. To determine the objective function and constraints of mathematical optimization problem, Jaffe's knowledge production function and its estimates were used. To test the effect of budget cuts and general investment in biotech R&D by the state government, the university's R&D expenditure and portfolio were changed. As a result, both budget cuts alone (Case 1) and with incentives to increase university's R&D in the biotech sector (Case 2) have significantly negative effects on patent output.

5.2. Policy Options

Although Minnesota has clear strengths in medical device area, the state has several weak areas such as pharmaceutical and medicine, a mismatch between university and industry R&D focus, and a relative lack of investment in the biotech sector compared to other Midwest states (Appendix A). The following section presents policy options for investments to address these weaknesses[19].

Status quo

As shown in LQ and AI analysis, Minnesota – specifically Minnesota's industry – excels in medical device area, while it is weak in pharmaceutical and medicine area. In addition, [Figure 12] shows the

[19] Which area should be invested is important, but the problem of who should invest really matters as well. This paper focuses on the former and the latter is outside of scope, that is, this paper did not explore what entities should invest.

current capacity of Minnesota's academy is strong in pharmaceutical and medicine area, while moderate in medical device area. It underscores that Minnesota's academy and industry do not correspond with each other.

Figure 12 The Capacity of Minnesota in Biotech Sector

	Academic R & D	Industry
Medical Devices	Moderate	Strong
Biopharma	Strong	Weak

Source: BioBusiness Alliance of Minnesota and Deloitte (2009)

According to the Minnesota Science & Technology Initiative (MSTI) which was submitted to the Minnesota Legislature on January 15, 2010 by the Minnesota Science and Technology Economic Development Project Committee, Minnesota is losing its competitiveness with declining science and technology leadership. Although Minnesota has had an edge on biotech sector, MSTI also addresses:

- The medical technology industry is growing at a rate of 15 percent per year nationally, but Minnesota is barely participating in that growth.
- Biologic and biopharmaceutical products are converging with medical devices. Minnesota is not a leader in the convergence of these industries and is at risk of losing its dominant role in the device industry.

To spell out aforementioned concerns about biotech sector in Minnesota, MSTI presented several levies of evidence to indicate that Minnesota is not first-runner in R&D expenditure but sixth or seventh runner of ten comparison states[20], although they are not limited to the Midwest, which are study regions in this paper, but include strong competitors such as New Jersey and California.

Policy options for the competiveness of Minnesota centered at industrial and technical areas

[Table 22] and [Table 23] show the BCG matrices with four categories – Stars, Rising Stars, Cash Cows, and Dogs – which can help policy makers focus on those industries and technologies that need development and investment. According to Clouston and Westcott (2005), this matrix contains four categories:

- *Cash Cows* need low investment for high returns. These should be the core industries and technologies.
- *Stars* need high investment but will also provide high returns. These are usually the newer industries and technologies which have been instigated and are developing.
- *Rising Stars* need high investment but will only provide low returns. These are often new industries and technologies or *Dogs*, which are taking much time and effort to organize but are not yet functioning effectively.
- *Dogs* need low investment for low returns. These may be industries and technologies that have been running for many years and are no longer popular.

Combining [Table 22] and [Table 23], which are results of LQ and AI analysis, and Clouston and Westcott's strategies above, this paper suggests that the following policy options should be considered:

- Policy Option 1: Invest in surgical and medical instruments, in particular electromedical apparatus, areas with highest priority and highest R&D expenditure. Because they are placed in

[20] The comparison states include Illinois, Pennsylvania, California, New York, Virginia, North Carolina, New Jersey, Connecticut, and Massachusetts.

Stars, those areas should be a pillar industry and technology supporting current Minnesota's competitiveness and bring high economic prosperity to Minnesota.

- Policy Option 2: Consider surgical appliances and supplies areas as high priority funding sources for other areas. Encourage these industries to invest in other high priority area. Because they belong to *Cash Cows*, those areas have been main industries and played a central role in maintaining the competitiveness of Minnesota. So, *Cash Cows* are to be treated as sources of funding to invest in *Rising Stars* to help them become *Stars*.
- Policy Option 3: Invest in pharmaceutical and dental equipments areas with high priority and high R&D expenditure, while monitoring growth over time to minimize risk. Because they are put into *Rising Stars*, those areas have a potential to grow up to *Stars*. But, they have also risk: If successful, *Rising Stars* became *Stars*. But, otherwise investment might be in vain.

