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Abstract

This paper surveys recent findings about how the financial markets value the knowledge assets of publicly traded firms. The motivation for using market value equation to price knowledge assets is discusssed and the theory behind this equation is briefly presented. Then the empirical literature that relates Tobin's q to R&D and patent measures is surveyed and new results based on U.S. data through 1995 are presented. The conclusion is that the market value of the modern manufacturing corporation is strongly related to its knowledge assets, and that the patent measures contain information about this value above and beyond that conveyed by the usual R&D measure.

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Innovation and Market Value

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"Possession of knowledge is worth a thousand pieces of gold."

from a Chinese fortune cookie, December 13, 1997.

1 Introduction[1]

Private firms and governments share an interest in evaluating the economic returns to their innovative activities. The most common quantitative approach to this measurement problem is to relate total factor productivity or profit growth to measures of innovation (see Mairesse and Mohnen 1995 for a recent survey of results using this methodology). But there are a variety of reasons why this approach may be incomplete or difficult to implement in some cases: first, the occasionally long and uncertain lags between spending on innovation and the impact of that innovation on the "bottom line" mean that in some cases (such as those of involving very basic research), the data will not cover a long enough time period to enable precise measurement of the total effect. Second, these same lags mean that one may have to wait a certain amount of time to see the effects in productivity, making the exercise of limited value for planning purposes. Third, measuring the returns to R&D

[1]Paper prepared for the NIESR Conference on Productivity and Competitiveness, London, February 5 and 6, 1998. The new research reported in this paper is drawn from work in progress that is joint with Daehwan Kim (Harvard University), Adam Jaffe (Brandeis University and NBER), and Manual Trajtenberg (Tel Aviv University and NBER). The data construction effort was partially supported by the National Science Foundation. I am grateful to Meg Ferrando of REI, Case Western Reserve University for excellent assistance in matching the patenting data to Compustat.

or other activities using firm or industry level data on profits or output requires careful attention to the measurement and timing of other inputs that may not be possible using available data (see Fisher and McGowan 1983 for a discussion of the general problem of using accounting data for this purpose).

For these reasons, some researchers have turned to another method of evaluating the *private returns* to innovative activity, relating the valuation placed by the financial markets on a firm's assets to its Research and Development expenditure, patenting activities, and other measures of innovation. This method is intrinsically limited in scope, because it can be used only for private firms and only where these firms are traded on a well-functioning financial market (such as the United States and the United Kingdom, where most of the work has been done to date). Nevertheless, using financial market valuation avoids the problems of timing of costs and revenues highlighted by Fisher and McGowan, and is capable of forward-looking evaluation, which the traditional productivity method does not do well. This method is also potentially useful for calibrating various innovation measures, in the sense that one can measure their economic impact using the widely-available United States firm data, possibly enabling one to validate these measure for use elsewhere as proxies for innovation value.

Interest in valuing innovation assets stems from several distinct sources, and as a result there has been more than one strand of literature: first, firms and their accountants have been anxious to develop methods to value intangible assets of the innovative kind, both to help guide decision-making, and sometimes for the purposes of transfer pricing or even the settlement of legal cases. This has lead to consideration of the problem in the financial accounting literature (see, for example, Chauvin and Hirschey 1993, Lev and

Sougiannis 1996). Second, financial economists and investors often try to construct measures of the "fundamental value" of publicly traded firms as a guide to investment; a concern with valuing the intangible assets created by R&D and other innovative activities is naturally a part of this endeavor. Finally, policy makers and economists wish to quantify the private returns to innovative activity in order to increase understanding of its contribution to growth and as a guide for strategies to close the gap between private and social returns. A byproduct of this goal is the desire to calibrate measures such as patent counts or innovation counts using market-based measures like firm value (see Griliches, Pakes, and Hall 1987 for an earlier survey of this work).

Why might the market value of firms be a useful measure of the private returns to innovation? In a market economy, the private economic "value" of a good is usually the price at which it trades in the marketplace. In the case of a knowledge asset, this price should embody all the tastes that consumers have for any particular innovation or the knowledge of how to make that innovation. That is, if we want to measure the returns or profit available from an intangible asset, the ideal would be to observe a market on which the asset trades and to measure the price at which the trade takes place. In the case of the output of the R&D performed by private firms, this is quite difficult.We observe consumer demand for particular products, but it is difficult to assign innovative inputs or outputs directly to these products in the absence of very detailed firm data. In any case, the relevant intangible assets that are necessary for producing these products and delivering them to the marketplace usually come bundled in ways that prevent us from separating them and selling them off to determine the appropriate price of a specific individual asset.

For example, the fact that it is not easy to separate the knowledge of how to make a particular chemical entity from the other assets of the pharmaceutical firm that converts this entity into a marketable drug is similar to the problem of determining the value of factory-installed automobile air-conditioning to consumers by selling it separately from the car in which it was installed. Thus many researchers confronted with this measurement problem use a solution familiar from the automobile demand literature, the hedonic regression method. That is, they try to determine the marginal value of a particular intangible asset by regressing the market price for firms that possess the asset on various characteristics of the firms, including the book value of the intangible asset in which they are interested. Implicitly they assume that financial markets price the bundles of assets that compose a firm (ordinary plant and equipment, inventories, knowledge assets, customer networks, brand names and reputation, and so forth) correctly and that the marginal shadow value (the gross rate of return) of the knowledge asset in the market place can be inferred from the regression coefficient estimate.

A few other market-based methods of valuing intangibles are feasible in particular settings: for example, consumer willingness-to-pay for particular innovations was used by Trajtenberg (1989), who studied hospital purchase of CAT scanners. Licensing fees for patents, determined by negotation between firms or between firms and universities, could be considered market-based measures of expected innovation value (Harhoff et al 1997). But few measures are available for as wide a range of technologies and industries as firm market value, although, of course, the downside of this measure is its aggregate nature.

The goal of the present paper is to outline how the market value approach has been used in the past for valuing innovative assets, and to survey some of the results in this literature, as well as presenting some new results for the United States, drawn from two research projects in which I am particpating (Hall and Kim 1997; Hall, Jaffe, and Trajtenberg 1998). The latter project is particularly novel, as it incorporates citation weights in constructing the patents variable, yielding a somewhat better measure than raw patent counts. There have been hints that this might be a useful measure in the literature earlier, but never using data over such a broad range of industries (see, for example, Trajtenberg 1990, Shane 1993, Austin 1993, and Harhoff, Narin, Scherer, and Vopel 1997).

2 Measuring the Value of Knowledge Assets

Using firm market value as a measure of innovation returns relies on the fact that publicly traded corporations are bundles of assets (both tangible and intangible) whose values are determined every day in the financial markets. In that sense, they are not different from other goods with heterogeneous characteristics, such as automobiles, personal computers, and even breakfast cereal. Since the pioneering work of Waugh (1928), Griliches (1961), and others, hedonic price equations have been widely used to measure the "prices" of individual characteristics that are bundled into heterogeneous goods. The market value application is not really different from the methodology used in those papers: we are measuring the marginal value of an additional dollar of investment in a given type of corporate asset, using as our data points a set of heterogeneous firms.

The typical model of market value hypothesizes that the market value of a firm is a function of the set of assets that it comprises:

$$V(A_1, A_2, A_3, ...) = f(A_1, A_2, A_3, ...) \tag{1}$$

where f is an unknown function that describes how the assets combine to create value. If the firm invests in the various assets $A_1, A_2, A_3, ...$ according to a value-maximizing dynamic program, and if the stock market is efficient, the function f will be the value function associated with that dynamic program. In the case with a single asset and constant returns to scale (linear homogeneity) of the profit function, we will obtain the well-known result that the market value V is a multiple of the book value of the asset A, with a multiplier (shadow price) equal to Tobin's q.

