The market valuation of knowledge assets in US and European firms

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Abstract:

The hedonic regression approach to measuring the market value of the knowledge assets owned by a firm is outlined and the various ways of measuring knowledge assets using observable data are discussed. Past results from applying the method to firm data on market value, capital, R&D, and patents are summarized, along with a more detailed presentation of some recent results for US and European firms. The conclusion is that measures based on R&D, patents, and citation-weighted patents are each highly significant in a market value regression, although patent-based measures tend to be somewhat less significant in the presence of R&D measures. According to the results, in most countries one dollar of additional R&D spending adds slightly less than a dollar to market value; an alternative interpretation is that R&D assets depreciate at a somewhat higher rate than 15 per cent per year.

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1 Introduction

Innovation is generally considered to be a major cause of economic growth and is an important source of the wealth of developed countries. A necessary condition for private innovative activity is, however, that innovation has a positive impact on profits of a firm. Because the returns to innovation rarely occur during the period in which investments in innovation occur, and in fact, may be spread over a number of years following such investment, current profits are generally a very partial and incomplete indicator of the returns to innovation. For this reason a number of researchers have turned to stock market value as an indicator of the firm's expected economic results from investing in knowledge capital, following the seminal contribution by Griliches (1981). It has to be noted that 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. Nevertheless, using financial market valuation avoids the problems of timing of costs and revenues, and is capable of forward-looking evaluation, something that studies analysing profitability during a given period of time are not able to do. Furthermore, the method is potentially useful for calibrating various innovation measures, in the sense that one can measure their economic impact and possibly enabling one to validate these measures 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 purpose of transfer pricing or even the settlement of legal cases. This has led to consideration of the problem in the financial accounting literature (see, for example, Hirschey, Richardson, and Scholtz 2001; Lev 2001; 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 assets 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 any potential gaps between private and social returns.

The remainder of this paper is as follows: in Section 2 we introduce the basic concept of the market value approach, and we discuss the measurement of knowledge assets in Section 3. Section 4 surveys the results of empirical studies on the market valuation of R&D and patents, and reports in more detail the results of recent comparative studies using US and European firms. The final section concludes.

2 Innovation and market value: Remarks on the estimation models

Several authors have tested the relationship of different types of innovation investment with firm-level performance measures derived from stock market data. In particular, studies analyzing the relationship between knowledge capital and market value implicitly or explicitly assume that the stock market values the firm as a bundle of tangible and intangible assets (Griliches 1981). We outline the model here, using a treatment that follows Hall (2000) and Hall and Oriani (2004).

In equilibrium, the market valuation of any asset results from the interaction between the capitalization of the) firm's expected rate of return from investment in that asset and the market supply of capital for that type of asset (Hall 1993a). Using this idea, it is possible to represent the market value V of firm i at time t as a function of its assets:

$$V_{it} = V\,(A_{it}, K_{it}, I_{it}^{1}, \ldots, I_{it}^{n}) \qquad [1]$$

where A_{it} is the book value of tangible assets, K_{it} is the replacement value of the firm's technological knowledge capital and I_{it}^{j} is the replacement value of the j^{th} other intangible asset. If single assets are purely additive, and ignoring the other intangible assets for the sake of simplicity, it is possible to express the market value of the firm as follows:

$$V_{it} = b\,(A_{it} + \gamma K_{it})^{\sigma} \qquad [2]$$

where b is the market valuation coefficient of firm's total assets, reflecting its differential risk, overall costs of adjusting its capital, and its monopoly position, γ is the relative shadow value of knowledge capital to tangible assets, and the product $b\gamma$ is the absolute shadow value of the knowledge capital. In practice, $b\gamma$ reflects the investors' expectations about the overall effect of K_{it} on the discounted value of present and future earnings of the corporation, while γ expresses the differential valuation of the knowledge capital relative to tangible assets. By definition, when γ is unity, a currency unit spent in knowledge capital has the same stock market valuation of a currency unit spent in tangible assets. Conversely, values of γ higher (lower) than unity suggest that the stock market evaluates knowledge capital more (less) than tangible capital.

