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Patent Valuation with Forecasts of Forward Citations

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Abstract: Patents without established market values (e. g., no negotiated royalty rates) are often valued by comparing the number of citations the patent has received to the numbers received by other patents whose market values are established. For recently-issued patents, which have not had time to accumulate citations, this procedure can be noisy or even inapplicable. The current paper generalizes this valuation method to incorporate patent characteristics that relate to the number of citations the patent is expected to obtain in the future. We estimate statistical models in which the explanatory variables are observable characteristics of the patent at a given time, and the dependent variable is the number of citations that the patent receives *after* that date. Using several examples, we demonstrate a procedure for patent valuation that incorporates the statistical results, such that the valuation reflects the number of citations the patent has already received as well as the number it is expected, based on its characteristics, to receive in the future.

Keywords: patent, evaluation, citations

1 Introduction

Patents grant the assignee exclusive ownership of a novel technology for a period of time. This economic monopoly gives patents inherent value. By their nature, patented technologies differ greatly in quality, and the distribution of patent values is highly skewed (see, e. g., Scherer 1965; Pakes and Schankerman 1984; Pakes 1986; Griliches 1990.) In an effort to value individual patents, evaluation analysts have focused on citations. All new patents are required to cite relevant previous patents and to list these citations on the front page of the new patent application. These citations are legally important: they limit the scope of the patent claims and the subsequent rights granted to the assignee. Applicants have a duty to declare any technological antecedents, or “prior art,”

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they relied on when developing the new technology. Patent examiners decide which citations to include in the final patent document, even adding citations to prior art of which the applicant may have been unaware.[1]

The citations that a patent receives from subsequent patents are called forward citations. The number of forward citations that a patent receives has been shown to be positively and significantly related to the value of the patent: After Carpenter, Narin, and Woolf (1981) and Trajtenberg (1990) estimated this relationship between forward citations and value, numerous empirical studies have verified their finding using different data and methodologies, e. g., Albert et al. (1991), Harhoff et al. (1999), Hall, Jaffe, and Trajtenberg (2005), Gambardella and Harhoff (2008), Kogan et al. (2012), and Moser, Ohmstedt, and Rhode (2013).[2] Reflecting this relationship, researchers have utilized forward citations as a proxy for patent value in analyses of R&D (Argyres and Silverman 2004; Singh 2008), innovation (Ahuja and Lampert 2001), and knowledge flows (Rosenkopf and Almeida 2003).

Forward citation analysis has become increasingly common for patent valuation in litigation, transfer pricing, and other purposes; see, e. g., Oracle v. Google, Finjan v. Blue Coat Systems, Realtek Semiconductor v. LSI and Agere.[3] The standard method is to compare the patent being valued against patents, or portfolios of patents, with established values, such as licensing fees or sales prices.[4] When possible the comparison is among patents of the same age and technology group, to account for the fact that older patents have had more time

1 "During the examination process, the examiner searches the pertinent portion of the 'classified' patent file. His purpose is to identify any prior disclosures of technology … which anticipate the claimed invention and preclude the issuance of a patent; which might be similar to the claimed invention and limit the scope of patent protection …; or which, generally, reveal the state of the technology to which the invention is directed … If such documents are found they are made known to the inventor, and are 'cited' in any patent which matures from the application … Thus, the number of times a patent document is cited may be a measure of its technological significance." (Patent and Trademark Office 1976, 167) as cited in Hall et al. (2005).

2 Abrams and Popadak (2013) found an inverted-U-shape for the relation between citations and value, with fewer citations for patents at the very highest end of their value measure. Moore (2005) used expiration of a patent as an indication of its having comparatively low value and found a negative relation between the number of forward citations and whether the patent had been allowed to expire, which implies a positive relation between citations and value.

3 Oracle America, Inc. v. Google Inc., 3:10-cv-03561-WHA (N.D. Cal. 24 August 2012); Finjan, Inc. v. Blue Coat Systems, Inc., 13-cv-03999-BLF (N.D.Cal. 14 July 2015); Realtek Semiconductor Corp. v. LSI Corp. and Agere Systems LLC, C-12-03451-RMW (N.D.Cal., 6 January 2014).

4 This method is often combined with other indications of value. In the current paper, we generalize only the citations-based approach; the other procedures remain the same.

to accumulate citations and that citation practices differ over technological fields (Griliches, Pakes, and Hall 1987).

This valuation approach treats the number of citations that a patent has received at the time of appraisal as indicative of the total number of citations that it will receive, at least within an age and technology group. For young patents that have had little time to accumulate citations, this assumption is limiting. At an extreme, a patent that has received no citations by the time of the appraisal can either not be valued or is assigned a value of zero, even though the patent might receive numerous citations over its life. If the patent has received only a few citations, but more than zero, then comparisons are subject to the noisiness of small numbers. And even for relatively old patents that have had time to accumulate many citations, two patents with the same number of citations currently will not, in general, have the same lifetime citations.

In this paper, the observable characteristics of patents at a given point in time are related statistically to the number of citations that the patent receives after that date. The estimated models are used to predict the number of citations a patent will receive after a given time in its life. This relation is used to generalize the standard method for patent valuation described above. Instead of comparing patents on the basis of the number of citations each patent has received at the time of appraisal, patents can be appraised on the basis of both (i) the citations it has received at the time of valuation, and (ii) the number of citations the patent is expected to receive after the time of valuation, given its characteristics. Stated equivalently, the characteristics of patents that relate to future citations enter the appraisal in addition to the current number of citations.

In Sections 2–4 below we describe, respectively, the statistical model that relates patent characteristics to future citations, the data that are used to estimate the model, and the estimation results. Section 5 demonstrates the generalized procedure for valuation.