Making the comparison to the ordinary hedonic price literature highlights several problems of interpretation or difficulties with this approach:

1. As is well known, the shadow price or hedonic price measures neither supply nor demand of the particular asset; it is a measure of the equilibrium between the two at a point in time. Because it is very far from a structural parameter, there is no reason for it to be stable over time, for example. For the purpose of evaluating expected returns to the investments that have been made, the fact that we are simply measuring the market price of these investments is not a problem (in fact, it is of interest), but it would not be appropriate to treat this market price as an invariant.

2. The functional form of equation (1) is not known, nor is it easy to compute one in closed form if one assumes a realistic profit-maximizing algorithm for the firm. In general, we will fall back on fairly *ad hoc* functions, such as linear or Cobb-Douglas (linear in the logs).

3. Unlike automobiles, computers, or breakfast cereal, it is sometimes fairly easy to unbundle the corporate assets and trade them separately, which means that we will need an assumption of market efficiency to use a hedonic equation to measure the value of the assets from data on firms. That is, we need to assume that at any point in time, value-increasing unbundling will already have taken place.

Given the difficulty of deriving the value function from an explicit dynamic program or maximization model (see Wildasin 1984 and Hayashi and Inoue 1991 for solutions to some simple models when there is more than one type of asset), empirical workers have fallen back on several simple solutions guided by the theory and basic econometric considerations, in much the same way that hedonic price equations have been constructed for other durable goods. A central question is whether the assets in a firm can be treated as additively separable (which implies that the firm is equal to the sum of its parts, or alternatively, that it would be possible to unbundle the assets and sell them separately for the same price they fetch when embedded in the firm) or whether a more complex multiplicative functional form must be used. In spite of the obvious unattractiveness of the additvely separable function, many of us have used it because of its simplicity, following the initial work of Griliches (1981).[2]

Thus the following two specifications of the value function are predominant in the literature: an additively separable linear specification, as was used by Griliches (1981) and his various co-workers, and then a multiplicative separable specification of the Cobb-Douglas form. These two forms differ

[2]Of course, it always possible to think of the additively separable form of the function as simply the first and most important terms in a more general approximation to the true function.

in that the additively separable version assumes that the marginal shadow value of the assets is equalized across firms, while the Cobb-Douglas version assumes that the value elasticity is equalized.[3]

The first (linear) model is given by

$$V_{it}(A,K) = q_t(A_{it} + \gamma_t K_{it})^{\sigma_t} \tag{2}$$

Taking logarithms of both sides, we obtain

$$\log V_{it} = \log q_t + \sigma_t \log A_{it} + \sigma_t \log(1 + \gamma_t K_{it}/A_{it}) \tag{3}$$

In most of the work reported on here,[4] the last term is approximated by $\gamma_t K_{it}/A_{it}$, in spite of the fact that the approximation can be relatively inaccurate for K/A ratios of the magnitude that are now common (above 15 percent). In this formulation, γ_t measures the shadow value of R&D assets relative to the tangible assets of the firm and $q_t\gamma_t$ measures their absolute value (when σ_t is approximately unity).

The second (log-linear) model has the Cobb-Douglas form:

$$V_{it}(A,K) = q_t A_{it}^{\sigma_t - \alpha_t} K_{it}^{\alpha_t} \tag{4}$$

In logarithms, this equation is the following:

$$\log V_{it} = \log q_t + \sigma_t \log A_{it} + \alpha_t(\log K_{it}/A_{it}) \tag{5}$$

[3]This is exactly parallel to the distinction between rate of return estimates and elasticity estimates in the productivity literature (about which many have written: see for example, Hall (1996) for a discussion of this issue). And much the same tension exists between the two: a constant shadow value across firms is more defensible from a theoretical (market efficiency) point of view, but the constant elasticity form tends to fit the data better and be less sensitive to outliers.

[4]See Hall and Kim (1997) for an exception to this rule. In that paper we use the nonlinear form of the equation explicitly.

In both models, the coefficient of $\log A$ is unity under constant returns to scale or linear homogeneity of the value function. If the assumption of constant returns is true (as it will be approximately in the cross section), it is possible to move the log of ordinary assets to the left hand side of the equation and estimate the model with the logarithm of the conventional Tobin's q as the dependent variable. The intercept of either model can be interpreted as an estimate of the logarithmic average of Tobin's q for the sample of firms during the relevant period. In order to compare the results of the second model to the results of the first, we need to compute the ratio of the marginal shadow value of K to that of A:

$$\frac{\partial V/\partial K}{\partial V/\partial A} = \frac{\alpha_t V_{it}/K_{it}}{(\sigma_t - \alpha_t)V_{it}/A_{it}} = \frac{\alpha_t A_{it}}{(\sigma_t - \alpha_t)K_{it}} \tag{6}$$

This measure can be compared to the γ_t estimated by the first model, but to do so we will need to use some kind of average value of A/K. The absolute shadow value of R&D capital is equal to $\alpha_t V_{it}/K_{it}$[5]

In passing, I note that a variant of equation (2) has been used by some researchers (notably Connolly, Hirsch, and Hirschey 1986 and Connolly and Hirsch 1988), where constant returns ($\sigma_t = 1$) and market equilibrium ($q_t = 1$) are imposed and A_t is subtracted from the left hand side to give the following:

$$V_{it}(K) - A_{it} = \gamma_t K_{it} \tag{7}$$

In this case the excess of market value over book value of the assets is regressed on various measures of intangibles. An obvious difficulty with this

[5]Unfortunately, this quantity is difficult to work with both because it is undefined for firms that do not do R&D, and also because of its very skew distribution for those that do. In Figure 3, I present an example that shows how much this estimate of the absolute shadow value can differ from those using the linear model when average values of the market value-knowledge capital ratio are used to evalute this expression.

version is that if Tobin's q differs from unity on average (as it almost always does), $(q_t - 1)A_{it}$ will end up in the disturbance and potentially bias the estimates of γ_t (which is an estimate of either the relative or the absolute shadow value of K in this formulation).

3 Market Value and R&D

Table 1 presents a summary of some of the earlier work relating the market value of individual firms to innovation indicators such as R&D and patenting. Most of this prior literature has used U.S. data and the linear form of the value equation. With the exception of Hall (1993a, 1994b), Chauvin and Hirschey 1993, and Stoneman and Toivanen (1997), parameter stability has been imposed on the relationship over time. The table shows that researchers using data for United States manufacturing firms generally conclude that R&D spending in the current year is capitalized into the market value at a rate between about 2.5 and 8 (with most estimates centered at 5 to 6) and that the stock of R&D (which is usually constructed from a perpetual inventory formula using a depreciation rate of 15 percent) is valued between 0.5 to 2 times the value of ordinary assets. A notable exception to the latter result is that of Jaffe, who finds a much higher R&D stock coefficient when he controls for the potential spillovers from firms that patent in related technology fields. In general, the addition of industry dummies (at the two-digit level) to the equation does not change the estimates, although including firm dummies or lagged Q does lower the R&D coefficient, which suggests that there are some permanent differences in the market value-R&D relationship across firms.

The focus of the particular studies summarized in Table 1 has varied: for example, Jaffe's 1986 paper was an innovative and careful investigation into the contribution of the R&D of other firms that are in the same technology space as the firm in question to its patenting, profits, and market value. He found that the raw contribution to market value was rather weak and slightly negative, but that the contribution was positive and significant when the firm in question had a good-sized R&D program of its own. Connolly, Hirsch, and Hirshey (1986) were concerned with the effects of unions on the incentives to undertake R&D and on the returns obtained from that R&D; they found, as expected, that firms in unionized industries were less likely to perform R&D and that when they did, the rents received were lower.

