Valuing Intangible Assets: The Stock Market Value of R&D Revisited

Bronwyn H. Hall and Daehwan Kim
UC Berkeley, Oxford University, and NBER; Harvard University and NBER

Hall (1993a,1993b) reported a substantial drop in the market price of R&D investment relative to that of ordinary investment during the 1980s, particularly in the electronics and computing sector. In this paper we take another look at the valuation problem, using data on a large panel of manufacturing firms through 1995. Although we confirm the earlier decline in relative market values, we find that its magnitude is quite sensitive to methods of measurement and we propose some more robust methods for determining the hedonic price of corporate assets. *(December 31, 1997; revised January 2000)*

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

from a Chinese fortune cookie, December 13, 1997.

1 Introduction

Hall (1993a,1993b) reported a substantial drop in the market value of R&D investment relative to that of ordinary investment during the 1980s, particularly in the electronics and computing sector. Using a comprehensive sample of publicly traded manufacturing firms, Hall (1993a) reported that the shadow value of R&D investment (the rate at which the investment is capitalized by the market) fell from about 6 in 1980 to 1.5 in 1990, with the corresponding price of the stock of R&D (the "Tobin's q" for R&D assets) falling from approximately unity to 0.2. Hall (1993b) showed that this finding resulted from two major causes: first, the market value of ordinary tangible capital was rising during the period in most sectors, probably because of the substantial restructuring and shrinkage of manufacturing, which tended to remove unproductive capital from the publicly traded sector. Second, the decline in the relative value of R&D capital was concentrated in the electrical, computing and electronics, and instruments sectors. The petrochemical

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[1] UC Berkeley, NBER, and Nuffield College, Oxford; Harvard University and NBER. Our collaboration was created and encouraged by the late Zvi Griliches and we are grateful to him for initiating the project and for many helpful discussions.

industry, pharmaceuticals, metals, machinery, autos, and other industries did not experience declines of the same magnitude.

Using estimates of the contribution of R&D to revenue productivity for these same firms, she was able to explain the result in terms of a decline in the private return to R&D in some of the manufacturing sectors. For example, large firms in the electrical and computing sectors had a particularly low private return to R&D, which probably reflected the write-off of past R&D investments in computer mainframes. With an efficient stock market, this translated into a low shadow value for the R&D assets in these firms. Since that paper was published, there has been a revival in the growth of firm-level R&D as well as advances in the measurement of Tobin's q, notably the work of Llewellyn and Badrinath (1997), so it seems an appropriate time to take another look at the valuation of R&D investment at the firm level and how it has changed in the 1990s.

Thus the present paper is motivated by a specific question: did the decline of the market value of R&D assets continue into the 1990s as the stock market took off, or did values revert towards those of the early 1980s? Along the way we explore various methods of measuring the "average" value of the various assets that make up a corporation, in an attempt to make our results more robust. We use a new methodology for measuring inflation-adjusted stocks of tangible assets suggested by Llewellyn and Badrinath (1997) and we report results for several different functional forms for the valuation equation. Changing the measurement of capital stock makes little different to our estimates, but the elasticity of value with respect to R&D is very sensitive to the precise functional form used to estimate it, implying substantial heterogeneity among our firms.

As we discuss in the first section of this paper, market value estimates of the type pioneered by Griliches (1981), and presented by many subsequent authors including Hall are an application of hedonic price methods to the problem of valuing corporate assets.[2] This methodology is useful for the valuation problem for the following reasons:

1. It is generally difficult to value assets that are not traded in the market separately; this is particularly true of "intangible" assets like those created by R&D investment.

2. Investment in innovation (R&D) does not depreciate at a constant rate across firms, time and industry as is often assumed (15%). Exploring the market value of these investments provides a way to estimate changes in the rate of obsolescence.

3. The intertemporal nature of the R&D investment decision means that current profits are not a good measure of the private returns to R&D. (See Fisher and McGowan....)

2 Valuing Intangibles: The Hedonic Price Equation for Corporate Assets

Publicly traded corporations are bundles of assets (both tangible and intangible) whose values are determined every day in the financial markets. In that

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[2] See, for example, Salinger (...), Blundell, Griffith, and Van Reenen (1995), Connolly and Hirschey (1990), Lev and Sougiannis (1996), etc.

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 application here 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 the particular set of heterogeneous firms that exist in the U.S. manufacturing sector.

That is, we hypothesize 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, and so forth 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.[3] The procedure we follow here is a generalization of that simple model, first suggested by

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[3] Cite someone here (Hayashi?Lucas?....)

Griliches (1981), but modified to take account of the fact that R&D assets are no longer a minor correction to the total assets of private firms.

Making the comparison to the ordinary hedonic price literature highlights several problems of interpretation or difficulties that we can expect to encounter:

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.

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.

3 Data

The data we use is drawn from the Compustat files. We have included all the firms in the manufacturing 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 following section, the data appendix, and the documentation in Hall (1990).

The variables we 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 property, 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.[4] 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.

We compute the book value of the plant and equipment in two different ways: the first uses the methods suggested by Brainard, Shoven, and Weiss (1982?) and adapted by Hall (1990) for use on the NBER masterfile and the second uses the method proposed by Llewellyn and Badrinath (1997). In the next section we discuss the details of implementing both procedures, describe how we overcame them, and then we give some comparisons of the two measures for our dataset. We apply the modified L&B procedure to the valuation of R&D investment, and find that the L&B procedure does not change the conclusion based on Hall's procedure. Comparison of q estimates based on the two alternative procedures explains why different procedures may produce the same conclusion.

4 The Measurement of Tobin's Q

Tobin's Q is defined to be the ratio of the current market value of the firm to the replacement value of its assets, which in market equilibrium with no adjustment costs and *with a full accounting of the firm's assets, tangible and intangible*, should be equal to each other. Measuring this quantity empirically using the usual balance sheet data available on a firm's 10-K encounters two sets of problems: first, security values (the quantities in the numerator,

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[4] Compustat item numbers for these quantities are given in the data appendix.

or liability side of the balance sheet) other than the common stock equity value of the firm are typically recorded at book value, that is the face value of the securities (long term debt or preferred stock). Second, the assets in the denominator, whether plant and equipment, inventories, or investments in other firms, are usually recorded at historical cost rather than at replacement value. The procedure proposed by Brainard, Shoven, and Weiss (1982, hereafter BSW) and used by Griliches (1981), Hall (1993a, 1993b), Lindenberg and Ross (???) among others is intended to produce corrected versions of the both the numerator and denominator of Tobin's Q; the corrected values are then related to various measures of intangible or rent-creating assets of the firm.

Llewellyn and Badrinath (1997) critiqued the method used by Brainard, Shoven, and Weiss (1982), primarily because the construction of the replacement cost of plant and equipment used a rather coarse approximation of the age of the plant and equipment to convert historical cost to replacement cost.[5] They also critiqued the construction of the market value of long term debt because........Our comparison here focuses on the construction of the property, plant, and equipment (net capital stock) measure, since this seems to be the most problematic, and because this asset is a large share of the denominator measure of the firm's assets.

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[5] It is worth noting here that the reason for the coarse approximation used by BSW was that the Compustat data with which they were working in 1982 did not contain the variables needed for the improved Llewellyn-Badrinath procedure, notably retirements. Of course, now that these variables are available, there is no reason to continue to use the inferior earlier method, even if the refinements make little difference.

4.1 The Brainard, Shoven, and Weiss Procedure

In the original BSW algorithm, the net value of the plant and equipment adjusted for inflation was obtained by multiplying the book value of the plant and equipment by the ratio of the GDP deflator for fixed nonresidential investment in the current year to the GDP deflator lagged a certain number of years (the average age A of the P&E). Define the replacement cost of fixed assets at the end of year T as RCF_T, the historical cost as HCF_T, and the fixed investment deflator as π_T^F. Then

$$RCF_T = HCF_T \frac{\pi_T^F}{\pi_{T-A}^F}$$

The firm-specific average age A was constructed as the ratio of accumulated depreciation (gross plant minus net plant) to depreciation this year, which assumes straight-line depreciation of a constant asset stock. For example, if accumulated past depreciation is one million dollars and the depreciation deduction in the current year is \$100,000, then the average age of the plant and equipment is assumed to be ten years.

Given the obvious rough nature of this computation when the asset stock fluctuates, smoothing was applied to the average age in the following way: a length of life N of the current plant and equipment was computed as the gross plant divided by this year's depreciation and a five-year moving average was taken of this series to smooth it. This year's average age is then adjusted by the ratio of this year's length of life to the moving average, which has the effect of smoothing the age series slightly. In addition, the average age was truncated at nineteen years, both to remove outliers and because the relevant deflator was not available before 1939.

