ALL PATENTS GREAT AND SMALL

A BIG DATA NETWORK APPROACH TO VALUATION

Andrew W. Torrance[1] & Jevin D. West[2]

I. INTRODUCTION

Measuring patent value is an important goal of scholars in both patent law and patent economics. However, doing so objectively, accurately and consistently has proved exceedingly difficult. At least part of the reason for this difficulty is that patents themselves are complex documents that are difficult even for patent experts to interpret. In addition, issued patents are the result of an often long and complicated negotiation between applicant and patent office (in the United States, the United States Patent & Trademark Office ("USPTO")), the result of which is an opaque "prosecution history" upon which depend the scope of claimed patent rights. In this Article, we approach the concept of patent value by using the relative positions of issued United States ("U.S.") patents embedded within a comprehensive patent citation network to measure the importance of those patents within the network. Thus, we tend to refer to the "importance" of patents instead of "value", but there is good reason to believe that these two concepts share a very similar meaning.

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[1] Earl B. Shurtz Research Professor, University of Kansas School of Law; Visiting Scholar, Sloan School of Management, Massachusetts Institute of Technology; Research Fellow, Gruter Institute for Law & Behavioral Research. Prof. Torrance wishes to thank Nathan Mannebach, Max McGraw, Edgar Acevedo-Pando, J.B. Fitzgerald, and Aaron Vanderpool for their excellent research assistance in assembling the gigantic database of patents litigated to a judicial decision. Nathan Mannebach and Max McGraw deserve considerable additional thanks for analyzing much of the data, conceiving of creative ways in which this data could be visualized, and doing prodigious review of the literatures of patent litigation, patent valuation, and patent citation networks.
[2] Assistant Professor, DataLab, Information School, University of Washington.

Patents are not merely isolated descriptions of inventions deemed new and useful enough to warrant government *imprimatur*. On the contrary, patents frequently cite other patents and references (*e.g.*, scientific articles, webpages, datasets)[3] and therefore are more than mere collections of isolated documents. World-wide, tens of millions of patents are interconnected by hundreds of millions of citations. Patents and the citations that interconnect them form a vast network, with patents as "nodes" and citations as "links" among them. This "patent citation network" represents the aggregation of millions of deliberate choices individual patent applicants and patent examiners have made about how to situate their inventions in relation to others' inventive ideas. The structure of this network contains a wealth of information about the patents, and the communities within which the patents reside. We use eigenvector centrality and hierarchical clustering methods to evaluate the patent citation network of all U.S. patents from 1976 to 2014.[4]

Using these methods, we ask the following question: *are patents litigated in federal court more important than non-litigated patents?* We also ask whether the importance of litigated patents rises with the level of federal court in which they are litigated. We test two related hypotheses:

(1) Litigated patents tend to be more important than non-litigated patents;

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[3] A patent may also make reference to a physical artifact, such as a commercial product, or processes capable of being carried out in the physical world. Under 35 U.S.C. §§102 and 103, physical objects or processes can constitute prior art capable of potentially anticipating or rendering obvious a patent claim.

[4] There may be a very small number of patents from this time period that are absent from our patent citation network. If so, the explanation is that USPTO has not made sufficient data about these patents available. The gigantic size of this collection of references makes verifying the perfect completeness of our patent data set mathematically difficult. Despite this *caveat*, we believe our collection of patents from 1976 to 2014 is complete.

(2) The higher the federal court level in which litigation takes place, the more important the patents there litigated tend to be.

As noted above, and explained in detail below, patent importance is measured as a property of a patent's position within the patent citation ecosystem.

II. PATENT LITIGATION

Litigated patents tend to possess disproportionately high private value to their owners.[5] An important component of these valuable assets is the ability they confer on their owners to file suit in federal court for patent infringement. Despite their value, it is rare for a patent to be litigated, with only about 2% making it to court in the U.S..[6] Litigation rates differ substantially across different areas of technology.[7]

From a modest starting point, patent litigation has exploded in the U.S. over the past generation. During the period spanning 1991 to 2014, the number of patent lawsuits filed in federal courts increased at a compound growth rate of 7%.[8] Over the same period of time, the number of patents issued by the United States Patent & Trademark Office ("USPTO") also rose

[5] *See* Dietmar Harhoff, Frederic M. Scherer, & Katrin Vopel, Citations, Family Size, Opposition and the Value of Patent Rights, 32 Research Policy 1343, 1359–60 (2003); John R. Allison et al., Valuable Patents, 92 Geo. L.J. 435, 438 (2004); John R. Allison, Mark A. Lemley, & Joshua Walker, Extreme Value or Trolls on Top? The Characteristics of the Most-Litigated Patents, 158 U. Pa. L. Rev. 1, 5 (2009).
[6] Jean O. Lanjouw & Mark Schankerman, Characteristics of Patent Litigation: A Window on Competition, 32 Rand J. Econ.129, 131; James Bessen & Michael J. Meurer, Lessons for Patent Policy from Empirical Research on Patent Litigation, 9 Lewis & Clark L. Rev. 1, 3 (2005).
[7] Lanjouw & Schankerman, *supra* note 6 at 131; Bessen & Meurer, *supra* note 6 at 26. This Article does not directly explore area of technology as a variable in its analysis. However, a future study will do so.
[8] Barry *et al*., 2015 Patent Litigation Study - A change in patentee fortunes, Price Waterhouse Coopers (available at http://www.pwc.com/us/en/forensic-services/publications/assets/2015-pwc-patent-litigation-study.pdf) (last visited on January 24, 2016).

rapidly, from 107,000 patents in 1991 to 304,000 in 2014 (approximately a 5% compound growth rate).[9] In a sudden departure from these upward trends, the 5,070 patent suits filed in 2014 represented a 17% decline from the peak of 6,114 such suits filed in 2013. Nevertheless, another *volte-face* occurred in 2015, with a 15% increase that took patent suits back up to 5,830, second only to the number filed in 2013.[10]

Complicating interpretation of these litigation trends is the rise of *inter partes* review ("IPR"), which is "a trial proceeding conducted at the Board to review the patentability of one or more claims in a patent only on a ground that could be raised under §§ 102 or 103, and only on the basis of prior art consisting of patents or printed publications".[11] Available since September 16, 2012, as part of the America Invents Act ("AIA"), IPRs are heard before the Patent Trial and Appeals Board ("PTAB"), a USPTO administrative court, and these proceedings have risen quickly in popularity possibly due, at least in part, to their increased speed and decreased costs compared to patent litigation in federal court.[12] From none prior to September 2012, IPRs reached a total of 1,654 petitions filed in 2015 alone.[13]

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[9] These are numbers are from our data set and are consistent with what is reported in Barry et al., 2015 Patent Litigation Study - A change in patentee fortunes, Price Waterhouse Coopers (available at http://www.pwc.com/us/en/forensic-services/publications/assets/2015-pwc-patent-litigation-study.pdf) (last visited on January 24, 2016).

[10] Howard, Brian (January 7, 2016), Lex Machina 2015 End-of-Year Trends - Patent Litigation (2015) (available at https://lexmachina.com/lex-machina-2015-end-of-year-trends/)(last visited on January 24, 2016).

[11] *Inter Partes* Review, Website of the United States Patent & Trademark Office (http://www.uspto.gov/patents-application-process/appealing-patent-decisions/trials/inter-partes-review) (last visited on January 24, 2016).

[12] *Inter Partes* Review, Website of the United States Patent & Trademark Office (http://www.uspto.gov/patents-application-process/appealing-patent-decisions/trials/inter-partes-review) (last visited on January 24, 2016).

[13] Howard, Brian (January 7, 2016), Lex Machina 2015 End-of-Year Trends - Patent Litigation (2015) (available at https://lexmachina.com/lex-machina-2015-end-of-year-trends/)(last visited on January 24, 2016).

Some have characterized this marked increase in patent litigation as a crisis.[14] Patent owners who assert their portfolios against alleged infringers, but do not themselves make, use, or sell products or processes claimed in patents they own, have been targets of especially-robust criticism over the past decade.[15] Owners who do not practice their patents are variously referred to as "non-practicing entities", "patent assertion entities", and "patent trolls". To remain somewhat neutral in a debate not directly addressed in this Article, the moniker non-practicing entity ("NPE") is employed herein.

III. PATENT IMPORTANCE

A. PATENTS AND VALUE

An effective method of patent valuation has consistently eluded patent scholars and practitioners, but not for a lack of effort. In fact, determining an accurate method of estimating patent value is something of a Holy Grail within patent studies and practice. Approaches ranging in complexity from the "rule of thumb", which arbitrarily divides licensing profits in a 25/75 split, to the Black-Scholes equation, which is more commonly used to value stock market options, have been applied to the problem, but none have satisfied the patent economics community.[16] All of the proposed approaches generally fit into two categories: financial

[14] Executive Office of the President (June 2013), Patent Assertion and U.S. Innovation (available at https://www.whitehouse.gov/sites/default/files/docs/patent_report.pdf) (last visited on January 24, 2016).