The expression [2] can be interpreted as a version of the model that is known in the economic literature as hedonic pricing model, where the good being priced is the firm and the characteristics of the good are its assets, both tangible and intangible. Taking the natural logs of both the sides in [2], assuming constant returns to scale (σ=*1*), and subtracting log A_{it} from both sides, we obtain the following expression:[1]

$$\log(V_{it}/A_{it}) = \log b + \log(1 + \gamma K_{it}/A_{it}) \qquad [3]$$

The ratio *V/A* is a proxy for average Tobin's q, the ratio of the market value of tangible assets to their physical value. The estimation of equation [3] allows one to assess the average impact of a euro or dollar invested in knowledge on the market value of a firm at a particular point in time. Bloom and Van Reenen (2002) and Hall et al. (2005) estimate equation [3] using non-linear least squares (NLLS). Other authors applying the same model have used the approximation $(1+x) \approx x$, obtaining the equation below, which can be estimated by ordinary least squares (Griliches 1981; Jaffe 1986; Cockburn et al. 1988; Hall 1993a, 1993b):[2]

$$\log(V_{it}/A_{it}) = \log b + \gamma K_{it}/A_{it} \qquad [4]$$

3 Measuring the knowledge capital

The concept of knowledge capital, measured by the variable *K* in the previous equations, is very broad and difficult to define empirically. There are in fact so many different types and levels of knowledge that it is practically impossible to aggregate them into one single index (Griliches, 1995). Nevertheless, even though the definition of a single comprehensive measure is not possible,

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[1] The assumption of constant returns to scale (homogeneity of degree one) in the value function has been confirmed repeatedly in the literature, at least for cross sections of firms.

[2] In order to investigate the appropriateness of equation [3] or [4], Hall and Oriani (2004) explored the use of semi-parametric estimation for the simple Tobin's *q*-R&D capital relationship by means of kernel regression using data for the United States. They found that the relationship resembles a logistic curve, with zero and very small amounts of R&D capital (less than about one per cent of tangible assets) having no effect on Tobin's q, a roughly linear relationship until $K/A=1$, and a flatter relationship thereafter. Above K/A value of one per cent, the relationship is somewhat better described by equation [3] than equation [4].

one can identify some indicators that correspond to specific dimensions of knowledge capital. Addressing this problem, Pakes and Griliches (1984) presented the path diagram shown in Figure 1. This diagram relates the unobservable ΔK, which is the net addition to knowledge capital K during a particular time period, to a set of observables (patents and R&D investments), random disturbances (ν, ω), and several indicators of performance (Z), including the stock market value of the firm. Firm performance is also assumed to be influenced by other observable variables such as investment and labor input (X) and unobservables (ε). The disturbance ω reflects the effects of informal R&D activities and the inherent randomness of inventive success, whereas v represents noise in the relationship between the patents a firm is granted and the associated increment to total technological knowledge.

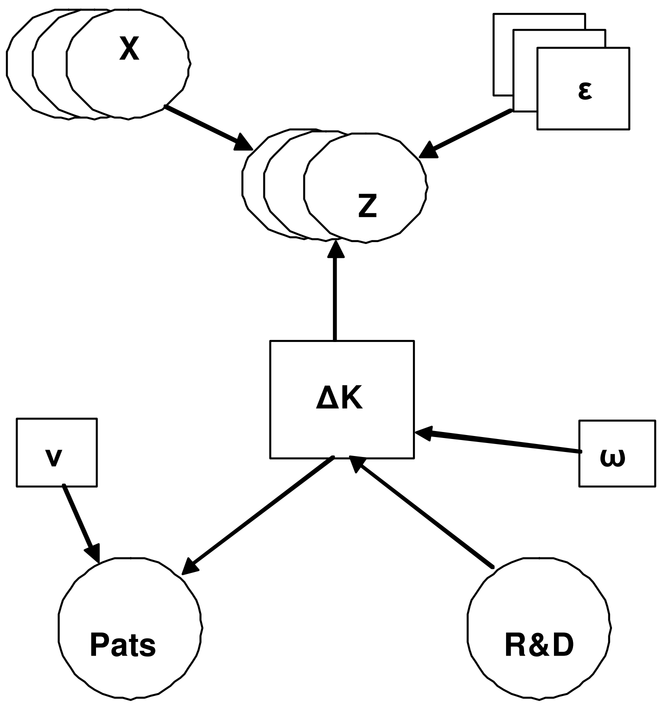

Figure 1: The measurement of knowledge capital (from Pakes and Griliches 1984)

Based on this framework, studies on innovation and market value have used two main proxies for K: R&D- and patent-based. In the absence of patent data, Griliches (1995) defines the following formal relationship between a firm's stock of technological knowledge and R&D investments:

$$K = G\,[W(B)R,\ \omega] \qquad [5]$$

where K is the current level of technological knowledge, $W(B)R$ is an index of current and past R&D expenditures and ω is the set of unmeasured influences on the accumulated level of knowledge described above. Accordingly, an R&D-based measure of a firm's technological knowledge has been often computed as the capitalization of present and past R&D expenditures using a perpetual inventory formula like that used for tangible capital (Griliches and Mairesse, 1984; Hall, 1990):

$$K_{it} = (1 - \delta)\, K_{i,t-1} + R_{it} \qquad [6]$$

where K_{it} is the R&D capital at time t, R_{it} is annual R&D expenditures at time t and δ is the depreciation rate of the R&D capital from year $t-1$ to year t. The use of expression [6] to capitalize R&D investments is needed because the Generally Accepted Accounting Principles (GAAP) in the US and the IAS accounting standards in Europe require R&D costs to be expensed as incurred (with a few exceptions) because of the lack of a clear link between these expenses and subsequent earnings (see Zhao 2002, for details). The use of a depreciation rate is justified by the fact that knowledge tends to decay or become obsolescent over time, losing economic value due to advances in technology.