Table 20 Four Categories of LQ of Minnesota

Rising Stars	Stars
NAICS 325412 Pharmaceutical preparation manufacturing	NAICS 325413 In-vitro diagnostic substance manufacturing
NAICS 339114 Dental equipment and supplies manufacturing	NAICS 334510 Electromedical apparatus manufacturing
	NAICS 339112 Surgical and medical instrument manufacturing
	NAICS 339115 Ophthalmic goods manufacturing
Dogs	**Cash Cows**
	NAICS 339113 Surgical appliance and supplies manufacturing
	NAICS 339116 Dental Laboratories

Note: Intended for six-digit NAICS and excluded ND (Not Disclosable)

Table 21 Four Categories of AI of Minnesota

Rising Stars	Stars
UPC 435 Chemistry: Molecular Biology and Microbiology	UPC 607 Surgery: Light, Thermal, and Electrical Application
UPC 433 Dentistry	UPC 128 Surgery (includes Class 600)
UPC 351 Optics: Eye Examining, Vision Testing and Correcting	UPC 606 Surgery (instruments)
	UPC 601 Surgery: Kinesitherapy
	UPC 623 Prosthesis (i.e., Artificial Body Members), Parts Thereof, or Aids and Accessories Therefor
Dogs	**Cash Cows**
UPC 424 Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	UPC 800 Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes
	UPC 604 Surgery (Medicators and Receptors)

Mathematical optimization technique can give more quantitative evidences for how much Minnesota's budget cuts on the University of Minnesota's R&D expenditure can have an effect on innovative activities of the state and how much Minnesota should invest in R&D to maximize the technological innovation, specifically in biotech sector. Based on the results of running GAMS software, the following policy option might be considered:

- Policy Option 4: Minnesota's R&D expenditure on the University of Minnesota has an important effect on innovative output (i.e. as measured by patents). Therefore, budget cuts to the University of Minnesota R&D should be avoided if growing biotech innovation in state (and ultimately economic competitiveness) is desired. According to the results of mathematical optimization on biotech patent output, which is a proxy for innovative activities of Minnesota, the state of Minnesota's budget cut on the University of Minnesota could cause a serious situation in Minnesota's competitiveness in biotech sector.

Reference

Acs, Zoltan et al. 1992. "Real Effects of Academic Research: Comment." *The American Economic Review*; 82 (1)

_____. 2002. "Patents and innovation counts as measures of regional production of new knowledge." *Research Policy*; 31 p.1069-1085

Anselin, Luc et al. 1997. "Local Geographic Spillovers between University Research and High Technology Innovations." *Journal of Urban Economics*; 42 p.422-448

_____. 2000. "Geographical Spillovers and University Research: A Spatial Econometric Perspective." *Growth and Change*; 31 p.501-515

BioBusiness Alliance of Minnesota and Deloitte Consulting LLP. 2009. "Destination 2025 Roadmap: Recommendations to Grow Minnesota's Life Science Industry."

_____. 2009. "Destination 2025 Minnesota's Biologic and Biopharmaceutical Industry: A Vision for the Future."

_____. 2009. "Destination 2025 Minnesota's Medical Device Industry: A Vision for the Future."

Clouston, Teena and Westcott, Lyn. 2005. "Working in Health and Social Care." Elsevier Limited.

Cortright, Joseph and Mayer, Heike. 2001. "A Comparison of High Technology Centers." The Brookings Institution.

Crow, Michael and Tucker, Christopher. 1999. "The American Research University as America's *de facto* Science Policy." *Science and Public Policy*; 28 (1)

Feldman, Maryann. 1999. "The New Economics of Innovation, Spillovers and Agglomeration: A Review of Empirical Studies." *Econ. Innov. New Techn.*; 8 p.5-25

Flamholtz, Eric and Randle, Yvonne. 1998. "Changing the Game: Organizational Transformations of the First, Second, and Third Kinds." Oxford University Press.