[15] As used in this Article, an owner includes either (1) one who owns all legal rights in a patent (*e.g.*, through assignment) or (2) one to whom the right to assert a patent has been licensed. Wherever the distinction between situation (1) and (2) is salient, the particular relevant type of ownership is specified. However, in most situations the distinction is not important. Executive Office of the President (June 2013), Patent Assertion and U.S. Innovation (available at https://www.whitehouse.gov/sites/default/files/docs/patent_report.pdf) (last visited on January 24, 2016).

[16] GOLDSCHEIDER, LICENSING AND THE ART OF TECHNOLOGY MANAGEMENT 11–17, sec. 11.4 (Thomson Reuters, Westlaw, 2011); F. Russell Denton & Paul J. Heald, Random Walks, Non-Cooperative Games, and the Complex Mathematics of Patent Pricing, 55 Rutgers L. Rev. 1175, 1177 (2003) ("[T]he Denton Variation

valuation methods and non-financial valuation methods. The method used in this Article is non-financial. Nevertheless, we provide a brief overview of other approaches to patent valuation to place our method in context.

1. FINANCIAL PATENT VALUATION METHODS

The literature on patent valuation consistently divides financial methods into three main categories of increasing complexity: cost, market, and income methods.

a) COST METHODS

The cost method values a patent asset by calculating the cost of replacing it, reconstructing it, or substituting it for another asset, and then equating that cost to the value of the new asset.[17] Simply knowing how much the licensor spent creating the patent is not enough, however, because the licensee could be a more efficient innovator, and the patent landscape would have changed from the time of invention to the time of valuation.[18] The cost method does not take into account other competitors in the market, any future benefits possibly derived from taking advantage of the patent, or the economic life of the patent, and those are but a few of the disadvantages of this method.[19] Input costs alone tend not to be good indicators of patent value because many individual inventors accidentally invent products or processes protected by

of the Black-Scholes equation, exploits the similarities between the option to buy stock and the option to develop an invention.").
[17] Technology Licensing and Development Agreements § 6.8.1 (Matthew Bender, Rev. Ed. 2015) [hereinafter *Bender Treatise*].
[18] *Id.*
[19] *Id.* at § 6.8.2.

extremely valuable patents, while many large, wealthy firms fail to develop valuable patents despite the investment of prodigious sums on research and development.

b) MARKET METHODS

The standard market method is another relatively straightforward valuation technique that involves using historical prices agreed upon for the subject patent asset, and then making adjustments based upon the current patent landscape, as well as the particular market needs of a new license.[20] Another, indirect, version of this method consists of finding similar technologies that have already been valued, and then basing estimation of a patent on the values of these similar technologies.[21] Both parties to a patent licensing negotiation are usually familiar with the subject patent's technological field, and, consequently, tend to be comfortable with this valuation method; however, unlike the housing market, there can often be substantial differences among even similarly-situated patent assets, which can confound the comparability of putatively similar patent assets.[22]

Another useful variation of this method, which is made possible when accurate historical information exists as to patent pricing, is the rating and ranking method because it quantifies the value differences between the subject patent and well-characterized patents.[23] The quantification of this difference is done by using a set of factors, generally the Georgia-Pacific

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[20] Michele Floyd & Lawrence Wu, THE REVOLUTION IN THE LAW AND ECONOMICS OF ANTITRUST CLASS CERTIFICATION § 3.03 (LexisNexis, Inc., 2015).
[21] *Id.*
[22] *Id.*
[23] Richard Razgaitis, Pricing the Intellectual Property of Early-Stage Technologies: A Primer of Basic Valuation Tools and Considerations 830 (2007).

factors[24], and analyzing how the subject patent compares in value to that of patents with known values.[25] If, after analyzing all 15 enumerated Georgia-Pacific factors, the subject patent outperforms the patents of known value, then the subject patent will tend to be valued more highly than the patents of known value, and *vice versa*.[26] One commentator even takes the unique approach of combining the rating and ranking method with non-financial indicators, such as payment of maintenance fees and technology class, to rank patents against each other to assign them a comparative value.[27] The problems of identifying patent assets of known value for comparison, deciding which comparative factors to use, and knowing how to rank the patent assets in light of each of those factors can be very challenging to solve, but this method at least provides approaches for quantifying patent assets.

c) INCOME METHODS

The final financial method for patent valuation is the income method, which is widely considered the most complex, but also the most economically-suitable, approach.[28] This method is based on the "assumption that the value of any asset can be expressed as the present value of the future stream of economic benefits that can be derived from its ownership."[29] To carry out this method, an interested party projects the cash flow a patent asset will earn for that party over the expected lifetime of that asset, that final value is offset by a discount rate that accounts for

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[24] Georgia-Pacific Corp. v. United States Plywood Corp., 318 F. Supp. 1116, 1119–20 (S.D.N.Y. 1970), modified and aff'd, 446 F.2d 295 (2d Cir.).
[25] Razgaitis, supra note 8 at 831.
[26] *Id.*
[27] Jonathan A. Barney, A Study of Patent Mortality Rates: Using Statistical Survival Analysis to Rate and Value Patent Assets, 30 AIPLA Q. J. 317 (2002).
[28] *Bender Treatise*, supra note 2 at § 3.03.
[29] F. Russell Denton & Paul J. Heald, Random Walks, Non-Cooperative Games, and the Complex Mathematics of Patent Pricing, 55 Rutgers L. Rev. 1175, 1188 (2003).

the interest rate and degree of risk, and finally that patent asset value is reduced to a present value.[30] This is yields a discounted cash flow.[31] There are many variables in this calculation, any of which may introduce calculation errors, though various income methods have been developed to account for those variables, including discounted cash flow, real options, binomial expansion, and Monte Carlo methods.

Discounted cash flow is the simplest method, but has two major, though subtle, variations. The first is a method that uses patent claim analysis to achieve a more accurate projected revenue stream.[32] The originators of this variation advocate a method in which deciphering the patent claims informs a company about which products are covered by those claims.[33] Knowing which products fall within a patent's claims allows a company more accurately to project the revenue associated with that patent.[34] Finally, that revenue stream is discounted at a patent-specific discount rate using the capital asset pricing model.[35] The other variation attempts to find future cash flows from a cost-reducing technology covered by a patent's claims by adding together the cash flows gained from competitive advantage, licensing income, and maintenance costs of the patent.[36] This variation on discounted cash flow only works with patents whose claimed technologies have already been well developed, and, thus, do not require substantial additional investments.[37]

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[30] *Id.*
[31] Razgaitis, *supra* note 8 at 839.
[32] Malcolm T. Meeks & Charles A. Eldering, Patent Valuation: Aren't We Forgetting Something? Making the Case for Claims Analysis in Patent Valuation by Proposing a Patent Valuation Method and a Patent-Specific Discount Rate Using the CAPM, 9 Nw. J. Tech. & Intell. Prop. 194, 234 (2010).
[33] *Id.*
[34] *Id.*
[35] *Id.* at 224–25.
[36] Sander van Triest & Wim Vis, Valuing patents on cost-reducing technology: A case study, 105 Int. J. Production Economics 282, 283 (2007).
[37] *Id.* at 284.

