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What is a Citation Worth?

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ABSTRACT

A robust finding in all studies is that citations are a positive and significant determinant of earnings over almost all of the observed range of citation levels. The marginal value of a citation (when the level of citations is zero) varies between $50 and $1,300. Some differences in marginal values may be due to differences in citation practices among disciplines while others may be due to differences among the studies in the control variables included in the salary regressions. Finally, no gain in explanatory power results from the inclusion in the salary regression of the costly nonfirst-author citation measure.

I. Introduction

Although exceptions are common, the main function of most citations is to refer the reader to important work relevant to the paper and to credit important predecessors for their contribution to the current work (Cole and Cole 1973 and Stigler 1982a). Such citations represent evidence that the person cited has done work that is viewed as relevant to the current research frontier and useful to those attempting to extend the frontier.

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No consensus yet exists on the economic significance of citations. Some (e.g., Cole and Cole 1967) have argued that citations can be viewed as a form of recognition and hence are a nonpecuniary reward for scientific activity. Others (e.g., Diamond 1984) claim that a citation is best viewed as a proxy for a certain sort of human capital of a research scientist, namely the ability to do quality research at the frontiers of a discipline. To the extent that the research university's output is primarily the advance of knowledge, such ability is an important input in the university's production function. Since the product of nonresearch-university employers of research scientists differs, we would expect that the marginal product of a citation would also differ depending on the contribution of research ability to the "firm's" product. For example the ability to do quality research at the frontier would be more important at a research university than at a teaching university or at a government or private lab. The marginal value of a citation would vary accordingly.

Rather than discuss further the theoretical interpretation of citations we instead focus on what is known from the estimation of earnings functions about citations as a determinant of salary. Since the use of citation data for evaluating individuals, departments, and journals is increasing not only within the economics profession (Davis and Papanek 1984, Liebowitz and Palmer 1984, Laband 1985) but also within the larger scientific community, learning the value of a citation should be of interest for practical in addition to scientific reasons.

In evaluating empirical results, the economics profession has focused increasing attention on the robustness of the results to changes in data and to changes in econometric specification (Feige 1975, "Editorial Comment" in *JPE* 1975, Leamer 1983; Leamer and Leonard 1979). The present study compares the estimates from two previous studies with as yet unpublished estimates in order to learn how the marginal value of a citation changes with differences in data or model specification.

II. What a Citation is Worth

The role of publication in determining academic salaries has been the object of much research (Hansen et al. 1978, Katz 1973, Siegfried and White 1973, Koch and Chizmar 1973). In "What is an Article Worth?" Tuckman and Leahey (1975, 957) note a limitation that their research shares with most of the rest of the literature: "because data are not available on the quality of a faculty member's publications, direct adjustments for quality cannot be made." In recent years the growing awareness of the *Science Citation Index* and the *Social Science Citation Index* has stimulated a few researchers to compile data sets that include the number of citations made to a scientist's work as a measure of the quality of the scientist's publications.

Hamermesh et al. in one study (1982, labelled *A* here) and Holtmann and Bayer in another (1970, labelled *B* here) have estimated earnings regressions that include citations as an independent variable. Table 1 summarizes the characteristics of the regressions in these two studies as well as additional regressions for new data (labelled *C* and *D*). The new data in *C* and *D* constitute the first longitudinal data set with information on both salary and number of citations. Longitudinal data are of value for learning the changes over time in the reward structure of science and in the relative quality of different cohorts of scientists. Such data are also useful for isolating life-cycle effects on the productivity and salaries of scientists (Diamond 1986). Sample *D*, in addition to being longitudinal, also contains information on number of articles and authorship category (sole author, first author, second author, etc.). One main value of the *D* data set, to be discussed later in this paper, is that it includes citations to nonfirst-author articles in addition to the standard first-author citation count. Elsewhere (Diamond 1985) the *D* sample has been used to learn whether the order of names on an article effects the returns to authorship. For more details on the *C* and *D* data sets see Diamond (1985 and 1986).

The marginal value of a citation that is implied by the regression coefficients is reported in Table 2 for the main regressions in each of the studies. All marginal values are in 1984 dollars (calculated with the CPI). Since the regressions using the Hamermesh and the two Diamond samples specify the log of salary as the dependent variable, a given level of salary was used to calculate the marginal values for these samples. For the Hamermesh sample the marginal values were calculated at the pooled mean (kindly supplied by Hamermesh) which was $51,378 in 1984 dollars. For the Diamond samples the marginal values were calculated at subsample means expressed in 1984 dollars. Specifically, for math, physics, chemistry, and economics, the sample means were $52,272; $53,884; $55,993; and $63,269; respectively.