4.2 The Llewellyn and Badrinath Procedure

Llewellyn and Badrinath (1997) proposed a new procedure to calculate the denominator of Tobin's q–the replacement cost of capital. When we applied the L&B procedure to our large data set, which includes many more firms than were used by L&B, we encountered two problems: First, the data requirement of the L&B procedure is such that we ended up with a heavily selected subsample of the original data set, either because of long asset lives or short firm histories in the data set. Second, assumptions of the L&B procedure are not satisfied for a large number of firm-years. We modified the L&B procedure to accommodate these problems and it is the modified version that we present here.[6]

In the L&B procedure, RCF_T is calculated as the sum of the net fixed asset vintages, NI_t, adjusted for inflation:

$$RCF_T = \sum_{t=T}^{T-(N-1)} NI_t \frac{\pi_T^F}{\pi_t^F} \tag{2}$$

The net fixed asset increment at vintage t, NI_t, equals the gross fixed asset increment at t (investment), I_t, adjusted for depreciation:

$$NI_t = I_t \frac{2N - 2(T - t) - 1}{2N} \tag{3}$$

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[6] We summarize only essential steps of the L&B procedure. See the Lewellen and Badrinath article for the details.

Investment I_t equals the change in the net fixed asset, NF_t plus the depreciation, D_t:

$$I_t = NF_t - NF_{t-1} + D_t \tag{4}$$

Finally, the length of asset life, N, can be determined from the fact that the sum of the increments to gross fixed assets should be equal to gross fixed assets GF_T:

$$\sum_{t=T}^{T-(N-1)} I_t = GF_T \tag{5}$$

It can be immediately seen from (4) and (5) that the L&B procedure cannot be applied to firm-years with long asset lives or a short history in the data file. To identify the investment undertaken $N-1$ years ago, we need data going back to $N-1$ years ago. Therefore, if a firm-year has a long asset life or if a firm-year does not have enough back data, we have to exclude that firm-year. The seriousness of this problem is apparent from Table 1, which shows the distribution of firm-year by estimated length of life[7] and the selection rate for each length of life when the L&B procedure is applied. In sum, we have to exclude about 75% of firm-years in our sample of 48,945 firm-years. The selection rate is highest when the length of life is 18 years or less, and then decreases.

We propose a simple way to include all firm-years in the calculation regardless of whether they have enough data history. Our modified procedure works in four steps. First, the depreciation rate is estimated for each firm

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[7] The length of life is estimated using our modified procedure explained in this subsection. Note that L&B procedure does not provide a way to estimate the length of life when a firm-year does not have enough back data.

using only current-year data. Second, based on the estimated depreciation rate, the length of asset life is estimated. Third, gross investment for the first observation of each firm is estimated based on the estimated length of asset life. Fourth, gross investment for all the other firm-years are estimated using (4) and (5). The details follow.

Assuming straight-line depreciation with half-year adjustment, the depreciation rate is the ratio of depreciation to the sum of the net fixed assets of the previous year and half of the current-year investment. Using (4), the depreciation rate, d, can be calculated using only the current year data; i.e.,

$$d = \frac{D_T}{NF_{T-1} + .5I_T} = \frac{D_T}{NF_T - .5I_T + D_T} \tag{6}$$

The length of asset life, N, is the reciprocal of the depreciation rate d, that is,

$$N = \frac{1}{d} \tag{7}$$

To estimate gross investment for the first observation of each firm, we assume that gross investment grows at a constant rate. If the growth rate of gross investment is g and the length of asset life is N, then gross investment I_t in year t is

$$I_t = (1+g)^{N-1-(T-t)} \frac{g}{(1+g)^N - 1} GF_T \tag{8}$$

The growth rate g is estimated by the in-sample growth rate of gross investment. Once we have calculated the gross fixed assets for the first observation, we can apply the L&B procedure to the remaining observations.

The second problem with applying the L&B procedure to the entire Compustat sample is that it assumes that the following two identities are true:

$$I_T = NF_T - NF_{T-1} + D_T \tag{9}$$

That is, gross investment is the change in net fixed assets (net investment) plus depreciation. And

$$R_T = GF_T - GF_{T-1} + I_T \tag{10}$$

That is, retirements are the change in gross fixed assets less gross investment. Gross fixed assets (GF), net fixed assets (NF), and depreciation (D) are supplied by the actual data set while gross investment (I) and retirements (R) are inferred from (9) and (10). If (9) and (10) are correct, then the estimated gross investment and retirements should be non-negative. However, in our pre-cleaning data set of 65,053 firm-years, estimated gross investment is negative for 4,187 firm-years and estimated retirements are negative for 5,329 firm-years.[8]

Though (9) and (10) are conceptually correct, they are not necessarily correct in terms of accounting practice. There are at least two reasons. First, reported depreciation may not include the depreciation of assets being retired in the current year, and may underrepresent the "true" depreciation. For example, suppose that an asset is purchased in year 1991 at the cost of $10 million and retires in year 1995. The book value of the asset may be depreciated by $2 million each year. However, the book depreciation of

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[8] These two sets of firm-years are not disjoint.

the asset in 1995 can be zero since the asset retires in 1995. Data confirm our claim. We looked at manufacturing firms for which Schedule V–Gross Fixed Asset Account and Schedule VI–Accumulated Depreciation Account in year 1990 are available.[9] For about 85% of firms, the retirement reported in schedule V is greater than the retirement reported in schedule VI, which implies under-reporting of depreciation. For about 5% of firms, the difference between schedule V retirement and schedule VI retirement is greater than 10% of gross fixed assets, an amount which we believe is not negligible.

Second, depreciation and retirement are not the only ways of reducing the asset value. Firms can adjust the value of assets downward without depreciation and retirement. For about 5% of manufacturing firms whose Schedule V in 1990 is available, the item named "Other Changes" exceeds 10% of gross fixed assets, which we believe is significant.

Negative gross investment and retirements cause practical as well as conceptual problems. If the values for gross investment and retirements are negative, then the gross fixed assets will be greater than the sum of the gross investments; thus, the length of asset life cannot be determined from (4) and (5). Rather than dropping all "bad" firm-years, we set the left-hand side of (9) and (10) to be zero if the calculated left-hand side value is between zero and the negative of 10% of gross fixed assets.

Our estimation procedure in equations (6) to (8) also has a limitation: 109 firm-years in our pre-cleaning data set have large estimated depreciation

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[9] More precisely, we looked at the manufacturing firms whose Schedule V and Schedule VI of year 1990 appears with valid numbers in the 1996 Compustat Current file. There are 1,138 such firms.

values, such that

$$NF_T + NF_{T-1} - D_T < 0 \tag{11}$$

Note that, as a restatement of (9),

$$NF_T - .5I_T = .5(NF_T + NF_{T-1} - D_T)$$

Thus the estimated depreciation rate will be greater than unity if (11) is the case. Therefore we set the left-hand side of (11) to be zero when the calculated left-hand side value of (11) is negative.

4.3 Comparison with the NBER procedure

There are at least three possible ways for different procedures of calculating Tobin's q to produce different results. First, in a study where Tobin's q is used to identify firms with a particular characteristic (e.g. financially distressed firms), change in the ordering of firms by Tobin's q will change the results. Second, in a cross-sectional study, changes in the variation of Tobin's q across firms will change the results. Third, in a panel study, changes in the variation of the growth-rate of Tobin's q across firms will change the results. We found that none of the above three possibilities occurs when a researcher switches from the BSW procedure to the L&B procedure or vice versa. In this subsection of the paper we provide evidence that this is the case.

First, Kendall's τ suggests that the ordering of firms by Tobin's q does not differ between the L&B method and the BSW method. Kendall's τ is defined as the ratio of Kendall's score to the total number of possible pairs drawn from a sample $[n(n-1)/2]$, where Kendall's score is the difference between the number of pairs for which the ranking by two variables are identical and the number of pairs for which the ranking by two variables is the reverse. Thus if the rankings are identical, Kendall's τ will be unity.

Table 2 reports the value of Kendall's τ for the fixed asset replacement cost and for Tobin's q using the two alternative methods. For the replacement cost of capital, Kendall's τ is between 95% and 98%, implying that for 97.5% to 99% of all possible pairs of observations, the ordering is identical whether the BSW or L&B method is used. For Tobin's q, Kendall's τ is between 89% and 95%. Note that these numbers are much higher than those reported by Llewellyn and Badrinath, possibly because our sample includes many more firms.

Second, the cross-sectional variation of the replacement cost and Tobin's q are not different across the two methods. Table 3 shows the median replacement cost and Tobin's q of the two alternative procedures. It also shows the cross-sectional correlation of replacement cost and Tobin's q measures computed by the two methods. Although the median replacement costs calculated by two methods differ by as much as $5 million, the cross-sectional correlation is consistently over 99%. Similarly, though the median Tobin's qs calculated by two methods differ by as much as 13%, the cross-sectional correlation of Tobin's q is consistently over 98%. That is, although the precise magnitude of the numbers computed may differ, the two methods will not produce different results in a typical cross-sectional study.

Third, the cross-sectional variation of the growth rate of replacement cost and Tobin's q are not very different for the two methods. Table 4 compares the cross-sectional distribution of the growth rate under the two alternative procedures. For the replacement cost estimates, the growth rates calculated by two methods differ by as much as 6%, but the correlation is between 94% and 99%. For Tobin's q, the growth rates calculated by two methods differ by as much as 5%, but the correlation is always higher than 98%. These numbers suggest that the results from a panel-data study will not depend strongly on whether we choose the BSW or L&B method.