2 Model

We use a standard Poisson model to relate patent characteristics to future citations. Hausman, Hall, and Griliches (1984) utilized a Poisson model to address the relationship between research and development expenditures of firms and the number of patents applied for and received. Many of the justifications they suggest for the efficacy of the Poisson model also apply to our analysis of forward citations, including that the dependent variable is a non-negative integer.

Let $C_n(t,s)$ be the number of citations that patent n receives in the period between time t and $t+s$. For example, with time measured in years, $C_n(0,1)$ is the number of citations that patent n receives within its first year after publication, and $C_n(1,4)$ is the number it receives during the subsequent four years. Let X_{nt} be a vector of variables that describes patent n as observed at time t. Importantly, this vector includes C_n (0,t), the number of citations that the patent has received up to time t. Our goal is to predict the number of citations received for a given period of time after t.

Under a Poisson specification, the probability of observing count $C_n(t,s)$ is:

$$P(C_n(t,s)=k)=\frac{e^{-\lambda_n(t,s)}(\lambda_n(t,s))^k}{k!};\ k=0,1,2,3,\ \ldots$$

where λ_n $(t,s)=\exp$ $(\beta_t{'}$ $X_{nt}+\alpha_t$ s) is the expected number of citations that the patent receives during the s years after t. We estimate this specification for years $t=0,1,2,\ \ldots,15$ of patents' lives, with separate coefficients for each year. The timespan, s, for each model is specified to be the period from t until the date we assembled our data on citations. That is,each model is estimated on the citations from t to the end of our data collection period.

3 Data

Our analysis is based on a random sample of all US patents published between May 1994 and March 2015.[5] To obtain the sample, we randomly selected 10 of the 251 months during this period and downloaded information about these patents on 24 April 2015.[6] This sample originally included 177,110 observations. Missing data on relevant explanatory variables reduced the sample to 110,724 patent records.

5 We downloaded patent data using Thomson Reuters' "Thomson Innovation" software. We chose to sample from May 1994 onward because data from the Derwent Patent Citation Index (DPCI) apparently only covers Inventor citations beginning in May 1994. While our list of citing patents actually relies on primary patent authorities and INPADOC data, we chose this date to be conservative in case other variables relied on the DPCI data collection that could potentially bias our data.

6 Chosen using a random number generator, the 10 months included in our sample are: February 2010, April 1998, January 2014, September 2010, January 2006, July 2013, July 2012, November 2000, August 1996, December 1997.

To obtain information on citations, we identified the publication numbers for all of the patent records that either cite (forward citations) or were cited by (backward citations) one of the patents in our sample. This yielded over 3.4 million unique publication numbers.[7] We downloaded data for these citing/cited patent records in order to generate variables for our model.[8]

Below we explain how the explanatory variables in our model were constructed and why they were chosen for inclusion:

3.1 Forward Citations as of Year *t*

This variable is the cumulative number of citations the patent has received as of year *t*.[9] As described in the introduction above, the standard method of valuation relies solely on this variable. Hall, Jaffe, and Trajtenberg (2005) assume a fixed citation intensity distribution, which is equivalent to including forward citations at a given time as an indicator of future cites as we do here. They do not, however, incorporate other observable patent characteristics into their forecasting method.

3.2 US Litigation as of Year *t*

This variable is "1" if the patent has been involved in US litigation as of year *t* of the patent's life, and "0" otherwise.[10] This information comes from Westlaw and is compiled from the electronic filings of the federal district courts.[11] Lanjouw and Schankerman (1997) study the relation between litigation and forward citations and find that litigated patents are far more heavily cited than a randomly chosen patent.

7 The Thomson Innovation database only had records for 3,387,226 of the 3,436,497 unique citing and cited patent numbers listed in our sample data (98.57 %). We omit citations with missing patent record information in our analysis.

8 These records were downloaded from 7–20 May 2015.

9 Note that these forward citation patent records are not necessarily granted patents. They may be patent applications, divisional patents, continuation patents, etc.

10 If the patent has been involved in litigation more than once, this variable reflects the first filing date.

11 Thomson claims that this information is updated weekly and that the time delay from informational availability from the courts to informational availability on Thomson Innovation is 1–6 days, so our data should reflect all cases filed as of mid-late April, 2015. See: http://www.thomsoninnovation.com/tip-innovation/support/help/patent_fields.htm#litigation_date.

3.3 Expired as of Year *t*

This variable is "1" if the patent has expired as of year *t* of the patent's life, and "0" otherwise.[12] Patents can expire before their maximum allowable term if the owner fails to pay maintenance fees.[13] This variable indicates that the owner did not believe that the patent had sufficient value to continue paying patent fees. If one accepts that forward citations are a proxy for patent value, then we would expect patents that have been allowed to expire to receive fewer forward citations. Moore (2005) found that: "Expired patents received fewer citations than patents that were maintained to the full term. The longer the patent was maintained, the greater the number of citations it received." By our including whether the patent has expired by year t our models can capture these relations.