Several aspects of the marginal values reported in Table 2 may merit brief comment. Citations are a statistically significant (at the .05 level) determinant of salary in all of the studies summarized even when other measures of quality, such as number of articles published and IQ are controlled for. In all regressions that were specified to permit a nonlinear effect of citations on salary (i.e., the Hamermesh and the two Diamond studies) the marginal value of an additional citation diminishes as the level of citations increases. The negative marginal value occasionally encountered at the highest level is probably more of an artifact of the functional form estimated than it is a discovery about the real world.[1]

The marginal value of a citation when the level of citations is zero falls within the range $50–$1,300. Differences in citation practices among disciplines are probably the most important determinants of differences in the marginal value of a cita-

1. The marginal values in the last line of Table 2 were calculated using the coefficients from Regression (2) in Table 3. When that regression was estimated with a citations cubed term, the cubed term was statistically significant and the marginal value of a citation was positive even at a level of 100 citations. The specification with the cubed term is not reported, however, in the interests of comparability with the regressions in Hamermesh et al. (1982) and because cubed terms are seldom significant in regressions for the other five departments in the C sample.

Table 1
Characteristics of Studies Reporting Effect of Citations on Salary

Characteristic	Study			
	(*A*) Hamermesh et al.	(*B*) Holtmann-Bayer	(*C*) Diamond	(*D*) Diamond
Career stage	full professors	5–7 years after Ph.D.	post-Ph.D. through full professor	post-Ph.D. through full professor
Disciplines	economics	the full range of the natural sciences with the notable inclusion of mathematics, statistics, and psychology	mathematics, physics, chemistry, economics	mathematics
Time period	1979–1980 academic year	1964	1961–1979	1965–1977
Number of scientists	148	3,506	297	45
Number of observations	148	3,506	3,647	506
Quality of departments	7 public universities	full range	6 departments ranked in the top 12 of their fields and located either at U. of Cal. at Berkeley or U. of Ill. at Urbana	U. of Cal. at Berkeley mathematics department

Correction for multiple author problem	included in unreported regressions a statistically insignificant alphabetical order variable	none	included in unreported regressions a statistically insignificant alphabetical order variable	included citations to non-first-authored articles in citation counts
Variables controlled for	experience, administration dummy, books and articles for some regressions	academic field; research, teaching, administration; dummy geographical region; experience; sex; time lapse between B.A. and Ph.D.; high school IQ; quality of Ph.D. department; rank of teaching position; quality of employing institution	experience, cohort, and period effects	experience, cohort and period effects; quantity of publications
Regression specification	OLS on additive functional form with log salary as dependent variable; includes experience squared and citations squared	OLS on additive and Cobb-Douglas functional forms with salary and log salary as dependent variables; no squared independent variables	OLS on additive functional form with log salary as dependent variable; includes experience squared and citations squared	OLS on additive functional form with log salary as dependent variable; includes experience squared

Table 2
What a Citation is Worth

Main Sample	Subsample	Number of Observations in Subsample[a]	Marginal Value of a Citation in $ at Citations = 0	at Citations = 10	at Citations = 100
A	Seven pooled economics departments	148	478	426	−36
A	Economics department #1 (includes books and articles)	25	365	344	159
A	Economics department #5 (includes books and articles)	21	1,285	709	−4,470
B	Business employment; additive form	965	51	51	51

B	Government employment additive form	1,067	54	54	54
B	Academic employment; additive form	1,463	63	63	63
C	Pooled math	1,352 (110)	397	392	355
C	Pooled physics	1,616 (129)	97	94	65
C	Urbana chemistry	379 (28)	54	54	52
C	Berkeley economics	300 (30)	186	170	16
D	Berkeley mathematics	506 (45)	392	387	−131

[a]For longitudinal data sets C and D the number of observations exceeds the number of persons because data for a person could be observed in more than one year. The numbers in parentheses report the number of persons in data sets C and D.

tion. In particular, in disciplines such as economics and mathematics, where the quantity of publication and citation tends to be relatively low, they tend to have relatively high marginal values, while in disciplines such as chemistry and physics, where the quantity of publication and citation tends to be relatively high, they tend to have relatively low marginal values.[2]

Less clear is the reason for the relatively low marginal values obtained from the Holtmann and Bayer study (1970), but a couple of explanations are possible. One is that the Holtmann and Bayer regressions include as independent variables several measures of quality besides citations. The omission of these variables from the analysis in the Hamermesh study and the two Diamond studies would bias the coefficient on citations upward if the various measures of quality were positively correlated. A second possible explanation for the lower marginal values in Holtmann and Bayer may be that all of the samples in the other studies are limited to scientists employed by research-oriented universities, whereas the Holtmann and Bayer samples include many scientists employed either in government and private industry or else in lower quality educational institutions. Perhaps these latter employers value citations less than do research-oriented universities. Note, as reported in Table 2, that the marginal value of a citation is higher in academic employment than in business or government employment.