We do not mean to imply that Llewellyn and Badrinath's method for computing the replacement costs of fixed assets is not an improvement over the Brainard-Shoven-Weiss methodology. Conceptually, except for its extensive data requirements, it clearly is. We merely wish to reassure the reader that results obtained using the older methodology are not invalid, and that one can rely to a great extent on the conclusions of the earlier empirical literature. The one caveat we would make is that the *absolute level of Tobin's* q is somewhat unreliable in the earlier estimates. However, most panel data studies control for the overall level using time dummies, so this fact will have no impact on the estimates of interest.

Table 5 presents some simple statistics for our key variables (market value, tangible assets, R&D capital, and the ratios of inventories, investments in unconsolidated subsidiaries, intangible assets (on the balance sheet), other investment, and R&D assets to tangible assets, forthe samples used for estimation in the following section. Note the increasing importance of R&D investment relative to ordinary investment over the 3 decades of our data, which is also reflected in the substantially higher q's for firms in the last decade. The fact that R&D capital and investment are no longer very small relative to ordinary capital and investment will affect our choice of functional form for the valuation equation in the next section of the paper.

5 Results

5.1 Initial Estimates

We consider the following two specifications of our model: an additively separable linear specification, as was used by Griliches (1981) and Hall (1993a, 1993b), and then a multiplicative separable specification of the Cobb-Douglas form. These two forms differ 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.[10]

The first model is given by

$$V_{it}(A, K) = q_t(A_{it} + \gamma_t K_{it})^{\sigma_t} \tag{12}$$

Taking logarithms of both sides, we obtain

$$\log V_{it} = \log q_t + \sigma_t \log A_{it} + \sigma_t \log(1 + \gamma_t K_{it}/A_{it}) \tag{13}$$

In earlier work (Griliches 1981 and Hall 1993a,b), the last term was approximated by $\sigma_t \gamma_t K_{it}/A_{it}$. We chose not to use this approximation exclusively

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[10] 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). 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.

here because it can be relatively inaccurate for K/A ratios of the magnitude that are now common (above 15 percent); however, we do report estimates using the approximation for comparison to previous work. In either 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:

$$V_{it}(A, K) = q_t A_{it}^{\sigma_t - \alpha_t} K_{it}^{\alpha_t} \tag{14}$$

In logarithms, this equation is the following:

$$\log V_{it} = \log q_t + \sigma_t \log A_{it} + \alpha_t (\log K_{it}/A_{it}) \tag{15}$$

In order to compare the results of estimating this model to the results of estimation using the model in equation (13), we need to compute the ratio of the marginal shadow value of K to that of A:

$$\frac{\partial V/\partial K}{\partial V/\partial A} = \frac{\alpha_t V_{it}/K_{it}}{(\sigma_t - \alpha_t)V_{it}/A_{it}} = \frac{\alpha_t A_{it}}{(\sigma_t - \alpha_t)K_{it}} \tag{16}$$

This measure can be compared to the relative shadow value γ_t estimated by the first model, but to do so we will need to use some kind of an average value of K/A. The absolute shadow value of R&D capital is equal to $\alpha_t V_{it}/K_{it}$.[11]

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[11] 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, we 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.

In both models, the coefficient of $\log A$ will be 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 conventional Tobin's q as the dependent variable. The intercept of either model can then be interpreted as an estimate of the logarithmic average of Tobin's q for manufacturing corporations during the relevant period. We follow this procedure, after estimating without imposing constant returns and obtaining estimates of σ that ranged from 0.98 to 1.00 using the different modeling approaches given above. In other words, although the shadow value of ordinary assets (q) appears to change from year to year, the scale coefficient (σ) does not, and in fact it appears to be quite close to unity.

To summarize, our three estimating equations are the following:

$$Nonlinear : \log Q_{it} = \log q_t + \log(1 + \gamma_t K_{it}/A_{it}) \tag{17}$$

$$Linear\ approx : \log Q_{it} = \log q_t + \gamma_t K_{it}/A_{it} \tag{18}$$

$$Log-linear\ (C-D) : \log Q_{it} = \log q_t + \alpha_t(\log K_{it}/A_{it}) \tag{19}$$

The relative shadow value of R&D capital in the first two cases is γ_t and in the last it is $\alpha_t/(1-\alpha_t) \cdot (A_{it}/K_{it})$.The absolute shadow value of R&D capital in the first two cases is $q_t\gamma_t$ and in the last it is $\alpha_t V_{it}/K_{it}$. The results of estimating these three models for the entire unbalanced panel between 1971 and 1995 are shown in Figures 1 and 2 and Table 6. In estimation, we also included measures of advertising expenditure plus a dummy for firm-years when advertising was not reported. Advertising is assumed to proxy for the intangible assets provided by brandnames and reputation. Figure 1 shows the estimates for all industries, using the median estimates of K/A to derive the relative shadow value of R&D capital in the case of the log-linear equation. Figure 2 shows the estimates for all industries, using the median estimates of V/K to derive the absolute shadow value of R&D capital in the case of the log-linear equation. Table 6 reports the R-squares of the regressions.

Looking first at the goodness of fit measures in Table 6, it appears that the nonlinear equation (17) is preferred to the two linear specifications. Equations (17), (18), and (19) can also be used to construct non-nested hypothesis tests using each form of the equation as the null in turn. When this is done, although the results are somewhat inconclusive, the data appear to prefer the forms in (17) and (19), with a slight preference for (19), the log-linear form. Comparing the nonlinear equation and its linear approximation in Figures 2 and 3, we see that estimates based on the former tend to lie substantially above those based on the latter, either for the relative or the absolute shadow value of R&D assets; this reflects the fact that R&D assets are a non-negligible portion of total assets.

All three specifications show similar results for both the relative and absolute shadow values. First, the values are very high in the early seventies when not all firms are reporting R&D, falling in the mid-seventies (probably because of the oil price shock effects), and then rising to high levels during the early eighties. This is followed by the long slow decline to 1990 that was documented in Hall (1993a, 1993b). The new result is that post-1990, both the relative and absolute shadow value of R&D assets climbs steadily, with the absolute shadow value reaching a level of 1.5 by 1995. The implication is that R&D capital is valued at one and one half times more than would be implied by market equilibrium with a rate of private obsolescence of R&D equal to 15 percent. Put another way and assuming that R&D grows by 5 percent per year, either firms are underinvesting in R&D in 1995 or the implied rate of obsolescence is closer to 60 percent per annum.

5.2 Entry and Exit Effects

A characteristic of the type of firmTo control for entry and exit effects, we estimated the shadow value of R&D capital from rolling two year balanced panels. For each year t from 1972 to 1995, a balanced panel data set was created from the firms for which valid data are available for year $t-1$ and year t. Using the panel data set of year t, the shadow value for year $t-1$ and for year t was estimated, and the growth rate of the relative shadow value from year $t-1$ to year t was computed. Repeating the estimation for each t, we obtained a series of growth rate of the shadow value, from which a level index was created with the base period 1990. Figure 3 plots the index of relative shadow value, and Figure 4 plots the index of absolute shadow value of R&D capital of all manufacturing industries. Table 7 reports R^2 of the regression.

5.3 Industry Effects

The shadow value of R&D capital of five industries–the chemical industry, the pharmaceutical industry, the electronoics industry, the machinary industry, and the other unclassified industries–are reported in Figure 5 and Figure 6. Table 8 reports R^2 of the estimation.

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7 Data Appendix

The sample is drawn from the Compustat industrial and over-the-counter files, both current (1976-1995) and back data (1957-1976). This yields a very large sample of manufacturing firms, about 6000. We deleted foreign-owned firms, duplicate observations, and firms that were present for less than 3 years. This kind of firm-level data is known to contain outliers, especially when ratio variables are used, so we developed a series of cleaning rules intended to find cases where either the numbers reported were not likely to be correct, or where the firm changed substantially (probably because of a major merger or divestiture) from one year to the next. The observations surrounding this change were deleted; in many cases they are the smaller firms in our sample. Note that we kept both sides of the major break, but we ensured that lagged observations from one side would not contaminate regressions for the "new" firm.

A related problem was the case where a firm reported R&D for several years and then stopped reporting it. In this case, we either deleted the R&D capital altogether (if it was small relative to the firm size) or we assumed that the firm in question had become a "new" firm when it stopped doing R&D and we did not carry the R&D capital forward.

Our basic rules for cleaning the sample are the following:

1. Sales, net plant, employment, market value (Tobin's q) not missing.

2. Employment growth, net plant growth, net capital (assets) growth, and R&D capital growth between -30% and 200%.
3. Real R&D growth lower than 400% if real R&D expenditure for previous year greater than $1 million.
4. R&D to assets ratio less than 3.
5. Tobin's q greater than 1 percent.
6. Total q (defined as market value to the sum of net capital and R&D capital) greater than .05 and less than 20.
7. R&D capital to assets ratio less than 20.

We also dropped about 100 observations with we suspected major changes in the data from year to year, and manually coded approximately 150 R&D capital stocks to zero where the firm did not have a stable history of R&D spending or the history was very slight.

In the regressions, items 5 and 7 above were varied in several ways. Our regression subsamples were the following:

1. *Clean:* Tobin's $q<25$.
2. *Tight Cleaning:* Tobin's $q \subset (0.05, 20)$, R&D capital to assets < 5.
3. *Very tight cleaning:* Tobin's $q \subset (0.1, 10)$, R&D capital to assets < 2.