Cockburn and Griliches (1987) attempted to use measures of appropriability from the Yale survey on innovation to explain variations in the shadow value of R&D in different firms and industries with very limited success, while Megna and Klock focused on the effects of rivalry in R&D in a specific industry (semiconductors).

Most of the earlier U.S. results reported are for the late sixties and seventies. Later work by myself and others (e.g., Hirschey, Richardson, and Scholz 1998) revealed both that this was a period of relatively high valuation of R&D in the market and that the shadow value of R&D does not display much stability over time. In Hall (1993a, 1993b), I found that the relative valuation coefficient had declined rather abruptly during the 1980s in the United States, and that the decline could be partially explained by two factors: 1) an increase in the value of ordinary assets, probably associated with the pervasive restructuring that took place during the period, and 2) a decline in the value of R&D assets that appeared to be concentrated in the electrical machinery, computing, electronics, and scientific instruments sector. This result was consistent with what we know about the pace of technical change in those industries, and suggested that the private returns to R&D done in those industries was not very long-lived. However, the size of the decline raised questions about the incentives for innovation in U.S. manufacturing in the late eighties and early nineties; clearly the behavior of firms suggested that many firms still viewed R&D as a profitable activity, in spite of the apparent market signal.

Daehwan Kim and I are currently engaged in a study that updates these results to 1995, and explores their robustness to changes in functional form, improvements in measurement of the other assets variables, and so forth. Figure 1 displays the sample of firms that we are using, which consists of essentially the entire publicly traded U.S. Manufacturing sector.[6] Figure 2 displays preliminary results obtained using both equations (5) (log linear) and (1) (linear in the stocks, in either a nonlinear or linear in variables form of the equation). We have computed the relative marginal product that corresponds to the coefficients from equation (5) using equation (6). The figure shows that the decline in the valuation of R&D assets that I observed through 1991 has begun to recover in the mid-1990s, although not to the level of the boom years of the early 1980s. Nonnested hypothesis testing suggests that the data prefer either the log linear (Cobb-Douglas) model or the nonlinear model, with the linear approximation to the nonlinear model a poor third. We are currently exploring the source of the differences in the

[6]The figure shows the number of firms we have available in each year using three different sets of criteria: the total number of firms for which we have some data, the number of firms that report R&D and have good data on capital, employment, sales, and market value, and finally the number of firms that pass our various data quality criteria in addition. These criteria remove firms with large jumps in their series, firms that only have tiny amounts of R&D, and a few other outliers.

results and how they vary over industrial sector and specification.

To my knowledge, there are only two studies of the market value of innovative assets that use non-U.S. data, both for the United Kingdom: Blundell, Griffith, and van Reenen (1997), who use innovation data rather than R&D, and Stoneman and Toivanen (1997) who use R&D data for 1989 through 1995.[7] I will discuss Blundell et al in the next section when I review the results using patents rather than R&D. Because required reporting of R&D has just begun in the United Kingdom, Stoneman and Toivanen are careful to estimate the relationship between market value and R&D using sample selection methods to correct for the probability of reporting R&D. They are also unable to construct a stock of R&D capital owing to the short history of spending for most firms, so they report estimates using a flow measure of R&D instead. They find that the coefficient of R&D spending varies over time for their firms, with a range from zero to 4.3; in most years it is significant and the average value seems to be about 3, which is slightly lower than the corresponding number for the United States in the early nineties (approximately 1 to 2). They also find the very interesting result that when a firm first announces its R&D (i.e., when it begins reporting the figure publicly), the multiplier is somewhat higher, with a value close to 5. This suggest some kind of timing of the announcement by the firms, perhaps.

[7] Unlike the United States, where financial accounting standards have required the reporting of "material" R&D expense since 1972, in the United Kingdom the requirement was imposed only in the late nineteen-eighties, so that public data on R&D spending is sparse before that time. And in many continental countries, R&D reporting is not part of the standard accounting requirements even today.

4 Market Value and Patents

Research that uses patents in the market value equation rather than R&D is somewhat more limited, primarily because of the difficulty of constructing firm datasets that contain patent data. Most of the work shown in Table 1 and described here has been done by Griliches and his coworkers using a database constructed at the NBER which contained data on patents only through 1981. This dataset did not include information on the citations related to the patents. The other papers in the table use a cross section constructed by Connolly et al for 1997 of Fortune 500 companies, and datasets involving UK data, one that includes innovation counts from a SPRU study rather than patents.

When patents are included in a market value equation, they typically do not have as much explanatory power as R&D measures, but they do appear to add information above and beyond that obtained from R&D, as one would expect if they measure the "success" of an R&D program. Griliches, Hall, and Pakes (1987) show that one reason patents may not exhibit very much correlation with dollar-denominated measures like R&D or market value is that they are an extremely noisy measure of the underlying economic value of the innovations with which they are associated. This is because the distribution of the value of patented innovations is known to be extremely skew (see Scherer 1997 for a recent study of this kind, other refs, etc.), implying that a few patents are very valuable, and many are worth almost nothing. Therefore the number of patents held by a firm is a poor proxy for the sum of the value of those patents and we should not expect the correlation to be high. Some small studies exist that suggest that the number of citations received by a patent may be correlated with its economic value (Trajtenberg 1990, Shane and Klock 199?, Harhoff, Narin, Scherer, and Vopel 1997), so that weighting patents by the number of citations they receive may improve the measure.

There is also good reason to think that the meaning of a patent to a U.S. corporation may have changed somewhat since 1981 (see the results of the Carnegie-Mellon (1993), or Yale II survey, which differed in some sectors from those of the Yale I survey of the early 1980s). For both these reasons, Adam Jaffe, Manuel Trajtenberg, and I have embarked on a project to create a new dataset of U.S. firms that contains data on all the patents held by the firms, including information on the citations received. I report preliminary results from that study here.

Figure 4 shows the fraction of firms in our sample in a given year who reported R&D expenditures to the SEC, the fraction who applied for a patent that was ultimately granted, and the fraction who have a nonzero stock of patents that year.[8] The fall in the later years in the number of firms with patent applications is due to the fact that patents may have been applied for but not yet granted. Figure 5 shows the ratio of citations made to patents held by firms in our sample to the number of patent grants, all dated by the application year of the patents, and the median citation count per patent at the firm level. Both these numbers also fall off beginning in about 1985 or earlier, because of the fact that in many cases citations are made more than 10 years after the original patent is issued. These facts need to be kept in

[8]The stock of patents is defined using a declining balance formula and a depreciation rate of 15 percent, by analogy to the stock of R&D spending:

$$PS_t = 0.85 PS_{t-1} + P_t \tag{8}$$

mind when looking at the estimates below.

Figure 6 shows the R-squares from 3 simple Tobin's q regressions that use different measures for the stock of innovations: the R&D stock, the stock of patents (measured at application date), and the stock of patents weighted by citations ever made. While neither patents nor citation-weighted patents do as well as R&D in explaining Tobin's q, clearly citation-weighted patents do better, especially in the earlier years where the measure is better.

Figure 7 shows the coefficients from this regression; in the case of patents and citation-weighted patents, the coefficients have been scaled so that they are in R&D units and can be compared with the R&D coefficient.[9] The patent measures exhibit the same decline in the 1980s as the R&D coefficients, but clearly the estimated shadow prices are much lower, which is to be expected given the way we normalized them. The main message of the figure is that the citation measures appear to work slightly better in the period where we think they are more or less complete (before 1985).

