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The Impact of Citation Timing: A Framework and Examples

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Abstract: The literature on research evaluation has noted important differences in citation time patterns between disciplines, high and low ranked journals and types of publications. Delays in the receipt of citations suggest that the diffusion of knowledge following discovery is slower and given the passage of time the research contribution may be less valuable. This paper provides a framework for the comparison of different citation time patterns. Using principles drawn from the literature on stochastic dominance we show that comparisons of time patterns can be based on very general characteristics of cost of delay functions. When a particular function is used to represent the cost of delay, the magnitude of the impact of differences in citation time patterns can be assessed using simple exponential discounting. We demonstrate the application of this framework in assessing different citation time patterns by applying it to comparisons of 10-year citation records for: leading journals in economics, different business subject areas, journals in economics compared with those in neuroscience and the research output of individual economists.

JEL classification: A19; C81; J24
Keywords: Citations; Citation time patterns; Discounting citations; Research measurement

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1 Introduction

The publication of research in academic journals can be viewed as resulting in the creation knowledge assets. Increasingly citations are used as indicators of the returns to these assets and the value of the research undertaken. Citations to academic research occur over time and thus provide indicators of the time patterns of returns and the diffusion of knowledge. As with other assets, taking into account the time pattern of returns is likely to affect the assessment of the value of the research undertaken. The purpose of this paper is to suggest a general framework for the assessment of the impact of time on the returns to academic research as indicated by citations and to provide some examples of its use.

This paper adds to the existing literature by showing how simple criteria relating to the impact of delays in the time before research is recognized can provide a basis for general comparisons of different citation time patterns. We illustrate the use of this framework by using four examples drawn from the existing literature to show how these simple criteria provide almost complete unambiguous comparisons of citation time patterns when comparing leading journals in different disciplines (economics compared with neuroscience) and academic subject areas (business subjects). In contrast, for different journals within economics and economists, comparisons of citation time patterns are more complex, although general comparisons of pairs of journals or individuals are possible. We also extend this framework using exponential discounting. Using exponential discounting enables complete comparisons on the basis of citation timing patterns, a consideration of the magnitude of the influence citation timing, and an assessment of its possible impact on the ranking of journals, business subjects and academic economists on the basis of patterns of citations per paper or citations.

Citation time patterns have been the subject of considerable research. It has been noted that some disciplines attract more citations and earlier citations than others (e.g. Evidence, 2007), that there is considerable variation between the citation patterns associated with individual papers (e.g. Levitt and Thelwall, 2008), that the time pattern of citations is different between high and low ranked journals in the same discipline (Anderson and Tressler, 2016) and that citation histories can be used to classify papers by type (for example, Redner, 2005).

The importance of these differences has been heightened by the direct and indirect use of bibliometrics in National Research Assessment Exercises (OECD, 2010). This has raised the issue of the reliability of citation data when it is collected over short periods (Tressler and Anderson, 2012). The timing of citation patterns is central to the question of whether short-term citation patterns can be used to predict long-term citations and thus research impact (see, e.g. Bruns and Stern, 2016 and Stern, 2014). Mechanistic models have also been used to predict citation outcomes and to represent the citation dynamics of individual papers based on key parameters (see, for example, Wang et al., 2013).

In a related literature stemming from the seminal work in economics of Jaffe et al. (1993), citations to patents have played a significant role in the empirical study of the diffusion of knowledge following discovery. This literature has considered the implications of delays in citations and empirical models of the pattern of patent citations over time[1]. The associated literature on the valuation of private knowledge assets has also dealt with the time discounting of private R&D expenditure and patent citations.[2]

It is clear from the literature cited above that the timing of the flow of citations does matter. The knowledge diffusion approach is based on the premise that the earlier a work is cited the greater its potential impact on other knowledge creation. It is also likely that given additions to knowledge decrease in value over time given advances in associated areas.[3] In considering flows of consumption or income over time, the existence of financial markets provides a clear rationale for using simple present value calculations to capture the influence of time.[4] In dealing with citations as indicators of knowledge development we seek a more general framework for the consideration of the influence of time.[5]

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[1] See for example Jaffe *et al.* (1993) and Mehta, Rysman and Simcoe (2010). While citations to patents have some of the characteristics of citations to papers in academic journals, in other respects they are very different. For example, Jaffe *et al.* note that citations to preceding patents have value implications for the citing patent, thus removing the likelihood of frivolous citations.

[2] See for example Hall (2005), Czarnitzki et al. (2005) and Rahko (2014).

[3] In the context of private sector R&D expenditure Czarnitzki et al. (2005) note that "…knowledge tends to decay or become obsolescent over time, losing economic value due to advances in technology." (p.6)

[4] Exponential discounting can also ensure time consistency in intertemporal decision making, see, for example, Gollier (2001).

[5] Although this paper centers on interpreting citations as an indicator of knowledge creation, citations to papers can also modelled as being the result of random and deliberate social interaction in networks, Jackson and Rogers (2007), or as the outcome of strategic decision making, see e.g. Kim et al. (2011).

In the literature on the economics of uncertainty, stochastic dominance has been useful in providing a theoretical foundation for comparisons of probability distributions. It also provides the basis for the definition of risk in economics. Stochastic dominance concepts have been applied in many contexts in economics, for example: in the characterization of inequality and poverty in relation to distributions of income (Atkinson, 1970, 1987) and Davies and Hoy, 1995), economic organization (Sah and Stiglitz, 1986) and the economics of the evaluation of citations received by a particular individual (Ravallion and Wagstaff, 2011). Jackson and Rogers (2007) use stochastic dominance concepts in describing efficiency results for social networks including networks of citations emanating from a single paper. Here stochastic dominance concepts are used to provide a framework for the characterization of some broad differences in the distribution of citation patterns over time based on very general principles such as a preference for lower delay in the recognition of research or the suggestion that time delays in recognition are more important in the periods closer to the publication of research. We also link this general framework to simple exponential discounting.

Citations are only one indicator of the contribution to knowledge derived from particular publications or sets of publication. Clearly there are many factors that also provide indicators of the likely contribution to knowledge from a particular publication such as: the research record of the authors, the journal in which the research is published, the length of the paper, etc. Similarly, there are a number of factors that will influence the likely contribution to knowledge that is indicated by a particular citation such as: the research record of the citing author, the quality of the journal in which the citation is made, where in the history of citations the particular citation occurs, etc. Here we consider only the influence of time on the contribution to knowledge that is indicated by citations. We concentrate on this factor because we are interested in differences in the time patterns of citations for different journals, papers in a subject or published by different individuals.

2 A Framework for the Comparison of Citation Timing Patterns

The common approach taken in literature on the valuation of research contributions using citations is to treat publication in an academic journal as representing the time at which the research contribution becomes available and to count citations to that publication in assessing the revealed value of the research. We follow this approach, but recognize that research papers are increasingly circulated, workshopped and presented at conferences prior to publication. There may also be a significant time lag between submission and publication.

To provide a simple framework we consider research published at time t_0 and the pattern of citations to that research received by time t_n.[6] Let the knowledge gained as indicated by these citations be represented by

$$K(t_0, t_n) = k_{t_0}h_{t_0} + \cdots + k_{t_n}h_{t_n}, \quad (1)$$

where k_{t_i} is the contribution to knowledge of a single cite at time t_i, and, h_{t_i} the number of cites at time t_i.[7] It is important to note that this formulation implies that the knowledge contribution from a particular cite does not depend on the number of other cites occurring at the same time and that all cites result in the same indication of contribution other than through the influence of time.[8] This is a simplification, but while the probability of a cite may well depend on the number of cites being made by others, it is not so clear why this should impact on the contribution to knowledge that a particular cite signals. The treatment of the signal provided by a cite as independent of the cites occurring around it is consistent with the way in which cites are treated in assessing the contributions of journals through impact factors or impact factor related metrics. If the value indicated by a particular cite depended on the number of cites made to a particular article, then to properly assess the value of a journal using cites it would be necessary to consider the distribution of cites across articles in an issue of a journal. The same would be true in assessing the value of the contribution made by a particular individual who has published a number of works.