When substantial investments are required, real option valuation based on the Black-Scholes equation is more apt.[38] The Black-Scholes equation was created to predict company revenues in order to properly value stocks.[39] Similarly, to properly value a patent, company revenues gained from that patent must be accurately predicted.[40] Denton and Heald suggest modifying the Black-Scholes equation to take advantage of "similarities between the option to buy stock and the option to develop an invention" such as "definite expiration dates and sequentiality of investment moments" to make patent valuations.[41] The major advantage of a real option valuation is that it allows for the possibility that a company will abandon an invention once it becomes clear that invention will not be profitable, allowing mitigation of risk.[42]

Binomial expansion is "a more advanced application of [r]eal [o]ption [v]aluation where there exists 'options on options'."[43] This allows a company to differentiate possible outcomes by "milestone" events, because at each one of these events the company can assign the likelihood of each outcome.[44] Although a single forecast takes these milestone events into consideration, breaking them out into a decision tree allows for more transparency as well as further analysis of the most critical valuation issues.[45]

Where binomial expansion only allows for binary outcomes of set probabilities, the Monte Carlo technique takes advantage of this result by simulating thousands of scenarios over

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[38] *Id.*
[39] Denton & Heald, *supra* note 14 at 1176.
[40] *Id.*
[41] *Id.* at 1176–77.
[42] *Bender Treatise*, *supra* note 2 at § 6.4 ("Real options treats risk differently than income method. The latter uses a discount premium rate to reduce expected income, whereas real options considers that the manager can dramatically reduce risk by making choices and using judgment as time goes by.").
[43] BUSINESS SPREADSHEETS, http://www.business-spreadsheets.com/help.asp?t=21.
[44] Floyd & Wu, *supra* note 5.
[45] *Id.*

different probability ranges.[46] For example, when the input costs for a given scenario are equally probable between $1 million and $3 million, the binomial expansion method would have to choose two numbers within that range, but the Monte Carlo technique allows the likelihood of every possibility in that range to be calculated.[47] The outcome of the simulation is a confidence interval of the most likely values, which gives the estimated worth of the patent being analyzed.[48] Some researchers have extended this method even further by using a sensitivity model to demonstrate how a value varies with the model's parameters because of the difficulty in adjusting for the appropriate discount rate.[49]

2. NON-FINANCIAL PATENT VALUATION METHODS

a) FORWARD AND BACKWARD CITATION METHODS

A large number of established, non-financial indicators of patent value exist including forward citations, backward citations, family size, number of claims, key inventors, and market value of corporation among others.[50] Forward and backward citations are the most studied, and, generally, the best validated of those these.[51] Considerable research suggests that the numbers of forward and backward citations associated with a patent are positively correlated

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[46] *Id.*
[47] Razgaitis, supra note 8 at 852.
[48] Gary S. Stacey, Valuing Intellectual Property, Technology Strategies 22–25 (1989).
[49] Jow-Ran Chang, Mao-Wei Hung & Feng-Tse Tsai, Valuation of Intellectual Property: A real option approach, 6 Journal of Intellectual Capital 339, 353 (2005).
[50] Markus Reitzig, Improving Patent Valuations for Management Purposes—Validating New Indicators by Analyzing Application Rationales, 33 Research Policy 939, 941 (2004).
[51] *See, e.g.*, Francis Narin, Kimberly S. Hamilton, & Dominic Olivastro, The Increasing Linkage between U.S. Technology and Public Science, 26 Research Policy 317, 317 (1997); Bronwyn H. Hall, Adam B. Jaffe, & Manuel Trajtenberg, Market Value and Patent Citations: A First Look, National Bureau of Economic Research (2000) (discussing different aspects of using patent citations).

with the value of that patent.[52] One recent study, relying on a confidential corporate dataset, has questioned how reliable citations are as indicators of value above a threshold of citations.[53] However, the weight of evidence spanning the past three decades robustly suggests that patent citations can be powerful indicators of patent value. Furthermore, as explained below, the method of weighting individual patent citations used in our analysis is especially comprehensive and accurate.

b) PATENT CITATION NETWORK METHODS

The method of analysis proposed in this paper is an improvement on the patent citation networks already suggested by several academics. Previously, patent citation networks have been shown to approximate "scale-free networks", which are characterized by a few, select hubs through which a large amount of information flows.[54] This network was made using the relatively simple method of counting the number of citations received by each patent and then mapping that information.[55] Further research has revealed that, not only do patent citation networks highlight the most cited patent in each technology field, but also the technological trajectory of the field.[56] Frequently, these citation networks are only used to show trends in a certain technology fields or productivity of certain patents without evaluating their individual

52 *See* Dietmar Harhoff, Frederic M. Scherer, & Katrin Vopel, Citations, Family Size, Opposition and the Value of Patent Rights, 32 Research Policy 1343, 1359–60 (2003).
53 David S. Abrams, Ufuk Akcigit, & Jillian Popadak, Understanding the Link between Patent Value and Citations: Creative Destruction or Defensive Disruption?, University of Pennsylvania and NBER (April 8, 2013).
54 Chaomei Chen & Diana Hicks, Tracing Knowledge Diffusion, 59 Scientometrics 199, 201 (2004).
55 *Id.* at 203.
56 Adam B. Jaffe & Gaetan de Rassenfosse, Patent Citation Data in Social Science Research: Overview and Best Practices, National Bureau of Economic Research 21–22 (2014).

value.[57] This Article improves these techniques by providing accurate individual patent valuations from the patent citation network.

c) LITIGATED PATENT METHODS

Litigated patents tend to possess disproportionately high private value.[58] Building off that assumption, researchers have identified trends in the characteristics litigated patents which can be applied to future patents to determine their value.[59] The researchers confirmed that litigated patents tend to have a greater number of forward and backward citations, but they also found that more claims, longer prosecution time, and larger patent family size were also positively correlated with value.[60] This study suggest that the more time and money a firm invests into patent prosecution, the more likely it is that the resulting patent will be litigated.[61] The fact that litigated patents have characteristics already proven to be associated with high value lends credence to the assumption that litigated patents themselves are more valuable.

Researchers empirically tested the hypothesis that litigated patents are more valuable by comparing patents that have been litigated once with those that have been litigated eight or more times.[62] If a litigated patents tends to be more valuable than non-litigated patents, a semi-overlapping group of researchers wondered, perhaps the more times a patent is litigated, the

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[57] *See* Id. at 22–23; *see also* Bernard Gress, Properties of the USPTO Patent Citation Network: 1963-2002, World Patent Information (2009).
[58] *See* Dietmar Harhoff, Frederic M. Scherer, & Katrin Vopel, Citations, Family Size, Opposition and the Value of Patent Rights, 32 Research Policy 1343, 1359–60 (2003); John R. Allison et al., Valuable Patents, 92 Geo. L.J. 435, 438 (2004); John R. Allison, Mark A. Lemley, & Joshua Walker, Extreme Value or Trolls on Top? The Characteristics of the Most-Litigated Patents, 158 U. Pa. L. Rev. 1, 5 (2009).
[59] John R. Allison et al., Valuable Patents, 92 Geo. L.J. 435, 438 (2004).
[60] *Id.* at 451–460.
[61] *Id.* at 461.
[62] John R. Allison, Mark A. Lemley, & Joshua Walker, Extreme Value or Trolls on Top? The Characteristics of the Most-Litigated Patents, 158 U. Pa. L. Rev. 1, 5 (2009).

more valuable it is. This latter group empirically demonstrated that patents litigated eight or more times tend to possess an even more striking constellation of *indicia* characteristic of valuable patents compared to patents litigated fewer times, especially a single time.[63] Combining this finding with previous research, Allison *et al.* concluded that "the intuitive relationship between value and litigation is indeed the right one."[64]

However, it should be noted that not all studies of litigated patents share the previously mentioned enthusiasm for forward and backward citations as a metric for valuing patents.[65] The studies that made these findings looked not only at what patents were litigated, but also at the outcomes of that litigation, and relied on the reasonable observation that a patent has no value if it is involved in litigation in which a court finds its claims invalid.[66] One study, which compared patents found invalid by a court with those not found invalid in a final adjudication, found that the number of citations a specific patent possesses is negatively correlated with a finding of validity.[67]

B. PATENT CITATIONS

Patents cite previous references relevant to their claims. These are known as backward citations. In turn, patents are cited by newer patents if the former are relevant to claims in the latter. These are known as forward citations. Both backward and forward citations can provide

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[63] *Id.* at 28.
[64] *Id.*
[65] *See* Michael Risch, A Generation of Patent Litigation: Outcomes and Patent Quality, 52 San Diego L. Rev. 67, 70. *See also* John R. Allison, Mark A. Lemley & Joshua Walker, Patent Quality and Settlement Among Repeat Patent Litigants,99 Geo. L.J. 677, 681, 686-87 (2011).
[66] Michael Risch, A Generation of Patent Litigation: Outcomes and Patent Quality, 52 San Diego L. Rev. 67, 68 (2015) ("Perhaps the simplest measure of quality is whether a patent is valid, that is, whether it is novel, nonobvious, and otherwise compliant with the Patent Act.").
[67] *Id.* at 118.

useful information about (1) a patent's value or importance and (2) about where the technology disclosed in the patent is situated within the wider universe of technological fields.

Citations to and from patents tend to be indicators of both private value to their owners and social value to society more generally.[68] Patent citations have been widely used in patent valuation analysis.[69] They can be rich sources of information about firm value[70], useful in assisting universities to predict which of the patents they own will most likely be licensed[71], and indicative of whether a patent application will be granted.[72] Patent citations have been found to correlate well with likelihood of litigation.[73] In fact, both backward and forward citations have also been found to be "unambiguously strong predictors of patent litigation", which has, itself, been found to be a robust indicator of high patent value.[74] Beyond economic value alone, forward citations can provide good estimates of the technological importance of inventions disclosed in patents.[75]

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[68] Trajtenberg, M. 1990. A penny for your quotes: patent citation and the value of innovations. *Rand J. Econ.* 21:172-187.