Most of the studies that have estimated the hedonic model have used a constant annual 15% depreciation rate (Jaffe 1986; Cockburn and Griliches 1988; Hall 1993a, 1993b; Blundell et al. 1999; Hall and Oriani 2004). Other studies have used an estimation procedure that allows one to determine industry- and time-specific economic depreciation rates (e.g. Lev and Sougiannis 1996).[3] There also exist analyses using annual R&D expenditures as an alternative measure of R&D capital (Cockburn and Griliches 1988; Hall 1993a, 1993b; Munari and Oriani 2005). Because R&D spending is usually fairly persistent over time at the firm level (Hall et al. 1986), results from specifications using the flow of R&D tend to be quite similar to those using the stock after they are adjusted by the appropriate capitalization rate (the inverse of the growth plus depreciation rates). That is, if R&D capital is constructed using equation [6] and real R&D has been growing at a rate g, we have the following relationship between real K and R:

$$K_t = \sum_{s=0}^{\infty} (1-\delta)^{t-s} R_{t-s} = R_t \sum_{s=0}^{\infty} \left(\frac{1-\delta}{1+g} \right)^{t-s} = \frac{1+g}{g+\delta} R_t \qquad [7]$$

[3] More precisely, the authors estimate a regression model in which the dependent variable is the annual operating income and the independent variables are the lagged values of total assets and advertising expenditures and a vector of the past R&D investments.

However, the use of R&D-based measures does not definitively resolve the questions related to the measurement of technological knowledge for several reasons, mostly related to the presence of the disturbance ω discussed above, which introduces noise into the relationship between R&D and the underlying increment to knowledge capital. The first problem is that the quality of corporate financial reporting on R&D activity and intangibles in general is often inadequate for economic analysis purposes (Lev, 2001). Therefore R&D investments can be a source of greater information asymmetries between ownership and management and may not be properly valued by the market (Aboody and Lev, 2000). Second, national accounting laws often do not require corporation to disclose the amount of their annual R&D expenditures. For example, in the European Union, the United Kingdom is one of the few countries where quantitative disclosure of R&D investments is obligatory, while in France, Germany, and Italy there exists only an obligation to report qualitative information about R&D (Belcher 1996; KPMG 2001). Because some firms nevertheless do report R&D expenditures, this creates a potential sample selection bias (see the discussion in the next section). Finally, R&D investments are a not an output but an input measure of the innovation process. Since the outcome of R&D is highly uncertain (e.g. Scherer and Harhoff 2000), in some cases the relationship between R&D investments and a firm's knowledge base may be rather imperfect.

In order to solve these problems, some studies have used patent-based measures of technological knowledge. Recently, the wider availability of patent data in an electronic format and the creation of freely usable databases have spurred the adoption of patent-based measures in the studies on innovation and market value.[4] The first analyses were based on patent counts (e.g., Griliches 1981; Cockburn and Griliches 1988), where the number of patents substitutes for R&D investment in expression [6]. However, such a measure often turns out to be barely significant in the presence of R&D. An explanation of this phenomenon was provided by Griliches *et al.* (1987), who showed that under reasonable assumptions about the distribution of patent *values*, patent *counts* are an extremely noisy measure of the underlying economic value of the innovations with which they are associated, because the distribution of the value of patented innovations is known to be extremely skew. A few patents are very valuable, and many are worth almost nothing (Harhoff *et al.* 1999; Scherer *et al.* 2000).

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[4] See Hall *et al. 2002* for a description of the NBER/Case Western patent database

In an effort to improve the patent measure, more recent studies have weighted the patent counts by the number of citations received by each patent from subsequent patents (Bloom and Van Reenen 2002; Hall *et al.* 2005). The number of citations a patent receives can be viewed as an indicator of its quality or importance, which should be reflected in its market value. At the individual patent level, the use of citations as a proxy for value has been justified by Trajtenberg (1990) and Harhoff *et al*. (1999). In this case, the main source of noise is related to the fact that citations can be added for different purposes, so that a citation does not necessarily imply a technological impact of the previous patent (see Jaffe *et al*. 2002 for a survey on the meaning of patent citations). Moreover, all patent-based measures suffer from the limitation that the propensity to patent significantly differs across industries (Levin *et al.* 1987; Cohen *et al.* 2000), which implies that in different industries patents will vary in quality as indicators of technological knowledge.