Figure 8 shows the coefficients that result when both patent stocks and citation-weighted patent stocks are included in the same Tobin's q equation (again measured in R&D units). The result is that the citation-weighted patent stock is clearly preferred in the pre-1985 period over the unweighted stock of patents, which has a coefficient that is zero or negative. Thus Hall, Jaffe, and Trajtenberg conclude that citation-weighted measures of patents

[9]The scaling is done in the following manner: for each year, we estimate a shadow price γ of a patent, in units of millions of dollars per patent using equation (3) with the patent stock in place of K. We convert this quantity to R&D units by dividing it by the average amount of R&D necessary to produce one patent in the sample as a whole (the ratio of R&D spending to patents for that year). We do the same computation for citations, using the average amount of R&D necessary in that year to produce one citation in the future. This is only an approximation, and a very poor one, since the meaning of citations and patents varies enormously across firms. But it does enable us to compare the estimates on the same chart.

have the potential to be a more precise "economic" measure of innovation than patents by themselves.

5 Conclusion

This paper has surveyed the somewhat limited literature on the market valuation of the intangible assets associated with industrial innovation. The key findings from the recent work the following:

1. R&D assets are valued by financial markets. A reasonable fraction of the variance in market value that remains after controlling for ordinary assets is explained by either R&D spending or the stock of R&D (with the flow coefficient averaging about 4-5 times the stock coefficient). However, there is still a fair amount of unexplained variance. This basic fact is true in the United States and the United Kingdom.

2. The R&D coefficient is not stable over time in either the United States or the United Kingdom. In the U.S., this coefficient reached a recent peak in the early 1980s and has declined since. This result seems to vary across industry, but industry-level findings are somewhat unstable and inconclusive.

3. Patents are informative above and beyond R&D, although the correlation is much weaker. The average R-squared for the Tobin's q-R&D relationship is approximately 0.15, while that for the patents-R&D relationship is about 0.08.

4. Citation-weighted patents are slightly more informative than patents. The average R-squared for citation-weighted patents alone is about

0.10. When both variables are included in a regression, the citation-weighted one clearly wins.

5. However, the pattern of the patents and citation-weighted patents coefficients in the market value regression over time appears to be identical: they are measuring the same thing, but citation weights improve precision.

Many areas remain for future work in this area. In particular, the specification and estimation of the valuation equation in a setting where the assets have a very wide and skew distribution is somewhat unsatisfactory at the moment and could be improved, both to reduce sensitiviy to outliers and to increase the stability of the coefficients over time, or to model the changes in the coefficients. The patents data I have used here is somewhat preliminary and work can be done to improve its accuracy and coverage. The weighted and unweighted stocks of patents ought to be adjusted for changes in patenting and citation propensity over time, and the role of self-citations explored. Finally, the very interesting question of the timing of the citation effects on valuation should to be explored. But the preliminary results using this new dataset show promise.

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7 Appendix

The data I use is drawn from the Compustat files and from files produced by the United States Patent Office. I have included all the firms in the manufacuring sector (SIC 2000-3999) between 1976 and 1995 in a large unbalanced panel (approximately 5000 firms). The firms are all publicly traded on the New York, American, and regional stock exchanges, or traded Over-the-Counter on NASDAQ. For details on data construction, see the documentation in Hall (1990), although I have drawn a new sample from a larger dataset than the file described there.

The chief variables from Compustat that I use are the market value of the firm at the close of the year, the book value of the physical assets, and the book value of the R&D investment. The market value is defined as the sum of the value of the common stock, the value of the preferred stock (the preferred dividends capitalized at the preferred dividend rate for medium risk companies given by Moody's), the value of the long-term debt adjusted for inflation, and the value of short-term debt net of assets. The book value is the sum of the net plant and equipment (adjusted for inflation), the inventory (adjusted for inflation), and the investments in unconsolidated subsidiaries, intangibles, and others (all adjusted for inflation). Note that these intangibles are normally the good will and excess of market over book from acquisitions, and are not included in the R&D investment. The R&D capital stock is constructed using a declining balance formula and the past history of R&D spending with a 15 percent depreciation rate.

The patents data have been cleaned and aggregated to the patent assignee level at the Regional Economics Institute, Case Western Reserve University. I have matched the patent assignee names with the names of the Compustat firms and their subsidiaries in order to assign patents to each firm. This project is still underway and the current success rate of name-matching is about two-thirds, although many of the remainder firms simply do no patenting. Most of the subsidiaries are not yet included. Thus the results in this paper involving patents must be viewed as extremely preliminary, but suggestive.

Table 1
Market Value - Innovation Studies with R&D and Patents

Study	Country (Industry)	Years	Functional Form	Other Variables	R&D Coeff	R&D Stock Coeff	Patent or Innov Coeff	Comments
Griliches 1981	US	1968-74	Linear (Q)	Time & Firm dummies, [log Q(-1)]		1.0-2.0	.08 to .25 ?	units appear to be 100 pats
Ben-Zion 1984	US	1969-76	Linear (V)	Ind dummies, Investment, Earnings	3.4 (0.5)		.065 (.055)	No time dummies?
Jaffe 1986	US	1973, 79	Linear (Q)	Time & tech dummies, C4, mkt share, Tech pool, interactions		7.9 (3.3)		3SLS even higher
Hirschey, Weygandt	US	1977	Linear (Q)	Adv, C4, growth, risk	8.3 (1.4)			Compare durable/non-dur.
Connolly, Hirsch, Hirschey 1986	US	1977	Linear (EV/S)	Growth,risk,age,Mkt share,C4,Adv, Union share, Ind dummies	7.0 (0.8)		4.4 (0.6)	Unexpected patents
Cockburn, Griliches 1987	US		Linear (Q)	Industry appropriability (Yale survey)				
Griliches, Pakes, Hall 1987	US							
Connolly, Hirschey 1988	US	1977	Linear (EV/S)	Growth, risk, C4, Adv	5.6 (0.6)		5.7 (0.5)	Bayesian estimation
Connolly, Hirschey 1990	US	1977	Linear (MV/S)	Adv, MS, C4, risk, growth, Inv	5.7 (0.7)		5.7 (0.5)	Patent surprise
Hall 1993a	US	1973-91	Linear (V)	Assets, Cash flow, Adv, Gr, time dummies	2.5-3.0 (.8)	0.48 (.02)		By year also
Hall 1993b	US	1972-90	Linear (Q)	time dummies	2.0-10.0	0.5-2.0		By year; LAD; absolute coeff
Johnson, Pazderka 1993	US							
Thompson 1993	US							
Megna, Klock 1993	semiconductors	1977-90	Linear (Q)	Rivals R&D and patents		0.82 (0.2)	0.38 (0.2)	Patent stock
Chauvin, Hirschey 1993	US	1988-90	Linear (V)	Cash Flow, growth, risk, adv, MS, ind dums	6.47 (.35)			Compares size, non-mfg/mfg
Blundell, Griffith, van Reenen 1995	UK	1972-82	Linear (V)	Time dummies,Assets,Mkt share			1.93 (.93)	Innovation counts
Stoneman, Toivanen 1997	UK	1989-95	Linear (V)	Assets,Debt,Growth,Mkt share,investment, Cashflow, time dummies, Mills ratio	2.5 (1.5)		Insig.	Selection correction; by year
Chauvin , Hirschey 1997	US	1974-90	Linear (V)	Cash flow, beta, growth-Adv, growth-MS interaction, ind dummies				can't derive R&D coeff.
Hirschey, Richardson, Scholz 1998	US	1989-95	Linear (Q)	Earnings, R&D and patents	1.7 (0.5)	0.20 (.06)	3.30 (.65)	Current impact, sci link, deprec