Rewriting equation (1) treating time as continuous and letting t_n=t_1

$$K(t_0, t_1) = \int_{t_0}^{t_1} k(t)h(t)dt, \quad (2)$$

[6] In the discussion, citations refer to: citations or citations per paper to articles; all articles in a journal; or to articles published by an individual in t_0. Alternatively, this could be citations per page or citations divided by the number of authors.

[7] Even this general formulation is restrictive as it assumes that the contribution to knowledge indicated by a citation at time t_i is independent of the patterns of citations in the period prior to or after that time period.

[8] The analysis could be applied to weighted cites allowing account to be taken of the quality of the citing journal as an indicator of the likely contribution to knowledge.

where $k(t)$ is the contribution to knowledge of a single cite at time t and $h(t)$ the rate at which citations are occurring at time t. For ease of exposition we treat time as continuous in what follows, although we will note key results for the discrete time case in which the periods are of equal length. Let N be the total number of cites received over the period t_0 and t_1, then

$$K(t_0, t_1) = \int_{t_0}^{t_1} k(t) N \frac{h(t)}{N} dt = N \int_{t_0}^{t_1} k(t) f(t) dt, \qquad (3)$$

where $f(t)$ is the proportional rate at which cites occur at time t. Alternatively, $f(t)$ could be viewed as the probability density for cites occurring between t_0 and t_1 where the timing of citations is thought of as a random variable. Equation (3) indicates that the contribution to knowledge $K(t_0,t_1)$ can be viewed as the product of the number of cites and a term that represents the time adjusted contribution to knowledge $\int_{t_0}^{t_1} k(t) f(t) dt$.

To provide an alternative representation, let the contribution to knowledge of a single cite at time t be $k(t)=D-d(t)$, where D can be thought of as the contribution to knowledge a cite would have if it had occurred at time t_0 and $d(t)$ the decline (or possibility increase) in the contribution to knowledge if the cite occurs at time t. Then

$$K(t_0, t_1) = N \int_{t_0}^{t_1} \big(D - d(t)\big) f(t) dt = N(D - \int_{t_0}^{t_1} d(t) f(t) dt).[9] \qquad (4)$$

In equation (4) $\int_{t_0}^{t_1} d(t) f(t) dt$ represents the expected decline in knowledge resulting from the distribution of citations over time. If $d'(t) > 0$ for all t then this would suggest that an increase in t always results in a decline in the contribution to knowledge, since the impact is delayed in time and the research has less value as a result, or that its influence on gains in knowledge has less time to develop. A preference for less delay in the recognition of research would seem to be a reasonable assumption.

Although less obvious, another plausible assumption is that $d''(t) < 0$ for all t. Here $k(t)=D-d(t)$, thus assumptions that $d'(t) > 0$ and $d''(t) < 0$ correspond to the assumptions that $k'(t) < 0$ and $k''(t) > 0$, or that as time t increases the contribution to knowledge indicated by a citation decreases, but at a decreasing (numerically increasing) rate, or the cost of

[9] Note that $\int_{t_0}^{t_1} f(t) dt = 1$.

delay is increasing but at a decreasing rate. With normal exponential discounting $k(t) = De^{-r(t-t_0)}$, where D is the value of a cite at time t_0. Thus, the assumption that $k''(t) > 0$, or $d''(t) < 0$, is consistent with normal discounting practice. That is, the decline in value in early time periods is greater than the decline further in the future, thus a one year delay from year zero is treated as having a larger impact on value than a one year delay from year 10. In terms of cites this corresponds to the assumption that a delay in a cite in early years after publication implies a greater impact on the likely development of knowledge than a delay in later years, or the suggestion that time delays in recognition are more important in the periods closer to the publication of research.

Applied to the framework above, the theory of stochastic dominance enables distributions of the proportional rate of cites to be compared.[10] Consider two distributions $f(t)$ and $g(t)$ and let $F(t) = \int_{t_0}^{t} f(t)dt$ and $G(t) = \int_{t_0}^{t} g(t)dt$ for $t\epsilon[t_0, t_1]$, then:

1. If $F(t) \leq G(t)$ for all $t\epsilon[t_0, t_1]$ and strictly less from some t, then $F(t)$ is said to dominate $G(t)$ in the first degree, i.e. in this sense cites will always occur later with $F(t)$ than $G(t)$ as the proportion of cites occurring up to t is always less for $F(t)$ than $G(t)$. For all functions $d(t)$ with $d'(t) > 0$ the expected delay in the contribution to knowledge $\int_{t_0}^{t_1} d(t)f(t)dt$ is always greater with $f(t)$ than $g(t)$ and thus the distribution of citations always suggests that knowledge is devalued more. These conditions can be extended to the discrete time period case.[11] For example, assume that citations are observed at the end of each of a finite number of n years, and let f_i and g_i be the proportion of cites received in year i. Let $F^r = \sum_{i=1}^{r} f_i$ and $G^r = \sum_{i=1}^{r} g_i$ be the proportion of cites received by time r, where $r \leq n$, then the patterns of citations represented by the f_i, i=0 to n dominates that represented by g_i, i=0 to n in the first degree if $F^r \leq G^r$ for all years $r \leq n$ and is strictly less for some years.

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[10] The classic article on first and second degree stochastic dominance as used here is Hadar and Russell (1969), see also Gollier (2001), Chpt. 3.

[11] Here citations are treated as if they are received at the end of a finite number of equal length time periods. This ignores the pattern of citations received over the single period.

2. If $\int_{t_0}^{t} F(t)dt \leq \int_{t_0}^{t} G(t)dt$ for all $t\epsilon[t_0, t_1]$ and strictly less for some t, then $F(t)$ is said to dominate $G(t)$ in the second degree. It follows that for all functions $d(t)$ with $d'(t) > 0$ and $d''(t) < 0$ f(t) results in a greater expected delay than $g(t)$ and thus the distribution of citations always suggests that knowledge is devalued more. For the discrete case, the patterns of citations represented by the f_i , i=0 to n dominates that represented by g_i , i=0 to n in the second degree if $\sum_{i=1}^{r} F^i \leq \sum_{i=1}^{r} G^i$ for all $r \leq n$ and strictly less for some t.

Table 1 describes two hypothetical comparisons over a ten-year time horizon. In the first comparison the distribution of the proportion of cites f_i comes unambiguously later than that of g_i which has the same pattern of cites, but starting one year earlier. In this case condition 1 is clearly satisfied, i.e., for all t the sum of the proportion of cites F^r is weakly less with f_i than the sum of the proportion of cites G^r with g_i and strictly less for some t. In the second comparison the distribution of cites is clearly less spread with h_i than with g_i even though the mean time at which cites occur is the same. Here h dominates g in the second degree, since $\sum H^i \leq \sum G^i$ for all t and strictly less for some t. Thus the contribution to knowledge is greater with g than h as delay costs are less with g.

Table 1. Examples of Distributions of Cites

	Year									
	1	2	3	4	5	6	7	8	9	10
Proportion of Cites f_i	0	0	¼	¼	¼	¼	0	0	0	0
Proportion of Cites g_i	0	¼	¼	¼	¼	0	0	0	0	0
∑Proportion of Cites $F^r=\sum f_i$	0	0	¼	½	¾	1	1	1	1	1
∑Proportion of Cites $G^r=\sum g_i$	0	¼	½	¾	1	1	1	1	1	1
Proportion of Cites g_i	0	¼	¼	¼	¼	0	0	0	0	0
Proportion of Cites h_i	0	0	½	½	0	0	0	0	0	0
∑Proportion of Cites $G^i=\sum g_i$	0	¼	½	¾	1	1	1	1	1	1
∑Proportion of Cites $H^i=\sum h_i$	0	0	½	1	1	1	1	1	1	1
∑∑Proportion of Cites $\sum G^i$	0	¼	¾	1 ½	2 ½	3 ½	4 ½	5 ½	6 ½	7 ½
∑∑Proportion of Cites $\sum H^i$	0	0	½	1 ½	2 ½	3 ½	4 ½	5 ½	6 ½	7 ½

Anderson and Tressler (2016) referred to comparisons of citation patterns that are similar to dominance in the first degree. They considered rates of citation capture, the percentage of cites received in each year of a ten-year period. These together with the number of citations per paper were used in comparing citation patterns. It was noted that this approach was similar to the comparisons made by Levitt and Thelwall (2008) who considered the percentage of cites within five-year sub-periods received by a limited number of articles over a thirty-five year period. Dominance in the first degree as considered here corresponds to comparisons of cumulative rates of citation capture. We are unaware of any comparisons in the citations literature similar to those relating to second degree dominance as considered here.

