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The Illinois Institute for Rural Affairs (IIRA) works to improve the quality of life for rural residents by partnering with public and private agencies on local development and enhancement efforts.

Western Illinois University

Deep-Tech Inventions in Illinois: An Empirical Analysis

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Introduction

A well-established proposition in economic development is that entrepreneurs create economic growth[2]. The lexical definition of an entrepreneur is "one who organizes, manages, and assumes the risks of a business or enterprise"[3]. The primary "risk" for a business is in understanding and catering to the 'needs' of the population[4]; addressing a need that is not salient for the population will result in business failure[5].

How could we think about changing consumer needs? Major principles of evolution suggest that evolution is transformation, not new formation[6]. Applied to consumer needs[7], the "transformation" theorem predicts evolution or new combinations of human needs; for example, electric vehicle as a need satisfier for the conjoined needs of "personal transportation" (automobile) and "pollution free environment".

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[2] See, for example, Bennett, R. J., Smith, H., Van Lieshout, C., Montebruno, P., & Newton, G. (2019). The Age of Entrepreneurship: Business proprietors, self-employment and corporations since 1851. Routledge.
[3] Merriam-Webster, https://www.merriam-webster.com/dictionary/dictionary.
[4] Peter Drucker, the eminent management scientist, observes that the purpose of business is to create a customer; see Drucker, P. F. (2006). Classic Drucker: essential wisdom of Peter Drucker from the pages of Harvard Business Review. Harvard Business Press.
[5] This is implied by the marketing concept; see Webster Jr, F. E. (1988). The rediscovery of the marketing concept. Business horizons, 31(3), 29-39.
[6] Bowler, P. J. (2003). Evolution (pp. 549-557). Routledge.
[7] Needs can be either physiological (for example, thirst), or learned (for example, automobile for personal transportation).

The contemporary label for a set of businesses that aims to address world's evolving needs is "Deep Tech'[8]. The term Deep Tech refers to start-up companies that develop products based on profound scientific breakthrough or engineering novelty[9]. They work to remove problems that plague the world such as lack of healthcare by combining emerging technologies such as internet of things and machine learning to diagnose and treat health issues[10]. The most prominent deep tech fields include advanced materials, advanced manufacturing, artificial intelligence, biotechnology, blockchain, robotics, photonics, electronics, and quantum computing.

What is the status of deep-tech inventions[11] in Illinois? Is it a region's human capital or cultural capital that is the salient correlate of deep tech in the region? This paper addresses these and other related questions using Illinois counties as the geographical unit of analysis.

Theorems and Hypotheses

The zeitgeist theory of creativity (invention) argues that it is the sociocultural system of a community that is responsible for technoscientific advances[12]; the individual creator is largely irrelevant. The reasoning is that cultures that discover high-level general principles, for example, breakthroughs in solid-state physics, would automatically facilitate midlevel inventions in the community (for example, motherboards / circuit designs) which in turn would lead to ground level inventions (for example, computers). Since higher education institutions are largely responsible for basic research, discovery of general principles, it is hypothesized that:

> **H_1**: The larger the number of higher education institutions in a community the larger would be the number of deep tech inventions in the community.

In contrast to the zeitgeist theory, the genius theory of creativity[13] states that technological inventions are produced by inventors who possess abilities and traits that are superior to the average person in the community; a genius is defined as one who transcends the limitations of the zeitgeist.

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[8] See, for example, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjjibnduq7xAhW9Ap0JHWQGAuoQFjABegQIBhAD&url=https%3A%2F%2Fivc-online.com%2FPortals%2F0%2FRC%2FPOSTS%2FDeep-Tech%2520Map%2520Final.pdf&usg=AOvVaw0OUcd9zEZF4wxZDjl6sBc3.

[9] See, https://www.techworks.org.uk/about/what-is-deep-tech

[10] see for example, Ratia, M., Myllärniemi, J., & Helander, N. (2018, October). Robotic process automation-creating value by digitalizing work in the private healthcare?. In Proceedings of the 22nd International Academic Mindtrek Conference (pp. 222-227).

[11] Innovation is broader in scope than invention, it includes implementation.

[12] Simonton, D. K. (2021). 3 Creativity in Society. Creativity: An Introduction, 31.

[13] See for example, Golden, W. T. (Ed.). (2018). Scientific Elite: Nobel Laureates in the United States. Routledge.

The distribution of mental traits in a population is approximately Gaussian[14] it suggests that only 2% of the population would be in the tail of the distribution (2σ)[15]. Since the number of geniuses in the population is dependent on the total population,

> **H_2**: Communities with larger population will produce more deep-tech inventions.