Figure A1 shows the time series behavior of our sample selection rules. The reason that the cleaning rules diverge post 1982 is primarily the R&D

capital to assets cut; during the 1980s there is a substantial increase in the number of firms with large amounts of R&D spending and few physical assets in the manufacturing sector (primarily in pharmaceuticals and biotechnology).

[Table 1] Data Availability for LB procedure

The length of asset life was estimated for each firm-year as explained in section 4. The age is the age of a given firm within the pre-cleaning sample. The number of good firm-years is the number of firm-years for which the age is greater than the estimated length of asset life, as required by L&B procedure.

Length of Asset Life	Number of All Firm-years (1)	Number of Good Firm-years (2)	Ratio of (2) to (1)
1	23	23	100.0%
2	257	92	35.8%
3	613	234	38.2%
4	974	337	34.6%
5	1651	541	32.8%
6	2281	686	30.1%
7	2917	796	27.3%
8	3400	836	24.6%
9	3901	914	23.4%
10	4160	980	23.6%
11	4187	991	23.7%
12	4080	920	22.5%
13	3836	985	25.7%
14	3452	933	27.0%
15	2986	862	28.9%
16	2408	671	27.9%
17	2053	575	28.0%
18	1600	466	29.1%
19	1242	332	26.7%
20	915	202	22.1%
21	663	152	22.9%
22	480	115	24.0%
23	315	72	22.9%
24	187	32	17.1%
25	128	23	18.0%
26	79	7	8.9%
27	50	8	16.0%
28	40	3	7.5%
29	32	6	18.8%
30	22	4	18.2%
31	5	0	0.0%
32	2	0	0.0%
33	3	0	0.0%
34	1	0	0.0%
35	1	0	0.0%
36	1	0	0.0%
Total	48945	12798	26.1%

[Table 2] Comparing the Ordering Implied by BSW and LB Methods

Kendall's tau is the ratio of two numbers. The denominator of Kendall's tau is the number of possible pairs drawn from a sample. The numerator, called Kendall's score, is the difference between the number of pairs for which the ranking by two variables are identical and the number of pairs for which the ranking by two variables are opposite. The third column in the table reports Kendall's tau between the replacement cost of BSW and of LB. The fourth column in the table reports Kendall's tau between Tobin's q of BSW and of LB. For the whole sample, Kendall's tau was computed by separately summing the denominator and the numerator of Kendall's tau of each year.

Year	Sample Size	Kendall's tau for Replcement Cost	Kendall's tau for Tobin's q
1966	694	0.964	0.938
1967	930	0.969	0.945
1968	1086	0.970	0.937
1969	1289	0.970	0.938
1970	1180	0.968	0.929
1971	1225	0.969	0.938
1972	1450	0.968	0.941
1973	1593	0.966	0.928
1974	1607	0.965	0.902
1975	1643	0.963	0.911
1976	1615	0.961	0.910
1977	1677	0.959	0.907
1978	1680	0.957	0.897
1979	1820	0.959	0.906
1980	1811	0.957	0.918
1981	1914	0.955	0.910
1982	1852	0.955	0.912
1983	1906	0.953	0.914
1984	1850	0.953	0.908
1985	1858	0.952	0.916
1986	1840	0.955	0.915
1987	1863	0.959	0.917
1988	1827	0.963	0.919
1989	1816	0.968	0.930
1990	1864	0.972	0.938
1991	1876	0.973	0.949
1992	1929	0.975	0.952
1993	1857	0.976	0.952
1994	1746	0.979	0.952
1995	1647	0.982	0.958
Total	48945	0.964	0.925

[Table 3] Comparing Levels of Variables Implied by the BSW and LB Method

Replacement cost refers to the replacement cost of physical capital, that is, the denominator of Tobin's q. Column (1) reports the median replacemnent cost calculated by BSW method. Column (2) reports the median replacement cost calculated by LB method. Column (3) reports the correlation between replacement cost calculated by BSW method and by LB method. Column (4) reports the median Tobin's q calculated by BSW method. Column (5) reports the median Tobin's q calculated by LB method. Column (6) reports the correlation between Tobin's q calculated by BSW and by LB method.

Year	Sample Size	Replacement Cost			Tobin's q		
		Median (BSW) (1)	Median (LB) (2)	Correlation (BSW,LB) (3)	Median (BSW) (4)	Median (LB) (5)	Correlation (BSW,LB) (6)
1966	694	36.01	37.78	0.998	1.222	1.169	0.998
1967	930	43.64	46.85	0.998	1.735	1.636	0.998
1968	1086	40.04	43.12	0.998	1.947	1.815	0.997
1969	1289	37.13	39.13	0.996	1.330	1.240	0.998
1970	1180	33.01	34.93	0.997	1.098	1.030	0.998
1971	1225	36.75	39.12	0.997	1.203	1.130	0.997
1972	1450	35.64	37.04	0.997	1.110	1.076	0.998
1973	1593	39.14	40.55	0.997	0.731	0.713	0.998
1974	1607	45.08	46.99	0.996	0.595	0.565	0.994
1975	1643	45.48	46.41	0.996	0.666	0.633	0.994
1976	1615	48.84	47.61	0.996	0.734	0.739	0.996
1977	1677	47.21	46.10	0.996	0.726	0.745	0.985
1978	1680	53.44	51.10	0.996	0.703	0.734	0.981
1979	1820	50.79	48.72	0.996	0.791	0.817	0.995
1980	1811	50.70	48.53	0.996	0.858	0.888	0.996
1981	1914	46.24	43.29	0.997	0.812	0.858	0.995
1982	1852	46.53	42.76	0.998	0.923	0.994	0.996
1983	1906	43.12	38.55	0.998	1.172	1.295	0.995
1984	1850	42.92	39.58	0.998	1.088	1.147	0.997
1985	1858	39.54	37.70	0.998	1.318	1.368	0.997
1986	1840	36.13	34.73	0.998	1.356	1.376	0.995
1987	1863	36.06	35.79	0.998	1.228	1.231	0.995
1988	1827	38.32	38.62	0.998	1.362	1.360	0.998
1989	1816	38.77	39.02	0.998	1.392	1.386	0.997
1990	1864	40.19	40.34	0.999	1.147	1.132	0.998
1991	1876	41.58	41.31	0.998	1.467	1.441	0.998
1992	1929	42.89	42.64	0.999	1.630	1.654	0.997
1993	1857	44.74	44.71	0.999	1.813	1.810	0.996
1994	1746	51.95	52.86	0.999	1.650	1.655	0.994
1995	1647	60.40	62.28	0.999	1.779	1.762	0.998

[Table 4] Comparing Growth Rates of Variables Implied by the BSW and LB Method

Replacement cost refers to the replacement cost of physical capital, that is, the denominator of Tobin's q. Growth rate is the geometric growth rate. Column (1) reports the median growth rate of replacemnent cost calculated by BSW method. Column (2) reports the median growth rate replacement cost calculated by LB method. Column (3) reports the correlation between the growth rate of replacement cost calculated by BSW method and by LB method. Column (4) reports the median growth rate of Tobin's q calculated by BSW method. Column (5) reports the median growth rate of Tobin's q calculated by LB method. Column (6) reports the correlation between the growth rate of Tobin's q calculated by BSW and by LB method.

Year	Sample Size	Growth of Replacement Cost			Growth of Tobin's q		
		Median (BSW) (1)	Median (LB) (2)	Correlation (BSW,LB) (3)	Median (BSW) (4)	Median (LB) (5)	Correlation (BSW,LB) (6)
1966	634	0.13	0.17	0.982	-0.194	-0.235	0.991
1967	666	0.09	0.12	0.985	0.247	0.214	0.997
1968	875	0.10	0.12	0.989	0.085	0.064	0.995
1969	1027	0.12	0.13	0.991	-0.344	-0.351	0.997
1970	983	0.08	0.09	0.990	-0.170	-0.175	0.997
1971	826	0.08	0.07	0.989	0.041	0.046	0.997
1972	1008	0.09	0.08	0.992	-0.053	-0.044	0.997
1973	1297	0.14	0.13	0.989	-0.393	-0.395	0.998
1974	1425	0.16	0.18	0.974	-0.249	-0.273	0.995
1975	1455	0.06	0.06	0.949	0.091	0.099	0.990
1976	1485	0.13	0.07	0.964	0.052	0.106	0.991
1977	1432	0.11	0.10	0.941	-0.049	-0.044	0.987
1978	1455	0.13	0.12	0.973	-0.043	-0.032	0.992
1979	1533	0.14	0.14	0.951	0.021	0.020	0.985
1980	1640	0.11	0.11	0.974	0.035	0.033	0.994
1981	1614	0.09	0.08	0.969	-0.098	-0.082	0.993
1982	1662	0.04	0.01	0.970	0.069	0.099	0.992
1983	1613	0.04	0.01	0.974	0.144	0.173	0.992
1984	1573	0.04	0.06	0.978	-0.090	-0.118	0.993
1985	1559	0.01	0.04	0.979	0.135	0.108	0.992
1986	1533	0.03	0.05	0.983	0.017	-0.010	0.994
1987	1520	0.06	0.06	0.983	-0.120	-0.129	0.996
1988	1529	0.06	0.07	0.982	0.061	0.042	0.994
1989	1548	0.05	0.06	0.986	0.011	-0.005	0.996
1990	1588	0.05	0.06	0.986	-0.194	-0.196	0.997
1991	1618	0.01	0.00	0.990	0.161	0.170	0.998
1992	1669	0.02	0.02	0.993	0.056	0.060	0.999
1993	1673	0.02	0.03	0.984	0.057	0.047	0.996
1994	1601	0.07	0.08	0.982	-0.067	-0.072	0.995
1995	1576	0.08	0.09	0.986	0.065	0.059	0.997

[Table 5] Descriptive Statistics: US Manufacturing Sample 1966-1995

Market value is the market value of equity and debt. Assets refer to the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. Tobin's Q is the ratio of the market value to the replacement cost of assets. N/A is the replacement cost of property, plant, and equipment normalized by the replacement cost of assets. K/A is the replacement cost of R&D stock normalized by the replacement cost of assets. Investment/A, R&D/A, and Inventory/A are defined similarly. Miscellaneous Assets refer to the replacement cost of investment and advances and intangibles. The number of firm-years in each sub-period is 12697, 17983, and 18265, respectively. The number of firms in each sub-period is 1851, 2948, and 2681.