4 Measuring the market value of knowledge assets

In this section of the paper we review the empirical results that have been obtained during the past 25 years on the market value of knowledge assets, using the three classes of measures described in section 3: measures based on R&D, measures based on patent counts, and measures based on citation-weighted patent counts.

4.1 The market value of R&D

Following the seminal contribution of Griliches (1981), a large number of studies have used a hedonic model like that in equation [2] to analyze the relationship between R&D (measured either by R&D capital or R&D expenditures) and market value. The main results are reported in Table 1, which reports the value of the estimated coefficient γ for either R&D capital (R&D cap) or R&D expenditures (R&D exp). Previous surveys of the studies on R&D and market value have highlighted two main results (Hall 2000). First, stock markets generally evaluate R&D investments in a positive way (i.e. $\gamma>0$). Second, market valuation of R&D has progressively decreased over time from the 1970s to the present time. The meta-analysis conducted by Oriani and Sobrero (2003) on a sub-sample of these studies has provided support for this finding. It is also worth noticing that these conclusions are based primarily on results using US data from the Compustat Database, whereas only recently has there been a significant amount for work using data on other countries: Australia, Japan, and European.

[Table 1 about here]

Looking at a recent example of such studies, Hall and Oriani (2004) analyze the market valuation of R&D investments in the Continental European countries, and compare it with the Anglo-Saxon countries (United Kingdom and United States). This paper is the first in-depth empirical analysis of the valuation of firms' R&D by the stock market in European countries other than the United Kingdom. Extending the analysis to these countries is important for several reasons: the importance of their economies, the different nature of their corporate governance systems as compared to Anglo-Saxon countries, and the variations in the public incentive schemes for private R&D. However, any analysis for countries like France, Germany and Italy must deal with two difficulties that limit data availability: the fact that R&D disclosure is not compulsory, drastically reducing the number of observations for which R&D is reported; and the small size of the public stock market, when compared to the United Kingdom and the United States, which restricts the number of publicly-traded firms that can be included in the sample.

Starting from the existing models on innovation and market value reviewed in Section 2, the authors tried to correct the potential biases arising from the problems discussed above by applying two estimation methods that have not been widely used in valuation analysis. First, they built a sample selection model in which the probability that a firm discloses R&D investments was modeled as a Probit function of firm size and leverage as well as industry-specific variables (R&D intensity and output growth). Second, they used panel techniques in order to account for left-out unobserved firm-specific effects.

The results obtained exhibited several interesting features. German and French samples show a statistically significant and robust positive evaluation of the R&D capital by the stock market. Moreover, the valuation of R&D capital in the countries is very similar when fixed firm effects are controlled for. However, the estimated coefficients of R&D capital are considerably less than unity in all countries, suggesting either that R&D investments are valued by the stock markets less than investments in tangible assets, or that the depreciation rate we used to construct the R&D capital, 15 per cent, was too low. They are also significantly smaller than the coefficients reported by previous studies on the US and the UK. Nevertheless, when permanent unobserved differences across firms were controlled for, the results for the Anglo-Saxon countries were consistent with those for the continental European countries, which confirms that the market valuation of R&D expenditures has decreased in all the countries over time, in line with the previous discussion. In addition, the very narrow gap observed between the R&D coefficients across countries is consistent with the anecdotal evidence of a progressive alignment of the European financial markets to the Anglo-Saxon ones within the last two decades (see Rajan and Zingales 2003).

An interesting finding is that the UK sample shows a substantially greater valuation of the R&D investments in the cross section. From the perspective of the financial investors, this means that a currency unit spent on R&D by a company in the United Kingdom has on average an impact whose magnitude is nearly three times larger than in France and Germany. The fact that Bond *et al.* (1998) find much higher marginal productivity of R&D in the UK than in Germany confirms that this result is probably real. A second interesting finding is that in France and Italy, the market places a significantly positive value on R&D spending only for firms without large controlling shareholders, even though there are quite a few firms controlled by a major shareholder that spend positive amounts on R&D. In some cases, especially in France, this may be because the large shareholder is the government (e.g., Bull, which is in our sample). In other cases, it may simply be that majority holders do not respond to market pressures that signal low values for their investment strategies. One avenue for future research could be further exploration of the relationship between the types of large shareholders (governments, families, or other firms) and the valuation of firm-level R&D strategy.