3.4 Reassigned as of Year *t*

This variable is "1" if the patent's reassignment has been reported to the USPTO as of year *t* of the patent's life, and "0" otherwise. Reporting of reassignment is a voluntary process, so this variable is not comprehensive and will not reflect changes in patent ownership that have not been reported to the USPTO.[14] Galasso, Schankerman, and Serrano (2013) study the effect of changes in patent

12 This variable was constructed using the "INPADOC Legal Status Code" and the "US Post Issuance" fields in Thomson Innovation's database, which describes official updates to the status of a patent. The update codes are country-specific, so *expired* takes on a "1" if the codes "FP", "FPB1", "FPB2", "FPB3", or "LAPS" are reported in the "INPADOC Legal Status Code" field or if "EXPI" appears in the "US Post Issuance" field. For expiration dates, this variable relies on the "INPADOC Legal Status Date" and the "US Post Issuance" fields in Thomson Innovation's database. Date information from the "US Post Issuance" field takes precedence if there is a discrepancy between the two fields. This is because the "US Post-Issuance" field reflects data from the USPTO, updated weekly. See: http://www.thomsoninnovation.com/tip-innovation/support/help/patent_fields.htm#inpadoc_legal_status; http://www.thomsoninnovation.com/tip-innovation/support/help/legalstatus_codes/lsc_us.htm; http://www.thomsoninnovation.com/tip-innovation/support/help/patent_fields.htm#post_issuance

13 To be clear, if the patent has been reinstated due to the acceptance of a late maintenance fee (or other reason), *expired* still takes on a value of "1" indicating that it was, at some point, allowed to expire. If the patent has been allowed to expire multiple times, this marks the earliest expiration date on record.

14 If the patent has been reassigned multiple times, this marks the earliest reassignment date on record. Reported changes to a patent's assignment can result from different types of transactions, including the assignment of assignor's interest, judgment, license, merger, release, sale, security agreement, security interest, or settlement. See: http://www.thomsoninnovation.com/tip-innovation/support/help/patent_fields.htm#reassignment_us.

ownership on litigation risk, and find that for patents originally owned by individual inventors, changes in patent ownership reduce the likelihood of litigation.

3.5 Generality Index as of Year *t*

Hall, Jaffe, and Trajtenberg (2001) define a "Generality Index" that describes the variety of fields of a patent's forward citations. For patent n, $Generality_n = 1 - \sum_{j}^{k_n} r_{nj}^2$ where r_{nj}^2 denotes the share of citations received by patent n that belong to patent class j, out of k_n patent classes. To construct this variable, we use 4-digit International Patent Classification (IPC) codes.[15] This measure is high if a patent is cited by other patent records belonging to a wide range of technological fields, and low if those forward citations are concentrated in a few fields. The measure is zero if the sample patent's forward citations all belong to the same IPC class.[16] In cases where citing patent records are classified in more than one IPC class, we treat each of these classes as if it were from a separate citation. In other words, these classifications are given equal weight. Because patents accumulate forward citations after their publication, we have constructed the "Generality Index" for the patent for each of the first 19 years of its life (19 is the oldest citation in our sample). The measure is cumulative. That is, the variable for year t is the index calculated for all citations received in the first t years. Put another way, this is the index of the generality of the patent as measured at the

15 The International Patent Classification (IPC), established by the Strasbourg Agreement of 1971 (which took effect on 7 October 1975), "provides for a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. The IPC divides technology into eight sections with approximately 70,000 subdivisions. Each subdivision has a symbol consisting of Arabic numerals and letters of the Latin alphabet. The appropriate IPC symbols are indicated on each patent document, of which more than 1,000,000 were issued each year in the last 10 years. The IPC symbols are allotted by the national or regional industrial property office that publishes the patent document. For PCT documents, IPC symbols are allotted by the International Searching Authority (ISA)." This variable utilizes the DWPI IPC dataset. According to Thomson Innovation, "the DWPI editorial team may apply these IPCs because the original patenting authorities have omitted them or because they feel the additional classifications are appropriate and helpful." See http://www.wipo.int/classifications/ipc/en/preface.html http://www.thomsoninnovation.com/tip-innovation/support/help/patent_fields.htm#dwpi_ipc Also note that IPC information was not available for 11,699 of the 115,571 observations.

16 Note that the "Generality Index as of year *t*" is not defined if the patent has not received any forward citations as of year *t*. WE assign a value of 0 in these cases and include a variable, described below, that identifies patents with no forward citations.

end of the t^{th} year.[17] This generality index has been used in a wide variety of studies. For example, Henderson, Jaffe, and Trajtenberg (1998) use it when comparing university and corporate patents, Layne-Farrar and Lerner (2011) include it in their examination of patent pools, and Galasso, Schankerman, and Serrano (2013) use it to inform the manner in which patent rights are enforced.

3.6 Originality Index

Hall, Jaffe, and Trajtenberg (2001) also define an "Originality Index" for a patent's backward citations. For patent n, $Originality_i = 1 - \sum_{j}^{k_n} r_{nj}^2$ where r_{nj}^2 denotes the percentage of patent records cited by patent n that belong to patent class j, out of k_n patent classes (we use 4-digit IPC classes to construct this variable as well). This measure will be high if a patent cites other patent records belonging to a wide range of technological fields, and low if those backward citations are concentrated in a few fields. The measure is zero if the sample patent's backward citations all belong to the same IPC class. In cases where cited patent records are classified in more than one IPC class, we treat each of these classes as if it were from a separate citation. In other words, these classifications are given equal weight.[18] These patent originality measures have also been used widely in the literature. For example, Gompers, Lerner, and Scharfstein (2005) use it to study the creation of start-ups, and Stahl (2010) indicates that she is using the index in ongoing work to study pre-merger and post-merger patent value.

3.7 Claims Count

The claims/assertions made in the granted patent outlines the subject matter and scope of the invention.[19] The number and content of these claims dictate the breadth of patent rights (Tong and Frame 1994). High claims counts have been shown to translate to higher expected patent value and that they are positively correlated with forward and backward citation counts (Lanjouw and Schankerman 2001, 2004).

17 For patents less than 22 years old (nearly all of the sample patents), the generality indices for years greater than the life of the patent are filled in with the most recent generality index figure. E.g. if a patent is 7 years old, *Generality_7 = Generality_8 = Generality_9, etc.*

18 These backward citation patent records are not necessarily granted patents. They may be patent applications, divisional patents, continuation patents, etc.