[69] Bronwyn H. Hall, Adam B. Jaffe, & Manuel Trajtenberg, Market Value and Patent Citations: A First Look, National Bureau of Economic Research (2000); Dietmar Harhoff, Francis Narin, F.M. Scherer, & Katrin Vopel, Citation Frequency and the Value of Patented Inventions, 81 Rev. of Econ. & Stat. 511, 511 (1999); Lanjouw, J.O., & Schankerman, M. 2001. Characteristics of patent litigation: a window on competition, *Rand J. Econ.* 32:129.

[70] Hall, B.H., Jaffe, A.B., and Trajtenberg, M. 2005. Market value and patent citations. *Rand J. Econ.* 36:16-38.

[71] Sampat, B., & Ziedonis, A. 2004. Patent citations and the economic value of patents. In *Handbook of Quantitative Science and Technology Research*, ed. Moed, H.F., Glänzel, W., and Schmoch, U., pp. 277-298. Dordrecht: Kluwer Acad.

[72] Palangkaraya, A., Webster, E., and Jensen, P. 2011. Misclassification between patent offices: Evidence from a matched sample of patent applications. *Review of Economics and Statistics* 93(3): 1063-1075.

[73] Lanjouw, J.O., & Schankerman, M. 2002. An empirical analysis of enforcement of patent rights in the United States, Working Paper, p.4.

[74] John R. Allison et al., Valuable Patents, 92 Geo. L.J. 435, 451 (2004).

[75] Carpenter, M., Narin, F., and Woolf, P. 1981. Citation rates to technologically important patents. *World Patent Information* 3(4):160-163; Narin, F., Noma, E., and Perry, R. 1987. Patents as indicators of corporate technological strength. *Research Policy* 16(2-4):143–155; Albert, M., Avery, D., Narin, F.,

Citation analysis of the scholarly literature also has a rich history, resulting in the standalone fields of bibliometrics and scientometrics. Librarians initially used citations to make journal subscription decisions.[76] This led to measures of journal prestige,[77] article quality,[78] author influence,[79] and even national intellectual output.[80]

C. PATENT CITATION NETWORKS

De Solla Price noted, more than half a century ago, the utility and structural properties of citation networks.[81] In patent citation networks, the nodes represent patents and the links represent citations between patents and the non-patent literature. A simple schematic of a patent citation network is shown in Figure 1.

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and McAllister, P. 1991. Direct validation of citation counts as indicators of industrially important patents. *Research Policy* 20(3):251-259.

[76] Gross, P., & Gross, E. (1927). College libraries and chemical education. Science, 66(1713), 385–389.

[77] Garfield, E. (1972). Citation analysis as a tool in journal evaluation. Science, 178(4060), 471–479.

[78] Walker, D., Xie, H., Yan, K., & Maslov, S. (2007). Ranking scientific publications using a model of network traffic. Journal of Statistical Mechanics: Theory and Experiment, 6, P06010.

[79] Hirsch, J. (2005). An index to quantify an individual's scientific research output. Proceedings of the National Academy of Sciences, 102(46), 16569–16572; West, Jevin D., et al. "Author‐level Eigenfactor metrics: Evaluating the influence of authors, institutions, and countries within the social science research network community." *Journal of the American Society for Information Science and Technology* 64.4 (2013): 787-801.

[80] May, R. (1997). The scientific wealth of nations. Science, 275(5301), 793.

[81] de Solla Price, D. (1965). Networks of scientific papers. Science, 149, 510–515.

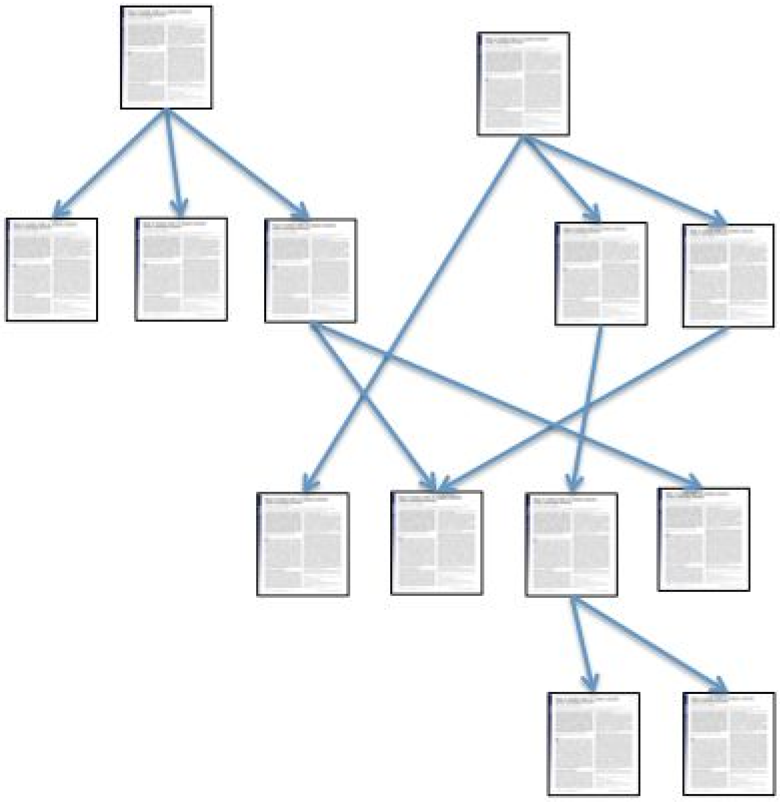

Figure 1: Patent Citation Network. Nodes in this network are patents and the links are citations. This type of network is time-directed in that random walks on these citations go inexorably backwards in time. This schematic contains 13 nodes and 12 links. Our network contains more than 6 million nodes and more than 60 million nodes.

All patent citations are not equally useful as indicators. A citation by a patent's listed inventor to her own previous work (*i.e.*, self-citation) would probably merit different weight than a citation to the same patent by a scientist highly-influential in the patent's technological field. Many past studies involving patent citation data have relied upon raw citation counts. A more powerful way to appropriately weight citations is to construct a patent citation network in which the positions of each patent helps determine its value. Citation networks represent hundreds of millions of decisions by scholars that can help bibliometricians trace the influence of ideas and inventions.

There have been many proposed metrics for extracting the structural information from citation networks. One of the authors of this paper developed the Eigenfactor[82] metrics, which have been the gold standard in ranking scholarly journals. They are now included in Thomson-Reuters' Journal Citation Reports (JCR). The underlying algorithm is similar to the PageRank algorithm[83] developed by the founders of Google, Larry Page and Sergey Brin. The algorithm captures a random walker following hyperlinks (links) from webpage (nodes) to webpage. The Eigenfactor algorithm captures a random process on scholarly citation networks. For patent citation networks, we use a modified version of the Eigenfactor algorithm called the article-level Eigenfactor (ALEF).[84] The algorithm placed 1st in North America and 2nd worldwide in Microsoft Research's WSDM Cup Challenge, a 2015 contest whose goal was to statically rank tens of millions of articles from the scholarly literature.[85] The contest provided additional evidence of the advantages of using the network rather than just counting raw citations. To calculate the ALEF scores, we constructed a comprehensive patent citation

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[82] Jevin D. West, Theodore C. Bergstrom & Carl T. Bergstrom, *The Eigenfactor Metrics: A Network Approach to Assessing Scholarly Journals*, 71 C. & Res. Libr. 236 (2010).
[83] Page, L., Brin, S., Motwani, R., & Winograd, T. (1998). The pagerank citation ranking: Bringing order to the web. Technical report, Stanford Digital Library Technologies Project. Retrieved from http://ilpubs.stanford.edu:8090/422/
[84] West et al (2016). Ranking and mapping article-level citation networks. In prep.
[85] Microsoft Research. 2015. WSDM Cup Challenge. Main website: https://wsdmcupchallenge.azurewebsites.net/; Winners leaderboard: https://wsdmcupchallenge.azurewebsites.net/Home/Leaderboard.

network that includes all issued U.S. patents from 1976 to 2015 using methods described by West and Vilhena[86] and West *et al.*[87].

IV. METHODS

In this section, we explain in detail the methods, databases, and analyses used to explore relationships between patents litigated to a decision in federal courts and the separately-derived importance of those patents.

A. LITIGATION DATA

In order to collect the necessary data, we followed a systematic approach for each respective district court. First, a search was conducted on legal research database LexisNexis for keyword "patent." The search was further refined by jurisdiction of the intended district court (*e.g.*, "1st Circuit"), and by the practice area and topics keyword "Patent Law."

