Market Value and Patent Citations: A First Look

Bronwyn H. Hall
UC Berkeley, Oxford Univ., and NBER
(joint work with Adam Jaffe
and Manuel Trajtenberg)

Introduction

Question: how to value intangible knowledge assets?

One answer: relate measures of economic value (profit, market value, consumer willingness-to-pay) to measures of innovation (R&D spending, patent counts,…)

Difficulties:

- R&D spending an input to innovation, not an output
- R&D not broken down by technology field
- Patents add very little additional info in the presence of R&D

Our Questions

1. Do the number of cites received by patents help to explain "value" in the presence of
   a. Patent counts themselves
   b. R&D spending
2. What is the timing? Is current market value better explained by past cites received or future cites not yet received?
3. Are self-citations more or less valuable than other citations?

Might citations be useful?

- R&D capital is an important explanatory variable for market value (in US and UK, $R^2 \sim 0.25$). Patents also matter, but are much less important, add little in presence of R&D (Griliches, Hall, Pakes 1987).

  WHY? Patent value distribution is very skew
- Citations have been used to proxy for spillovers and to describe research trajectories (Jaffe, Trajtenberg, and Henderson 1993, Ham 1998, etc.). Limited evidence that they correspond to anything "economic."

Correlations with firm market value can help to validate the use of citations in economic analysis.

Outline

- What are patent citations?
- The context: previous research on innovation valuation(very briefly)
- How do we use citations?
  - Measurement and modeling issues
- Results
- Future research

What are patent citations?

Somewhat like Citations in a Research Paper:

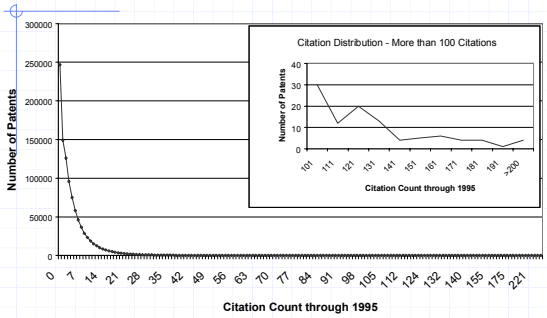
- References to prior technology, either patents or other scientific literature on which the current patent builds or which it uses
- Some added by the USPTO examiner (the "referee")
- Some added after the fact (not used by inventor)
- Some added to avoid infringement (limit scope, defense against suits)
- Some added for "teaching" (like survey articles)

(See Jaffe, Trajtenberg, Fogarty inventor survey, NBER)

Some facts about citations

- Prior work finds more valuable patents are cited more.
- One quarter of patents receive no citations.
- 0.01% receive more than one hundred citations.
- Lag distribution is skew to the left with a mode at about 3.5 years. Most cites happen by 10 years, but there can be long lags (30 years).
- Number included per patent has increased recently with advent of computerized search.

Figure 3
Citation Distribution



Early evidence using patent citations to predict value

- Trajtenberg (1990) - consumer welfare for CAT scanners and citations
- Klock and Shane (1995) - market value of citation weighted patents in semiconductors
- Austin (1993) - event studies on citation-weighted biotech patents

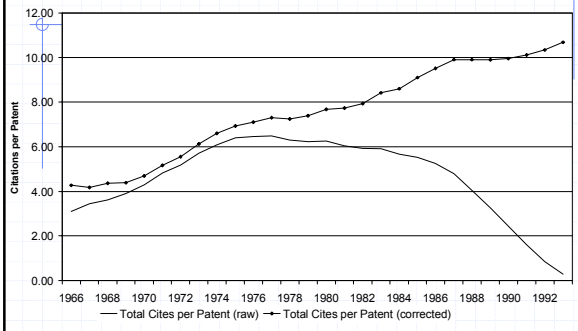
Recent work on citation value

- Hirschey et al (1998); Lev et al (1998) - accounting-based work similar to ours.
- Sampat (1998) and Ziedonis (1998) - correlating university licensing revenue with citations. (reverse regression)
- Harhoff, Narin, Scherer, and Vopel (1997) - German inventions patented in the U.S. Expected discounted profits correlated with citations.
- Lanjouw and Schankerman (1997) – correlated with litigation probability.

Our data and variables

- Approximately 4000 U.S. manufacturing firms 1976-1995.
- Variables: capital stock, leverage, sales or earnings growth, market value (debt plus equity), innovation measures:
  - R&D stock
  - Patent stock
  - Citation-weighted patent stock (i. e., Cite stock)
- All stocks constructed with 15% depreciation.
- Citations corrected for truncation.