Another explanation for deep-tech inventions is serendipity, chance finding of valuable things not sought for[16]. There is empirical evidence that creativity exhibits a random output pattern, fits a Poisson distribution[17]. This suggests that invention is neither controlled by the environment nor the individual:

> **H_3**: Time pattern of creativity is random.

Methodology

To explore the magnitude of deep-tech inventions, patented inventions were analyzed[18]. Only patents filed in Illinois that matched the following criteria were analyzed: new, useful, and unobvious[19]. To be labeled 'new', the invention must be new to the world; to be 'useful', the creative output must have some economic merit. The 'unobvious' criterion ensures that the invention transforms the field of endeavor in a significant way.

Table 1 lists the variables used in the analysis; data were for the period 2010 to 2020. Hypotheses 1 and 2 were tested using zero-order correlations, Pearson's coefficients. For H_3, the question of interest is to ascertain whether the frequency of inventions in Illinois is random or of the variable cause groups, c.f. the zeitgeist and the genius theories; the Shapiro-Wilke test informed our statistical decision to accept or reject the hypothesis[20].

[14] See, Neisser, U. E. (1998). The rising curve: Long-term gains in IQ and related measures. American Psychological Association.
[15] Standard normal probability, for z = 2 = 0.0228.
[16] Merriam-Webster online: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjdqaXE_bfxAhWT4J4KHcKlCT0QFjAAegQIBhAD&url=https%3A%2F%2Fwww.merriam-webster.com%2F&usg=AOvVaw1O5lShmmtSkcIr1NHf82CA.
[17] Huber, J. C. (1988). Invention and inventivity as a special kind of creativity, with implications for general creativity, Journal of Creative Behavior, 32, 58-72.

[18] The USPTO's Endpoints were queried using API for data. Patents issued during 2010 to 2020 were analyzed.
[19] See, https://www.uspto.gov/patents/basics.
[20] Wackerly, D., Mendenhall, W., & Scheaffer, R. L. (2014). Mathematical statistics with applications. Cengage Learning.

Table 1: Variables and their Definitions

Variable	Definition and Value Label	Level	Data Source
Invention	Area of invention: 1600 = Biotechnology; 1700 = Chemical and materials engineering; 2100 = Computer architecture, software, and Info. Security; 2400 = Computer networks, video distribution and security; 2600 = Communications; 2800 = Semiconductors, electrical and optical systems; 3600 = Transportation, construction, electronic commerce; 3700 = Mechanical engineering, Manufacturing products.	Nominal	USPTO
Year	Year patent was issued; 2010 to 2020.	Interval	
Geography	Illinois County	Nominal	
Population	County population	Ratio	ACS
Higher ED	Number of higher education institutions in Illinois counties	Ratio	NCES

Note: USPTO = United States Patent and Trademark Office; ACS = American Community Survey; NCES: National Center for Education Statistics.

Results and Discussion

Descriptive Analysis

During 2010-2020, approximately 51,400 inventions or patents originated from Illinois. One-in-five of these patents were from category 3600: transportation, construction, electronic commerce, and agriculture. Mechanical engineering and manufacturing patents were a close second, 19% (Table 2).

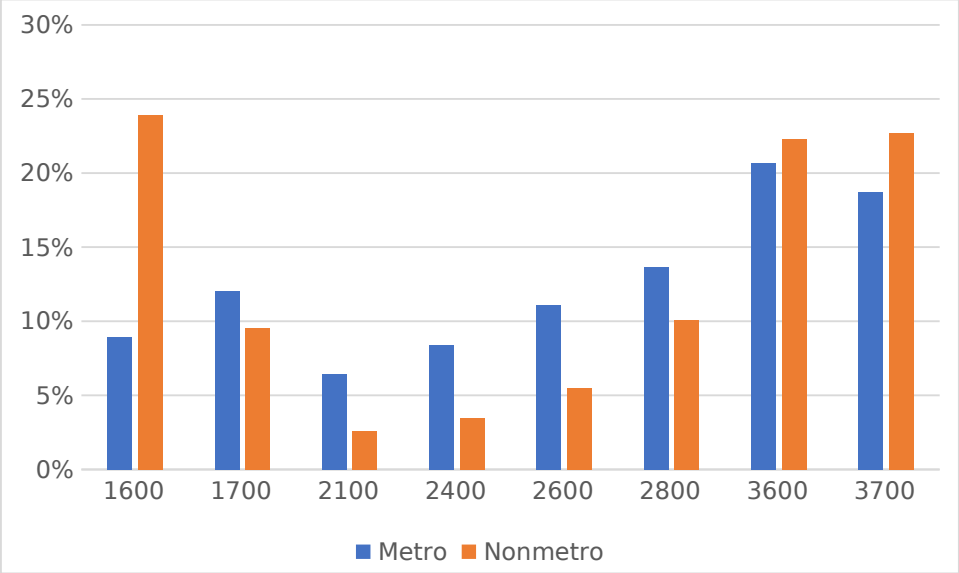
Geographically, rural Illinois is home to, eight percent of the patents, the median number for 2010-2020. Approximately, 25% of the patents from the nonmetro are biotechnology related. In contrast, only 9% of the patents from the metro are biotechnology patents; metro regions of Illinois produce more computing technology patents (Figure 1).