III. Total vs. First-Author-Only Citation Counts

Simply counting the citations under a scientist's name in a volume of the *Science Citation Index* is the least time-consuming citation count. As a measure of the quality of a scientist's current research, such counts have been criticized in various ways. Some have suggested that citations would be a better proxy for quality if some kinds of citations were excluded from the count. The most commonly mentioned candidates for exclusion have been: self-citations (Stigler 1982a, 186–88), citations to older works, citations to texts, citations to edited volumes, citations from articles published in minor journals, citations from articles outside the scientist's main field, and citations that are critical. In a similar vein, Stigler (1982a, 202) has suggested that some weighting might be appropriate when one article references another several times. Without such a weighting, the problem is that a citation from the *Science Citation Index* could equally represent a single irrelevant reference in an obscure footnote or twenty crucial references in the main line of the argument.

2. I compiled data for the number of publications in 1972 from the *Directory of Graduate Research* for chemistry, *Physics Abstracts* for physics, *Mathematical Reviews* for mathematics, and the *Index of Economic Articles* for economics. For the members of the data sets used in this study the mean number of publications in 1972 was 6.2 for chemists, 2.4 for the physicists, 0.8 for the mathematicians, and 1.1 for the economists. Some have claimed that one reason for the high publication rates in the hard sciences is that scientists in those disciplines are dividing their articles into "least publishable units" in order to increase the length of their publication list (Broad 1981, Ney 1983, Trigg 1983).

Although all of the just mentioned modifications to the standard count are worth considering, the most frequently suggested modification has not yet been mentioned: the addition to the standard count of citations made to articles of which the scientist was not the first author. The results reported in Table 2 did not include such additional citations. The reason for the omission is that under a scientist's name the *Science Citation Index* only includes citations to those articles for which the scientist was the first author. A total citation count is thus much more costly than a first-author citation count because the researcher must first find, using some source other than the *Science Citation Index*, an authoritative list of all the scientist's multiple-authored publications and then the researcher must separately look up in the *Science Citation Index* each nonfirst-author article under the first author's name. The adequacy of first-author citation counts has been much discussed in the literature (Lindsey 1980, Long et al. 1980, Long and McGinnis 1982, Lindsey 1982, Rustum et al. 1983) but so far no study has estimated the gain in explanatory power when citations to nonfirst-author articles are added as an independent variable in the salary regression.

To test for any bias introduced by the omission of nonfirst-author citations and to address the related issue of the value of citations to multiple-author articles (see Diamond 1985b), citation counts for the University of California at Berkeley mathematics department were constructed that included citations to coauthored articles of which the mathematician was not the first author. Multiple authorship in mathematics is considerably less common than in the physical sciences. Total citation counts for mathematics are therefore less costly to obtain, but also perhaps less informative, than total citation counts would be in the physical sciences. Berkeley was chosen from among the universities with highly ranked departments because it, as a state-supported school, is required by law to make faculty salary data publicly available. The basic sample was obtained from mathematics department faculty listings in a Berkeley catalog from the late 1970's. Since these listings underrepresented those who were nearing the end of their careers in the early years of the *Science Citation Index* (i.e., the 1960's) the sample was augmented by the addition of all those full and emeritus professors listed in a catalog from the middle 1960's who were not listed in the catalog from the late 1970's. From these samples, any mathematician was dropped for whom biographical information was never available from any of the editions of Cattell's *American Men and Women of Science*. Occasionally a mathematician was also omitted from the sample if his name was identical to that of another mathematician or scientist as listed in the *Science Citation Index* since it would have been too costly to distinguish citations to his work from those to the work of the other scientist with the same name.

Longitudinal data for the years 1965–77 were used to estimate the effect of experience, the cumulative lifetime[3] number of mathematics articles, and the annual

3. In regressions not reported we also included the annual number of mathematics articles in addition to and instead of the lifetime number of articles. The two counts were highly collinear and when both were included, only lifetime articles was statistically significant.

number of citations on the natural log of annual salary. The main advantage of using a longitudinal data set in this context is that it allows the researcher to control for period and cohort effects in the salary regressions. Period effects might include, for instance, changes over time in the demand for mathematicians while cohort effects might include changes in the quality of cohorts due, say, to secular improvements in education.