Next, the search results were organized using the timeline function to specify the desired time range for cases. For this study, cases from the years 2000 to 2014 were examined. Once the cases were filtered, the judicial opinion in each case examined to determine if a patent had actually been litigated. Usually, key language clearly indicated a patent had been litigated (*e.g.*, "the patent(s) at issue are . . ."), however, at times, further reading of the opinion was necessary to determine which patents were at issue in the case. If a patent was indeed litigated, but the

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[86] West, J.D., and Vilhena, D. 2014. A network approach to scholarly evaluation. In *Bibliometrics & Beyond: Metrics-Based Evaluation*, ed. Cronin, B., and Sugimoto, C.R., pp. 151-166. Cambridge: MIT Press.

[87] West, J.D., Torrance, A.W., Rosvall, M., Vilhena, D., and Bergstrom, C.T. 2013. Systems and methods for data analysis. PCT Application (Filed February 1, 2013).

patent number not indicated in the opinion, any pleadings or supplemental documents included with the case were examined in an effort to determine the correct patent number. The proper United States Patent Number was copied into a Microsoft Excel spreadsheet, along with the case name, year of the decision, and district court in which the case was decided. To double-check the data set, the same search and procedure was performed utilizing Bloomberg's legal search engine to determine if any cases were not included in the LexisNexis database. Each litigated patent was then assigned a patent value number as calculated from the patent citation network.

B. PATENT CITATION NETWORK

We assembled the largest patent citation network known in the literature as of the writing of this Article. It includes 130 million citations (*i.e.*, "*links*") from nearly 6 million US patents (*i.e.*, "*core nodes*") from 1976 to 2015. The core nodes include about 4.5 million utility patents, 450k design patents, 20k plant patents, 16k reissue patents, 2k statutory invention registrations, and 500 defensive publications. About half the citations from these core nodes point to other core nodes (66 million citations). The other 60 million citations point to another 20 million nodes, which includes non-US patents from other countries, to patents from before 1976, and to non-patent references[88]. Citations are also labeled as originating from the inventor or the examiner. There were approximately 24 million examiner citations (15 million when isolated to core patent citations). For this analysis, we focus on the core nodes and the citations (both inventor and examiner citations) to/from the core nodes. This resulted in about 6 million nodes and 60 million citations.

[88] Non-patents citations are citations to items like the scholarly literature, books, newspapers, manuals, websites, etc. There are approximately 10 million citations.

Most patents receive a small number of citations, but there are some patents that receive a large number of citations. The highest cited patent in our database is U.S. Patent Number 4,683,202 ("Process for amplifying nucleic acid sequences"), invented by Kary Mullis, with more than 3000 citations.[89] The average degree (the number of in-citations to each patent) is 10.3 in-citations per patent. This large number of citations per patent creates a dense network, with high in-degree and out-degree. When compared to other citations networks like the scholarly literature, this is highly dense for a citation network, and probably reflects the affirmative legal obligation under U.S. patent law for patent applicants to cite relevant and material prior art to the USPTO. Remarkably, there are fewer than 30k completely isolated patents that have neither backward nor forward citations.

Our database includes patent number, patent application number, patent title, USPTO technology classification codes, IPC technology classification codes, assignees, inventors (including nationality), prosecuting attorneys and/or law firms, prosecuting patent examiners, abstracts, claims, figures, etc. The citation network allows for more complex queries using these data attributes. For example, one can identify the emergence of technology fields and the influencers of these technologies of fields using citations over time. Since the database includes all patents issued from 1976 until 2015, any of these fields can be queried either statically (*i.e.*, at a particular point in time) or dynamically over any included range of times. In addition to the data fields derived from the patent metadata itself, the patent citation network can be analyzed using real-time, 'natural' technology clusters, which are groups of otherwise-unrelated patents

[89] Unsurprisingly, this patent claims the polymerase chain reaction ("PCR"), which is one of the foundational technologies underlying biotechnology. Kary Mullis shared the 1993 Nobel Prize in Chemistry for this invention. (http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1993/) (Website last visited January 3, 2016).

that have strong mutual affinities within the network. To determine these natural clusters, we use the MapEquation framework.[90] We have compared USPTO, IPC, and our natural classifications of technology groups. We use these natural groupings for analyzing litigated patents in specific technology areas since the PTO and IPC classifications are rarely updated and having real-time groupings is important for these comparisons.

V. RESULTS

The individual patent importances were combined for the federal district courts, federal circuit, and supreme court in order to conduct a statistical analysis. First, the average patent importances were calculated for all district courts, the federal circuit, and the supreme court and compared to the overall average patent importance of 1.0 (Figure 2).

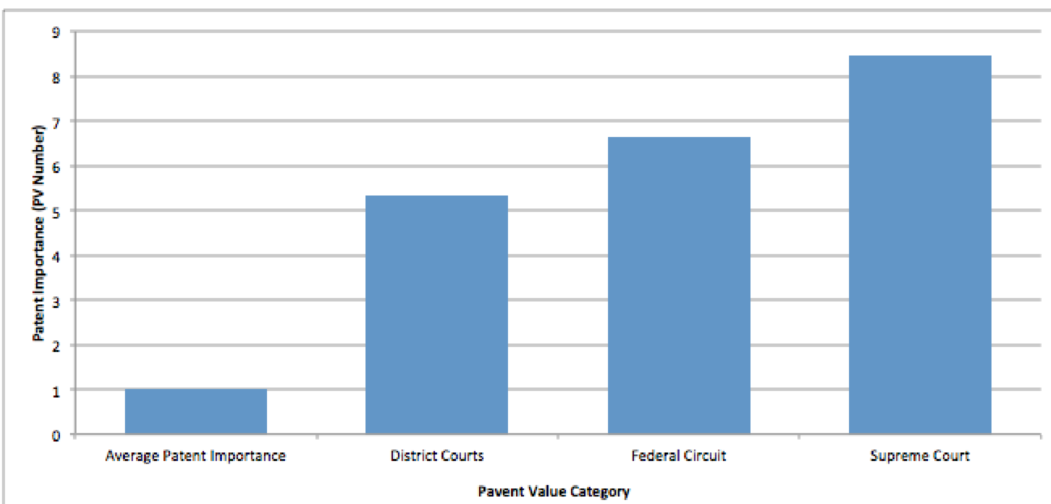

Figure 2: Average patent value for district courts, federal circuit, and supreme court compared to overall average patent importance (1.0).

[90] Rosvall, Martin, Daniel Axelsson, and Carl T. Bergstrom. "The map equation." The European Physical Journal Special Topics 178.1 (2010): 13-23.

Overall, this graph shows that patents that are litigated at least through the district court level, have, on average, higher patent importances when compared to the overall average for all patents, litigated or unlitigated. Using a Cohen's d effect size metric, we found differences in mean values between court levels were highly significant for all court level pairings at the 0.95 confidence interval. From 2000 to 2014, the district courts decided litigations involving 23,221 patents, the Court of Appeals for the Federal Circuit ("Federal Circuit") decided litigations involving 3,711 patents, and the U.S. Supreme Court ("Supreme Court") decided litigations involving 49 patents. Patents litigated in the Supreme Court had the highest average patent importance, followed by those litigated in the Federal Circuit, trailed by patents litigated in federal district courts. This suggests that the higher the court level in which a patent is litigated to a decision, the higher the importance of that patent will tend to be.

Next, average patent importances were calculated for the federal district courts located in federal appeals circuits, and these importances were compared to the average patent importances for all district courts, the Federal Circuit, and the Supreme Court (Figure 3). Quartile data for these categories is also displayed in box-and-whisker plots (Figure 4).