19 In our sample data, *Claims Count* is missing for 54,965 of the 177,110 sample patents (31.0 %).

3.8 Count of IPC Subclasses

This variable is the count of unique four-digit (subclass level) International Patent Classifications (IPC's) for the sample patent. We follow Lerner (1994), who uses this measure as a proxy for patent scope and shows that the breadth of patent protection significantly affects valuations in his sample of biotechnology firms. He also shows that patents assigned to more four-digit IPC classes are more likely to receive forward citations.[20] Matutes, Regibeau, and Rockett (1996) also find scope to be an important dimension of patent regimes and suggest it should be used to induce early disclosure of fundamental innovations.

3.9 Individual Assignee

This variable is "1" if the original patent assignee is an individual (as opposed to a corporation) and "0" otherwise. For patent records with multiple assignees, this field takes on a "1" if any of the assignees are classified by DWPI as an individual.[21] Galasso, Schankerman, and Serrano (2013) show that individually owned patents are cited at different rates than corporate patents on average. They find only very minor differences in citation rates for traded patents, however, which further justifies the inclusion of both this and our *reassignment* variable.

3.10 Backward Non-patent Citations

This variable is the number of backward citations to non-patent documents. It counts the number of all the non-patent records cited by the sample patent. Non-patent citation sources generally include abstracts and articles from scientific and technical literature.[22] Harhoff, Scherer, and Vopel (2003) examine

20 Many studies follow Lerner's approach (Squicciarini, Dernis, and Criscuolo 2013; Harhoff, Scherer, and Vopel 2003; Lanjouw and Schankerman 1997). Harhoff, Scherer, and Vopel (2003) find the measure to be insignificant in their models for patent value, while Lanjouw and Schankerman (1997) find this measure of scope has a small statistically significant negative effect on the probability of infringement litigation.

21 This field was created using the Assignee Code – DWPI variable in Thomson Innovation. Assignee information was not available for 19,240 of the 177,110 observations (10.9 %).

22 Thomson Innovation states that these data come from the primary/"first level" patent authorities and from INPADOC, which stands for International Patent Documentation. INPADOC is an international patent collection produced and maintained by the European non-patent citations in their valuation models and find that the measure is also informative of patent value. Czarnitzki, Hussinger, and Schneider (2011) and Cassiman, Veugelers, and Zuniga (2008) find that academic involvement in patenting appears to generate more forward citations.

3.11 Backward Patent Citations

This variable is the total number of patent records cited by the sample patent (backward citations).[23] Harhoff, Scherer, and Vopel (2003) employ the use of backward citation counts in their patent valuation models and determine that it is a statistically significant positive indicator of patent value.[24] Lanjouw and Schankerman (2001) show that large numbers of backward citations may indicate smaller, more incremental inventions.

3.12 ipc_A, ipc_B, ipc_C, ipc_D, ipc_E, ipc_F, ipc_G, ipc_H, ipc_N

Each variable is marked as "1" if the patent has been classified into the corresponding IPC section (1-digit classification), and zero otherwise.[25] Including these field indicators allows the model to control for the different citation practices across technology groups.

3.13 Zero Forward Citations Indicator

This variable is "1" if the patent has received zero forward citations as of year *t* and "0" otherwise. The inclusion of this variable accounts for the fact that the generality index is not defined and given a value of 0 when there are no forward citations.

Patent Office (EPO). The data are updated every Thursday. (See http://www.epo.org/searching/subscription/raw/product-14-11.html)

23 As discussed above, Thomson Innovation only had records for 3,387,226 of the 3,436,497 unique citing and cited patent numbers listed in our sample data (98.57 %). The citations that could not be located in Thomson's database are not included in this variable.

24 Lanjouw and Schankerman (1997) include the number of backward citations per claim in their probit analysis of litigation, but do not obtain statistically significant results.

25 Note that a patent may be classified into more than one IPC section.

3.14 Days until Truncation

This variable is the number of days until truncation for each year t equal to: $(April\ 24, 2015 - Publication\ Date) - (365{*}t)$. When using the models for prediction, this variable becomes the length of the forecast period.

4 Estimation Results

Table 1 shows the estimated models for all years. Standard errors were calculated by the bootstrap, using the month and year of the patent as resampling clusters.[26] We also calculated standard errors by bootstrapping with resampling of patents individually and by the usual asymptotic formulas, both of which give somewhat smaller standard errors than those in Table 1.

The number of citations the patent has received by the given time (the first explanatory variable) is significantly related to the number of citations that the patent receives subsequently. This result justifies the current practice of using citations at the time of evaluation as a measure of value. Importantly, however, other characteristics also enter significantly. If future citations were proportional to past citations, as the current valuation procedures implicitly assume, then these other characteristics would not enter significantly. The estimation results justify generalizing the evaluation procedure to include the influence of these other factors.

Some of the explanatory variables have coefficients that are estimated to remain fairly stable over the model years. As expected, however, the significance and importance of many indicators are estimated to diminish over time, since past citations become, as the patent ages, a more reliable indicator of future citations. This result conforms to the estimates of Hall, Jaffe, and Trajtenberg (2005) that the mean backward citation lag is approximately 15 years and that forward citations are received at non-declining rates even after 25 years.

The estimates are consistent with several findings in the literature. As in Lanjouw and Schankerman (1997), *Litigation* is found to lead to higher forward citation rates, especially if that litigation occurs early in a patent's life. The importance of litigation diminishes over time, and eventually becomes insignificant. Patents that have been allowed to expire early have lower forward citation

26 As described in section 3, the sample of patents was obtained by sampling months within the time period covered by the patent database and including all patents within the selected months. Bootstrapping by clusters of months' patents represents this sampling process.