Figure 1
Cleaned Sample of US Manufacturing Firms

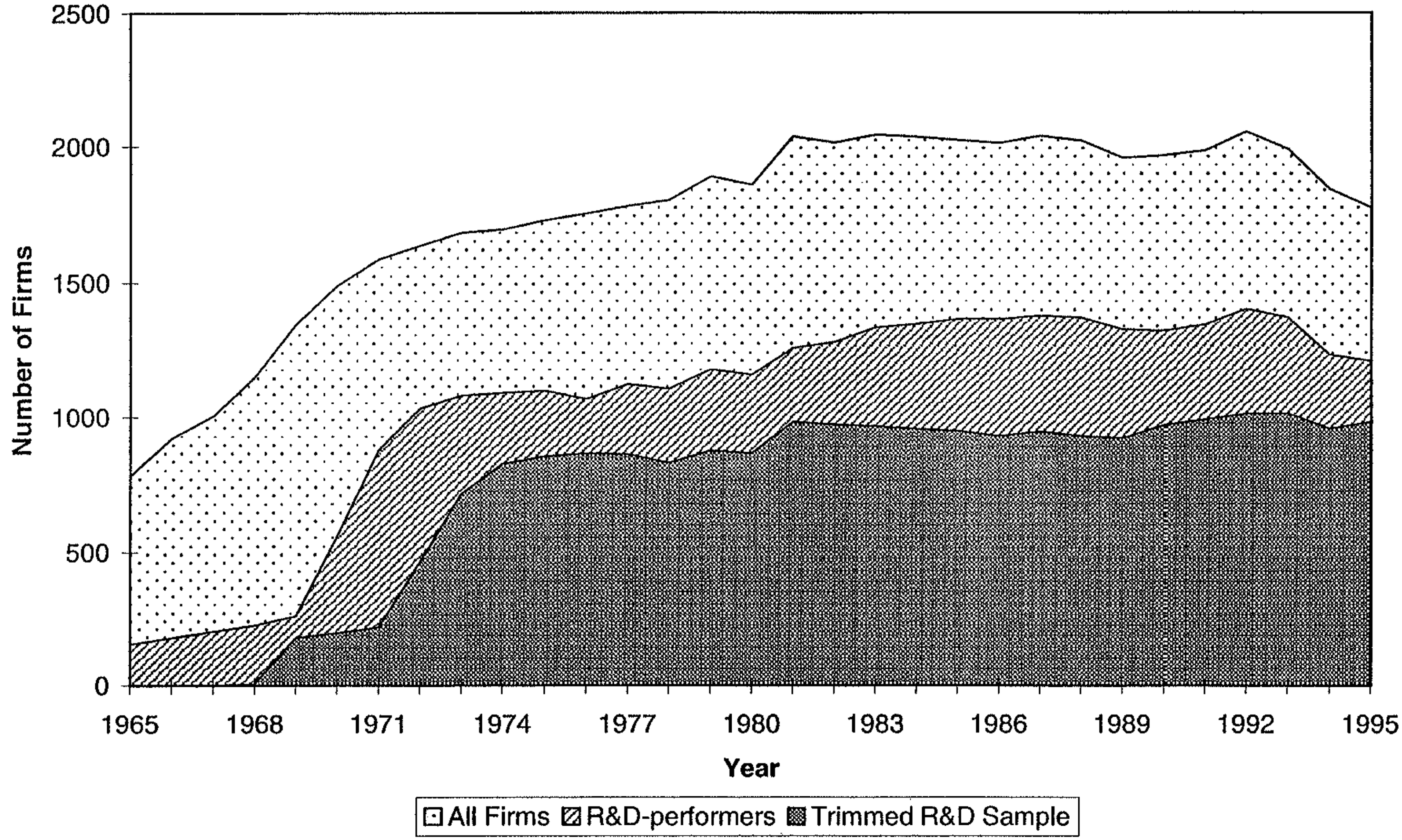


Figure 2
R&D Doing Firms - Trimmed Sample - Comparing Specifications

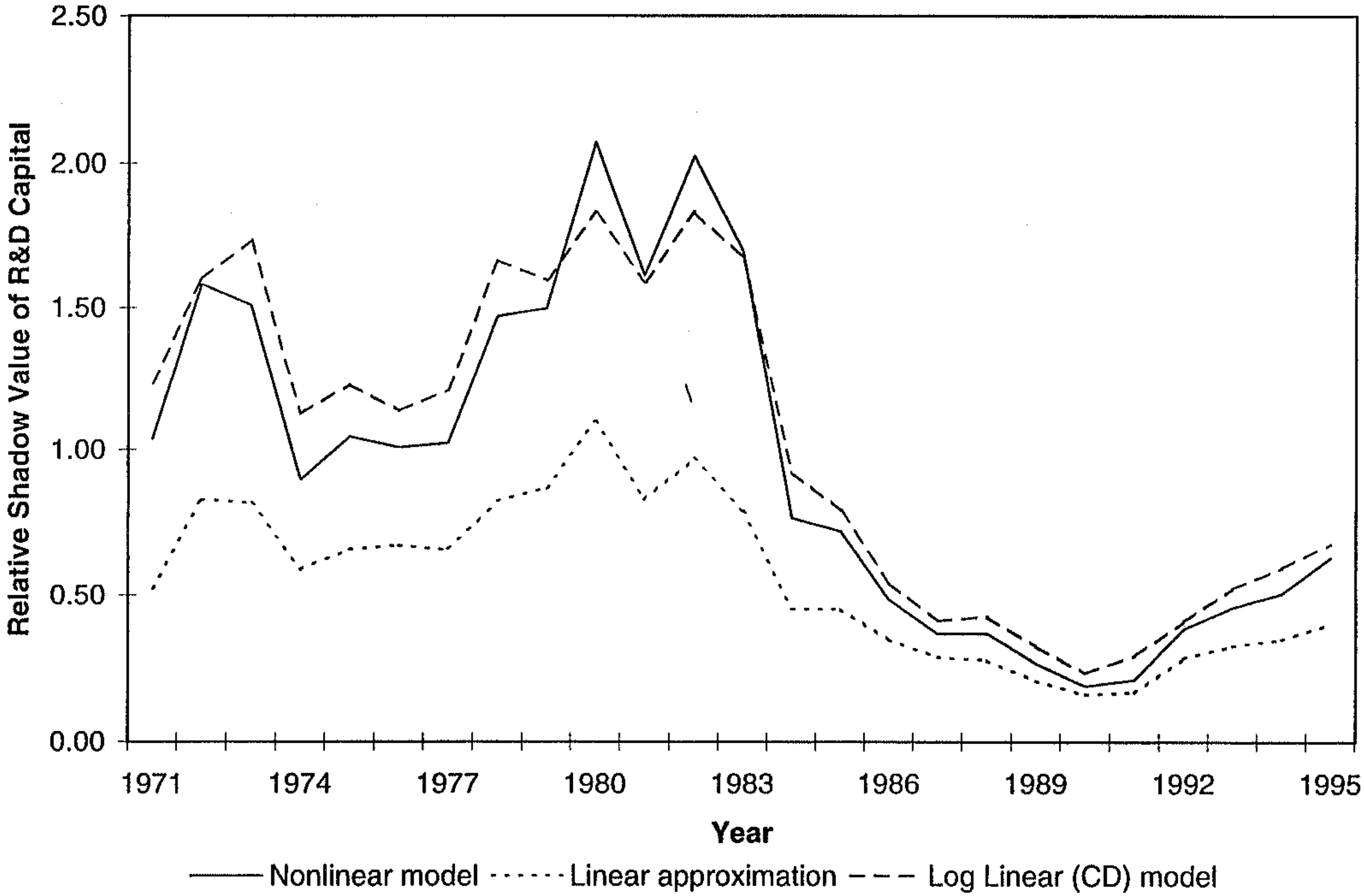


Figure 3