This treatment of time corresponds to the usual present value assessment in the special case in which $d(t) = D - De^{-rt}$ for some D as above representing the value of a cite at time t_0 and discount rate r. For this function $d'(t) = r\bar{D}e^{-\ rt} > 0$ and $d''(t) = -r^2D\bar{k}e^{-rt} < 0$ as assumed above. Setting $t_0 = 0$, in this case

$$K(0, t_1) = N\int_0^{t_1}(D - d(t))f(t)dt = N\int_0^{t_1}\big(D - (D - De^{-rt})\big)f(t)dt =$$

$$= N\int_0^{t_1} De^{-rt}f(t)dt. \qquad (5)$$

Thus $K(0, t_1)$ represents the number of cites over the total period multiplied by the present value of a cite, i.e. the proportional flow of cites discounted at the constant discount rate r. For the discrete case, the patterns of citations represented by the f_i , i=0 to n would have lower present value than that represented by g_i, i=0 to n if $N\sum_{i=1}^{n} De^{-ri}f_i \leq N\sum_{i=1}^{n} De^{-ri}g_i$.

If this particular value decline function is used it is possible to compare any two distributions of cites in terms of the number of cites occurring over a given time period N, the value of single cite D and the discount factor applying to each distribution, $\sum_{i=1}^{n} e^{-ri}f_i$ and $\sum_{i=1}^{n} e^{-ri}g_i$. In this case the ratio of the value of cites would be independent of the number of cites. Without loss of generality we treat the value of an undiscounted cite D=1.

In the literature on the evaluation of research through citations there are relatively few examples of discounting or the use of particular discount rates. One example of the discounting of citations in the economics discipline is the use of discounted impact factors and recursive discounted impact factors by the CitEc project that is part the Research Papers in Economics (RePEc) collaboration.[12] The discount factor that is used here is

[12] In a broader context Jin et al. (2007) and Holden et al. (2005) also suggest discounting by the age of the article, but not the time between the publication of the cited article and the cite. Järvelin and Persson (2008) also consider discounting based on the age of the cite using a logarithmic function.

one divided by the age of the citing paper in years with the current year having a value of one. It is important to note that this is not discounting the delay in a citation from publication as considered here, but discounting of the age of the cite. Thus, a citation from a paper one year ago receives a weight of 0.5 and two years ago 0.33.[13] If this discounting method was applied to the delay between publication and citation, then a cite received one year after publication would receive a weight of 0.5 and two years after publication 0.33. This would not be consistent with exponential discounting as used to represent the cost of delay here. The implied discount rates are very high, with r=0.693 for a cite one year out, r= 0.543 two years out, r=0.462 three years out and r=0.255 ten years out.[14] In terms of the framework used in this paper a RePEc type delay function could be written as $d(t) = D - 1/(t+1)$. For this function $d'(t) > 0$ and $d''(t) < 0$ as assumed above.

In the literature on the market valuation of private sector knowledge assets most studies have discounted R&D expenditure at 15%, although Czarnitzki et al. (2005) note that "...an appropriate private obsolescence rate for R&D investment is probably somewhat greater that 15 per cent, more in the neighborhood of 20 to 30 per cent" (p.15). Hall (2005) estimates discount rates between 0 and 40%.[15]

3 Application of the Framework

In this section we apply the framework developed above using four examples of citation patterns collected as part of two other studies (Tressler and Anderson, 2012 and Anderson and Tressler, 2016).[16] Tressler and Anderson (2012) consider citation lags for New Zealand economists and suggests that they make it difficult to rely on citation counts as meaningful measures of research output in time-limited research assessments. Anderson and Tressler (2016) use citation capture rate data to descriptively compare citation timing patterns between social sciences, business subjects and science, and between leading and lower ranked journals in economics. They show that short-term citation counting favours science over social

[13] See https://ideas.repec.org/top/top.series.discount.html or Zimmermann (2013).

[14] This form of discounting is less severe in comparison to exponential discounting as the paper age becomes higher.

[15] See also Rahko (2014).

[16] The articles from which these examples are drawn provide a broad based descriptive discussion of the differences in citation patterns and links to related literature.

science and within economics, lower quality journals overs higher quality ones.

The examples used in this paper illustrate the application of this framework in four very different contexts. We compare the time patterns of citations to publications: in a number of economics journals, in different business subject areas, in leading journals in economics compared with those in neuroscience, and by different academic economists. All the examples are for citations made over a 10-year period in the early 2000s. The applications made in these four examples formalize comparisons previously made in the literature, introduce the role of second degree dominance based comparisons of citation time patterns, and evaluate the magnitude of the impact of time differences using exponential discounting. Using these examples we also investigate the potential impact of taking account of time differences in knowledge dissemination on rankings of academic journals, subjects and individual economists based on citations per paper or citations.

3.1 Citation Patterns for Journals in Economics

Anderson and Tressler (2016) considered the citation time patterns in the five economics journals that had the highest *Journal Citation Report* five year impact factors in 2012 and compared these with the top five journals in neuroscience. [17] Here we illustrate the application of the framework considered above using the 10 year citation patterns for research published in five journals that are typically regarded as leading journals in economics: *Journal of Political Economy* (*JPE*), *Quarterly Journal of Economics* (*QJE*), *American Economic Review* (*AER*), *Review of Economic Studies* (*RES*) and *Econometrica* (*EM*). For comparison purposes two 'letters' journals *Applied Economics Letters* (*AEL*) and *Economics Letters* (*EL*) are also considered. Letters journals are often assumed to provide the opportunity for research results to be disseminated rapidly. Rapid dissemination is a stated aim of *Economics Letters*. Here we are interested in comparing the differences in knowledge dissemination as indicated by the citation time patterns for these journals using the general framework introduced above. When exponential discounting is applied the magnitude of these differences in

[17] The five economics journals considered were: the *Journal of Economic Literature*, *Quarterly Journal of Economics*, *Journal of Finance*, *Journal of Economic Perspectives* and *Econometrica*.

citation time patterns can be assessed and whether these differences would be likely to influence the ranking of these journals based on citations per paper alone. We also considered whether letters journals do result in more rapid knowledge dissemination. All citation data is collected from Thomson Reuters/WoK. Papers eligible to receive citations are those published in the journals considered in 2003 while citations to these papers are from all journals in the WoK databases from 2003 to 2012.[18]

Table 2 presents the basic data, showing the percentage cites to articles published in 2003 over each of the ten years. On average less than one percent of cites were received in the first year rising to almost 16% in Year 10. The sum of the proportion of cites and the double sum of the proportion of cites required for the stochastic dominance based comparisons are also provided.

Based only on the assumption that delay reduces the value of cites (i.e. for any delay function *d(t)* with $d'(t) > 0$), the cost of the delay in the uptake of knowledge, as indicated by citations, is unambiguously greater for the *QJE* compared with the *JPE*, the *QJE* compared with the *AER*, the *EL* compared with AER and the RES compared with AEL. Alternatively, let $f \succcurlyeq_d^1 g$ indicate that the distribution of citations for *f* has unambiguously more delay than the distribution g in the first degree, then $QJE \succcurlyeq_d^1 JPE$, $QJE \succcurlyeq_d^1 AER$, $EL \succcurlyeq_d^1 AER$ and $RES \succcurlyeq_d^1 AEL$. If, in addition, the assumption that increased delay in early years is more important than in later years, i.e., $d'(t) > 0$ and $d''(t) < 0$, then the delay in the uptake of knowledge is unambiguously greater for the AER in comparison to the *JPE* and *QJE* relative to the *EM*. Thus, if $f \succcurlyeq_d^2 g$ indicates that the distribution of citations for *f* has unambiguously more delay than the distribution *g* in the second degree, then $JPE \succcurlyeq_d^2 AER$ and $QJE \succcurlyeq_d^2 EM$. It follows that $QJE \succcurlyeq_d^1 JPE \succcurlyeq_d^2 AER$ for all *d(t)* with $d'(t) > 0$ and $d''(t) < 0$.