Griliches, Zvi. 1979. “Issues in Assessing the Contribution of Research and Development to Productivity Growth.” *Bell Journal of Economics*, The RAND Corporation; 10 (1) p.92-116

Griliches, Zvi. 1990. “Patent Statistics as Economic Indicators: A Survey.” *Journal of Economic Literature*; 28

Hirabayashi, Jim. 1999. “Revisiting the USPTO Concordance Between the U.S. Patent Classification and the Standard Industrial Classification Systems.” *Science and Public Policy*; 28 (1)

Intriligator, Michael. 2002. “Mathematical Optimization and Economic Theory.” Society for Industrial and Applied Mathematics, Philadelphia

Jaffe, Adam. 1989. “Real Effects of Academic Research.” *American Economic Review*; 79 (5)

John Adams Innovation Institute. 2009. “2008 Index of the Massachusetts Innovation Economy.” (www.masstech.org/institute2009/the_index/index2008-21909.pdf)

Klosterman, Richard. 1990. “Community analysis and planning techniques.” Rowman & Littlefield Publishers, Inc.

Kuznets, Simon. 1962. “Inventive Activity: Problems of Definition and Measurement.” National Bureau of Economic Research, Inc.

Milken Institute. 2009. “The Greater Philadelphia Life Sciences Cluster 2009: An Economic and Comparative Assessment.” (www.milkeninstitute.org/pdf/PhillyLifeSciencesRprt.pdf)

_____. 2005. “The Greater Philadelphia Life Sciences Cluster 2005: An Economic and Comparative Assessment.” (www.milkeninstitute.org/pdf/Philadelphia_sciences_0605.pdf)

Minnesota Science and Technology Economic Development Project Committee. Jan 15, 2010. “Minnesota Science & Technology Initiative.”

Murray, Fiona and Stern, Scott. 2007. "Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis." *Journal of Economic Behavior & Organization*; 64 p.648-687

National Science Foundation. 2010. "Science and Engineering Indicators 2010."

Nunn, Samuel and Worgan, Amy. 2002. "Spaces of Innovation: Patent Activity in Indiana Metropolitan Areas, 1990 to 1998." *Economic Development Quarterly*; 16

Pavitt, Keith. 1985. "Patent Statistics as Indicators of Innovative Activities: Possibilities and Problems." *Scientometrics*; 7 p.77-99

Petersen-Perlman, Nina. 3/3/2006. "Biomed funds top U agenda." *The Minnesota Daily*. (http://www.mndaily.com/2006/03/03/biomed-funds-top-u-agenda)

Worgan, Amy and Nunn, Samuel. 2002. "Exploring a Complicated Labyrinth: Some Tips on Using Patent Data to Measure Urban and Regional Innovation." *Economic Development Quarterly*; 16

Brian Silverman's Research and Data Page (http://www.rotman.utoronto.ca/~silverman/research.htm)

U.S. Bureau of Labor Statistics (http://www.bls.gov)

U.S. Census Bureau (http://www.census.gov)

U.S. Patent and Trademark Office (http://www.uspto.gov)

Appendix A: Big Ten Universities and Their States

Big Ten Universities

Institution	Location	County	Founded	Joined Big Ten	Affiliation	Undergrad Enrollment
University of Minnesota	Minneapolis, Minnesota	Hennepin (small part: Ramsey)	1851	1896	Public	38,645
University of Illinois at Urbana-Champaign	Champaign, Illinois	Champaign	1867	1896	Public	30,895
Northwestern University	Evanston, Illinois	Cook	1851	1896	Private	8,284
Indiana University	Bloomington, Indiana	Monroe	1820	1899	Public	30,394
Purdue University	West Lafayette, Indiana	Tippecanoe	1869	1896	Public	31,290
University of Iowa	Iowa City, Iowa	Johnson	1847	1899	Public	20,907
University of Michigan	Ann Arbor, Michigan	Washtenaw	1817	1896	Public	26,083
Michigan State University	East Lansing, Michigan	Ingham (small part: Clinton)	1855	1950	Public	36,072
Ohio State University	Columbus, Ohio	Franklin (small part: Delaware, Fairfield)	1870	1912	Public	40,212
Pennsylvania State University	State College, Pennsylvania	Centre	1855	1990	Public	36,612
University of Wisconsin–Madison	Madison, Wisconsin	Dane	1848	1896	Public	28,999