Even for longitudinal data, however, a regression that incorporates experience, period, and cohort effects is underidentified (see, e.g., Heckman and Robb 1985). To see this consider the usual definition of each effect. For scientist i the cohort is the year of his Ph.D. (c_i), the period is the year of the observation (t) and experience in the year of the observation (e_i) is the difference between the two. Formally:

$$t = c_i + e_i$$

Since there is exact multicollinearity between the variables, a regression that included all three would be underidentified. Heckman and Robb suggest replacing either the period or cohort variables with more sharply focused behavioral variables. Unfortunately, for our data set no good behavioral variables exist that measure the kinds of effects intended by the period and cohort variables. To proceed with estimation of the effect of experience, one of various identifying assumptions must be maintained. For example, the cohort effect could be assumed to be zero (following Johnson and Stafford 1974), the period effect could be assumed to be zero (following Weiss and Lillard 1978), or the interaction between cohort and period effects could be assumed to be zero (following Bloom 1984). We estimated the regressions using the first two assumptions and found that the qualitative results for the citations and experience coefficients were robust.[4] Due to space constraints only the results are reported for the (randomly chosen) assumption where the cohort effects are set equal to zero.

Although some studies have shown unobserved person effects to be statistically significant in determining earnings, we do not control for them here. The justification is that, given our data, the tractability of a fixed effects model is greatly reduced due to differences in the number of observations for each scientist. The lack of control for person effects will not bias the estimates of the observed variables if the standard assumption is true that the observed variables are uncorrelated with the unobserved person effects (Rosen and Taubman 1982, 329).

The first regression includes number of articles as a regressor but does not include a measure of citations. In this respect it is representative of an earlier generation of salary studies (e.g., Tuckman and Leahey 1975). The measure of citations used

4. In order to test for structural shifts over time we also estimated the regressions with regressors for the interaction between time period and citations as well as the interaction between time period and number of articles. When either of the interactions is included as a regressor, the result is severe multicollinearity.

in the second regression is the simplest to obtain from the *Science Citation Index*. The measure includes only citations to an author's first-author works, but includes citations to all such works whether they are published or unpublished, whether they are books or articles, and whether they are in mathematics or science. The regressors in the third regression include, in addition to the first-author measure just mentioned, a measure of citations to nonfirst-author mathematics articles. In order to obtain the nonfirst-author measure, a list of each mathematician's nonfirst-author mathematics articles was obtained from the annual volumes of the *Mathematical Reviews.* The listings in the *Reviews* provided the name of the first author of each of the mathematician's nonfirst-author articles. By looking up each coauthored article under the first author's name we obtained a count of the citations to a mathematician's nonfirst-author mathematics articles.

The estimated coefficients for each of the regressions are reported in Table 3. Since number of citations and number of articles are positively correlated (Cole and Cole 1967), we would expect that in a regression omitting number of citations, the coefficient on number of articles would be biased upward. A comparison of the coefficient on number of articles in Regression (1) with the coefficients on number of articles in Regressions (2) and (3) confirms the expectation. Evaluated at the sample mean salary of $52,272 (in 1984 dollars) the marginal value of a mathematician's first article implied by the .0084 coefficient in Regression (1) is $439. In Regression (2) the marginal value implied by the .0044 coefficient is $230 while the marginal value implied by the .0039 coefficient in Regression (3) is $203. These marginal values are of the same order of magnitude as those found by earlier investigators using single equation earnings functions for other samples (Tuckman and Leahey 1975, 963; Siegfried and White 1973, 94; and Katz 1973, 472). Estimation of a multiequation model, however, resulted in higher marginal values than those reported here[5] (Hansen et al. 1978, 736).

The coefficient on citations to nonfirst-author math articles in Regression (3) is positive and significant, as we would expect. Perhaps also consistent with prior expectations, the coefficient on citations to nonfirst-author articles is smaller in magnitude than that on citations to first-author sources. At a level of 0 citations the marginal value (in 1984 dollars) of a citation to a nonfirst-author article is $314 while that of a citation to a first-author source is $402.[6]

5. In principle almost every variable is endogenous and, if tractable, should be so treated by the use of simultaneous equation models. The main problem with tractability is identification. The only attempt to estimate a multi-equation model in the scientific productivity literature is the paper by Hansen et al. Some of the identifying assumptions used in that paper are open to reasonable doubt, e.g., that experience only affects earnings through the productivity equation, but not directly in the earnings equation (1978, 731). Sufficient doubt thus remains about the identification of multi-equation models to justify the continued estimation of single equation models in this literature.