Variable	Period	Mean	SD	Min	Q1	Med	Q3	Max
Market Value (M$)	1966-75	371.8	1536.2	0.1	14.6	45.1	176.8	45499.8
	1976-85	546.9	2476.3	0.1	12.8	46.0	208.3	97437.1
	1986-95	1114.0	4811.2	0.0	16.5	70.1	367.7	128657.1
Assets (M$)	1966-75	298.9	1152.2	0.1	14.6	41.4	153.4	34113.6
	1976-85	603.5	2784.4	0.1	11.9	44.4	198.0	75449.6
	1986-95	718.5	3534.0	0.0	9.3	42.2	217.7	103417.9
Tobin's Q	1966-75	1.538	1.818	0.052	0.631	0.968	1.679	28.771
	1976-85	1.562	2.372	0.058	0.636	0.925	1.561	49.466
	1986-95	2.706	4.078	0.055	0.977	1.457	2.585	51.289
N/A	1966-75	0.542	0.189	0.006	0.410	0.536	0.679	1.000
	1976-85	0.518	0.192	0.007	0.382	0.514	0.652	1.000
	1986-95	0.485	0.218	0.001	0.322	0.479	0.639	1.000
K/A	1966-75	0.084	0.206	0.000	0.000	0.000	0.077	3.409
	1976-85	0.216	0.511	0.000	0.000	0.057	0.245	18.475
	1986-95	0.657	1.507	0.000	0.000	0.163	0.663	24.877
Investment/A	1966-75	0.093	0.068	0.000	0.048	0.076	0.117	0.663
	1976-85	0.104	0.088	0.000	0.048	0.080	0.131	1.854
	1986-95	0.109	0.123	-0.008	0.047	0.084	0.138	9.515
R&D/A	1966-75	0.019	0.040	0.000	0.000	0.000	0.022	1.246
	1976-85	0.046	0.102	0.000	0.000	0.012	0.050	2.737
	1986-95	0.117	0.248	0.000	0.000	0.029	0.123	3.096
Inventory/A	1966-75	0.380	0.185	0.000	0.242	0.378	0.506	0.961
	1976-85	0.400	0.191	0.000	0.263	0.393	0.531	0.991
	1986-95	0.395	0.218	0.000	0.228	0.375	0.548	0.987
Misc Assets/A	1966-75	0.078	0.110	-0.047	0.004	0.039	0.105	0.973
	1976-85	0.082	0.126	0.000	0.000	0.031	0.113	0.960
	1986-95	0.120	0.173	-0.019	0.000	0.042	0.177	0.994

[Table 6] Estimating the Shadow Value of R&D Capital: Goodness of Fit

C-D equation is

$$\log Q = b0 + b1*\log(K/A) + b2*\log(ADV/A) + b3*MISADV$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV is set to one. MISSAD is the dummy variable for missing or zero ADV. Nonlinear equation is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

When ADV is missing, ADV is set to zero. Linear equation is

$$\log Q = b0 + b1*K/A + b2*ADV/A + b3*MISADV/A$$

The linear equation was estimated by median regression rather than by mean regression. When ADV is missing, ADV was set to zero. An observation was not included in the regression if Q is less than 0.1 or greater than 10 or if K/A is greater than 2. The last line reports the ratio of the sum of model sum of square(MSS) to the sum of residual sum of square(RSS).

Year	Sample Size	R squared		
		C-D Eq	Nonliner Eq	Linear Eq
1971	502	16.6%	15.3%	7.3%
1972	819	18.3%	18.6%	11.3%
1973	965	10.2%	12.3%	9.2%
1974	1032	5.5%	6.7%	4.7%
1975	1070	8.8%	11.0%	8.2%
1976	1066	9.0%	10.2%	8.2%
1977	1061	10.6%	12.6%	10.7%
1978	1106	14.0%	19.5%	17.8%
1979	1242	12.6%	17.0%	14.3%
1980	1217	16.1%	23.3%	20.7%
1981	1245	15.6%	18.4%	15.4%
1982	1249	17.7%	22.2%	18.6%
1983	1249	19.5%	23.1%	18.8%
1984	1232	15.3%	18.4%	16.6%
1985	1255	13.8%	17.5%	15.9%
1986	1213	11.6%	14.5%	10.9%
1987	1191	6.3%	10.6%	9.6%
1988	1167	7.5%	10.7%	9.9%
1989	1165	6.8%	10.7%	10.1%
1990	1197	4.7%	8.2%	6.9%
1991	1182	6.6%	9.2%	7.4%
1992	1198	8.9%	11.3%	9.6%
1993	1181	9.8%	13.8%	12.5%
1994	1104	7.9%	13.7%	12.4%
1995	1110	9.0%	15.4%	14.0%
Total	28018	11.2%	14.8%	12.4%

[Table 7] Estimating the Shadow Value of R&D Capital from Rolling Two Year Balanced Panels: Goodness of Fit

The equation estimated is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV was set to zero. MISSAD is the dummy variable for missing or zero ADV. The absolute shadow value of R&D capital is exp(b0)*b1.

For each year t from 1972 to 1995, a balanced panel data set was created from the firms for which valid data are available for year t-1 and year t. Using this data set, the equation above was estimated for year t-1 and for year t, R squared is the ratio of the sum of model sum of square(MSS) of year t-1 and year t to the sum of total sum of squre(TSS) of year t-1 and year t.

Year	Sample Size	R squared
1972	482	19.2%
1973	782	16.3%
1974	909	11.3%
1975	964	11.1%
1976	987	10.4%
1977	979	12.5%
1978	973	15.9%
1979	1037	17.0%
1980	1140	20.2%
1981	1133	21.9%
1982	1151	18.5%
1983	1128	22.4%
1984	1115	19.2%
1985	1094	17.0%
1986	1080	16.1%
1987	1044	13.0%
1988	1013	10.2%
1989	1024	9.1%
1990	1056	9.1%
1991	1071	8.0%
1992	1083	9.2%
1993	1063	12.7%
1994	1000	14.1%
1995	1030	13.4%

[Table 8] Estimating the Shadow Value of R&D Capital of Five Industries: Goodness of Fit

The equation estimated is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV was set to zero. MISSAD is the dummy variable for missing or zero ADV.

For each year t from 1972 to 1995, a balanced panel data set was created for each industry from the firms for which valid data are available for year t-1 and year t. Using this data set, the equation above was estimated for year t-1 and for year t, R squared is the ratio of the sum of model sum of square(MSS) of year t-1 and year t to the sum of total sum of squre(TSS) of year t-1 and year t.

Year	Sample Size					R squared				
	Chem	Pharm	Elec	Mach	Others	Chem	Pharm	Elec	Mach	Others
1972	86	34	90	126	146	10.5%	11.4%	14.3%	2.9%	24.4%
1973	120	40	141	227	254	6.6%	13.4%	15.2%	4.2%	13.2%
1974	135	49	158	261	306	3.5%	15.9%	11.8%	3.2%	5.7%
1975	140	53	175	259	337	1.5%	18.1%	11.0%	6.8%	6.5%
1976	143	51	183	264	346	0.5%	17.4%	9.2%	4.0%	6.8%
1977	139	60	183	252	345	1.5%	12.4%	11.2%	6.3%	8.4%
1978	142	55	188	245	343	2.4%	14.8%	11.5%	3.4%	3.0%
1979	151	57	205	270	354	9.1%	19.9%	10.4%	4.6%	1.7%
1980	155	67	269	285	364	1.6%	25.8%	7.3%	6.7%	0.8%
1981	154	62	279	279	359	2.1%	28.3%	7.5%	9.8%	2.4%
1982	159	72	272	291	357	9.1%	13.9%	3.2%	10.0%	8.5%
1983	152	70	280	282	344	15.7%	14.8%	9.7%	12.9%	11.6%
1984	146	78	306	264	321	14.6%	23.1%	4.4%	12.4%	12.0%
1985	140	89	306	253	306	15.1%	19.3%	6.9%	7.7%	12.3%
1986	125	92	335	244	284	15.0%	20.5%	6.2%	5.0%	15.5%
1987	120	100	326	239	259	18.6%	25.5%	3.7%	7.5%	20.0%
1988	119	113	312	221	248	9.1%	9.9%	8.4%	4.8%	11.4%
1989	123	123	318	221	239	7.2%	6.8%	7.3%	3.8%	14.8%
1990	130	133	323	224	246	6.7%	2.4%	9.9%	5.8%	14.0%
1991	135	131	322	229	254	3.5%	2.0%	10.3%	4.2%	12.4%
1992	129	133	323	242	256	5.5%	1.8%	9.7%	7.4%	17.7%
1993	120	134	310	240	259	14.7%	4.0%	10.1%	7.7%	19.9%
1994	113	129	279	224	255	13.2%	8.6%	7.6%	10.9%	17.5%
1995	118	140	288	230	254	4.4%	7.6%	5.6%	12.7%	12.9%