Figure 2
Citation Counts before and after Truncation Correction



Constructing knowledge stocks

$$K_t = (1-\delta)K_{t-1} + R_t$$

where K_t = knowledge stock at end of period t
R_t = flow of R&D or patents during t
δ = depreciation rate of K, usually = 15%

Note: if R grows at a constant rate g over time,

$$K_t \cong R_t/(\delta + g)$$

$$\Rightarrow K_t \cong R_t/(0.15+0.05) = 5R_t \text{ in this sample}$$

=> Low coefficient on K or R may imply δ >>0.15

"Theory"

How to choose a functional form for the value equation?

Ideal: model investment in tangible and knowledge (intangible) assets under uncertainty using a dynamic program for the firm. Yields a value function for the assets of the firm.

Practice: use an ad hoc hedonic equation to price the assets (generalized Tobin's q approach):

$$V_{it}(A_{it},K_{it}) = q_t [A_{it} + \gamma K_{it}]$$

$$\log V_{it} - \log A_{it} = \text{Log } Q_{it} = \log q_t + \gamma K_{it}/A_{it}$$

where Q is Tobin's q, and γ is the relative shadow value of K

Hedonic regression for market value

Practice(2): (without using $\log(1+\varepsilon) \cong \varepsilon$)

$$\text{Log } Q_{it} = \log q_t + \log(1+\gamma_t Kit/A_{it}) + \alpha_t d(K_{it} = 0)$$

where $Q_{it} = V_{it}/A_{it}$ (market to book or Tobin's Q)

Interpretation:

α_t = Premium or discount for the absence of K assets.

q_t = overall market level (approximately one).

γ_t = Relative shadow value of K assets (=1 if depreciation correct, investment strategy optimal, and no adjustment costs).

1. Basic results

- Year-by-year specification compares the different K measures (Figure 4) – horse race.
- Exploration of the functional form using pooled data, constant coefficients (Tables 2, 3, and 4).

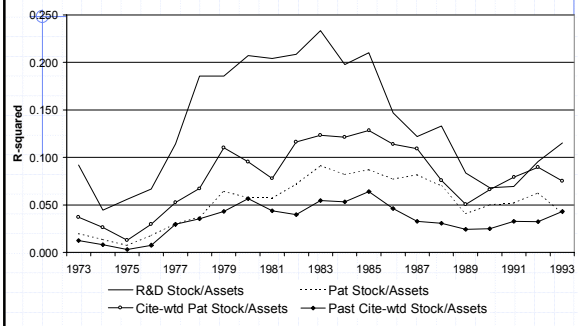
  Conclusion: R&D stock has the highest explanatory power for market value, but citation-weighted patent stocks are significantly more related to value than ordinary patent stocks

Table 2 (Excerpt)
"Horse Race" Regressions Comparing R&D, Patents, and Cites
U. S. Manufacturing Firms that have R&D

	Period: 1976-1984		
Number of observations	10,761		
R&D Stock/Assets	1.741 (.070)		
D(R&D=0)	- -		
Patent Stock/Assets		0.493 (.042)	
Cite Stock/Assets			0.087 (.006)
D(Pats=0)		0.252 (.019)	0.282 (.018)
R-squared	0.249	0.127	0.161
Std. Err.	0.683	0.737	0.722
Ratio of Total Pats or Cites to Total R&D ($1980M)		0.550	4.125
Coefficient scaled by ratio of totals	1.741	0.271	0.359

Heteroskedastic-consistent standard errors.
All equations have a complete set of year dummies.
Stocks are computed using 15 percent annual depreciation rate.
Citation stocks are patent stocks weighted by all the cites they received before 1994 plus an estimate o

Figure 5a
R&D Performing Firms - R-Squared from Tobin's Q Equation



2. Exploration of cites variable

- Table 3 - include stock of R&D, patents per R&D, and cites per patent. Cites per patent are more important than patent yield itself:

  Increase of one cite per patent is associated with an increase of 3-4% in market value
- Table 5 - break up cites per patent into five ranges: 0 to 4, 4 to 6, 6 to 10, 10 to 20, over 20

  Only the latter three categories are positive; the other two are zero – 50-75% boost to market value if citations per patent average above 20!