4.2 The market valuation of patents in the US and Germany

Since the output of R&D investments is inherently uncertain, some R&D projects will result in the creation of more valuable knowledge capital than others. If this success can be observed by investors, then the associated R&D should impact market value more than unsuccessful R&D. Empirical testing of this formulation requires an observable proxy for R&D success and the literature suggests using patent indicators for this purpose. Because R&D and patents are highly correlated in the cross section, it is necessary to be careful about the choice of specification when both variables are entered into the same market value equation. The two possibilities are either to include a measure of the stock of patents held by the firm in place of the stock of R&D, or to include a patents-per-R&D yield variable in addition to the R&D variable:

$$\log\left(V_{it}/A_{it}\right) = \log b + \gamma_1 K_{it}/A_{it} + \gamma_2 P_{it} / K_{it} \qquad [8]$$

In the above equation, P_{it} is a measure of the patent stock constructed according to equation [6], but with patent grants by date of application rather than R&D spending. The coefficient γ_2 measures the contribution to market value of acquiring an additional patent per unit of R&D stock. Its units therefore depend on the units in which R&D stock is measured, which sometimes makes studies difficult to compare.

When patents are included in the market value equation in addition to R&D, a number of studies have shown that patents add a small amount of information above and beyond that obtained from R&D. Table 2 shows results from various studies using US and UK data. In most studies patents contribute positively to firms' market value, although Toivanen *et al.* (2002) found that in some years they were negative for UK firms.

[Table 2 about here]

In a recent study, Czarnitzki and Hall (2005) compare the market valuation of patent stocks in US and German firms. Due to a large difference in the share of publicly traded firms relative to the total number of firms in the US and continental Europe, the authors employ matched firm samples in the analysis. They first constructed the German sample of publicly traded firms (352 firms), and then drew a matched sample of US firms using industry and size rank, recognizing that, on average, the German firms in the sample are smaller then the US firms. Nevertheless, the resulting samples roughly correspond to the market leading firms in both countries. The firm-level data was then linked to US and German patent data, respectively.[5] The patent stocks are calculated from the annual time series at the individual firm level using the perpetual inventory method and an equation like that in equation [6].

In contrast to the US patent data where only granted patents are observed, the German patent database offers two options for the measurement of the knowledge capital to assets ratio using patents (*K/A*): patents applied for and issued patents. That is, we also observe patents that have not passed the examination process and may never be issued. Given these differences, it is possible to investigate the question of using applied for or granted patents in the market value equations. If the aim of the researcher is to approximate the R&D stock, it would be appropriate to count patent applications. If, however, the results of R&D activities are expected to be inherently different with respect to their value, it might be better to stick to granted patents to reduce the noise created by research with a low inventive step in the market value equation. Hence, a patent may actually reveal its value in two stages: the number of observed applications serves as a proxy for R&D activities, and, second, its additional value could uncover with the grant, because the owner of a

[5] The German patent data contain patent application that have been filed with the German patent office and also those filed with the European Patent Office and where the applicant requested patent protection for Germany.

granted patent may license or sell it, for instance. For this reason, Czarnitzki and Hall explore different specifications for the patent assets in Germany.

These authors estimate pooled cross-sectional regressions (nonlinear least squares on eq. [3] and ordinary least squares on the linearized model of eq. [4]), fixed and random effects panel data models, instrumental variable panel regressions as well as non-parametric kernel regressions. In both the pooled cross-sectional regressions and panel data estimations the patent stock of firms contributes significantly to their market value. Surprisingly, the results from the German sample are very similar to the US in terms of the size of the impact. The significant impact in the German sample is quite robust in the panel data estimation that control for fixed effects, while in the cross-section it is important to control for industry differences in average market value.

The patent variables based on applications and grants lead to fairly robust estimation results, with the marginal shadow value of a patent application less than the value of a patent grant. These findings point again to the conclusion that the value of R&D is inherently heterogeneous among projects and firms. R&D that leads to a patent application represents some value. However, increased value from the R&D program is revealed when a patent is finally granted and the firm is able to fully exploit its property right to the invention. While the patent application protects the corresponding invention from the date of filing the patent, the actual grant of the patent enables the firm to trade or to license their intellectual property, for instance, which may well yield additional earnings aside from implementing the technology or the product in its own operational business.

4.3 Accounting for patent heterogeneity using citation-weighted patent stocks

As already pointed out in Section 3, one disadvantage of using patent indicators is the large variance in the significance of value of individual patents, rendering patent counts an extremely noisy indicator of R&D success. One way to account for patent heterogeneity is by means of citation-weighted patent counts, that is, a firm's patent counts are supplemented with the number of subsequent citations to get a better measure of R&D success. A number of researchers have demonstrated that measures of innovation output or profitability are related to the number of times a patent on the relevant invention is cited by other later patents (e. g., Trajtenberg 1990; Deng *et al.* 1999; Harhoff *et al.* 1999).