[Figure 1] Relative Shadow Value of R&D Capital

C-D equation is

$$\log Q = b0 + b1*\log(K/A) + b2*\log(ADV/A) + b3*MISADV$$

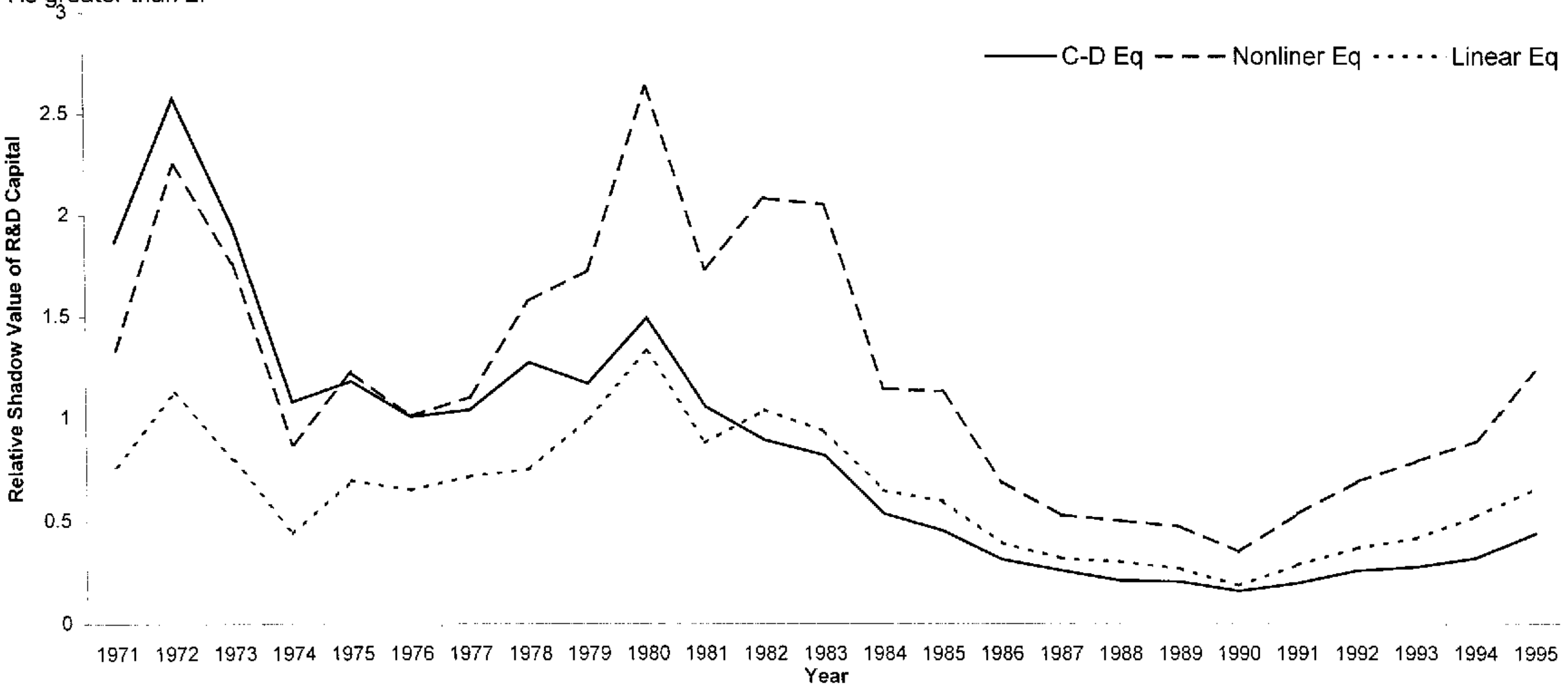
Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV is set to one. MISSAD is the dummy variable for missing or zero ADV. The relative shadow value of R&D capital for C-D equation is b1/(1-b1)*med(A/K). Nonlinear equation is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

When ADV is missing, ADV is set to zero. The relative shadow value of R&D capital for nonlinear equation is b1. Linear equation is

$$\log Q = b0 + b1*K/A + b2*ADV/A + b3*MISADV/A$$

The linear equation was estimated by median regression rather than by mean regression. When ADV is missing, ADV was set to zero. The relative shadow value of R&D capital for linear equation is b1. An observation was not included in the regressions if Q is less than 0.1 or greater than 10 or if K/A is greater than 2.



[Figure 2] Absolute Shadow Value of R&D Capital

C-D equation is

$$\log Q = b0 + b1*\log(K/A) + b2*\log(ADV/A) + b3*MISADV$$

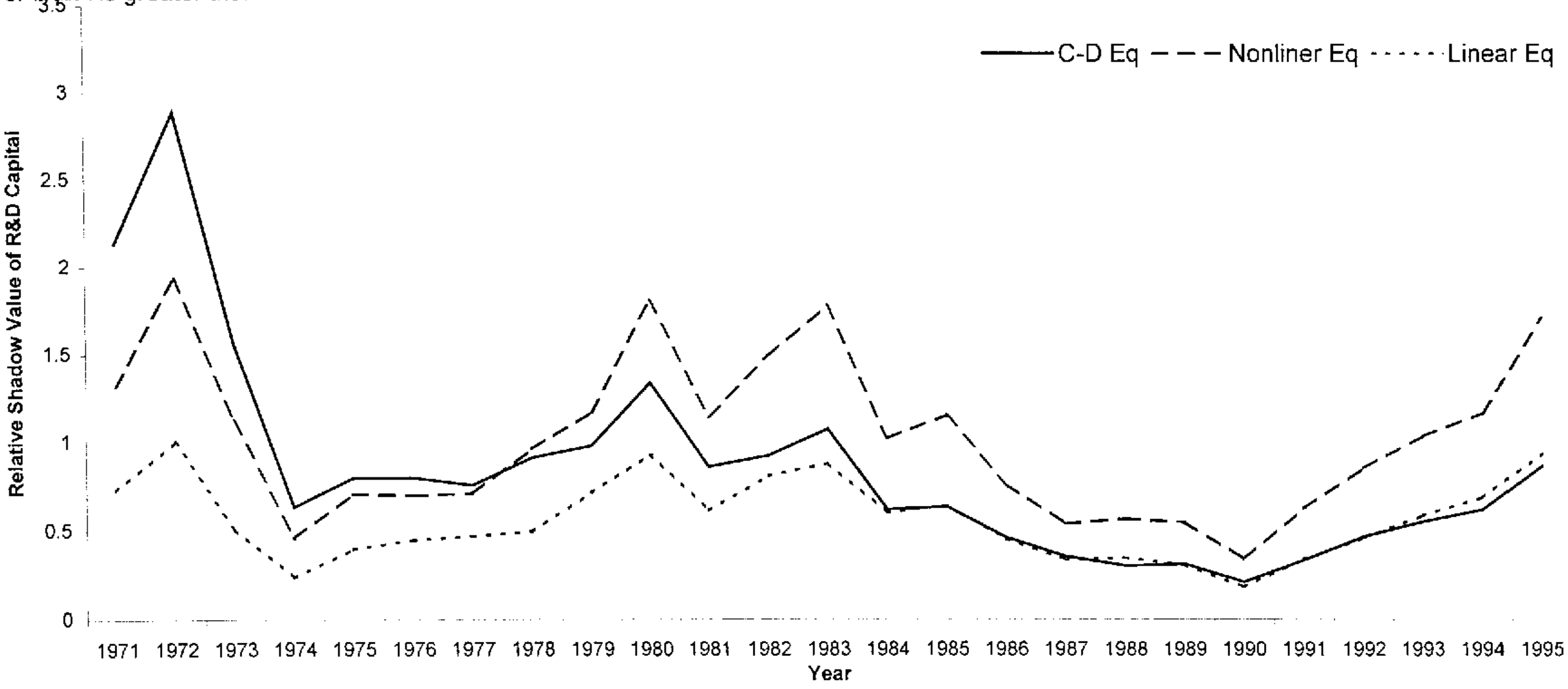
Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV is set to one. MISSAD is the dummy variable for missing or zero ADV. The absolute shadow value of R&D capital for C-D equation is b1*med(V/K). Nonlinear equation is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

When ADV is missing, ADV is set to zero. The absolute shadow value of R&D capital for nonlinear equation is exp(b0)*b1. Linear equation is

$$\log Q = b0 + b1*K/A + b2*ADV/A + b3*MISADV/A$$

The linear equation was estimated by median regression rather than by mean regression. When ADV is missing, ADV was set to zero. The absolute shadow value of R&D capital for linear equation is exp(b0)*b1. An observation was not included in the regression if Q is less than 0.1 or greater than 10 or if K/A is greater than 2.