Table 2: Number of Registered Patents, Illinois, 2010-2020

	Category, Patent Area							
	1600	1700	2100	2400	2600	2800	3600	3700
2010	626	659	250	306	383	647	915	979
2011	589	731	321	376	463	671	999	1083
2012	720	739	346	450	564	769	1251	1228
2013	653	796	342	420	586	778	1222	1251
2014	590	780	426	493	579	815	1272	1252
2015	639	621	315	472	612	778	1355	1155
2016	540	620	403	507	612	785	1262	1063
2017	484	607	420	490	650	743	1275	955
2018	323	399	209	396	620	516	805	591
2019	98	122	110	202	390	283	296	182
2020[21]	15	11	11	10	30	30	25	9

Note: Area of invention: 1600 = Biotechnology; 1700 = Chemical and materials engineering; 2100 = Computer architecture, software, and Info. Security; 2400 = Computer networks, video distribution and security; 2600 = Communications; 2800 = Semiconductors, electrical and optical systems; 3600 = Transportation, construction, electronic commerce; 3700 = Mechanical engineering, Manufacturing products.

Figure 1: Number of Registered Patents: Differences between Metro and Nonmetro Regions, 2010-2020



Note: See Table 1 for category labels; metro, N = 46,260; nonmetro, N = 3,777

[21] Data are for January-March, 2020.

Tests of Hypotheses

Both the hypotheses, H_1 and H_2 were confirmed; each variable, population and number of universities, explains about 80% of the variance in the criterion variable, number of inventions. The assertion of H_3, that invention is a chance occurrence, was rejected (Table 3). Appendix 1 provides the county-level data used in the statistical analysis.

Table 3: Results of Hypothesis Testing

Hypothesis	Prediction	Test Results
H_1	Higher the number of higher education institutions in a county, higher will be the number of inventions in the county.	r = 0.96; t = 37.51; p < 0.01
H_2	Larger the population, higher the number of inventions.	r = 0.98; t = 49.61; p < 0.01
H_3	Creativity is random.	For the innovation category, 1600: Statistics=0.854, p=0.066; sample is random; For all other categories, samples are not random.

Invention or creative thinking at the individual level is to do with our responses to stimuli; we become aware of an object, we produce a response to that object, and we evaluate our products of thought. Creativity is analyzed at the production level; one's 'production' could either converge to one right answer or diverge in different directions or responses. Research suggests that divergent thinking indicates creativity[22]. Data on inventions and structural characteristics of counties indicate that creativity is being developed by higher education institutions.

Furthermore, the genius explanation for creativity is also evidenced by the strong correlation between population numbers and creativity.

[22] Taylor, I. A., & Getzels, J. W. (Eds.). (2017). Perspectives in creativity. Transaction Publishers.

Summary and Conclusion

This paper explores deep-tech inventions in Illinois using the USPTO data on patents. During 2010-2017, Illinois experienced a positive growth for inventions, the exponential growth rate was around 2% per annum. However, for the last few years, the state has been losing ground on Inventions; during 2017-2019, the annual compound growth rate in patents granted to Illinoisans was -60% (see Table 2).

To explore the correlates of inventions, three competing explanations about determinants of inventions were tested. The zeitgeist theory suggests structural factors such as universities as determinants. In contrast, the genius theory claims that creative individuals, not culture, determines the magnitude and scope of inventions in a community. Finally, some suggest that invention is a random occurrence. Our data analysis suggests that invention is not a random process; we observed both individual and structural correlates of inventions.

In conclusion, in this era of deep-tech ventures, it is essential that county economic developers know about invention activities in their county. This research not only provides data on inventions, but also highlights the correlates of inventions at the county level.