Hall, Jaffe, and Trajtenberg (2005) extend the market value equation with respect to the patent yield of R&D (i.e., the ratio of patent count stocks to R&D stocks), and the average citations received by these patents (i.e., the ratio of citations to patent stocks). Thus equation [3] is modified as following:

$$\log\left(V_{it}/A_{it}\right)=\log b+\log\left(1+\gamma_1\frac{R\,\&\,D_{it}}{A_{it}}+\gamma_2\frac{PAT_{it}}{R\,\&\,D_{it}}+\gamma_3\frac{CITES_{it}}{PAT_{it}}\right), \qquad [9]$$

where *R&D*, *PAT* and *CITES* stand for the stocks of R&D, patent stocks, and citations, respectively.

Employing a sample of more than 3,000 US firms observed in the period from 1976 to 1992, Hall and her co-authors find that each of the ratios in expression [9] has a statistically and economically significant impact on market value. Table 3 shows one estimation from the recent Hall et al. study, where they include dummies for six sectors: Drugs and Medical Instrumentation (henceforth just "Drugs"); Chemicals; Computers and Communications ("Computers"); Electrical; Metals and Machinery; and miscellaneous (low-tech industries), and interact them with the knowledge stock ratios. In column (2) we can see that there is a high premium to being in the Drugs or Computers sector, which comes mostly at the expense of the coefficient of R&D intensity, which drops by a half when the sector dummies are included. The full interactions in column (3) reveal wide differences across sectors in the effects of each knowledge stock ratio. In general, the differential importance of patent yield and of citations per patent rises, at the expense of R&D intensity. Thus, whereas in no sector is the effect of R&D/Assets much larger than the average effect picked up in the base specification displayed in column (1), the impact of patent yield for Drugs is three times the average effect (.10 versus .031), and that of Computers twice as high; similarly but not as pronounced, the impact of Citations/Patents for Drugs is over 50% higher than the average effect, while that for Computers is small, and lower than that for the other sectors except for the low-tech sector. This contrast is consistent with the differing roles played by patents in the two sectors: Drugs is characterized by discrete product technologies where patents serve their traditional role of exclusion, and some of them are therefore valuable on an individual basis, as measured by citations. Computers and Communications is a group of complex product industries where any particular product may rely on various technologies embodied in several patents held by different firms. In this industry patents are largely valued for negotiating cross-licensing agreements, so their individual quality is not as important, although having them is.[6]

[Table 3 about here]

In conclusion, not only does the market value R&D inputs and R&D outputs as measured by patent counts, but also it values "high-quality" R&D output as measured by citation intensity. Hall *et al.* also report a number of interesting detailed findings about the value of citations. First, the value-citation relationship is highly nonlinear: firms having two or three times the median number of citations per patent display a 35% value premium, and those with 20 citations and more command a staggering 54% market value premium. Second, the market value premia associated with patent citations confirm the forward-looking nature of equity markets: at a given point in time, market value premia are associated with future citations rather than those that have been received in the past, and the portion of total lifetime citations that is unpredictable based on the citation history at a given moment has the largest impact.

Finally, self-citations (i.e., those coming from later patents owned by the same firm) are more valuable than citations coming from external patents. This could be explained by cumulative or sequential innovations (see Scotchmer, 1991). Firms citing their own patents is a reflection of the cumulative nature of innovation and the increasing returns property of knowledge accumulation. Self-citations indicate that the firm has a strong competitive position and is in a position to internalize some of the knowledge spill-overs created by its own developments. This implies both that the firm has lower costs because there is less need to acquire technology from others, and that it may be able to earn higher profits without risking rapid entry since it controls a substantial stretch of the underlying technology. However, the effect of self-citations decreases with the size of the patent portfolio held by the firm simply because the more patents a firm has, the higher the probability that a citation from a new patent it gets will be given to a patent it already has.

[6] See Arora *et al*. (2004) for further discussion of this contrast and Hall and Ziedonis (2001) for evidence on semiconductors.

5 Conclusions

The line of research described in this survey is now 25 years old and it has reached a level of maturity that allows us to draw certain conclusions from it, conclusions both about the ability of financial markets to value the intangible assets of firms and about appropriate methodology to apply to the problem. As the tables show, several empirical regularities have emerged from the various studies.

First, in most countries and in most time periods R&D capital is valued somewhere between 0.5 and 1 times ordinary capital. The implication of this finding is that the appropriate private obsolescence rate for R&D investment is probably somewhat greater than 15 per cent, more in the neighborhood of 20 to 30 per cent. This conclusion is reinforced by the fact that current R&D spending usually has a coefficient of around 3 to 4, rather than the 6 implied by a 15 per cent depreciation rate. In the UK, R&D seems to be valued more highly than in the other countries. An implication is that firms in the UK may be underinvesting in R&D.