6. In an earlier study (Diamond 1985a) when citations to nonmathematics publications were excluded, it was found that the marginal return to a citation to a multiple authored article was higher than that to a singly authored article. "Multiple authored articles" in the earlier study included articles where the mathemetician was first author. The category is thus not equivalent to the "nonfirst-author articles" category used in this paper.

Table 3
Regressions to Determine Importance of Including Nonfirst-Authored Articles in Citation Counts[*a]

Variable	Regression (1)	(2)	(3)
Citations to first-author math and nonmath sources	—	.0075 (10.066)	.0077 (9.960)
Citations to Nonfirst-author math sources	—	—	.0060 (3.225)
Citations squared[b]	—	−.00005 (−7.870)	−.00006 (−7.817)
Cumulative number of math articles	.0084 (6.431)	.0044 (3.494)	.0039 (3.068)
Above squared	−.00003 (−2.506)	−.00001 (−.933)	−.000008 (−.630)
Years since Ph.D.	.0394 (14.731)	.0387 (15.934)	.0397 (15.945)
Above squared	−.0006 (−10.810)	−.0006 (−11.535)	−.0006 (−11.699)
Period 1969–73	−.0213 (−1.341)	−.0414 (−2.849)	−.0444 (−3.043)
Period 1974–77	−.1494 (−8.462)	−.1758 (−10.867)	−.1835 (−10.918)
Constant	10.317 (423.105)	10.310 (463.390)	10.304 (461.189)
Number of observations[c]	506	506	506
Number of mathematicians	45	45	45
R^2	.72	.77	.77

[a] t-statistics are reported in parentheses. The dependent variable was the natural log of salary. The omitted period is 1965–1968.

[b] In regression #2 the 'Citationas Squared' variable is the square of 'Citations to First-Author Math and Non-Math Sources' while in regression #3 the 'Citations Squared' variable is the square of the sum of 'Citations to First-Author-Math and Non-Math Sources' and 'Citations to Non-First-Author Math Sources'.

[c] The number of observations exceeds the number of mathematicians because data for each mathematician could be observed in up to 10 years.

Note, however, that the explanatory power, as measured by the coefficient of determination, is the same for both Regression (2) and Regression (3). A tentative inference from this finding is that the less-costly-to-obtain first-author citations may suffice if the objective is mainly to predict salaries (see also Rustum et al. 1983). To make the inference less tentative the robustness of the results should be tested using data from disciplines besides mathematics as well as additional data on mathematicians.

IV. Conclusion

A robust finding in all of the studies summarized here is that citations are indeed a positive and significant determinant of earnings over almost all of the observed range of citation levels. Not surprisingly, the marginal value of a citation decreases as the level of citations increases. The coefficient of determination for a regression including a measure of citations to nonfirst-author math articles as a regressor was the same as the coefficient of determination for a regression that omitted the regressor.

The results are compatible with one of a couple of interpretations. One is that departments are more or less explicitly taking citations into account in salary decisions. The other is that departments value the quantity and quality of a faculty member's research and these characteristics tend to be correlated with the number of citations. Under the former interpretation a faculty member's best strategy given Nash rationality might be to increase self-citations and to develop citation-exchange relationships with other scientists whereby the scientists tacitly agree to cite each other more frequently than is justified solely on the basis of the cogency of the cited material. Clearly if such strategies became common, universities would make less use of citations as a measure of faculty productivity. If the second interpretation is correct that citations are not directly used by the university as a measure of productivity, but only tend to be correlated with such productivity, then even under Nash rationality the faculty member would not have an incentive to adopt strategies to boost his citation count.

For the nonastute faculty member, the results reported here might highlight the importance of quality of research as a determinant of salaries at research-oriented universities. For the astute faculty member the results will confirm prior beliefs.

One fruitful avenue for future work would be to test, within the framework of an explicit model, whether citations are best interpreted as a nonpecuniary reward for scientific output or as a proxy for that output. If the reward interpretation is correct, then we would expect, holding all else constant, that salaries would be negatively related to citations whereas if the output interpretation is correct we would expect the opposite. Of the studies summarized here, that of Holtmann and Bayer (1970) does the best job of holding all else constant by including as independent variables several measures of a scientist's quality such as IQ, time taken to complete Ph.D. and quality of the university from which the scientist received his Ph.D. Since the coefficient on citations is always positive and significant in Holtmann and Bayer's regressions, the best present evidence is favorable to interpreting citations as a proxy for output. If citations are indeed a good proxy for output, then longitudinal data sets (such as those in the two Diamond studies) may be useful in resolving the ongoing controversy (Medoff and Abraham 1980, 1981, Brown 1983) concerning whether life-cycle differences in earnings are due to life-cycle differences in productivity or to other factors.

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