When exponential discounting is used in order to assess the impact of delay all journals can be compared and the magnitude of the influence of time assessed. The discount factors ($\sum_{i=1}^{n} e^{-ri} f_i$) for the journals for a number of discount rates are shown in Table 3.

18 The increase in the number of JCR listed economics journals over the 10 year period would have also increased citations over this period.

Table 2. Citation Patterns for Economics Journals, 10YR ISI Cites to 2003 Publications

Journal[1]	**Distributions of Cites/Paper**[2]	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Cites/ Paper**	**Pres. Val. Cites/Paper r=0.1**
JPE	% Cites, 100**f*	0.66	2.49	5.92	8.60	10.15	11.32	14.65	15.50	14.98	15.74	50.69	28.72
	∑Proportion of Cites, *F*=∑*f*	0.0066	0.0315	0.0907	0.1766	0.2781	0.3913	0.5378	0.6928	0.8426	1.0000		
	∑∑Proportion of Cites, ∑*F*	0.0066	0.0380	0.1287	0.3053	0.5834	0.9746	1.5124	2.2053	3.0479	4.0479		
Q J E	% Cites, 100**g*	0.45	2.25	5.06	7.00	8.24	12.08	14.25	15.58	17.37	17.70	78.58	43.40
	∑Prop ortion of Cites, *G*=∑*g*	0.0045	0.0271	0.0777	0.1477	0.2301	0.3510	0.4935	0.6492	0.8230	1.0000		
	∑∑Proportion of Cites, ∑*G*	0.0045	0.0316	0.1093	0.2570	0.4871	0.8380	1.3315	1.9808	2.8038	3.8038		
AER	% Cites 100**h*	0.67	3.19	5.98	7.93	9.81	12.55	14.01	15.45	15.03	15.36	40.55	23.07
	∑Proportion of Cites, *H* =∑*h*	0.0067	0.0387	0.0985	0.1778	0.2759	0.4014	0.5415	0.6961	0.8464	1.0000		
	∑∑Proportion of Cites, ∑*H*	0.0067	0.0454	0.1439	0.3217	0.5976	0.9990	1.5406	2.2367	3.0831	4.0831		
RES	% Cites 100**j*	0.41	2.84	5.62	8.66	10.93	14.12	13.81	14.64	15.15	13.81	52.43	29.97
	∑ Proportion of Cites, *J*=∑*j*	0.0041	0.0325	0.0887	0.1753	0.2845	0.4258	0.5639	0.7103	0.8619	1.0000		
	∑∑Proportion of Cites, ∑*J*	0.0041	0.0366	0.1253	0.3005	0.5851	1.0108	1.5747	2.2851	3.1469	4.1469		
EM	% Cites 100**k*	0.75	2.64	5.39	6.79	9.07	11.12	14.46	16.25	15.65	17.88	42.05	23.43
	∑ Proportion of Cites, *K*=∑*k*	0.0075	0.0339	0.0878	0.1557	0.2464	0.3576	0.5022	0.6647	0.8212	1.0000		
	∑∑Proportion of Cites, ∑*K*	0.0075	0.0415	0.1293	0.2850	0.5315	0.8891	1.3913	2.0560	2.8772	3.8772		
EL	% Cites, 100**m*	0.61	3.10	5.83	7.24	7.94	10.95	15.79	14.33	16.78	17.43	8.83	4.94
	∑Proportion of Cites, =∑*m*	0.0061	0.0371	0.0954	0.1678	0.2472	0.3567	0.5146	0.6579	0.8257	1.0000		
	∑∑Proportion of Cites, ∑*M*	0.0061	0.0432	0.1386	0.3064	0.5536	0.9102	1.4248	2.0827	2.9084	3.9084		
AEL	% Cites 100**n*	0.47	3.26	6.52	11.34	11.65	12.73	14.44	12.89	13.51	13.20	3.25	1.90
	∑ Proportion of Cites, *N*=∑*n*	0.0047	0.0373	0.1025	0.2158	0.3323	0.4596	0.6040	0.7329	0.8680	1.0000		
	∑∑ Proportion of Cites, ∑*N*	0.0047	0.0419	0.1444	0.3602	0.6925	1.1522	1.7562	2.4891	3.3571	4.3571		
Ave.	**% Cites**	0.58	2.83	5.76	8.22	9.68	12.13	14.49	14.95	15.50	15.87	39.48	

[1] *Journal of Political Economy* (*JPE*), *Quarterly Journal of Economics* (*QJE*), *American Economic Review* (*AER*), *Review of Economic Studies* (*RES*), *Econometrica* (*EM*), *Economics Letters* (*EL*), *Applied Economics Letters* (*AEL*)

[2] The superscripts and subscripts are not shown in the row descriptors. Summations are to the year on the column head.

Differences in these numbers for a given discount rate represent the impact of differences in citation timing between a pair of journals as a proportion of the undiscounted value of a single cite. Here, these differences seem quite small, less than 4% for all discount rates and often less than 1%. Of course the impact of these differences as a percentage of the discounted values is much higher. Thus, for example, at a discount rate of 10%, the maximum difference in discount factors is between the *QJE* and *AEL* at 3.2% of the undiscounted value of a cite (equal to 1.0) and 5.8% of the discounted value of a cite in the *AEL.* At higher discount rates the differences are greater. At a discount rate of 40% the maximum difference in discount factors is 2.9% of the undiscounted value of a cite and 23% of the discounted value.

Table 3. Discount Factors over 10 Years for Economics Journals

	Discount Rates					
	r=0.01	r=0.05	r=0.1	r=0.2	r=0.3	r=0.4
Journal of Political Economy (*JPE*)	0.942	0.748	0.567	0.340	0.216	0.145
Quarterly Journal of Economics (QJE)	0.940	0.738	0.552	0.323	0.200	0.131
American Economic Review (*AER*)	0.943	0.749	0.569	0.343	0.219	0.148
Review of Economic Studies (*RES*)	0.943	0.751	0.572	0.345	0.219	0.147
Econometrica (*EM*)	0.941	0.741	0.557	0.329	0.206	0.138
Economics Letters (*EL*)	0.941	0.743	0.559	0.332	0.209	0.140
Applied Economics Letters (*AEL*)	0.945	0.759	0.584	0.361	0.235	0.161

For all discount rates under 32%, the rank of the journals from the lowest discount factor to the highest remains the same: *AEL*, *RES*, *AER*, *JPE*, *EL*, *EM* and *QJE*. *Applied Economics Letter* gathers cites the fastest and the *Quarterly Journal of Economics* the slowest.

Does taking account of citation timing change conclusions on the ranking of journals? Table 2 also shows the present value of 10 year citations per paper for each journal at a discount rate of 10%. The ranking of journals based on the present value of cites is the same as that based on cites per paper, the undiscounted value of cites. The ranking of journals based on this value would be the same for all discount rates under 17%. At rates above 18% the order of the *AER* and *EM* reverses. Higher discount rates would not future affect the ranking of journals unless they are above 90%. Thus, based on the comparison of these journals it seems unlikely that taking into account delays in the dissemination of knowledge would influence journal rankings significantly, but may influence the rankings of individual journals if discount rates are high.