Source: Wikipedia

US utility patent awards, by university: 1998-2008

Characteristic	1998–2008	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Patents granted	1,757,785	147,510	153,482	157,490	166,033	167,328	169,020	164,291	143,804	173,771	157,282
Patents granted to U.S. owners	947,448	83,842	87,499	88,428	91,038	89,677	90,223	86,476	76,619	92,029	81,568
Patents granted to U.S. nongovernment owners	800,819	67,223	70,671	72,230	75,787	75,361	76,545	74,174	66,182	80,141	71,628
Patents granted to U.S. universities	37,467	3,490	3,698	3,461	3,612	3,587	3,537	3,288	2,952	3,572	3,228
Top 200 R&D institutions in 2007	35,983	3,373	3,553	3,345	3,471	3,427	3,393	3,127	2,844	3,429	3,083
University of Wisconsin	941	85	89	70	76	82	89	74	79	106	99
University of Michigan	770	55	58	75	59	57	75	76	86	81	68
University of Minnesota	481	48	55	48	42	42	43	46	42	39	40
Michigan State University	473	60	54	44	40	50	50	29	25	36	37
Pennsylvania State University	467	27	45	40	63	58	56	45	34	34	31
University of Illinois	446	20	34	29	36	34	44	63	37	51	47
University of Iowa	301	27	34	20	41	25	31	20	19	33	27
Northwestern University	283	39	26	20	35	30	21	20	18	20	24
Ohio State University	274	24	25	26	21	21	23	33	31	31	22
Purdue University	263	22	23	13	18	24	25	26	27	29	34
Indiana University	156	23	12	17	20	18	20	8	14	9	9

Source: NSF (2010)

Total R&D and gross domestic product by state: 2007

Rank/state	R&D (current $millions)	GDP (current $millions)	R&D/GDP (%)	Rank in R&D/GDP	U.S. R&D (%)	Cumulative percent
5 Michigan	17,402	379,934	4.58	6	4.8	43.6
8 Illinois	14,287	617,409	2.31	20	4.0	56.2
10 Pennsylvania	13,510	533,212	2.53	15	3.8	63.9
12 Ohio	10,041	462,506	2.17	23	2.8	69.5
15 Minnesota	7,533	252,472	2.98	11	2.1	76.8
18 Indiana	5,980	249,229	2.40	18	1.7	82.4
21 Wisconsin	4,555	233,406	1.95	28	1.3	86.6
31 Iowa	1,882	129,911	1.45	33	0.5	95.5

Source: NSF (2010)

US university patents awarded in bio sector: 1988-2008

Technology area	1988–2008	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
All university patents	54,446	804	1,245	1,219	1,388	1,620	1,732	1,905	2,041	2,345	2,680	3,490	3,698	3,461	3,612	3,587	3,537	3,288	2,952	3,572
Biotechnology	8,120	83	83	91	107	148	205	196	213	359	538	683	748	657	735	578	490	467	377	494
Pharmaceuticals	7,599	112	176	179	197	177	227	229	266	368	439	578	589	553	508	519	509	408	331	438
Medical electronics	1,761	31	43	47	48	67	53	85	90	82	80	96	112	125	125	116	145	122	42	75
Medical equipment	2,183	60	61	88	74	81	67	88	88	105	108	147	164	132	118	147	157	122	111	98

Source: NSF (2010)

Appendix B: Basic Theory of Mathematical Optimization

Weierstrass Theorem

If the opportunity set Ω of a mathematical program is compact (i.e. closed and bounded) and nonempty, and the objective function F(x) is continuous on Ω, then F(x) has a global maximum either in the interior or on the boundary of Ω. This theorem is a sufficient condition for the existence of a global maximum.

Local-Global Theorem

If the opportunity set Ω of a mathematical program is compact (i.e. closed and bounded) and nonempty, and Ω is convex, and the objective function F(x) is continuous and concave, then a local maximum is a global maximum.

Linear Programming (LP)

The LP problem can be stated as:

$$\text{Maximize: } CX$$

$$\text{Subject to } AX \leq b;\ X \geq 0$$

The Lagrangian function is:

$$L[X, \lambda] = CX + \lambda[b - AX]$$

And the Kuhn-Tucker conditions can be stated as follows:

$$\partial L/\partial X = C - \lambda A \leq 0;\ [\partial L/\partial X]X = [C - \lambda A]X = 0;\ X \geq 0$$

$$\partial L/\partial \lambda = b - AX \geq 0;\ \lambda[\partial L/\partial \lambda] = \lambda[b - AX] = 0;\ \lambda \geq 0$$

The Kuhn-Tucker conditions are necessary and sufficient for a (strict) local maximum if the objective function is (strictly) concave and the constraint functions are convex.