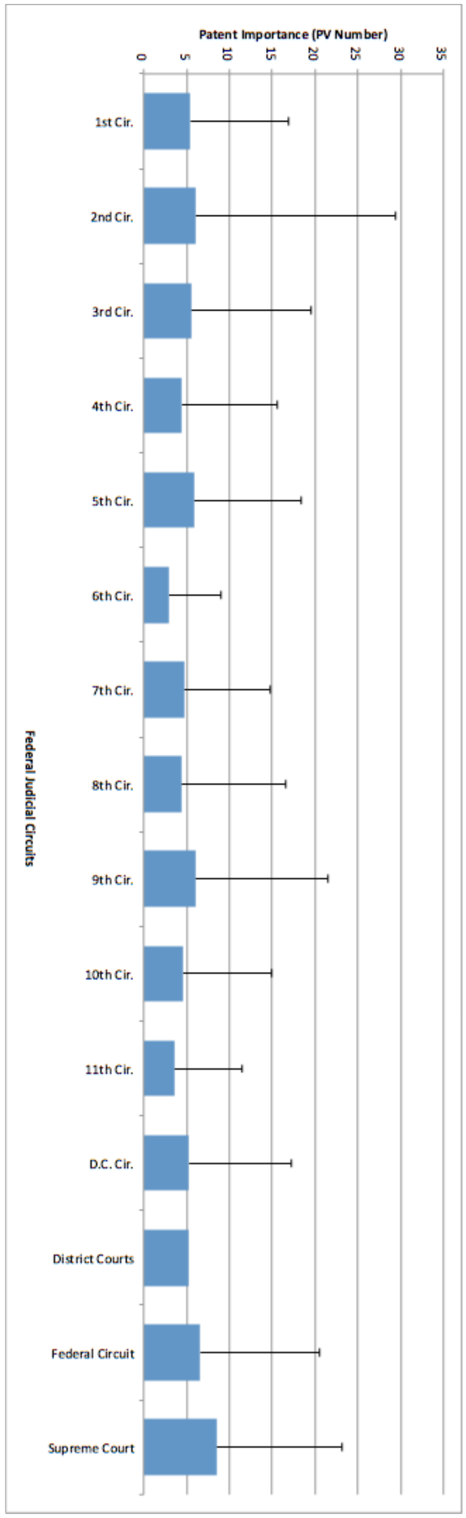

Figure 3: Average patent value for individual federal circuits, all district courts, the Federal Circuit, and the Supreme Court.

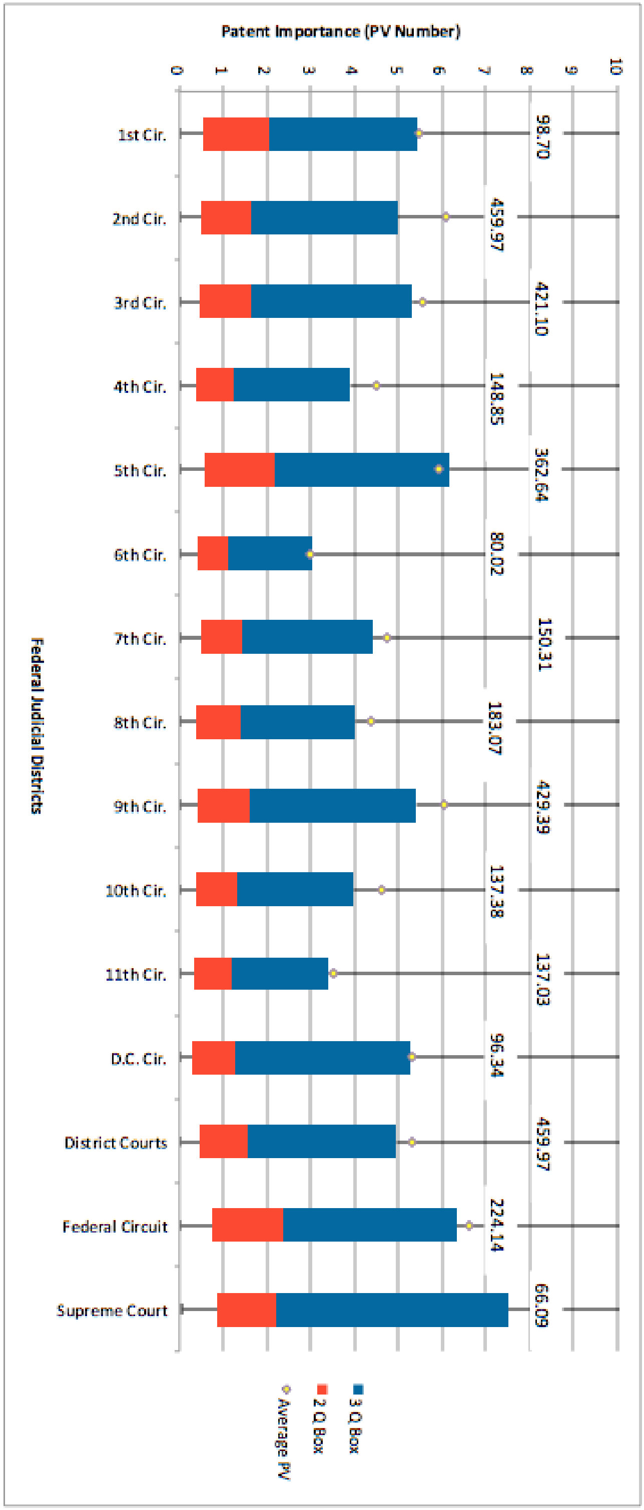

Figure 4: Quartile data for individual district courts, all district courts, the Federal Circuit, and the Supreme Court.

Average patent importances for federal district courts grouped by appeals circuit range from 2.98 (6th circuit) to 6.08 (2nd circuit). Among the notably high patent importance jurisdictions were the 9th Circuit, with litigated patents having mean patent importance of 6.03, and the 5th Circuit, with litigated patents having mean patent importance of 5.92.

The average litigated patent importance was also calculated for each federal district court (Figure 5). Overall, the average importances of patents litigated in each individual federal district court ranged from a low of 0.13 (Middle District of Alaska) to a high of 17.07 (District of Connecticut), with the overall mean patent importance for all federal district courts combined of 5.23.

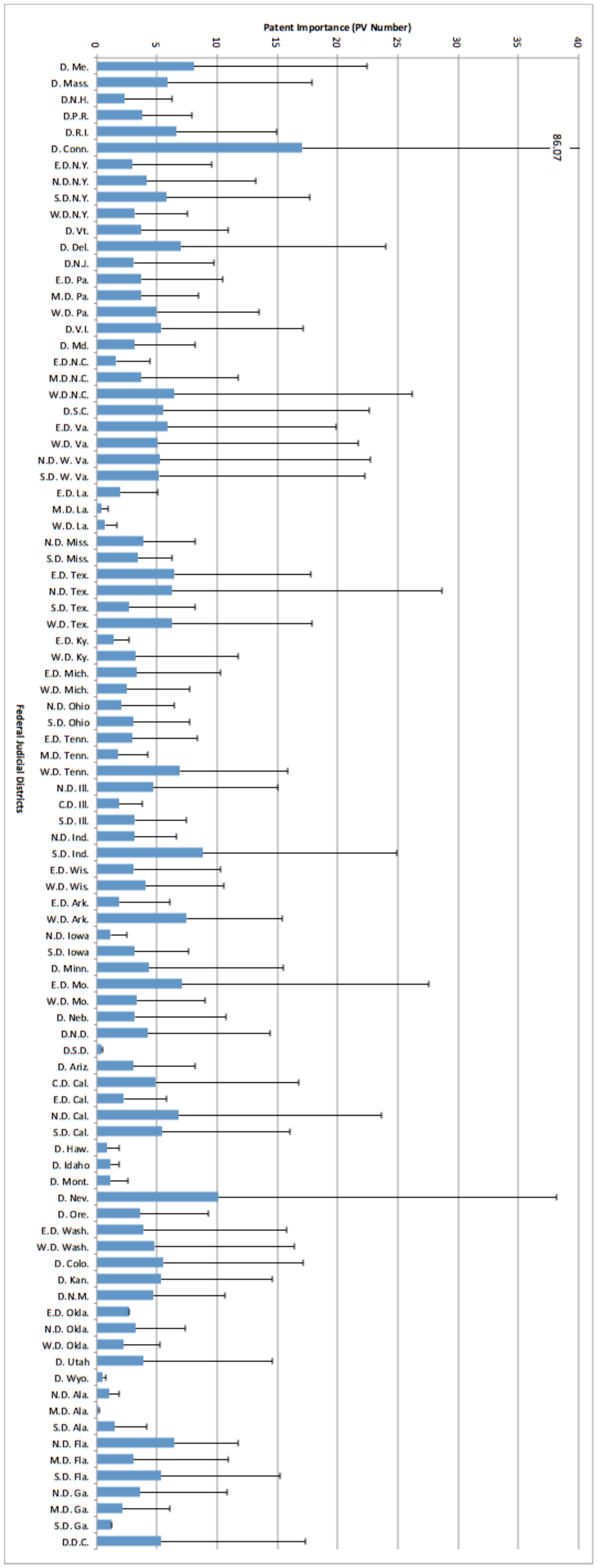

Figure 5: Average patent values litigated in federal district courts.

The District of Connecticut has the highest average patent importance when compared to all other district courts (17.07), but it is notable that there are outlier patents whose importances disproportionately skew the importance levels in this district upwards. In particular, the 2004 case *Applera Corp. v. MJ Research, Inc.* involved three patents that have very high importances of 459.97, 429.39, and 132.29. Because the District of Connecticut is within the 2nd circuit, this also skews that jurisdiction's mean patent importance upwards. The federal district court patent importance data is also presented in the form of the choropleth graph (Figure 6) for ease of detecting geographic patterns in litigated patent importance.