R&D Doing Firms - Trimmed Sample - Comparing Specifications

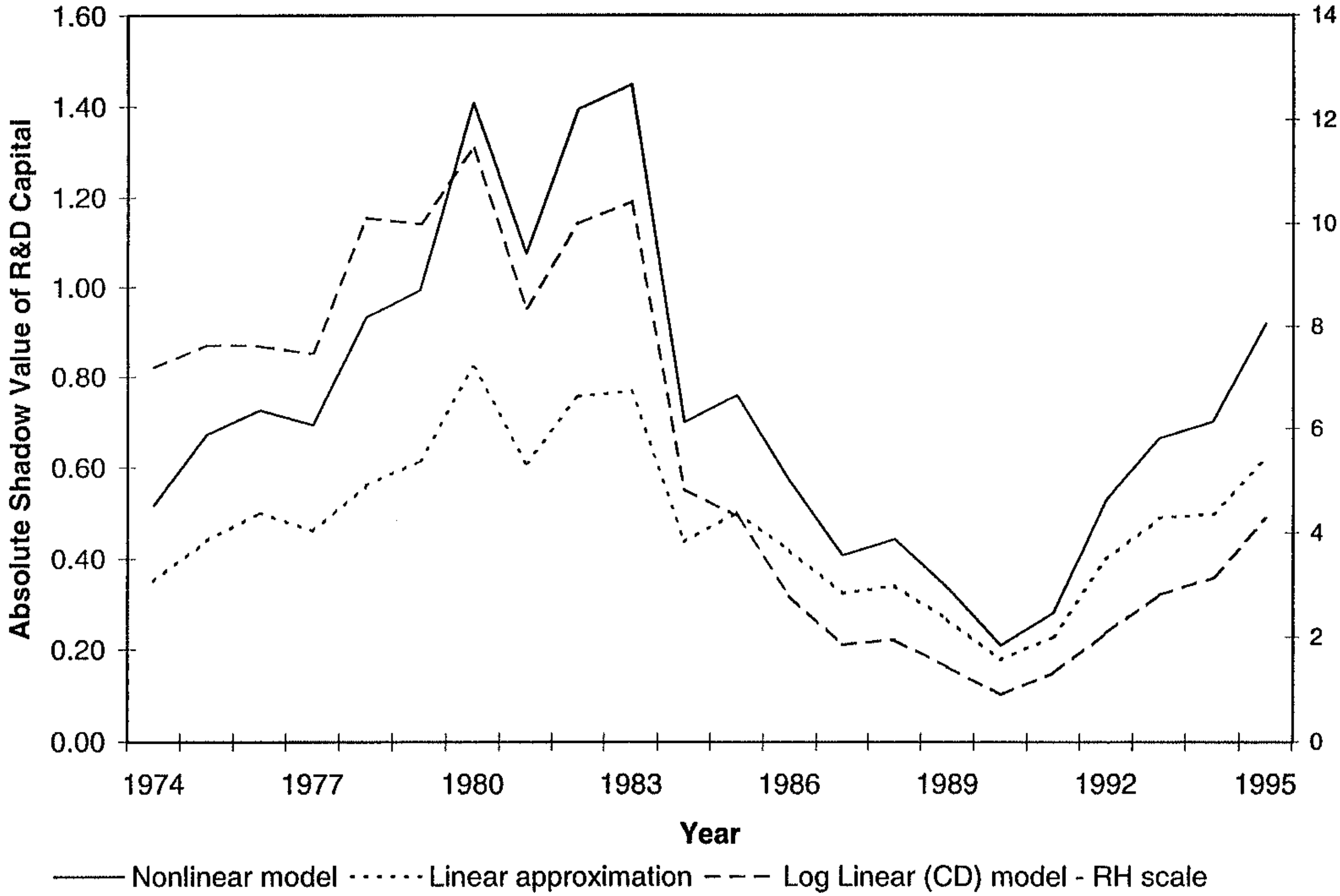


Figure 4
U.S. Manufacturing - Cleaned Sample

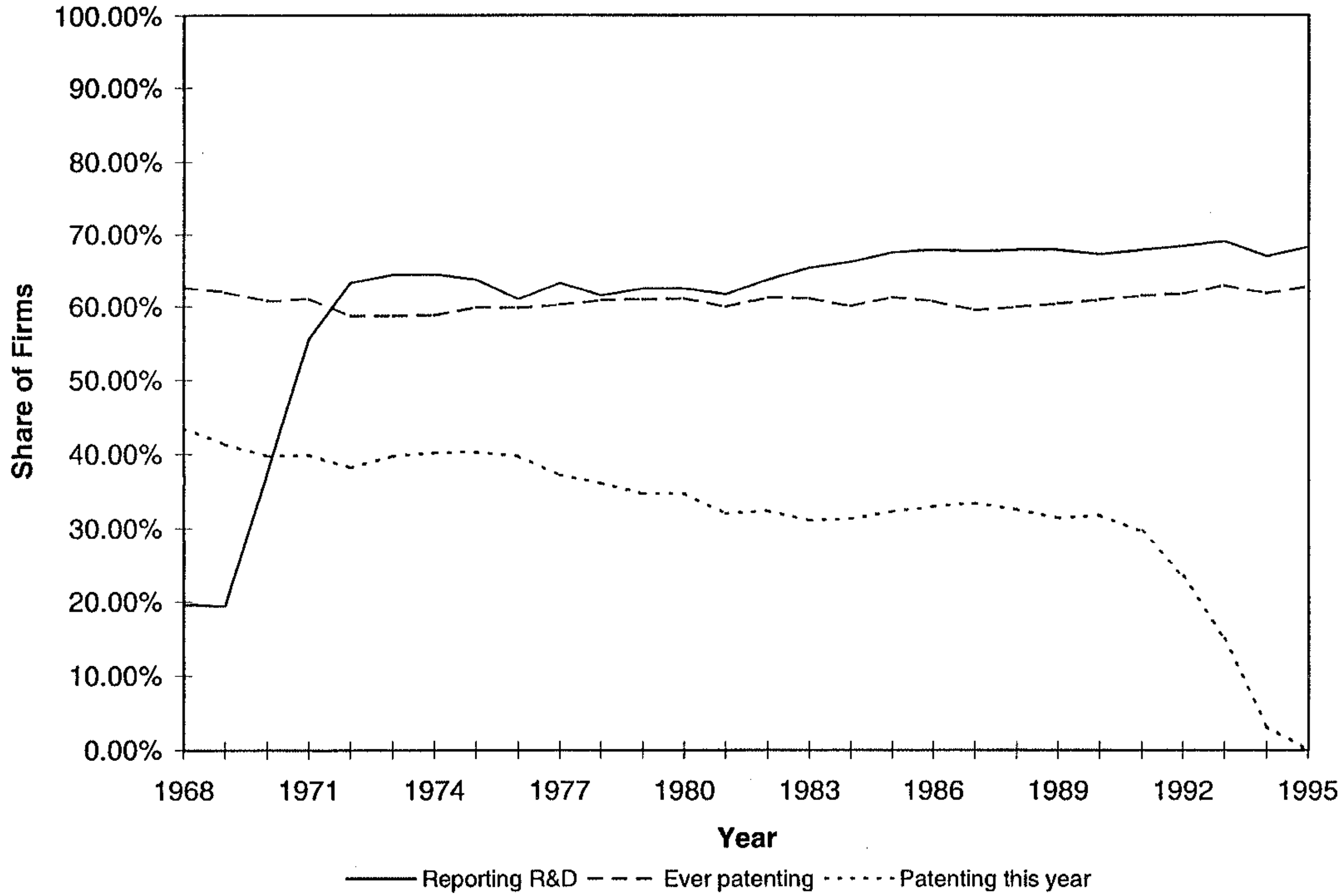


Figure 5