Appendix C: GAMS programming code

```
$TITLE INNOVATIVE ACTIVITY MAXIMIZATION PROBLEM
$OFFSYMXREF OFFSYMLIST
* Youngbok Ryu, Humphrey Institute of Public Affairs, University of Minnesota

OPTION LIMCOL=0, LIMROW=0;

* In Full Patent Model
PARAMETER  ALPHA Coefficient of Log(Iit)         /0.989/;
PARAMETER  BETA  Coefficient of Log(Uikt)        /0.385/;
PARAMETER  GAMMA Coefficient of Log(Uit)         /0.194/;
PARAMETER  SIGMA Coefficient of Log(Uikt)Log(Cikt) /0.152/;

* In Industry R&D equation
PARAMETER  A Coefficient of Log(Uikt) /0.730/;
PARAMETER  B Coefficient of Log(Uit)  /1.078/;
PARAMETER  C Coefficient of Log(POP)  /0.421/;
PARAMETER  D Coefficient of Log(VA)   /0.787/;

* Constants
PARAMETER  POP    Log of POPULATION             /3.597/;
PARAMETER  GEO    Log of GEOGRAPHIC COINCIDENCE   /0.000/;
PARAMETER  VA     Log of Manufacturing Value Added /0.100/;

* Endowments
PARAMETER  IRDTOT  Log of INDUSTRY R&D TOTAL       /5.989/;
PARAMETER  URDTOT  Log of UNIVERSITY R&D TOTAL     /4.020/;
PARAMETER  URDBIO  Log of UNIVERSITY R&D BIO       /3.391/;

* Maximazation
VARIABLES  IT, UT, UB, Z;
POSITIVE VARIABLES IT, UT, UB;
```

```
EQUATIONS  INNOVATION, INDUSTRY, IRD, URD1, URD3, URD4;


INNOVATION..  Z =E= ALPHA*IT + BETA*UB - GAMMA*UT + SIGMA*UB*GEO;

INDUSTRY..   IT =E= B*UT - A*UB + D*VA + C*POP;

IRD.. IT =L= IRDTOT;

URD1.. UT =L= URDTOT;

URD3.. UB =L= UT;

URD4.. UB =G= UT/4;


IT.L = 1;

UT.L = 1;

UB.L = 1;


MODEL KnowProdJaffe /ALL/;


SOLVE KnowProdJaffe USING LP MAXIMIZING Z;
```