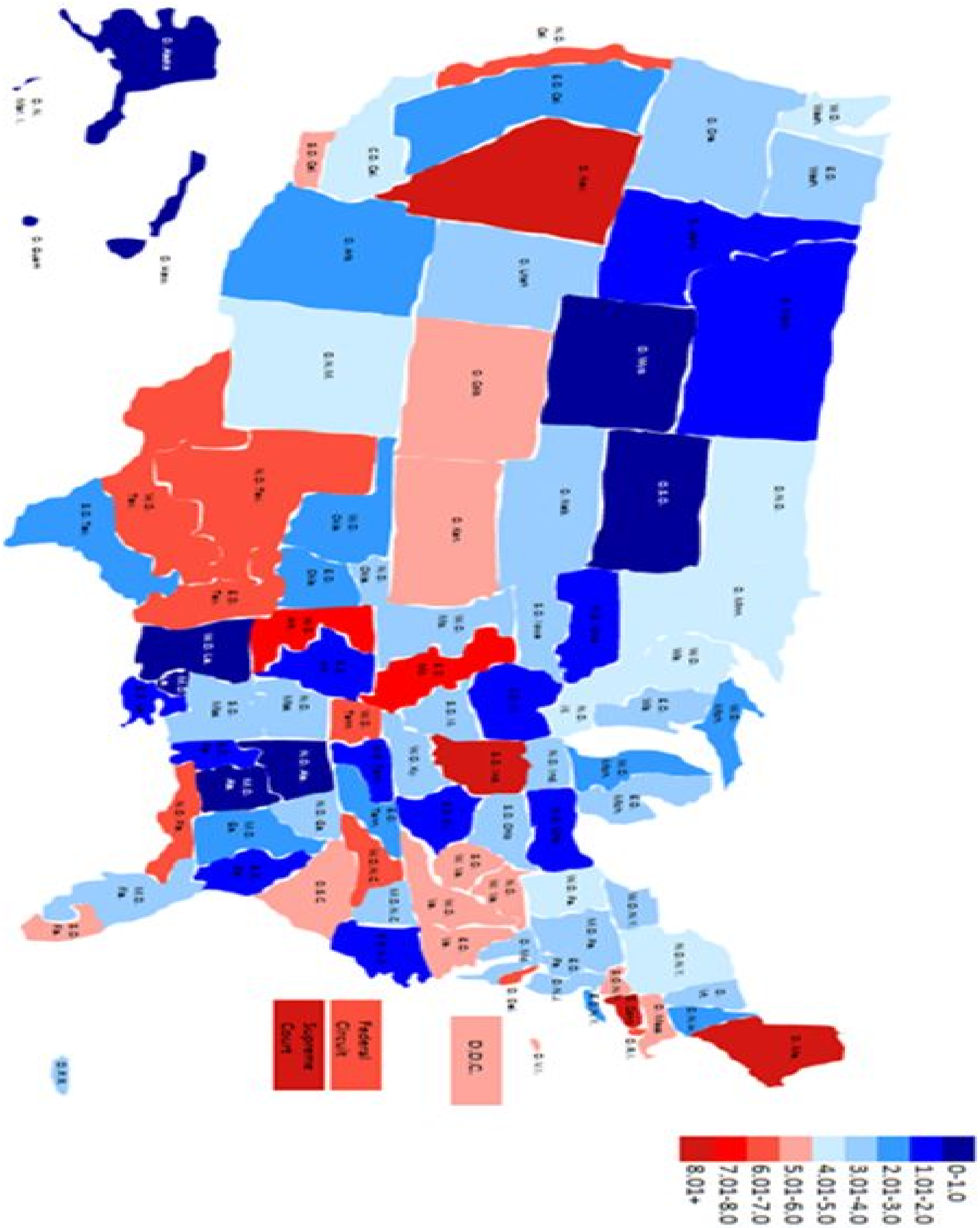

Figure 6: Average patent values litigated in federal district courts.

Patent importance was tracked from 2000 through 2014 for all federal district courts, the Federal Circuit, and the Supreme Court (Figure 7).

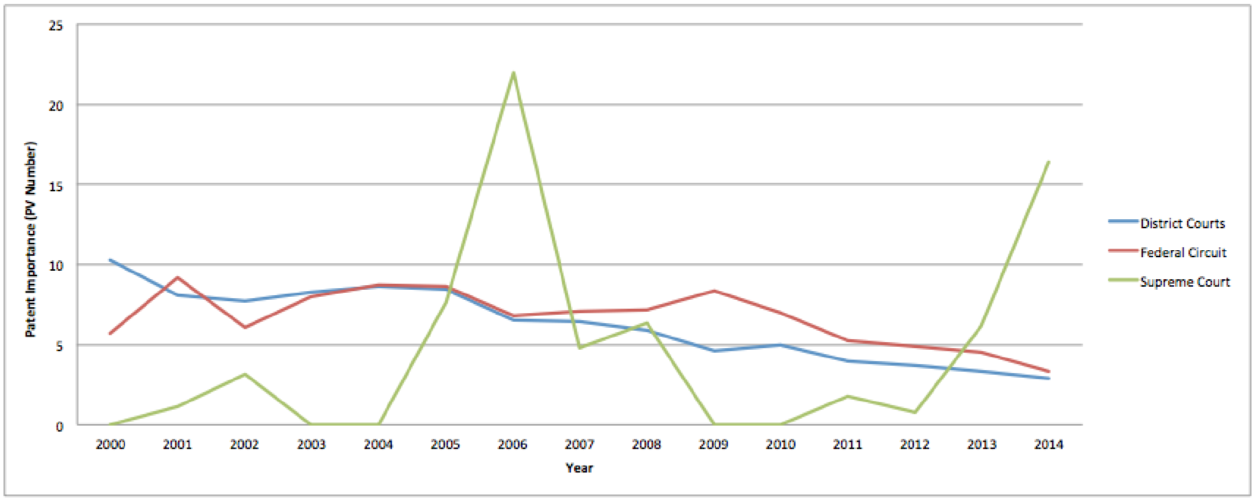

Figure 7: Patent importance over time for federal district courts, the Federal Circuit, and the Supreme Court.

Overall, patent importances have decreased from 2000 to 2014 for both the federal district courts and the Federal Circuit. This may be due to the fact that patents tend to accumulate more citations as they age, so more recently-issued - and, usually, more recently-litigated - patents will tend to have fewer citations than older patents. The Supreme Court heard cases in 2006 that skewed the mean patent importance for patents litigated there in that year to a relatively high 21.94. This spike in mean patent importance resulted largely from the *eBay v. MercExchange* decision, in which patents claiming online auction technology had a very high patent importance of 50.36. It would be advantageous to normalize these patent importance trend data to correct for passage of time, and the the authors hope to develop a method to accomplish this in the future.

VI. DISCUSSION

A. LITIGATED PATENTS TEND TO BE MORE IMPORTANT

The results of our analysis allow several conclusions to be made. First, neither of the hypotheses we tested in this study can be considered falsified by the data. To express this conclusion more positively, both of the hypotheses we tested are consistent with the data. Specifically, it does appear that

(1) Litigated patents tend to be more important than non-litigated patents; and

(2) The higher the federal court level in which litigation takes place, the more important the patents there litigated tend to be.

These twin findings are consistent with the findings of influential studies carried out by Allison et al. in 2004 and 2009, in which litigated patents were generally found to be more valuable than non-litigated patents, and those litigated most often were found to be especially valuable.[91] On the other hand, our findings do not appear to contradict any empirical findings published heretofore.

A commonsense narrative offers itself to explain why litigated patents might be more important. If one assumes that owners of patents tend to be rational, at least in the economic sense, then they would be more likely to choose to litigate the better (more important) patents in their portfolios in preference to the poorer (less important) patents. Litigation is an expensive process, and patent litigation even more so. The mean cost of litigating a patent dispute to a

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[91] John R. Allison et al., Valuable Patents, 92 Geo. L.J. 435, 438 (2004); John R. Allison, Mark A. Lemley, & Joshua Walker, Extreme Value or Trolls on Top? The Characteristics of the Most-Litigated Patents, 158 U. Pa. L. Rev. 1, 5 (2009).

decision at the federal district court level is a staggering $5,000,000.[92] Only more important patents are likely to warrant expenditure of so much money. Patent owners tend to be more intimately acquainted with the importance of their own patents than other parties, so the decisions they make about pursuing or avoiding litigation are likely to have some basis in rational decisionmaking. Furthermore, decisions as to whether to spend additional large amounts of money on appeals of patent cases to the Federal Circuit or Supreme Court are likely to act as increasingly-stringent decisionmaking filters through which patent owners are likely to let only the most important of patents pass. The expected result of this simple narrative would be a pattern similar to that shown in Figure 2.