Citations per Patent by Year of Application

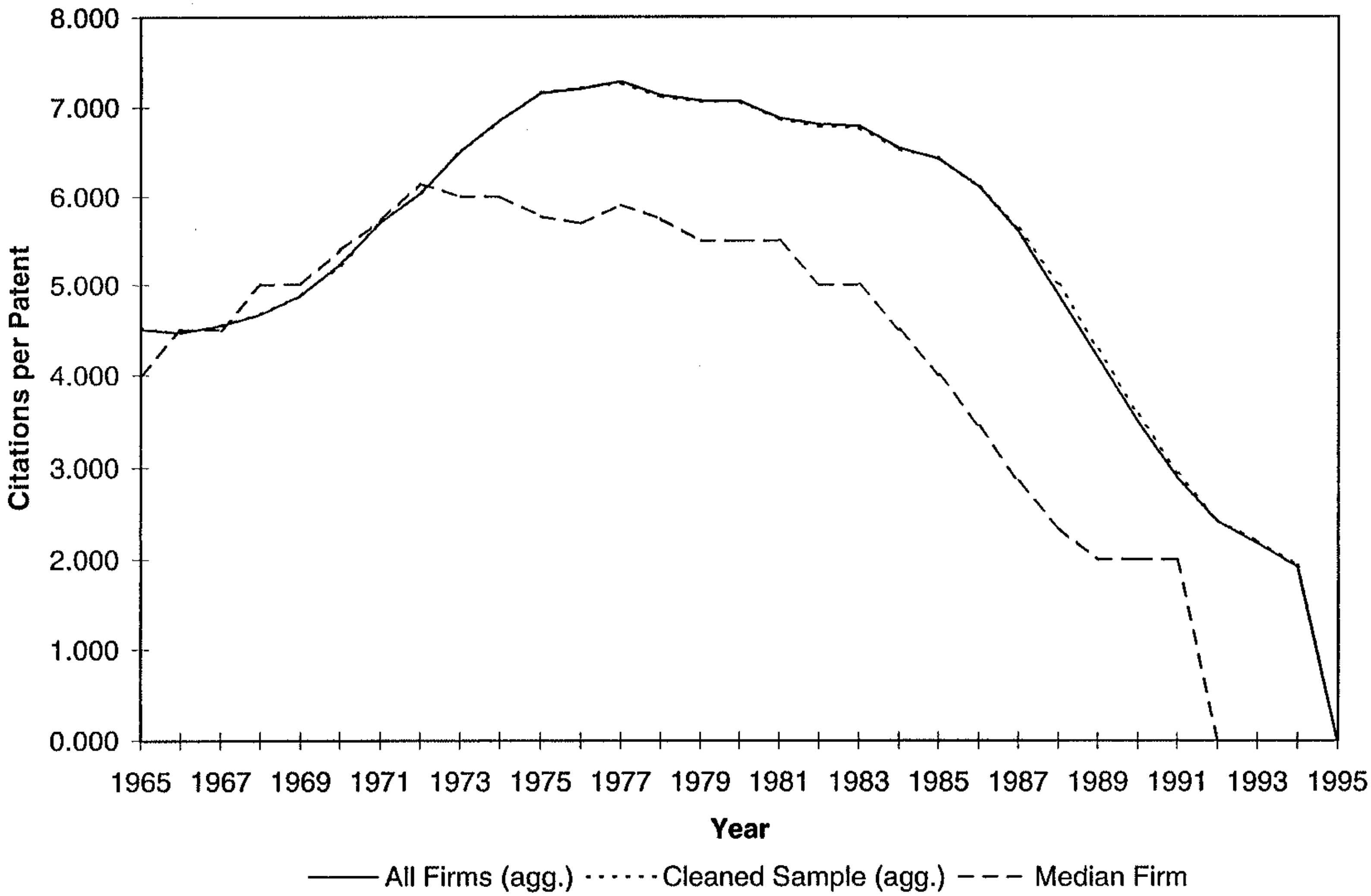


Figure 6
Explaining Market Value with Innovation Stocks

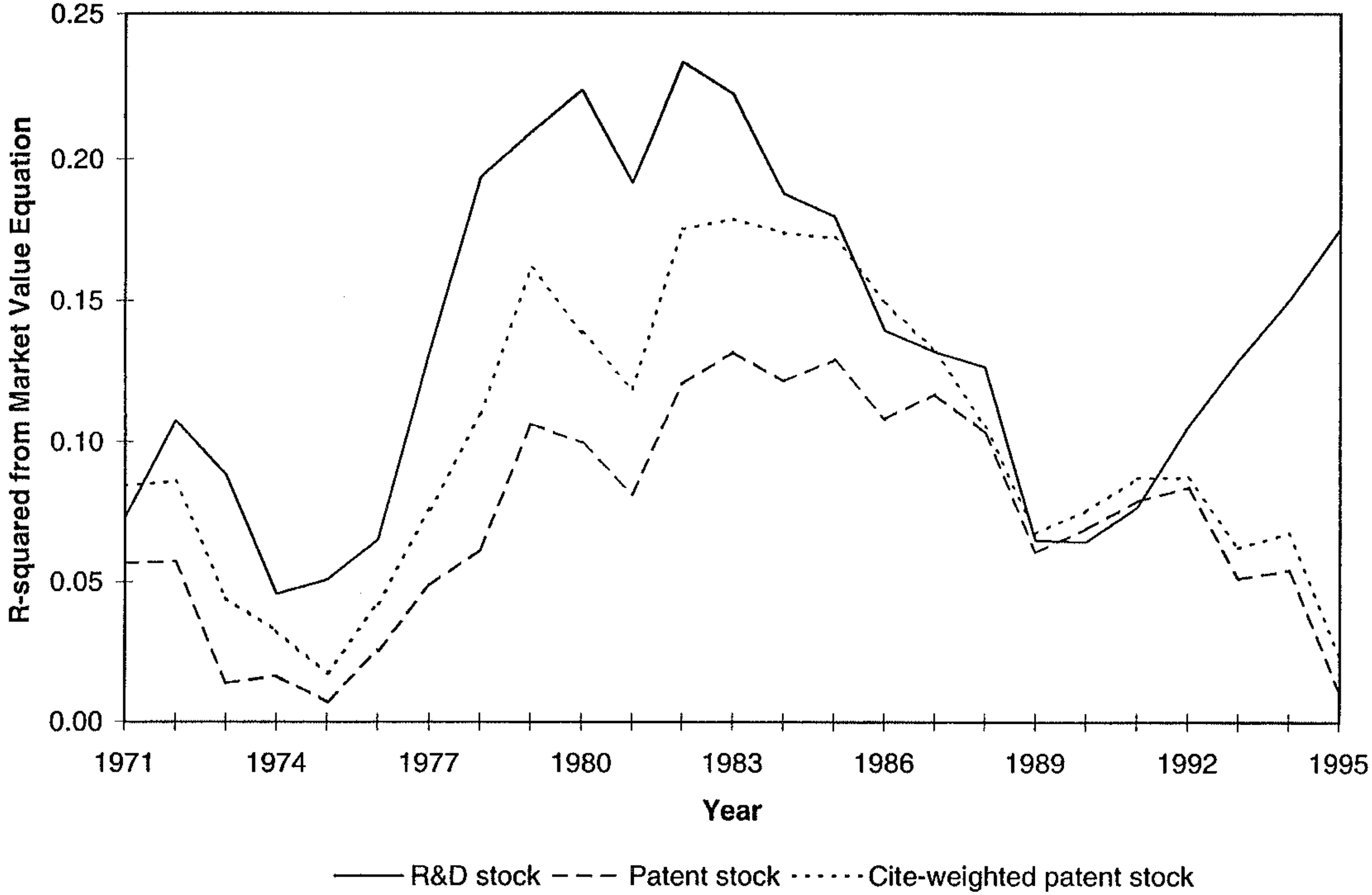


Figure 7
Explaining Market Value with Innovation Stocks