Appendix D: GAMS output

```
COMPILATION TIME     =        0.000 SECONDS      2 Mb  WIN233-233 Nov 17, 2009
GAMS Rev 233  WIN-VIS 23.3.2 x86/MS Windows           04/22/10 04:18:25 Page 2
INNOVATIVE ACTIVITY MAXIMIZATION PROBLEM
Model Statistics    SOLVE KnowProdJaffe Using LP From line 48


MODEL STATISTICS

BLOCKS OF EQUATIONS          6     SINGLE EQUATIONS           6
BLOCKS OF VARIABLES          4     SINGLE VARIABLES           4
NON ZERO ELEMENTS           13


GENERATION TIME      =        0.016 SECONDS      3 Mb  WIN233-233 Nov 17, 2009


EXECUTION TIME       =        0.016 SECONDS      3 Mb  WIN233-233 Nov 17, 2009
GAMS Rev 233  WIN-VIS 23.3.2 x86/MS Windows           04/22/10 04:18:25 Page 3
INNOVATIVE ACTIVITY MAXIMIZATION PROBLEM
Solution Report     SOLVE KnowProdJaffe Using LP From line 48


           S O L V E      S U M M A R Y

     MODEL   KnowProdJaffe       OBJECTIVE  Z
     TYPE    LP                  DIRECTION  MAXIMIZE
     SOLVER  CPLEX               FROM LINE  48

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      1 Optimal
**** OBJECTIVE VALUE               4.7429

 RESOURCE USAGE, LIMIT          0.034      1000.000
 ITERATION COUNT, LIMIT         1    2000000000

ILOG CPLEX       Nov  1, 2009 23.3.2 WIN 13908.14598 VIS x86/MS Windows
Cplex 12.1.0, GAMS Link 34

LP status(1): optimal
Optimal solution found.
Objective :          4.742870


                   LOWER     LEVEL     UPPER    MARGINAL

---- EQU INNOVATION      .          .          .         1.000
---- EQU INDUSTRY       1.593      1.593      1.593      0.989
---- EQU IRD            -INF       5.193      5.989       .
---- EQU URD1           -INF       4.020      4.020      0.788
```

```
---- EQU URD3          -INF     -3.015      .        .
---- EQU URD4           .        .       +INF     -0.337

                 LOWER     LEVEL     UPPER    MARGINAL

---- VAR IT            .        5.193     +INF       .
---- VAR UT            .        4.020     +INF       .
---- VAR UB            .        1.005     +INF       .
---- VAR Z           -INF      4.743     +INF       .


**** REPORT SUMMARY :        0     NONOPT
                      0 INFEASIBLE
                      0  UNBOUNDED


EXECUTION TIME       =       0.000 SECONDS      2 Mb  WIN233-233 Nov 17, 2009


USER: GAMS Development Corporation, Washington, DC   G871201/0000CA-ANY
     Free Demo,  202-342-0180,  sales@gams.com,  www.gams.com   DC0000


**** FILE SUMMARY

Input      F:\PA8082 Working Group\math opt\KnowProd_Jaffe_S10.gms
Output     C:\Users\user\Documents\gamsdir\projdir\KnowProd_Jaffe_S10.lst
```

Appendix E: Other indicators of Minnesota's competitiveness in the biotech sector

Indices of Minnesota

Indicator	Minnesota's Rank (of 10 comparison states)
SBIR Awards to Companies per Capita	6
Dollar Value of SBIR Awards per Capita	6
Medical Device Pre-market Notifications	5
Medical Device Pre-market Approvals	3
Biotechnology Drugs in Development	10
Corporate R&D Expenditures per Headquarters	7
Federal R&D Expenditures per Capita	10
Federal R&D Expenditures at Academic and Non-profit Research Institutions per Capita	9
NIH Funding per Capita	7
Patents Issued per Capita	3
Dollar Value of Venture Capital Investments	9
Growth Rate of Venture Capital Investments (2003-07)	1

Source: John Adams Innovation Institute (2009)[21]

Competitiveness of Minneapolis – St. Paul Metro Area in Biotech Sector

Indicator	Mpls-St. Paul's Rank (of 11 comparison areas)	
	2005	2009
Current Impact of Therapeutics and Devices	NA	8
Current Impact of Pharmaceuticals	10	8
Current Impact of Medical Devices	1	1
Current Impact of Biotechnology	9	11
Current Impact of R&D in Life Sciences	9	11
Current Impact of Health Services	NA	10
Current Impact of Life Science Supporting Industries	8	4

Indicator	Mpls-St. Paul's Rank (of 11 comparison areas)	
	2005	2009
Life Sciences Bachelor's Degrees Awarded	4	11
Life Sciences Graduate Students	NA	7
Life Sciences Master's Degrees Awarded	9	9
Life Sciences Ph.D.s Awarded	5	8
Medical Doctor Degrees Awarded	6	6
Life Sciences Postdocs	NA	9
Number of Life Sciences Ph.D.-granting Institutions	10	10

Indicator	Mpls-St. Paul's Rank (of 11 comparison areas)	
	2005	2009
Innovation Pipeline: Life Sciences R&D	10	8
Innovation Pipeline: Risk Capital	6	7
Innovation Pipeline: Human Capital	9	8
Innovation Pipeline: Life Sciences Workforce	9	9
Innovation Pipeline: Innovation Output	7	6

Source: The Milken Institute (2005, 2009)[22]

[21] The comparison states include Illinois, Pennsylvania, California, New York, Virginia, North Carolina, New Jersey, Connecticut, and Massachusetts.

[22] The comparison areas include ten metro areas: Greater Philadelphia, Greater New York, Boston, Greater San Francisco, Greater Raleigh-Durham, Greater Los Angeles, Chicago, San Diego, Seattle, (Washington D.C., and Dallas).