Table 1: Model estimation results.

Dependent Variable: Remaining Cites	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Natural Log of Forward Citations as of year t		1.154***	0.898***	0.875***	0.879***	0.895***	0.921***
		(0.0625)	(0.0463)	(0.0266)	(0.0195)	(0.0288)	(0.0265)
US Litigation as of year t	−0.333	0.690***	0.592***	0.389***	0.184*	0.164**	0.193***
	(0.599)	(0.164)	(0.0674)	(0.0958)	(0.0973)	(0.0695)	(0.0482)
Expired as of year t		−0.563**	−0.358	−0.450	−0.208	−0.129***	−0.101***
		(0.284)	(0.341)	(0.396)	(0.351)	(0.0192)	(0.0175)
Reassigned as of year t	−0.158***	−0.143***	−0.129***	−0.110***	−0.0910***	−0.0747***	−0.0641***
	(0.0254)	(0.0202)	(0.0178)	(0.0212)	(0.0193)	(0.0125)	(0.0130)
Generality Index as of year t		0.145***	0.104***	0.103***	0.106***	0.0943***	0.0954***
		(0.0383)	(0.0331)	(0.0192)	(0.0333)	(0.0247)	(0.0222)
Originality Index	0.267***	0.254***	0.285***	0.266***	0.242***	0.221***	0.173***
	(0.0329)	(0.0442)	(0.0646)	(0.0395)	(0.0278)	(0.0260)	(0.0240)
Claims Count	0.0133***	0.0114***	0.00922***	0.00748***	0.00604***	0.00452***	0.00338***
	(0.000687)	(0.000644)	(0.000439)	(0.000560)	(0.000572)	(0.000455)	(0.000378)
Count of IPC Subclasses	0.0581***	0.0511***	0.0376***	0.0377***	0.0385***	0.0298***	0.0254***
	(0.00907)	(0.00927)	(0.00754)	(0.00456)	(0.00367)	(0.00386)	(0.00395)
Individual Assignee	−0.157***	−0.142***	−0.0877***	−0.0552	−0.0263	−0.00588	−0.0103
	(0.0337)	(0.0317)	(0.0335)	(0.0400)	(0.0376)	(0.0318)	(0.0262)
Backward Non-patent Citations	0.000739	0.000794	0.000766	0.000784	0.000927	0.00155	0.00198
	(0.000610)	(0.000633)	(0.000904)	(0.00123)	(0.00115)	(0.00131)	(0.00143)
Backward Patent Citations	0.00142***	0.00128***	0.00123***	0.00128***	0.00108***	0.000935***	0.000726*
	(0.000425)	(0.000307)	(0.000410)	(0.000227)	(0.000159)	(0.000241)	(0.000429)
ipc_A	0.371***	0.391***	0.411***	0.399***	0.387***	0.404***	0.409***
	(0.0269)	(0.0233)	(0.0281)	(0.0230)	(0.0163)	(0.0145)	(0.0105)
ipc_B	−0.324***	−0.288***	−0.226***	−0.210***	−0.202***	−0.186***	−0.181***
	(0.0371)	(0.0382)	(0.0261)	(0.0165)	(0.0144)	(0.00763)	(0.00930)
ipc_C	−0.593***	−0.504***	−0.362***	−0.278***	−0.241***	−0.211***	−0.183***
	(0.0197)	(0.0353)	(0.0232)	(0.0301)	(0.0282)	(0.0208)	(0.0197)
ipc_D	−0.381***	−0.325***	−0.252***	−0.220***	−0.219***	−0.186***	−0.167***
	(0.0476)	(0.0484)	(0.0437)	(0.0459)	(0.0365)	(0.0496)	(0.0522)
ipc_E	−0.0626	−0.0358	0.0386	0.0631	0.0863*	0.0984*	0.118***
	(0.0691)	(0.0633)	(0.0396)	(0.0413)	(0.0466)	(0.0517)	(0.0398)
ipc_F	−0.286***	−0.296***	−0.250***	−0.209***	−0.185***	−0.167***	−0.145***
	(0.0570)	(0.0438)	(0.0315)	(0.0212)	(0.0202)	(0.0242)	(0.0171)
ipc_G	0.0827***	0.0538**	0.0484*	0.0444*	0.0366*	0.0306	0.0308
	(0.0231)	(0.0214)	(0.0266)	(0.0230)	(0.0202)	(0.0209)	(0.0242)
ipc_H	0.0136	0.00807	−0.0242	−0.0560***	−0.0881***	−0.0973***	−0.0976***
	(0.0167)	(0.0196)	(0.0198)	(0.0133)	(0.00881)	(0.0108)	(0.0175)
Zero Cumulative Forward Citations Indicator		0.332***	0.250***	0.301***	0.365***	0.403***	0.459***
		(0.0461)	(0.0339)	(0.0474)	(0.0551)	(0.0557)	(0.0427)
Natural Log of Days Until Truncation	1.493***	1.510***	1.281***	1.109***	1.000***	0.847***	0.816***
	(0.0270)	(0.0444)	(0.0840)	(0.215)	(0.162)	(0.127)	(0.162)
Constant	−10.18***	−10.68***	−8.924***	−7.761***	−7.106***	−6.040***	−6.012***
	(0.207)	(0.366)	(0.725)	(1.854)	(1.391)	(1.045)	(1.325)
Observations	110,723	110,723	91,119	66,405	66,405	50,923	44,174

Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
0.936***	0.951***	0.960***	0.978***	1.003***	1.028***	1.052***	1.082***	1.122***
(0.0238)	(0.0161)	(0.00750)	(0.00472)	(0.00530)	(0.00517)	(0.00531)	(0.00507)	(0.0111)
0.205***	0.204***	0.172*	0.259**	0.242**	0.218**	0.142	0.0870	0.0230
(0.0685)	(0.0783)	(0.0938)	(0.105)	(0.116)	(0.104)	(0.113)	(0.124)	(0.0681)
−0.0781***	−0.0669***	−0.144***	−0.129***	−0.109***	−0.0883***	−0.143***	−0.110***	−0.0762***
(0.0194)	(0.0161)	(0.0185)	(0.0165)	(0.0148)	(0.0185)	(0.0212)	(0.0316)	(0.0232)
−0.0568***	−0.0510***	−0.00867	−0.0112	−0.0107	−0.0320***	−0.00710	−0.0136	−0.0213
(0.0137)	(0.0160)	(0.00874)	(0.00744)	(0.0173)	(0.0116)	(0.0103)	(0.0138)	(0.0142)
0.0940***	0.0925***	0.0962***	0.116**	0.136**	0.0905	0.134**	0.195***	0.223***
(0.0274)	(0.0331)	(0.0339)	(0.0583)	(0.0594)	(0.0635)	(0.0559)	(0.0461)	(0.0374)
0.158***	0.143***	0.123***	0.0956***	0.0741***	0.0755***	0.0445*	0.00934	−0.00311
(0.0262)	(0.0183)	(0.0238)	(0.0233)	(0.0285)	(0.0290)	(0.0257)	(0.0390)	(0.0221)
0.00296***	0.00260***	0.00195***	0.00146***	0.00113***	0.00101***	0.000550	0.000622	0.000624
(0.000334)	(0.000148)	(0.000125)	(0.000228)	(0.000254)	(0.000290)	(0.000420)	(0.000534)	(0.000576)
0.0233***	0.0228***	0.0200***	0.0164***	0.0131***	0.0126***	0.00796*	0.00153	−0.00452
(0.00404)	(0.00455)	(0.00483)	(0.00530)	(0.00469)	(0.00487)	(0.00444)	(0.00533)	(0.00334)
−0.00390	−0.00134	0.0358	0.0400	0.0395	0.0282	0.0506	0.0468	0.0464***
(0.0251)	(0.0222)	(0.0238)	(0.0294)	(0.0340)	(0.0260)	(0.0327)	(0.0300)	(0.0152)
0.00212	0.00219*	0.00233	0.00187	0.00146	0.00136	0.00102	0.000393	−0.000905
(0.00130)	(0.00130)	(0.00147)	(0.00147)	(0.00150)	(0.00140)	(0.00134)	(0.00160)	(0.000675)
0.000466	0.000537	0.000999**	0.00137**	0.00141**	0.00121**	0.000981*	0.000925	0.000926***
(0.000491)	(0.000454)	(0.000450)	(0.000593)	(0.000581)	(0.000537)	(0.000563)	(0.000578)	(0.000168)
0.419***	0.422***	0.442***	0.456***	0.486***	0.505***	0.510***	0.505***	0.471***
(0.00706)	(0.00548)	(0.0112)	(0.0104)	(0.0171)	(0.0241)	(0.0236)	(0.0311)	(0.0183)
−0.186***	−0.197***	−0.204***	−0.201***	−0.192***	−0.175***	−0.155***	−0.122***	−0.105***
(0.0106)	(0.0114)	(0.0137)	(0.0146)	(0.0166)	(0.0170)	(0.0211)	(0.0226)	(0.0216)
−0.160***	−0.141***	−0.133***	−0.107***	−0.0882***	−0.0749***	−0.0533*	−0.0447*	−0.0364
(0.0228)	(0.0227)	(0.0243)	(0.0201)	(0.0211)	(0.0228)	(0.0305)	(0.0252)	(0.0361)
−0.193***	−0.211***	−0.228***	−0.226***	−0.220***	−0.214***	−0.173**	−0.143	−0.122***
(0.0614)	(0.0552)	(0.0574)	(0.0614)	(0.0612)	(0.0616)	(0.0786)	(0.0906)	(0.0470)
0.124***	0.134**	0.149***	0.150**	0.151**	0.157***	0.148***	0.160***	0.158***
(0.0432)	(0.0529)	(0.0561)	(0.0626)	(0.0694)	(0.0566)	(0.0409)	(0.0317)	(0.0249)
−0.129***	−0.131***	−0.120***	−0.102***	−0.0855**	−0.0574	−0.0340	0.000836	0.0263
(0.0226)	(0.0270)	(0.0331)	(0.0370)	(0.0384)	(0.0425)	(0.0547)	(0.0635)	(0.0475)
0.0307	0.0246	0.0204	0.0211	0.0178	0.00280	−0.0122	−0.00690	−0.00560
(0.0240)	(0.0225)	(0.0233)	(0.0285)	(0.0322)	(0.0347)	(0.0415)	(0.0558)	(0.0468)
−0.100***	−0.113***	−0.130***	−0.133***	−0.138***	−0.147***	−0.144***	−0.127**	−0.107**
(0.0181)	(0.0163)	(0.0178)	(0.0239)	(0.0292)	(0.0381)	(0.0524)	(0.0623)	(0.0516)
0.505***	0.591***	0.686***	0.791***	0.766***	0.702***	0.729***	0.743***	0.850***
(0.0341)	(0.0472)	(0.0352)	(0.0631)	(0.0878)	(0.111)	(0.142)	(0.167)	(0.147)
0.899***	0.965***	1.026***	0.948	0.996	1.095**	1.199***	1.229***	1.268***
(0.0641)	(0.118)	(0.103)	(1.169)	(0.903)	(0.480)	(0.346)	(0.233)	(0.153)
−6.889***	−7.572***	−8.174***	−7.685	−8.211	−9.060**	−9.959***	−10.37***	−10.86***
(0.535)	(0.984)	(0.836)	(9.192)	(6.979)	(3.650)	(2.545)	(1.653)	(1.099)
44,174	44,174	44,174	31,778	31,778	31,778	31,778	31,778	28,729

Note: Bootstrapped standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

counts as one would expect if we accept the hypothesis that forward citations are a proxy for patent value.