Given exponential discounting do "letters journals" disseminate knowledge more rapidly in economics? As shown in Table 3 the discount factor for *EL* is equal to or lower than that for all other journals except the *QJE* and *EM* at all the discount rates shown. It follows that there is at least as much delay in the receipt of citations for research published in *EL* as for the other journals considered except the *QJE* and *EM*. Thus, this citation data does not suggest that *Economics Letters* results in the rapid dissemination of new ideas relative to a number of the discipline's leading journals. In contrast, the discount factor for *AEL* is greater than the discount factor for all other journals at all discount rates, suggesting that for this data there is evidence of more rapid dissemination of knowledge through publication with the *Applied Economic Letters* than the other journals considered.[19]

As noted in Section 2 the citation analysis considered here ignores the influence of the pre-publication availability of research on citations and citation time patterns. It is likely that research published in the leading economics journals is more likely to have been circulated prior to publication than that published in letters journals. The comparisons ignore citations to pre-publication versions of the published research papers, and the impact of the earlier availability of research on the time pattern of citations post publication. The first of these may result in an understatement of the early research impact of research in leading journals, while the second is likely to increase it.

3.2 Citation Patterns for Business Subject Areas

Anderson and Tressler (2016) considered citation time patterns for business subjects including economics and noted that the time patterns for Business, Business Finance and Economics are similar. It was also noted that while Business and Management had above-average cites per paper they generated relatively few cites in the early years after publication. In this section we use the framework introduced above to consider these differences in more detail. We show that there are very clear differences between the citation time patterns for business subjects. Given exponential discounting we also considered the magnitude of these differences and show that these are not likely to be large enough to influence a ranking of these subject areas on the basis of citations per paper.

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[19] It is possible that particular types of journal should attract different discount rates.

We look at citation patterns for a number of Thomson Reuters/Web of Knowledge (WoK) Journal Citation Report subject categories relevant to a business school: Business (*Bus*), Business Finance (*Bus Fin*), Communication (*Com*), Industrial Relations and Labor (*Ind Rel & Lab*), Information Science and Library Science (*If Sc & Lib Sc*) and Management (*Mgt*). As above, all citation data is collected from Thomson Reuters/WoK. Papers eligible to receive citations in each discipline category are those published in the journals considered in 2003, whereas citations to these papers are from all journals in the WoK databases from 2003 to 2012. In Table 4 we report time patterns of citations per paper for all publications in the subject areas considered. As noted in the table, on average these subject areas have less than 1% of citations received in the first year, rising to 15.47% in year nine and 15.23% in year 10.

In contrast to the results for journals in economics, the general stochastic dominance based comparisons of the citation patterns lead to an almost complete unambiguous ranking of these subject areas in terms of delay patterns. Here, if less delay is valued, i.e. for any delay function *d(t)* with $d'(t) > 0$, the cost of the delay in the uptake of knowledge is unambiguously greater for *Mgt* than all other subjects; *If Sc & Lib Sc* is unambiguously less than *Bus*, *Bus Fin*, *Econ* and *Ind Rel & Lab*; *Ind Rel and Lab* is unambiguously less than *Bus*, *Bus Fin* and *Econ*; *Econ* is unambiguously less than *Bus*, but greater than *Com*; *Com* is less than *Bus* and *Bus Fin*; and *Bus Fin* is less than *Bus*.

If in addition, increased delay in early years is more important than in later years, i.e. for any delay function *d(t)* with $d'(t) > 0$ and $d''(t) < 0$, *Econ* has unambiguously greater delay than *Bus Fin,* and *Com* has unambiguous greater delay than *If Sc & Lib Sc*. Only for comparison of *Com* and *Ind Rel and Lab* are rankings not possible. Putting these pairwise rankings together using the notation above it is possible to conclude that either:

$$Mgt \succcurlyeq_d^1 Bus \succcurlyeq_d^1 Econ \succcurlyeq_d^2 Bus\ \ Fin \succcurlyeq_d^1 Com \succcurlyeq_d^2 If\ \ Sc\ \ \&\ \ Lib\ \ Sc,$$

or

$$Mgt \succcurlyeq_d^1 Bus \succcurlyeq_d^1 Econ \succcurlyeq_d^2 Bus\ \ Fin \succcurlyeq_d^1 Ind\ \ Rel\ \ \&\ \ Lab \succcurlyeq_d^1 If\ \ Sc\ \ \&\ \ Lib\ \ Sc$$

.

Table 4. Citation Patterns for Business Subjects, 10YR ISI Cites to 2003 Publications Journals

Subject	**Distributions of Cites/Paper**[1]	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Cites/ Paper**	**Pres. Val. Cites/ Paper r=0.1**
Bus	% Cites, 100*f	0.45	2.23	4.68	6.73	8.87	12.34	15.63	16.57	16.25	16.26	27.50	15.24
	∑Proportion of Cites, $F=\sum f$	0.0045	0.0268	0.0736	0.1410	0.2296	0.3530	0.5093	0.6750	0.8374	1.0000		
	∑∑Proportion of Cites, $\sum F$	0.0045	0.0313	0.1049	0.2459	0.4755	0.8285	1.3378	2.0127	2.8502	3.8502		
Bus Fin	% Cites, 100*g	0.83	3.31	6.07	8.17	8.96	12.29	14.10	15.26	15.53	15.48	17.44	9.92
	∑Proportion of Cites, $G=\sum g$	0.0083	0.0414	0.1021	0.1838	0.2734	0.3963	0.5373	0.6899	0.8452	1.0000		
	∑∑Proportion of Cites, $\sum G$	0.0083	0.0497	0.1518	0.3356	0.6089	1.0052	1.5424	2.2323	3.0775	4.0775		
Com	% Cites 100*h	0.91	3.54	6.79	8.95	9.95	12.12	14.78	14.83	15.04	13.10	14.05	8.13
	∑Proportion of Cites, $H=\sum h$	0.0091	0.0445	0.1124	0.2019	0.3014	0.4226	0.5703	0.7186	0.8690	1.0000		
	∑∑Proportion of Cites, $\sum H$	0.0091	0.0536	0.1660	0.3679	0.6692	1.0918	1.6621	2.3807	3.2497	4.2497		
Econ	% Cites 100*j	0.72	3.19	5.97	7.81	9.32	12.02	14.76	15.07	15.20	15.93	19.14	10.86
	∑ Proportion of Cites, $J=\sum j$	0.0072	0.0391	0.0988	0.1770	0.2701	0.3904	0.5380	0.6887	0.8407	1.0000		
	∑∑Proportion of Cites, $\sum J$	0.0072	0.0463	0.1451	0.3221	0.5922	0.9826	1.5206	2.2093	3.0500	4.0500		
Ind Rel & Lab	% Cites 100*k	1.16	4.01	7.32	8.01	8.63	11.53	14.32	15.63	15.17	14.22	14.31	8.26
	∑Proportion of Cites, K=$\sum k$	0.0116	0.0517	0.1249	0.2050	0.2913	0.4066	0.5498	0.7061	0.8578	1.0000		
	∑∑Proportion of Cites, $\sum K$	0.0116	0.0633	0.1882	0.3932	0.6845	1.0911	1.6409	2.3471	3.2049	4.2049		
Inf Sc & Lib Sc	% Cites, 100*m	1.64	4.58	7.43	9.28	10.06	12.79	13.87	13.87	13.29	13.19	15.02	8.87
	∑Proportion of Cites, M =∑m	0.0164	0.0622	0.1364	0.2293	0.3299	0.4577	0.5965	0.7352	0.8681	1.0000		
	∑∑Proportion of Cites, $\sum M$	0.0164	0.0785	0.2150	0.4442	0.7741	1.2318	1.8283	2.5635	3.4316	4.4316		
Mgt	% Cites 100*n	0.44	1.89	4.12	6.68	8.32	11.30	14.72	16.33	17.78	18.43	37.06	20.22
	∑ Proportion of Cites, $N=\sum n$	0.0044	0.0233	0.0645	0.1313	0.2144	0.3274	0.4746	0.6379	0.8157	1.0000		
	∑∑ Proportion of Cites, $\sum N$	0.0044	0.0277	0.0922	0.2235	0.4380	0.7654	1.2400	1.8779	2.6936	3.6936		
Ave.	**%Cites**	0.88	3.25	6.05	7.95	9.16	12.05	14.60	15.37	15.47	15.23	22.01	

[1] The superscripts and subscripts are not shown in the row descriptors. Summations are to the year on the column head.