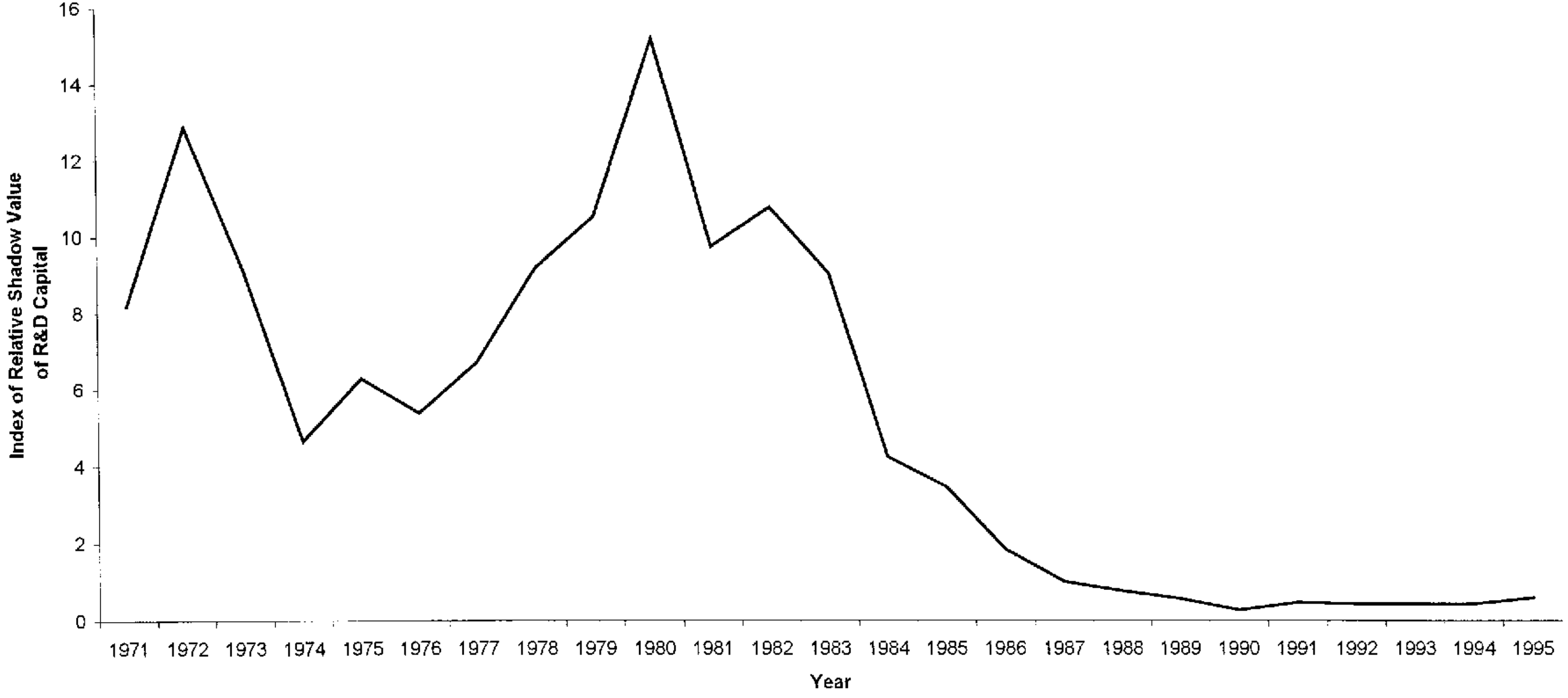
[Figure 3] Relative Shadow Value of R&D Capital (Estimated from Rolling Two Year Balanced Panels)

The equation estimated is

$$\log Q = b0 + \log(1 + b1{*}K/A + b2{*}ADV/A + b3{*}MISADV/A)$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV was set to zero. MISSAD is the dummy variable for missing or zero ADV. The relative shadow value of R&D capital is b1.

For each year t from 1972 to 1995, a balanced panel data set was created from the firms for which valid data are available for year t-1 and year t. Using this data set, the relative shadow value for year t-1 and for year t was estimated, and the growth rate of the relative shadow value from year t-1 to year t was computed. From the growth rate series, a level index with base period 1990 was created, which is plotted below.



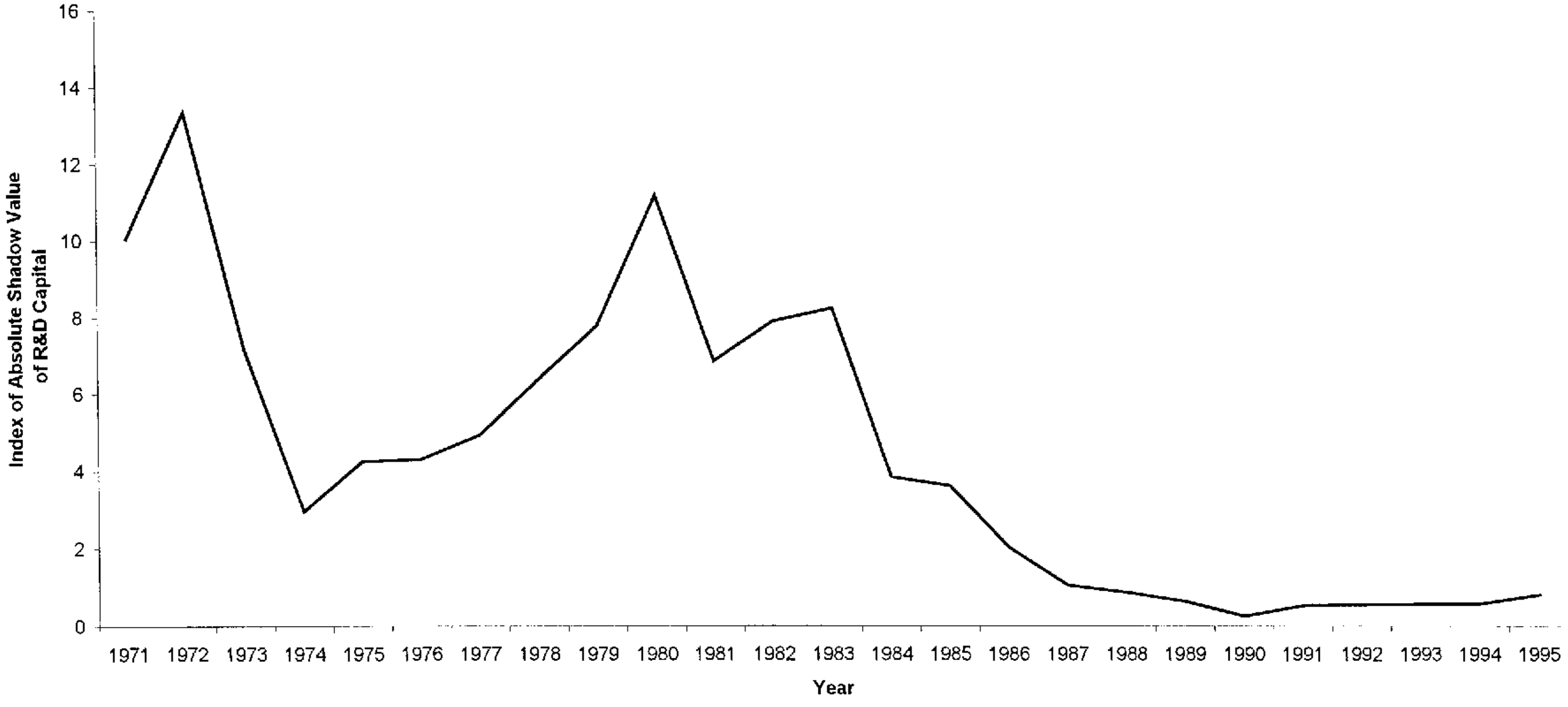
[Figure 4] Absolute Shadow Value of R&D Capital (Estimated from Rolling Two Year Balanced Panels)

The equation estimated is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV was set to zero. MISSAD is the dummy variable for missing or zero ADV. The absolute shadow value of R&D capital is exp(b0)*b1.

For each year t from 1972 to 1995, a balanced panel data set was created from the firms for which valid data are available for year t-1 and year t. Using this data set, the absolute shadow value for year t-1 and for year t was estimated, and the growth rate of the absolute shadow value from year t-1 to year t was computed. From the growth rate series, a level index with base period 1990 was created, which is reported in the table below.