Second, patent coefficients are more variable than R&D coefficients, partly because the specifications using patents are more variable. Where they can be compared, it appears that patent yield has a much smaller effect on value than R&D, but this is to be expected if patents are a very noisy measure of the underlying inventive success. Using citation-weights improves the patent measure, but it is still a relatively weak predictor of value. The best predictor of value turns out to be citations not yet received by the patents, so the measure is of limited use for forecasting.

Third, although most of the studies are either for the entire manufacturing or for the entire publicly traded firm sector, the impact of knowledge assets on market value varies considerably across technology sector and industry, with pharmaceuticals having higher values and computing and electrical sectors having much lower values.

With respect to methodology, it has become increasingly clear that research in this area would be helped by agreement on a common specification of the market value equation. Using kernel regression methods, Hall and Oriani (2004) have confirmed that the nonlinear version of the model (equation [3]) is probably preferred to a linear version, because it dampens the impact of R&D on market value when firms are extremely R&D intensive. When there are multiple indicators (such as patents and R&D) in the same equation, for interpretive reasons it is preferable to include these variables in a roughly orthogonal way (e.g. R&D and patents per R&D), especially in the presence of substantial measurement error in the patents variable. There remains the challenge of interpreting the meaning of the patent coefficient when it is normalized by R&D measures which can be in various currency units, and for comparative reasons, it may be preferred to express this coefficient as an elasticity by multiplying it by the patents-R&D ratio.

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Table 1
Overview of empirical findings on the market valuation of R&D

Study	**Dependent variable**	**R&D coefficient (Standard error)**	**Sample characteristics (country, no. of firms, years, data source)**
Griliches (1981)	log Q	Predicted R&D exp: 1.23 (.54) Surprise R&D exp: 1.58 (.44)	US, 157 firms, 1968-1974, Compustat
Ben-Zion (1984)	log V	R&D exp: 3.376	US, 93 firms, 1969-1977, Compustat
Jaffe (1986)		R&D cap: 2.95 (1.52) R&D cap * Spillover: .526 (.192)	US, 432 firms, 1973 and 1979, Compustat
Cockburn and Griliches (1988)	log Q	R&D exp: 11.96 (1.368) R&D exp * Appropr.: 2.788 (1.231) R&D cap: 1.442 (.174) R&D cap * Appropr.: .303 (.115).	US, 722 firms, 1980, Compustat
Hall (1993a)	log V	R&D exp: 3.10 (.08) R&D cap: .48 (.02)	US, 2400 firms, 1973-1991, Compustat
Hall (1993b)	log Q	*By year (1971-1990):* R&D exp: from 2.0 to 10.0 R&D cap. from .5 to 2.0	US, 3000 firms, 1959-1991, Compustat
Megna and Klock (1993)	Q	R&D cap: .488	US semiconductor, 11 firms, 1972-1990, Compustat
Haneda and Odagiri (1998)		R&D cap: ~2.3	Japan, 90 firms, 1981-1991, NEEDS database
Blundell *et al.* (1999)	log Q	R&D cap (1.582) R&D cap * Market share (1.745)	UK, 340 firms, 1972-1982, LBS Share Price Database and Datastream
Bosworth and Rogers (2001)	log V	R&D exp: 2.268	Australia, 60 firms, 1994-1996, Australian Stock Exchange and IBIS database
Rogers (2001)	log V	R&D exp: 3.405	Australia, 721 firms, 1995-1998, Australian Stock Exchange and IBIS database
Toivanen *et al.* (2002)	log V	*By year:* R&D exp: from 2.6 to 4.2	UK, 877 firms, 1989-1995, Extel financial company analysis
Hall and Oriani (2004)	log Q	*France* - R&D cap: 0.28 (.08) *Germany* - R&D cap: .33 (.04) *Italy* - R&D cap: .01 (.12) *UK* - R&D cap:.88 (.10) *US* - R&D cap: .33 (.02)	France (51 firms), Germany (80 firms), UK (284 firms), Italy (49 firms) 1989-1998; Datastream, Global Vantage, Worldscope, Centrale dei bilanci
Greenhalgh and Rogers (2005)	log V	R&D exp: 3.703	UK, 347 firms, 1989-1999, Extel financial company analysis and Thomson
Munari and Oriani (2005)	log Q	*Privatized* R&D exp: -1.41 (1.26) *Private* R&D exp: 3.059 (1.21)	Finland, France, Germany, UK, Italy, Netherlands, 1982-1999, 38 privatized firms and 38 control firms, Datastream and Centrale dei bilanci
Hall *et al.* (2005)	log Q	R&D cap: 1.736 (.069)	US, 4800 firms, 1965-1995, Compustat