When exponential discounting is used to assess the impact of delays, then for all discount rates less than 24%, cites in *Com* journals involve less delay than in *IR Rel & Lab*, but for discount rates above 25% the order is reversed.

Given exponential discounting, does citation timing influence the ranking of subject areas based on the volume of citations/paper? Table 4 above also shows the ranking of subjects in terms of citations per paper. If the citations per paper are discounted using a discount factor of 10%, then the subject ranking by discounted citations per paper are the same as for undiscounted citations per paper. The ranking remains the same for all discount rates under 36%. Thus, although there are clear differences between business subjects in the dissemination of knowledge as indicated by citations, with exponential discounting these are still not significant enough to influence the ranking of business subjects by citations per paper.

Table 5. Discount Factors over 10 Years for Business Subjects

	Discount Rates					
	r=0.01	r=0.05	r=0.1	r=0.2	r=0.3	r=0.4
Business	0.94	0.74	0.55	0.32	0.20	0.13
Business Finance	0.94	0.75	0.57	0.34	0.22	0.15
Communication	0.94	0.76	0.58	0.36	0.23	0.16
Economics	0.94	0.75	0.57	0.34	0.22	0.15
Industrial Relations and Labour	0.94	0.75	0.58	0.35	0.23	0.16
Information Science and Library Science	0.95	0.76	0.59	0.37	0.25	0.18
Management	0.94	0.73	0.55	0.31	0.19	0.12

With exponential discounting, what is the magnitude of the influence of citation timing? Table 5 shows the discount factors ($\sum_{i=1}^{n} e^{-ri} f_i$) for subjects at various discount rates. The magnitude of these is similar to those for economics journals above. The maximum difference is between the subjects Management (Mgt) and Information Science and Library Science (Inf Sc & Lib Sc) relative to the undiscounted value of a cite of 4.5% at 10%, 5.7% at 20% and 5.3% at 40%. These translate to differences of 8.3%, 18.3% and 42.7% of the discounted value of cites. Thus, for business school subjects, differences in citation timing have a significant impact on the estimated differences in contributions to knowledge when exponential discounting is used to determine the value of delay, particularly at high discount rates.

3.3 Leading Journals in Economics and Neuroscience

A number of papers have commented on differences in citation patterns across disciplines.[20] Anderson and Tressler (2016) compare citation and citation time patterns for subject groupings formed from *JCR* discipline categories: Economics; a Business School Group; Social Sciences; Life Sciences; Physics, Chemistry and Geology; and Applied Sciences. These comparisons show that the rate of citation capture is generally much higher in the sciences than in economics and the social sciences. Similar results follow from a comparison of citations to publications in the leading economics and neuroscience journals. In this section we confirm these results using the dominance techniques introduced in this paper and indicate the possible importance of the differences using an exponential delay function.

Table 6 reports 10-year citation patterns for three leading journals in neuroscience, *Nature Reviews Neuroscience* (*NRN*), *Annual Review of Neuroscience* (*ARN*), *Nature Neuroscience* (*NN*), and three leading journals in economics, *Journal of Economic Literature* (*JEL*), *Quarterly Journal of Economics* (*QJE*) and *Econometrica* (*EM*).[21] Again papers eligible to receive citations in each discipline category are those published in the journals considered in 2003 while citations to these papers are from all journals in the WoK databases from 2003 to 2012. As indicated by a comparison of the sum of the proportion of cites reported in Table 6, based only on the assumption that value decreases with delay $d'(t) > 0$, publications in the neuroscience journals unambiguously involve less delay that those in economics in all pairwise comparisons.

Given exponential discounting, what is the magnitude of the influence of citation timing for journals from these different disciplines? Table 7 gives the discount factors for the six journals at different discount rates.

[20] See for example Nederhof (2006), Evidence (2007), Levitt and Thelwall (2008) and Baker (2018).

[21] Comparisons involving further journals are available in Anderson and Tressler (2016).

Table 6. Citation Patterns for Leading Economic and Neuroscience Journals 10YR ISI Cites to 2003 Publications

Journal[1]	**Distributions of Cites/Paper[2]**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Cites/ Paper**	**Pres.Val. Cites/ Paper r=0.1**
JEL	% Cites, 100**f*	0.80	3.87	6.94	9.14	9.34	13.08	16.34	13.28	12.47	14.74	71.38	11.51
	∑Proportion of Cites, *F*=∑*f*	0.0080	0.0467	0.1161	0.2075	0.3009	0.4316	0.5951	0.7278	0.8526	1.0000		
	∑∑Proportion of Cites, ∑*F*	0.0080	0.0547	0.1708	0.3783	0.6791	1.1107	1.7058	2.4336	3.2862	4.2862		
QJE	% Cites, 100**g*	0.45	2.25	5.06	7.00	8.24	12.08	14.25	15.58	17.37	17.70	121.03	15.83
	∑Proportion of Cites, *G*=∑*g*	0.0045	0.0271	0.0777	0.1477	0.2301	0.3510	0.4935	0.6492	0.8230	1.0000		
	∑∑Proportion of Cites, ∑*G*	0.0045	0.0316	0.1093	0.2570	0.4871	0.8380	1.3315	1.9808	2.8038	3.8038		
EM	% Cites 100**h*	0.75	2.64	5.39	6.79	9.07	11.12	14.46	16.25	15.65	17.88	63.26	8.70
	∑Proportion of Cites, H=∑*h*	0.0075	0.0339	0.0878	0.1557	0.2464	0.3576	0.5022	0.6647	0.8212	1.0000		
	∑∑Proportion of Cites, ∑*H*	0.0075	0.0415	0.1293	0.2850	0.5315	0.8891	1.3913	2.0560	2.8772	3.8772		
NRN	% Cites 100**j*	1.19	6.82	10.47	11.23	11.38	11.28	11.65	12.07	11.69	12.22	236.46	47.93
	∑ Proportion of Cites, *J*=∑*j*	0.0119	0.0800	0.1848	0.2971	0.4109	0.5237	0.6402	0.7609	0.8778	1.0000		
	∑∑Proportion of Cites, ∑*J*	0.0119	0.0919	0.2767	0.5738	0.9847	1.5083	2.1485	2.9094	3.7873	4.7873		
ARN	% Cites 100**k*	0.94	8.30	12.94	12.96	11.80	11.47	11.15	10.58	10.19	9.68	213.74	48.06
	∑ Proportion of Cites, *K*=∑*k*	0.0094	0.0924	0.2217	0.3513	0.4693	0.5840	0.6955	0.8013	0.9032	1.0000		
	∑∑Proportion of Cites, ∑*K*	0.0094	0.1017	0.3234	0.6747	1.1440	1.7280	2.4235	3.2248	4.1279	5.1279		
NN	% Cites, 100**m*	2.14	8.65	11.14	11.45	11.03	10.93	11.34	11.13	11.29	10.89	167.89	37.88
	∑Proportion of Cites, =∑m	0.0214	0.1079	0.2193	0.3338	0.4441	0.5534	0.6669	0.7782	0.8911	1.0000		
	∑∑Proportion of Cites, ∑*M*	0.0214	0.1293	0.3487	0.6825	1.1267	1.6801	2.3470	3.1251	4.0162	5.0162		

[1] *Journal of Economic Literature (JEL), Quarterly Journal of Economics (QJE), Econometrica (EM), Nature Reviews Neuroscience (NRN), Annual Review of Neuroscience (ARN), Nature Neuroscience (NN)*

[2] The superscripts and subscripts are not shown in the row descriptors. Summations are to the year on the column head.