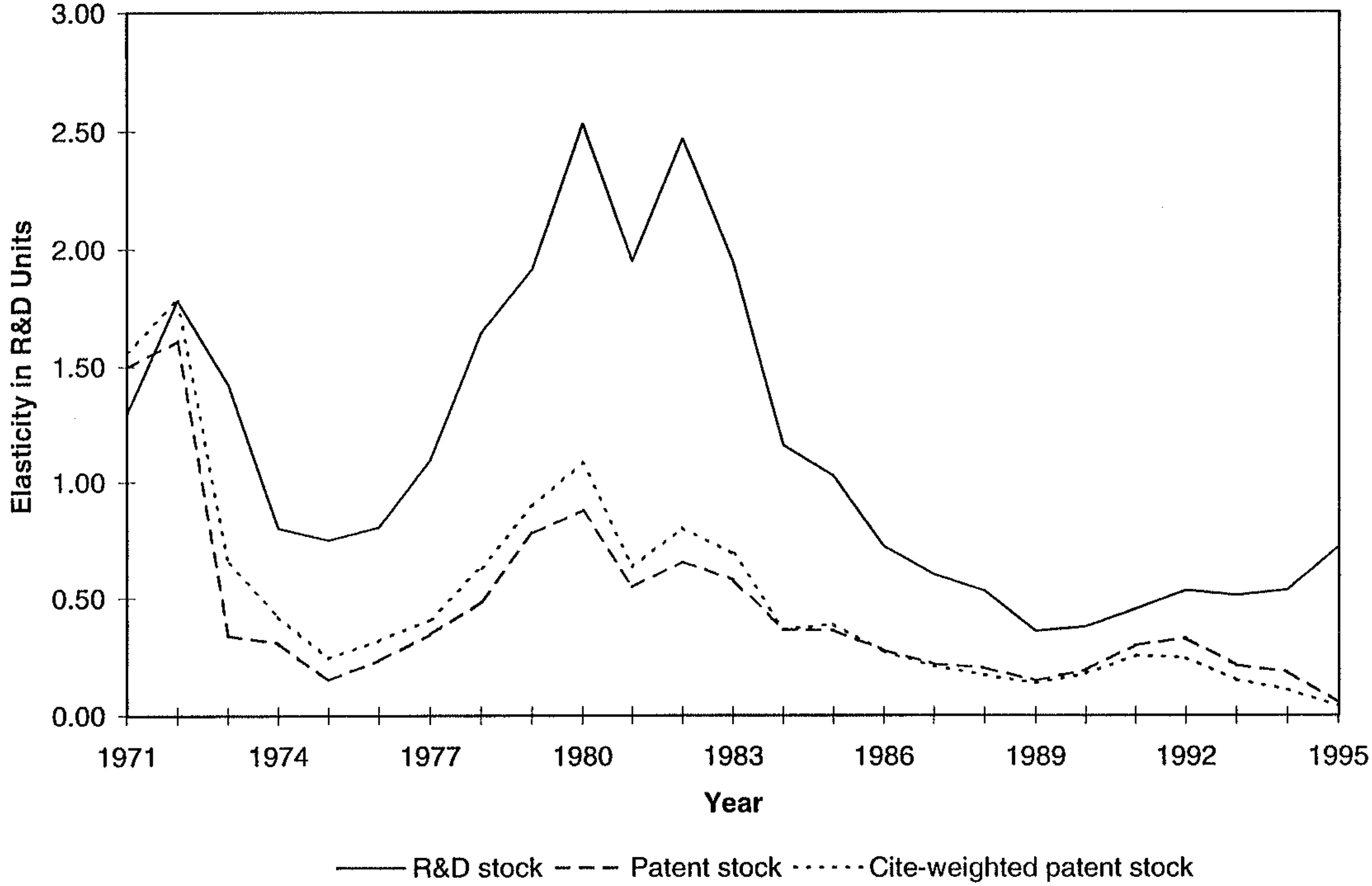
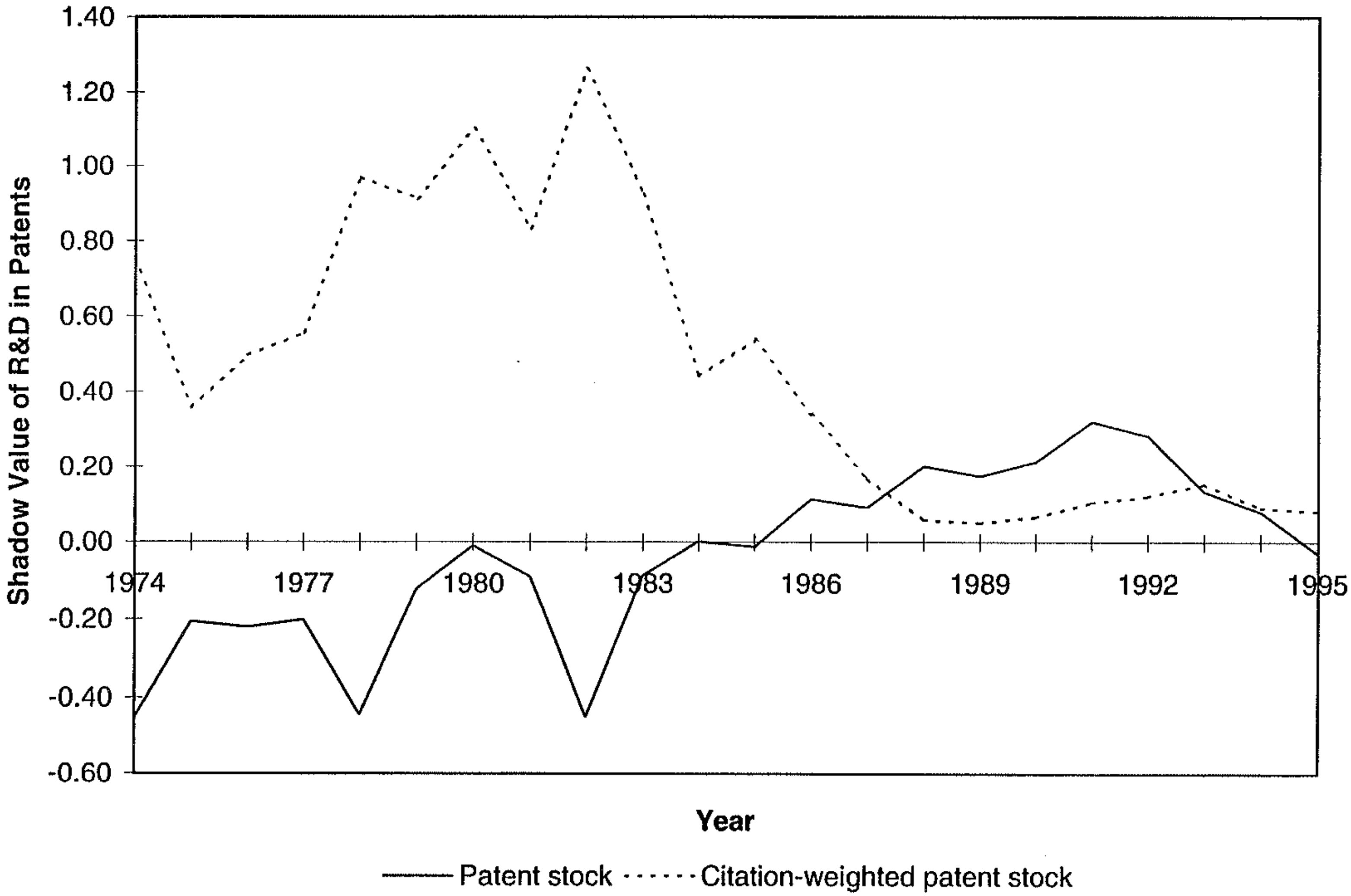


Figure 8
Patent Valution Coefficients in R&D Units



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