Some critics of patent litigation have suggested that patent litigation is driven by more quixotic motives. Perhaps only the largest and wealthiest of firms pursue patent litigation, without much regard for the importance of the patents they assert, hoping, perhaps, to win by outspending or outlasting weaker opponents. Maybe the choice of patent to be litigated has little to do with its importance than with the relevance of its claims to allegedly infringing products or processes; certainly, even important patents will tend not to fare well if their claims do not cover the activities of alleged infringers. Another possibility is that most patent litigation has little to do with patent importance, and is, instead, driven by the business models of NPEs who must assert their patent portfolios to make revenue, since, as their acronym suggests, they do not themselves produce products claimed by, or practice, their own patents.

The results of this study do not support any of these scenarios. However, our data is based on patent litigations resulting in judicial decisions, so settled or abandoned patent

[92] James Bessen & Michael J. Meurer, The Private Costs of Patent Litigation, 9 J.L. Econ. & Pol'y 59 (2012).

litigations are not reflected in the results of our analysis. If settlement, abandonment, or other non-decisive outcomes do not tend to involve more important patents, then our results may not be reflective of the broader population of patent litigations. This is a potential source of error for our study. However, if the commonsense narrative we offer above is reflective of reality, then one would expect litigated patents in general to tend to be more important, even if the litigations in which they are involved do ultimately end in a judicial decision.

The most parsimonious interpretation of our results is that litigated patents tend to be more important, and ever more important the further up the hierarchy of federal courts they are litigated, because patent owners tend to make litigation decisions based on the importance, and consequent probability of prevailing, of the patents involved.

B. REGIONAL PATTERNS IN LITIGATED PATENT IMPORTANCE

In the United States, industries associated with developing advanced technologies tend to be geographically concentrated.[93] High technology companies are most abundant in Silicon Valley and its environs, with smaller clusters located in Boston's Route 128 corridor, and Seattle.[94] Similarly, biotechnology firms are most common around Boston, the San Francisco Bay area, and San Diego.[95] Given these coastal distributions, one might expect patent litigation to be focused there too, with less activity occurring in the states between the Atlantic and Pacific coasts. If the importance of litigated patents were taken into account, one might predict that

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[93] David B. Audretsch, Agglomeration and the Location of Innovative Activity, 14 Oxford Review of Economic Policy 18, 18 (1998).
[94] *Id.*
[95] *Id.* at 27-28.

these coastal technological hotspots would see a disproportionate share of important patents being litigated as well. However, our results suggest that the actual pattern is more complicated.

As shown in Figure 6, federal judicial districts characterized by litigations of relatively important patents are found throughout the country, and are not concentrated on the coasts. The districts with the highest averages of importance for patents litigated are the District of Connecticut, Nevada, and Southern Indiana. The District of Maine decides litigations involving patents of higher average importance than the District of Massachusetts (which includes Boston). Although the Northern and Southern Districts of California tend to decide cases having patents of relatively high importance, no other federal districts on the west coast particularly stand out.

There are three notable clusters of litigated high importance patents. Two are is on eastern seaboard: (1) the Districts of Maine, Massachusetts, Rhode Island, Connecticut, and Southern New York; and (2) South Carolina, Western North Carolina, Eastern Virginia, Western Virginia, Southern West Virginia, Northern West Virginia, and the District of Columbia. However, the largest concentration of litigation of high importance patents involves nine federal districts in the south middle of the U.S.: Colorado, Kansas, Eastern Missouri, Southern Indiana, Western Tennessee, Western Arkansas, Eastern Texas, Northern Texas, and Western Texas. This latter hotspot of important patent litigation confounds expectations of a pattern of bicoastal importance separated by a sort of "patent fly-over country" of unimportance.

There are several possible explanations for the existence of these important patent litigation clusters. One is that the received wisdom suggesting that important technologies, and, by extension, important patents, are predominantly developed on the east and west coasts is incorrect. Another is that where important patents originate does not correspond cleanly with where these patents are litigated. There is considerable evidence that patent litigants often engage in forum shopping to find federal districts most friendly to their interests.[96] Such behavior would seem rational if it tended to result in patent decisions beneficial to forum-choosing patent owners. Whatever the explanation, our results suggest it is not as neat and tidy as is often assumed.

C. LITIGATED PATENTS IMPORTANCE AND PATENT CITATIONS

An important implication of our results is that the patent citation network we constructed appears to carry within its nodes and links strong and meaningful signals about patent importance[97]. Previous studies have shown that litigated patents tend to be more valuable than those not litigated.[98] If patent value corresponds with patent importance, then one would predict that litigated patents would tend to be important patents. As discussed above, litigated patents do tend to be more important than non-litigated patents, and the higher the federal court level in which litigation takes place, the more important the patents there litigated tend to be. Thus, our results and those of Allison et al. (2004) and Allison et al. (2009) are mutually reinforcing. One would expect patents selected for litigation to be more important, and they are. One would further expect patents whose owners opt to pursue litigation at the CAFC or Supreme Court to be even more important, and they are.

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[96] Kimberly A. Moore, Forum Shopping in Patent Cases: Does Geographic Choice Affect Innovation?, 83 J. Pat. & Trademark Off. Soc'y 558, 571 (2001).
[97] We should note that the results of this study would not change if we only used raw citation counts. We chose to use the ALEF ranking because it provides a more accurate approximation of patent importance.
[98] John R. Allison et al., Valuable Patents, 92 Geo. L.J. 435, 438 (2004); John R. Allison, Mark A. Lemley, & Joshua Walker, Extreme Value or Trolls on Top? The Characteristics of the Most-Litigated Patents, 158 U. Pa. L. Rev. 1, 5 (2009).

Interestingly, the results show that citations provide some signal of patent quality, influence and/or possibly value. Patents that are litigated at the highest courts presumably are worth, on average, more to companies than patents litigated only at the lowest courts. We find that litigated patents at higher courts have higher citations. This indicates that more important patents tend to be cited more often.

D. FUTURE RESEARCH

This study investigated two relatively simple questions:

(1) Do litigated patents tend to be more important than non-litigated patents?; and

(2) Does the degree of importance of litigated patents tend to increase with the higher level of federal court in which litigation takes place?

Having assembled two massive sets of patent data to answer these questions, we can now address a variety of related questions about patents, patent importance, and patent litigation. Combining our comprehensive set of all patent litigation decisions from 2000 to 2014 with our complete patent citation network of all patents issued from 1976 onwards, we can investigate subsets of litigated patents by technology area (from gross to fine resolution), assignee, inventor, and patent examiner. In addition, we can explore trends of time in any of these variables. With specific reference to the litigation dataset, we intend to enrich the data we have for each specific litigation by adding details on findings on patent validity (including specific grounds for findings of invalidity), infringement, defenses, and remedies (*i.e.*, both damages and injunctive relief). We are also interested in figuring out when these litigated patents accumulate citations: is it before or after litigation? We have the temporal data to answer this question. From a machine learning perspective, this litigation data and the results of the study can be used to create training sets for predicting litigated patents before they are litigated.

VII. CONCLUSIONS

Our study of patent litigation and patent importance suggests that litigated patents tend to be more important than non-litigated patents, and that the higher the federal court level in which litigation takes place, the more important the patents there litigated tend to be. These findings are consistent with the findings of influential studies on patent value carried out by Allison *et al.* in 2004 and 2009, in which litigated patents were generally found to be more valuable than non-litigated patents, and those litigated most often were found to be especially valuable.[99] Our findings also reveal marked differences in the mean and median importances of patents litigated in different federal district courts. Finally, we find several geographic clusters of federal district courts characterized by the litigation of disproportionately-important patents. These clusters do not cleanly correspond to traditional assumptions about where importance technologies, and the patents that claim them, are located. Somewhat unexpectedly, the largest geographic cluster of federal district courts where highly important patents tend to be litigated spans the southern-central United States.[100] We plan to address a number of additional questions in the future that relate to our findings in this article.

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[99] John R. Allison et al., Valuable Patents, 92 Geo. L.J. 435, 438 (2004); John R. Allison, Mark A. Lemley, & Joshua Walker, Extreme Value or Trolls on Top? The Characteristics of the Most-Litigated Patents, 158 U. Pa. L. Rev. 1, 5 (2009).
[100] This geographic pattern belies the existence of a "patent fly-over country" between the Atlantic and Pacific coasts.