When exponential discounting is used to indicate the magnitudes of the impact of time delay, the differences are significantly greater than those obtained in the comparisons considered above. As a percentage of the undiscounted value of a cite the maximum differences in the discount factor is between the *QJE* and *ARN* at 8.2% for a discount rate of 10% and 10.4% for a discount rate of 20%. These are 14.7% and 32.3% of the discounted value of a cite, respectively. At a discount rate of 40% the maximum difference in the undiscounted value of a cite is between the *QJE* and *NN* at 9.5%, which is 72.5% of the discounted value. In this case, the substantial differences between the number of cites per paper mean that taking into account the cost of delay does not change the ranking of journals by citations per paper until discount rates exceed 37%, at which point the *NRN* and *ARN* switch.

Table 7. Discount Factors over 10 Years for Economics and Neuroscience Journals

	Discount Rate					
	r=0.01	r=0.05	r=0.1	r=0.2	r=0.3	r=0.4
Journal of Economic Literature (*JEL*)	0.94	0.76	0.58	0.36	0.23	0.16
Quarterly Journal of Economics (*QJE*)	0.94	0.74	0.55	0.32	0.20	0.13
Econometrics (*EM*)	0.94	0.74	0.56	0.33	0.21	0.14
Nature Reviews Neuroscience (*NRN*)	0.95	0.78	0.61	0.40	0.28	0.20
Annual Review of Neuroscience (*ARN*)	0.95	0.79	0.63	0.43	0.30	0.22
Nature Neuroscience (*NN*)	0.95	0.79	0.63	0.42	0.30	0.23

The comparisons considered above ignore differences in the pre-publication availability of research and publication practice between economics and neuroscience. Since these disciplines may have different research cultures, these differences may well influence both the number of citations and their time pattern.

3.4 Leading Individual Economists in New Zealand

In all of the examples above we have dealt with cases in which there were a relatively large number of papers to which citations could be attracted, all articles in a journal in a particular year, or all articles in all journals in a subject area in a particular year.

Table 8, Citations Patterns for Seven NZ Economists, 10YR ISI Cites to 2000&2001 Publications

Individual	**Distributions of Cites[1]**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Total Cites**	**Pres. Val. Cites r=0.1**
McCann (*Mc*)	% Cites, 100**f*	0.53	0.53	4.79	7.45	16.49	10.11	18.62	11.70	14.36	15.43	188.00	106.00
	∑Proportion of Cites, *F*=∑*f*	0.0053	0.0106	0.0585	0.1330	0.2979	0.3989	0.5851	0.7021	0.8457	1.0000		
	∑∑Proportion of Cites, ∑*F*	0.0053	0.0160	0.0745	0.2074	0.5053	0.9043	1.4894	2.1915	3.0372	4.0372		
Sul (*Su*)	% Cites, 100**g*	0.00	3.08	12.31	13.85	9.23	7.69	9.23	7.69	16.92	20.00	65.00	38.09
	∑Proportion of Cites, *G*=∑*g*	0.0000	0.0308	0.1538	0.2923	0.3846	0.4615	0.5538	0.6308	0.8000	1.0000		
	∑∑Proportion of Cites, ∑*G*	0.0000	0.0308	0.1846	0.4769	0.8615	1.3231	1.8769	2.5077	3.3077	4.3077		
McDermott (*McD*)	% Cites 100**h*	0.00	0.00	2.33	20.93	9.30	9.30	9.30	23.26	9.30	16.28	43.00	24.40
	∑Proportion of Cites, *H* =∑*h*	0.0000	0.0000	0.0233	0.2326	0.3256	0.4186	0.5116	0.7442	0.8372	1.0000		
	∑∑Proportion of Cites, ∑*H*	0.0000	0.0000	0.0233	0.2558	0.5814	1.0000	1.5116	2.2558	3.0930	4.0930		
Gibson (*Gi*)	% Cites 100**j*	2.63	2.63	7.89	15.79	7.89	2.63	10.53	21.05	13.16	15.79	38.0	22.28
	∑ Proportion of Cites, *J*=∑*j*	0.0263	0.0526	0.1316	0.2895	0.3684	0.3947	0.5000	0.7105	0.8421	1.0000		
	∑∑Proportion of Cites, ∑*J*	0.0263	0.0789	0.2105	0.5000	0.8684	1.2632	1.7632	2.4737	3.3158	4.3158		
Hyslop (*Hy*)	% Cites 100**k*	2.94	2.94	5.88	14.71	11.76	14.71	14.71	8.82	8.82	14.71	34.0	20.57
	∑ Proportion of Cites, *K*=∑*k*	0.0294	0.0588	0.1176	0.2647	0.3824	0.5294	0.6765	0.7647	0.8529	1.0000		
	∑∑Proportion of Cites, ∑*K*	0.0294	0.0882	0.2059	0.4706	0.8529	1.3824	2.0588	2.8235	3.6765	4.6765		
Holmes (*Ho*)	% Cites, 100**m*	0.00	0.00	3.70	7.41	11.11	14.81	3.70	3.70	29.63	25.93	27.00	14.22
	∑Proportion of Cites, =∑m	0.0000	0.0000	0.0370	0.1111	0.2222	0.3704	0.4074	0.4444	0.7407	1.0000		
	∑∑Proportion of Cites, ∑*M*	0.0000	0.0000	0.0370	0.1481	0.3704	0.7407	1.1481	1.5926	2.3333	3.3333		
Fielding (*Fi*)	% Cites 100**n*	0.00	0.00	8.70	13.04	8.70	4.35	8.70	17.39	17.39	21.74	23.00	12.72
	∑ Proportion of Cites, *N*=∑*n*	0.0000	0.0000	0.0870	0.2174	0.3043	0.3478	0.4348	0.6087	0.7826	1.0000		
	∑∑ Proportion of Cites, ∑*N*	0.0000	0.0000	0.0870	0.3043	0.6087	0.9565	1.3913	2.0000	2.7826	3.7826		
Ave.	**%Cites**	0.87	1.31	6.51	13.31	10.64	9.09	10.68	13.37	15.66	18.55		

[1] The superscripts and subscripts are not shown in the row descriptors. Summations are to the year on the column head.

Tressler and Anderson (2012) used data on publications and citations for all academic economists in New Zealand to consider whether citation counts could be used in nationwide research evaluation exercise when the publications and citations to them are gathered over a limited period. They suggest that time-lags between publication and citation make it difficult to rely on citation counts in evaluating research output in this context. Here we use data collected as part of this research and the framework introduced above to consider citation time patterns for individual researchers. New Zealand is a relatively small country with eight university based economic departments or groups, all of which participate in a national research assessment exercise the Performance-Based Research Fund. Given the relatively small number of New Zealand academic economists it is possible to collect publication records and citations for the whole group. This enabled the selection of a group of academic economists to compare who have a similar research standing and the number of publications required to make the comparisons meaningful. To our knowledge this is the first comparison of citation time patterns for individual researchers.

We select the top seven New Zealand economists in terms of the total number of WoK citations received over a ten-year period to articles published in 2000 and 2001.[22] The citations reported are based on the total citations recorded over 10 years only to the papers published by these economists in 2000 and 2001. They are not the total citations received during the 10 years to all papers published by these economists. The seven economists are *Philip McCann (Mc), Donggyu Sul (Su), John McDermott (McD), John Gibson (Gi), Dean Hyslop (Hy), Mark Holmes (Ho)* and *David Fielding (Fi)*. Since we are dealing with a relatively small number of papers for each individual more variation in the data would be expected. The citation timing patterns for each of the seven individuals over the 10 years

[22] Cites are from WoK journals in economics using a definition of economics based on journals listed as economics journals in the Journal Citation Reports. The seven economists are those with the highest number of share-adjusted cites to articles published in 2000 and 2001 and collected over a 10-year period commencing in the year of publication. Note that: (a) the pool from which our seven economists were selected consisted of all full-time economists employed in New Zealand university-based economics departments on the 15th of April 2007 and/or the 15th of April 2009; and (b) we have adopted the 1/n rule to allocate cites between authors of multi-authored papers, where n equals the number of authors on a paper.

are described in Table 8 along with the sum of the proportion of cites and the double sum of the proportion of cites required for the stochastic dominance based comparisons. The data here is for the total cites received divided by the number of authors, not the cites per paper.