Table 5 (excerpt)
The Shape of the Citations-Value Relationship
U.S. Manufacturing Firms 1979-88

	R&D-Doing Firms (12,771 obs)		
Indep Variable	K and C/P	K, P/K, C/P	P/A only
R&D Stock (K)/Assets	0.961 (.041)	0.995 (.043)	
D(R&D=0)	--	--	
Pat Stock/A			0.520 (.039)
Pat Stock/K		0.024 (.006)	
D(Pats=0)	0.246 (.022)	0.270 (.023)	0.460 (.024)
4-6 Cites per Patent (3,211 observations)	-.019 (.022)	-.019 (.022)	-.058 (.023)
6-10 Cites per Patent (3,900 observations)	0.085 (.021)	0.086 (.021)	0.081 (.022)
10-20 Cites per Patent (1,853 observations)	0.357 (.027)	0.357 (.027)	0.456 (.028)
>20 Cites per Patent (508 observations)	0.583 (.047)	0.590 (.047)	0.835 (.044)
R-squared	0.245	0.249	0.180
Standard error	0.710	0.708	0.740

3. Timing of the relationship

- Two separate cite-weighted patent stocks
  - Pre and post the date of market value measure.
- Past stock is slightly negative in the presence of the total stock, which implies future citations are what matter.
- Orthogonal decomposition - unpredictable citations have a higher coefficient than predictable, both are positive.

Table 4 (excerpt)
Splitting Citation Stocks into Past and Future
U.S. Manufacturing 1979-88

	Dep. Var.: logQ		
Independent Variable	(1)	(2)	(3)
Cite Stock/A	0.117 (.006)		
Past Cite Stk/A		-0.056 (.019)	
Future Cite Stk/A		0.162 (.008)	
Pred. Cite Stk/A			0.106 (.005)
Unpred. Cite Stk/A			0.159 (.008)
D(P=0)	0.204 (.012)	0.202 (.012)	0.202 (.012)
R-squared	0.140	0.145	0.145
Standard error	0.740	0.737	0.737

4. Self citations

- Self cites = citations to patents owned by the same firm.
  - More valuable => "owning" a technology trajectory, cumulativeness is valuable
  - Less valuable => cite whatever is at hand, does not necessarily signify any value
- Measures
  - Share of citations that are self cites
  - Self cites/patent – highly skew distribution
  - Dummy for zero self cites

Self-citation share distribution

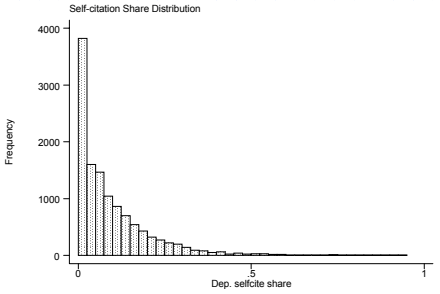
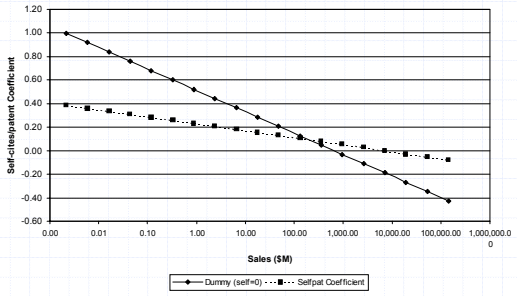


Table 6 (excerpt)
Self-Citations and Market Value
U.S. Manufacturing Firms 1979-88

12,030 Firm-years 1979-88			
Variable	(1)	(3)	(4)
K/Assets	1.203 (.056)*	1.385 (.078)*	1.081 (.069)*
D(K=0)	0.017 (.017)	0.072 (.019)*	0.009 (.018)
Pat stock/K		0.032 (.008)*	0.015 (.006)*
Citations per patent		0.049 (.004)*	0.045 (.004)*
Self citations per patent		0.058 (.015)*	0.104 (.017)*
Log (S) = log(sales)-mean			-.0480 (.0059)*
Log (S)*Self cites per patent			-.0258 (.0057)*
D(no self citations)		0.161 (.051)*	0.127 (.047)*
Log (S)*D(no self)			-.079 (.065)
Chi-squared versus col. (1)		622.6	815.4
Degrees of freedom		4	7
Chi-squared per d.f.		155.7	116.5

Self-citation value and firm size



Answers to our questions

1. Do the number of cites received by patents help to explain "value" in the presence of
   a. Patent counts themselves - yes
   b. R&D spending - yes
2. What is the timing? Is current market value better explained by past cites received or future cites not yet received? - future cites
3. Are self-citations more or less valuable than other citations? - more valuable

Questions for further work

- Controlling for field - citations and/or patents
- How far into the future does the market see citations?
- Generality - is it worth more or less? Does it depend on the firm?