The *Generality* and *Originality* indices enter with positive and significant coefficients over the age of the patent. In regard to generality: patents that are cited by a wider variety of patents (in this case variety is defined in terms of technological heterogeneity) are likely to receive a higher number of citations in the future. This result is consistent with Hall, Jaffe, and Trajtenberg (2001) who find that highly cited patents tend to have higher generality scores. For originality, we find that the wider variety of prior art that a patent draws upon, the more forward citations it will receive on average. Hall, Jaffe, and Trajtenberg (2001) describe an observed correlation between originality and backwards citations; they do not mention a correlation with forward citations.

Our results show that *Claims Count* is significant and positive, as we would expect from the literature (Lanjouw and Schankerman 2001, 2004). And while this result might appear on the surface to be obvious, since a larger number of patent claims imply a larger amount of prior art to which future patents could cite, the finding actually has more substance. Through discussions with patent examiners, we understand it to be common practice for examiners to cite to references in the systems and methods sections of the prior art, not the claims, and therefore number of claims would not be expected to correlate as directly with higher citation counts.

Our proxy for patent scope, *Count of IPC Subclasses* is positive and significant for most of the patent life. We expect these findings for *Count of IPC Subclasses* from the literature (Lerner 1994).

Backward Patent Citations and *Backward Non-patent Citations* both positively and significantly affect forward citation rates. Our non-patent citation finding fits with Czarnitzki, Hussinger, and Schneider (2011)), and backward patent citations are found to play a bigger role in determining forward citation counts than non-patent citations.

Lastly, the fixed effects for the diverse IPC sections display different signs, implying, as expected, that patents from varied technological groups are cited at different rates.

It has been hypothesized that some assignees try to "bury" prior art by submitting patent applications with an overwhelmingly large number of cited documents in the hopes of fulfilling their legal requirement to disclose prior art, while limiting the examiner's ability to carefully compare the new claims with those of each piece of prior art. The *Originality Index*, *Backward Patent Citations*, and *Backward Non-Patent Citations* would be highly correlated if these types of applications were skewing the results. As shown in Table 2, this does not appear to be the case.

Table 2: Correlation among selected independent variables.

	Originality index	Count of IPC subclasses	Backward patent citations	Backward non-patent citations
Originality index	1			
Count of IPC subclasses	0.3916	1		
Backward patent citations	0.1151	0.0778	1	
Backward non-patent citations	0.1016	0.1224	0.4775	1

5 Valuation

In this section, we illustrate the use of the estimated models in patent valuation. We give three examples that increase in complexity. Table 3 gives the relevant statistics for each example.

Table 3: Examples for citation analysis using future predicted citations.

	Number of forward citations				
	Observed citations	Predicted future citations		Total citations	
		Point estimate	Standard error	Point estimate	Standard error
Example 1: Two one-year old patents, same technology group					
Patent A	0	61.6	3.733	61.6	3.733
Patent B	0	142.3	31.056	142.3	31.056
Difference (A-B)	0	−80.7	28.222	−80.7	28.222
Ratio (A/B)	–	0.43	0.055	0.43	0.055
Example 2: Two four-year old patents, same technology group					
Patent A (4 years old)	8	128.2	16.569	136.2	16.569
Patent B (9 years old)	11	72.7	4.736	83.7	4.736
Difference (A–B)	−3	55.5	15.613	−52.5	15.613
Ratio (A/B)	0.73	1.76	0.223	1.63	0.192
Example 3: Patent A is four years old, patent B is nine years old, same technology group					
Patent A (4 years old)	17	138.9	6.626	155.9	6.626
Patent B (9 years old)	25	48.9	2.576	73.9	2.576
Difference (A-B)	−8	90.0	7.582	82.0	7.582
Ratio (A/B)	0.68	2.84	0.217	2.11	0.125

Note: All standard errors are bootstrapped with 100 replications using month-year clusters.

5.1 Example 1: Two One-Year-Old Patents in the Same Technology Group with no Citations

The evaluator's task is to assess the value of patent A, which was published in January of 2014 and is in technology groups (IPC sections) A, G, and H. The evaluator has identified patent B of the same age and technology fields that has been licensed at a freely negotiated fee. Neither patent has received any citations. What is a reasonable fee for patent A? Using current cites only, the two patents might be considered equally valuable. But the fact that they both have the same number of cites (zero) mainly reflects the fact that they are too young to have cites. Using the model in Table 1 for year 1 (i. e., patents that are one year old), patent A is predicted to receive 61.6 citations (standard error: 3.733) and patent B is predicted to receive 142.3 citations (standard error: 31.056) over their remaining lives. The difference is −80.7 with a standard error of 28.222,[27] such that the hypothesis of that Patent A will obtain as many or more citations as patent B can be rejected at the usual levels of confidence. So if the evaluator assumes that a patent with more citations is more valuable, then the value of patent A is *less* than the licensing fee that has been charged for patent B. The ratio of predicted future cites for patent A relative to patent B is 0.43 (standard error: 0.055). If the evaluator assumes that value is proportional to number of citations, then the value of patent A is 43 % of the licensing fee of patent B, with a confidence interval of 33 % to 54 %.