If only less delay is valued, i.e. with $d'(t) > 0$, the cost of the delay in the uptake of knowledge is unambiguously greater for: *Mc* compared with *Hy*, *Ho* compared with *Mc*, *Ho* compared with *Su*, *Fi* compared with *Su*, *McD* compared with *Hy*, *Ho* compared with *Gi*, *Fi* compared with *Gi*, *Ho* compared with *Hy* and *Fi* compared with *Hy*. If delay in early years is more important than in later years, i.e. for $d'(t) > 0$ and $d''(t) \quad < 0$, in addition to these comparisons delay is unambiguously greater for Mc compared with *Gi*, *McD* compared with *Su*, *McD* compared with *Gi* and *Ho* compared with Fi. Using the notation above it follows that $Ho \succcurlyeq_d^1 Mc \gtrsim_d^1 Hy$, $Ho \succcurlyeq_d^1 Mc \gtrsim_d^2 Gi$ and $Ho \succcurlyeq_d^2 Fi \gtrsim_d^1 Su$. Overall, while comparisons of a number of pairs are possible in terms of the cost of delay, there are only a small number of three person comparison chains.

Table 9. Discount Factors over 10 Years for Individual Economists

	Discount Rate					
	r=0.01	r=0.05	r=0.1	r=0.2	r=0.3	r=0.4
McCann (*Mc*)	0.94	0.75	0.56	0.33	0.21	0.13
Sul (*Su*)	0.94	0.76	0.59	0.37	0.25	0.17
McDermott (*McD*)	0.94	0.75	0.57	0.34	0.21	0.14
Gibson (*Gi*)	0.95	0.76	0.59	0.37	0.25	0.18
Hyslop (*Hy*)	0.95	0.77	0.61	0.39	0.26	0.19
Holmes (*Ho*)	0.94	0.72	0.53	0.29	0.17	0.11
Fielding (*Fi*)	0.94	0.74	0.55	0.33	0.20	0.13

Table 9 shows the discount factors ($\sum_{i=1}^{n} e^{-ri} f_i$) for a range of discount rates. For all discount rates shown under 40%, the rank of individuals from the highest discount factor (lowest delay) to the lowest discount factor (greatest delay) remains the same: *Hy*, *Gi*, *Sul*, *McD*, *Mc*, *Fi* and *Ho*.[23] For individuals, given the exponential delay function, the cost of time delays as a percentage of the undiscounted value of a cite differs by a maximum of 7.8% at a 10% discount rate for *Hy* compared with *Ho*, rising to 9.6% at a discount rate of 20% and 8.4% at 40%. These differences represent 14.9%,

[23] There are some changes in discount rates for discount rates over 40%.

32.7% and 78.7% of the value of a discounted cite at these discount rates. Thus, the magnitude of the impact of differences in the timing of citations on estimates of the value of knowledge contributions can be very significant.

As shown in the table, when the seven economists are ranked by total citations received over the 10 year period, the ranking is *McC, Sul, McD,Gi, Hy*, *Ho* and *Fi*. When the cost of time delay is taken into account, this ordering changes at interest rates over 24%. Between 24% and 25% *McD* and *Gi* change order, between 29% and 30% *Ho* and *Fi* change order and between 30 and 31% *McD* and *Hy* change order. Thus, for these economists, taking into account the timing of the flow of citations would affect the ranking of the economists by research productivity, but only for high discount rates.[24]

4 Conclusions

Citations are widely used as indicators of the returns to the knowledge contributions made by research publications. There can be significant differences in the time patterns of citations to research in various academic journals, subject areas or published by different individuals. These differences are likely to matter, since time delays in the recognition of research often mean that contributions are less valuable when used and that knowledge diffusion is slower.

In this paper we have provided a framework for comparing different time patterns of citations. Citations and the pattern of citations over time can be considered in terms of the number of citations and the proportion of citations received over time. We show how time patterns of citations can be compared if it is accepted that time delays in recognizing research contributions are costly, and how further comparisons are possible if in addition it is assumed that early delays in recognition are more important than later delays. In general these general assumptions make possible only a partial ordering of the citation time patterns being compared. If a particular delay function is assumed then a complete ordering is obtained and the magnitude of differences can be determined. As an example we have used a delay function that leads to exponential discounting.

[24] These discount rates are not high compared with the implicit discount rates used by RePEc, or in valuing private sector R&D.

We have applied this framework to four examples of 10-year citation patterns drawn from existing research for: different economics journals, different subject areas within business, leading journals in economics compared with neuroscience, and publications by individual economists. In two of the examples considered broad based conclusions are possible given only the general assumptions about delays in the recognition of research considered above. For the data from publications in different business subjects an almost complete order based on the general assumptions is possible. For example, ordered from the greatest delay in the recognition of research to the highest the subjects can be ranked as: *Management*, *Business*, *Economics*, *Business Finance*, *Communication* and *Information Science and Library Science.*[25] The data from our comparison of leading journals economics and neuroscience suggest that time delays in the recognition of research in economics are unambiguously greater than in neuroscience. In the other examples presented the general assumptions only allow comparisons of pairs of the alternatives considered. Thus, for example, our data suggests that delays in the recognition of research are greater for the *Quarterly Journal of Economics* than *Journal of Political Economy* or *American Economic Review*.

When a delay function consistent with exponential discounting is used complete comparisons are possible. Thus, for example, from the data for economics journals considered, at a discount rate of 10% the order from the greatest to the lowest delays in the recognition of research is: *Quarterly Journal of Economics*, *Econometrica*, *Economics Letters*, *Journal of Political Economy*, *American Economic Review*, *Review of Economic Studies* and *Applied Economics Letters*. With exponential discounting it is also possible to consider the magnitude of difference in impact of the time delay in the recognition of research. Thus, for example the maximum difference between economics journals is 7.8% and 9.6% of the discounted value of citations per paper at discount rates of 10% and 20% respectively. In comparison, when considering differences between leading journals in economics and neuroscience the maximum difference is for the *Quarterly Journal of Economics* and *Annual Review of Neuroscience* and amounts to 14.7% and 32.3% of the discounted value of a cite at discount rates of 10% and 20% respectively.

[25] An alternative ordering is: *Management*, *Business*, *Economics*, *Business Finance*, *Industrial Relations and Labor* and *Information Science and Library Science.*

With exponential discounting it is also possible to consider whether taking into account the costs of delays in the recognition of research contributions is likely to influence the rankings of economics journals or difference business subjects in terms of citations per paper, or academic economists in terms of citations. Data for the examples we have considered suggests that generally differences in citations per paper or citations would outweigh the influence of differences in the citation time, i.e. the rankings of the alternatives considered would be unaffected, except for high discount rates. Thus, for example, the ranking of economics journals using citations per paper would be the same as that using the discounted value of citations per paper for discount rates under 17%, i.e., *Quarterly Journal of Economics*, *Review of Economic Studies*, *Journal of Political Economy*, *Econometrica*, *American Economic Review*, *Economics Letters*, *Applied Economics Letters*. For discount rates of 18% or higher the ordering of the *American Economic Review* and *Econometrica* changes.

There are clearly many important questions that remain in assessing the impact of citation timing. In particular, we have ignored the influence of the pre-publication availability of research on citations and the timing of citations before and after publication. Extending the analysis to recognise the pre-publication availability of research and pre-publication citations not only significantly complicates data gathering, but would require the distinction between pre and post-publication time periods given the influence of publication itself on citation practice. We have also assumed that when citations are used as indicators of contributions to knowledge made in a research publication, the contribution signaled by a citation does not depend on the number of citations occurring at the same time or the number that has been received previously. While this is consistent with the way in which citations are typically used in research evaluation, it is clearly a simplification. A more general approach would be to develop a formal model of knowledge diffusion. Such an approach might also be able to provide a more complete characterization of appropriate restrictions on delay functions and a basis for considering approaches to discounting.

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