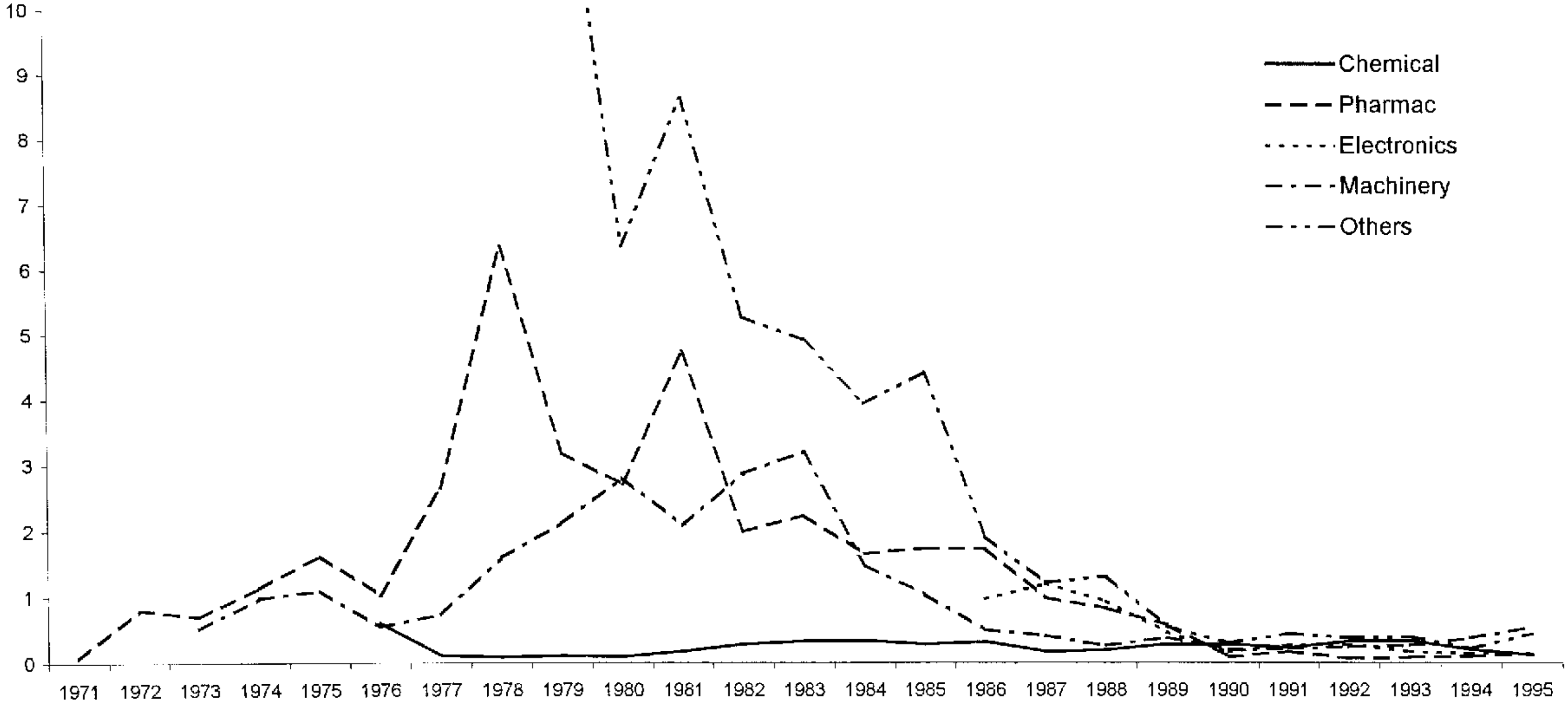
[Figure 5] Relative Shadow Value of R&D Capital of Five Industries

The equation estimated is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV was set to zero. MISSAD is the dummy variable for missing or zero ADV. The relative shadow value of R&D capital is b1.

For each year t from 1972 to 1995, a balanced panel data set was created for each sector from the firms for which valid data are available for year t-1 and year t. Using this data set, the relative shadow value for year t-1 and for year t was estimated, and the growth rate of the absolute shadow value from year t-1 to year t was computed. From the growth rate series, a level index with base period 1990 was created, which is reported in the table below. If the growth rate is greater than 9 or lower than 0.1, the index was not computed.



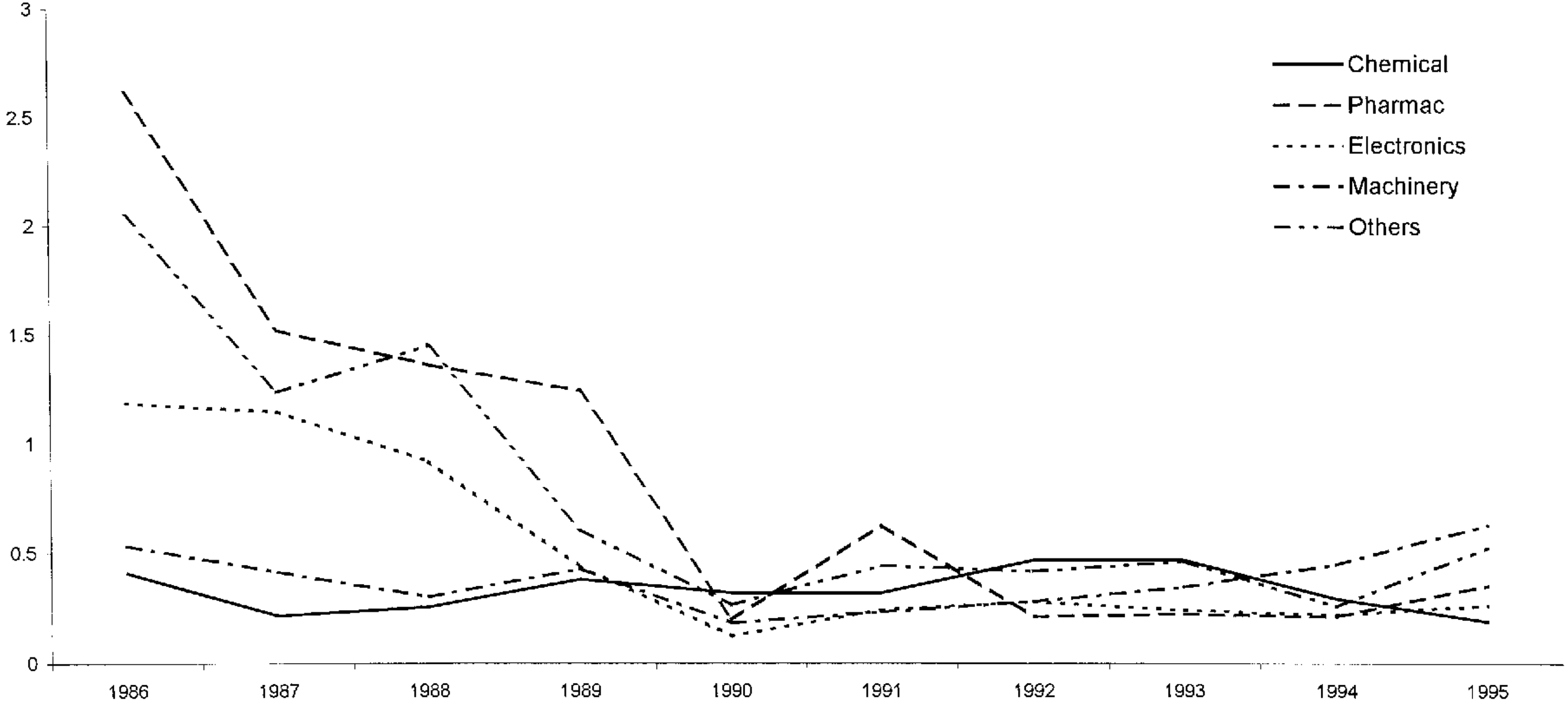
[Figure 6] Absolute Shadow Value of R&D Capital of Five Industries

The equation estimated is

$$\log Q = b0 + \log(1 + b1{*}K/A + b2{*}ADV/A + b3{*}MISADV/A)$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV was set to zero. MISSAD is the dummy variable for missing or zero ADV. The absolute shadow value of R&D capital is exp(b0)*b1.

For each year t from 1972 to 1995, a balanced panel data set was created for each sector from the firms for which valid data are available for year t-1 and year t. Using this data set, the absolute shadow value for year t-1 and for year t was estimated, and the growth rate of the absolute shadow value from year t-1 to year t was computed. From the growth rate series, a level index with base period 1990 was created, which is reported in the table below. If the growth rate is greater than 9 or lower than 0.1, the index was not computed.



[Figure 6] Absolute Shadow Value of R&D Capital of Five Industries

The equation estimated is

$$\log Q = b0 + \log(1 + b1*K/A + b2*ADV/A + b3*MISADV/A)$$

Q is the ratio of the market value to the replacement cost of assets. K is the replacement cost of R&D capital. A is the replacement cost of property, plant, and equipment, inventory, investment and advances, and intangibles. ADV is the expenditure on advertising. When ADV is missing or zero, ADV was set to zero. MISSAD is the dummy variable for missing or zero ADV. The absolute shadow value of R&D capital is exp(b0)*b1.

For each year t from 1972 to 1995, a balanced panel data set was created for each sector from the firms for which valid data are available for year t-1 and year t. Using this data set, the absolute shadow value for year t-1 and for year t was estimated, and the growth rate of the absolute shadow value from year t-1 to year t was computed. From the growth rate series, a level index with base period 1990 was created, which is reported in the table below. If the growth rate is greater than 9 or lower than 0.1, the index was not computed.