5.2 Example II: Two 4-year-old Patents in the Same Technology Group with a Small Number of Citations Each

Patent A, which is being valued, has received eight citations, and patent B, which has a licensing fee, has received 11 citations. The two patents are both four years old and are in the same technology groups. Using current citations only, patent A is considered less valuable than patent B and, under proportionality, is worth 27 % less than the licensing fee of patent B. Using each patent's full array of characteristics in the model for year $t = 4$, patent A is predicted to receive 128.2 (16.569) patents in future; when added to the eight citations that the patent has already received, the total citations is predicted to

27 The standard error on the difference is less than the square root of the sum of squared standard errors on the two predictions because the two predictions are correlated through their reliance on the same model parameters.

be 136.2 (16.569).[28] Note that the standard error for the total number of citations is the same as for the predicted future citations because the current number of citations is observed rather than estimated. Patent B is predicted to receive 72.7 (4.736) citations in the future for a total of 83.7 (4.736). The difference is 52.5 (15.613), and the hypothesis that patent A receives fewer citations that patent B can be rejected. The ratio of total patents is 1.63 (0.192). Under a cardinal relation of citations and value, patent A is worth more than B, which is opposite of what would be concluded by looking only at current citations and not considering the other observable attributes of the patents. Under a proportional relation, patent A is worth 63 % more than patent B's licensing fee; however, the confidence interval is quite wide: from 25 % to 100 %.

5.3 Example III: Patents of Different Age

The usual approach is to adjust cites for age differences. The evaluator might do this by using Hall, Jaffe, and Trajtenberg (2005) model to predict future citations based on technology group and age. This adjustment accounts for the patents' age difference but does not account for other differences between the patents. The models in Table 1 can be used to adjust for the other observed characteristics of the patents at the time of evaluation. For example, consider four-year-old patent A with 17 citations and nine-year-old patent B with 25 citations. Both patents are in the same technology group. Using the model for $t = 4$, patent A is predicted to obtain 155.9 (6.626) citations including those already obtained. Using the model for $t=9$, patent B is predicted to obtain 73.9 (2.576) citations in total. The difference is 82 (7.582), such that the hypothesis that patent A receives fewer citations than patent B can be rejected, which suggests that patent A is worth more than patent B. The ratio is 2.11 (0.125), which, under proportionality, implies that patent A is worth 111 % more than patent B, with a confidence interval of 86 % to 135 %.

Some evaluators compare each relevant patent to a "cohort" of patents of similar age and technology groups. The same procedure can be used for each patent in the cohort, to allow the evaluation to be based on predicted future citations in addition to the current citations. Also, evaluators often allocate an established value for a portfolio of patents to the individual patents within the

28 Note that the standard error for the total number of citations is the same as for the predicted future citations because the number of current citations (8) is observed, not estimated.

portfolio. The procedures for this allocation can be generalized to include predicted future citations for each patent in the portfolio as well as current citations.

6 Data and Computer Codes

The data and Stata codes that were used for the models in Table 1 and the three examples above are available from the authors on request. Analysts can use these materials to calculate predicted citations for patents of interest to the evaluator, and to obtain standard errors of relevant statistics in the comparison. The analyst can also revise the codes to estimate models with different specifications, and/or to calculate standard errors by different methods. The analyst needs to provide the explanatory variables for each relevant patent: our codes do not automate this task. These variables can be obtained from Thomson or other patent databases.[29]

7 Conclusions and Further Analysis

The standard practice in forward citation analysis relies solely on observed forward citations at the time of evaluation. This procedure suffers from the "zero" problem, in that it predicts young patents without any forward citations yet will continue to receive no citations. The model also predicts that two patents with the same number of citations after the same number of years will receive the same number of citations in the future.

In this study, we provide a mechanism to generalize this procedure. We find that observable patent characteristics, beyond the number of citations the patent has already received, relate significantly to future forward citations. Moreover, these characteristics are found to be significant indicators long into the patent's life.

While most of our independent indicators positively correlate to higher forward citation counts, we find *Reassignment* and *Individual Assignee* both significantly negatively affect the number of future forward citations a patent will receive. These findings have not been clearly documented in the literature to

29 The most complex variables to calculate are the originality and generality indices, since they require IPC codes for each of the cited and citing patents respectively. If these variables cannot be calculated, then the evaluator can re-estimate the models without them and make predictions on the alternative model.

our knowledge and the larger question of how/when/why patents are reassigned, whether reassignment rates are higher for patents assigned to individuals, and the value distribution of reassigned/individually owned patents as compared to other types of patents necessitates further study.

The passing of the American Inventors Protection Act (1999) required the publication of patent applications for the vast majority of filings made after 29 November 2001.[30] It is our understanding that the number of citations made to patent applications after this time is non-negligible, and that some experts in patent valuation are beginning to consider citations to the applications as well as the granted patents in a family for patents with published applications. Developing a forecasting model for family citations, therefore, may become more applicable if this procedure becomes the norm.

Last, but certainly not least, it is important to consider the possibility of gamesmanship, by which characteristics to be used in valuation procedures (e. g., those in the current study) are manipulated by patent holders for the purpose of obtaining higher valuations. The growth of non-practicing entities (sometimes referred to as patent trolls) makes this possibility quite real. Patent holders know that forward citations are used in current valuation methodologies, and it would be naïve to assume that non-practicing entities, whose only assets are patents and whose profits consists largely of litigation settlements, would not manipulate patents' statistics to raise their valuations. In fact, economic theory of self-interest implies that such gaming is rational and expected from any patent holder. The future may necessitate models that mitigate this potential gamesmanship, while still discerning estimates of patent value from patent characteristics and statistics.

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