Table 2
Overview of empirical findings on the market valuation of patents

Study	Dependent variable	Patent Coefficient (Std. err)	Sample characteristics (country, no. of firms, years, data sources)
Griliches (1981)	log Q	Pat/assets: 10-25?	US, 157 firms, 1968-1974, Compustat and USPTO
Ben-Zion (1984)	log V	Pat/assets: 0.065 (0.055)	US, 93 firms, 1969-1977, Compustat and USPTO
Connolly *et al.* (1986)	Value/sales	Pat/sales: 4.4 (0.6)	US, 376 firms, 1977, Compustat and Fortune Magazine, USPTO
Cockburn and Griliches (1988)	log Q	Pat stk/assets: 0.11 (.09)	US, 722 firms, 1980, Compustat and USPTO
Connolly and Hirschey (1988)	Value/sales	Pat/sales: 5.7 (0.5)	US, 390 firms, 1977, Compustat and Fortune Magazine, USPTO
Megna and Klock (1993)	Q	Pat stk: 0.38 (0.2)	US semiconductor, 11 firms, 1972-1990, Compustat and USPTO
Blundell *et al.* (1995)	log V	Pat stk/R&D stk: 1.93 (0.93)	UK, 340 firms, 1972-1982, LBS Share Price database and Datastream, NBER patent database
Shane and Klock (1987)	log Q	Pat/assets: -0.41 (.25) Cites/assets: .012 (.005)	US semiconductor, 11 firms, 1977-1990, Compustat and CHI Research
Haneda and Odagiri (1998)	log Q	Pat stk elasticity: ~0.3	Japan, 90 firms, 1981-1991, NEEDS database
Deng *et al.* (1999)	Q	Pat elasticity: .007 Cite elasticity: .165	US, 411 firms, 1985-1995, Compustat and CHI Research
Hirschey and Richardson (2001)	V/A	Pat/assets: 2.8 (0.2) US ~0 Japan	US, 256 firms, 1989-1995, Compustat and CHI Research Japan, 184 firms, 1989-1995, not given
Bloom and Van Reenen (2002)	log Q	Pat stk elasticity: 0.08 (.03) Cite stk elasticity: 0.12 (.03)	UK, 172 firms, 1969-1994, Datastream and NBER patent database
Toivanen *et al.* (2002)	log V	Pat/assets insignificant	UK, 877 firms, 1989-1995, Extel financial company analysis
Hall *et al.* (2005)	log Q	Pat/assets: .607 (.042) Cite stk/assets : .108 (.006)	US, 4800 firms, 1965-1995, Compustat

Table 3
Market value regression from Hall, Jaffe, and Trajtenberg (2005)

Sample: 1,982 Patenting Firms, 1979-88 - 12,118 observations
Nonlinear Model with dependent variable: log Tobin's q

	(1)	(2)	(3)
D (Drugs)		.536 *(.028)*	.005 *(.102)*
D (Chemicals)		.026 *(.020)*	-.231 *(.061)*
D (Computers)		.311 *(.022)*	.361 *(.050)*
D (Electrical)		.166 *(.021)*	.093 *(.061)*
D (Metals & Machinery)		.015 *(.016)*	-.261 *(.047)*
R&D/Assets			
interacted with,	1.362 *(.068)*	.686 *(.057)*	.883 *(.198)*
Drugs			.561 *(.310)*
Chemicals			-.017 *(.333)*
Computers			-.575 *(.204)*
Electrical			-.343 *(.253)*
Metals & Machinery			.595 *(.241)*
Patents/R&D			
interacted with,	.030 *(.007)*	.025 *(.006)*	-.020 *(.006)*
Drugs			.120 *(.051)*
Chemicals			.059 *(.018)*
Computers			.078 *(.017)*
Electrical			.022 *(.006)*
Metals & Machinery			.070 *(.014)*
Citations/Patents			
interacted with,	.052 *(.004)*	.036 *(.003)*	.014 *(.004)*
Drugs			.065 *(.015)*
Chemicals			.048 *(.012)*
Computers			.014 *(.006)*
Electrical			.022 *(.011)*
Metals & Machinery			.037 *(.009)*
D (R&D=0)	.066 *(.019)*	.099 *(.018)*	.123 *(.020)*
R^2	.254	.292	.308
Standard Error	.671	.654	.647
Robust Wald Test for added effects (degrees of freedom)		503.5 *(5)*	142.6 *(15)*

Estimation method: nonlinear least squares.
Heteroskedastic-consistent standard errors in parentheses.
All equations include year dummies.
The left-out category is miscellaneous (low-tech industries).