Measuring corporate R&D returns

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1. Why is this an interesting topic?

In March 2000, the European Council in Lisbon set out a ten-year strategy to make the EU the world's most dynamic and competitive economy.[2] One of the main priority areas in the Lisbon strategy or Lisbon agenda (as it is sometimes known) is to increase investments in knowledge, research, and education, both by governments and by enterprises. Increasing such investment has remained one of the most important areas for action in subsequent Commission communications on the progress of the Lisbon strategy. In 2002, the Commission named one of three priority areas as

> "Increasing investment in knowledge to ensure future competitiveness and jobs. The European Union must step up the effort in the areas of research, innovation, education and training, and increase its impact by pursuing a more integrated approach and place these policies under a common banner: a European area of knowledge…" (European Commission 2002).

And in 2004, the goal had hardly changed:

> "Improving investments in knowledge and networks, by implementing the 'Growth Initiative', all the while giving greater priority to the level and quality of investments in research, education and training;" (European Commission 2004).

These goals have been widely interpreted as calling for increased R&D spending in Europe, in order to attain a target of in the neighborhood of 3 per cent of GDP overall. From Figure 1, which shows the composition of the R&D/GDP ratio for three maJor EU regions (the 27 member countries, the 15 pre-accession member countries, and the 15 countries in the euro zone) along with the US and Japan, we can draw two conclusions: first, the 3 per cent target lies somewhere between the performance of the US and Japan, and second, the shortfall is entirely in business R&D.[3]

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[1] This draft is incomplete and possibly incorrect in places. It has not been reviewed by the second author. Comments are welcome, especially from JM.

[2] http://europa.eu.int/comm/lisbon_strategy/index_en.html

[3] These numbers are based on the latest figures at Eurostat as of October 2008, which actually come from 2005 and 2006. There are numerous problems in collecting the data and making it comparable, partly because the structure of the economies vary, but for this rough comparison the data are accurate enough.

In an earlier paper written for this group, O'Sullivan reviewed the more detailed evidence on the question of an R&D deficit and concluded the following:

> "Its (that is, the Commission's) revised estimates suggested a very clear conclusion: the ICT sector was responsible for the bulk of the R&D deficit between the EU and the US." (*O'Sullivan, p. 4, draft of September 2006*).
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> "The Scoreboard analysis confirms that the major source of the difference in R&D intensity between the EU and the US is the sectoral composition of industry and, in particular, the greater specialisation of US companies in the production of information technology, both hardware and software. However, the main reason for this difference is not that existing EU players in these industries have a lower R&D intensity than their US counterparts but that there are fewer EU companies which are active in these sectors than in the US." (*O'Sullivan, p. 5, draft of September 2006*)

To these conclusions, one could perhaps add the observation that they would be even more true if the comparison were with Japan rather than the US. Using the statistics from the OECD STI Scoreboard the share of R&D going to high technology in Japan appears to be roughly comparable to the share in the US, which implies that the amount of R&D investment is higher.

If we conclude that business R&D spending is "too low" in Europe, simple economic analysis tells us that this might be for two reasons, both of which can occur together: supply of funds problems (too high a cost of capital) and/or R&D demand shortfalls (firms do not find opportunites profitable enough, or they find the cost of inputs too high). From the perspective of policy, one would need to measure the marginal returns to R&D to decide which problem deserves the most attention. That is, if the rate of return to R&D among European firms is found to be high, that suggests that the cost of capital they face is high and requires that attention be paid to the functioning of financial markets. If the rate of return to R&D is found to be low, then our attention is directed to a number of other ares that influence the opportunities for R&D investment - the presence of lead markets, the size of the market, entrepreneurship, regulation, the role of standards, the cost and availability of R&D labor and so forth. Evidence in O'Sullivan paper and elsewhere suggests that both of these may be true in Europe, possibly in differing industries and member states. Thus it may be useful to evaluate the rate of return to R&D by country and sector.

The larger question is whether increasing R&D spending in Europe to US and Japanese levels is the appropriate target for policy to improve European innovative performance. Although this paper does not take a position on this question, we argue that a deeper understanding of the reasons for the "deficit" can help to inform us about the innovative process in which R&D does play a large part.

1.1 Prior analytic surveys

There are a number of prior surveys of the literature on the economic measurement of returns to R&D. Some have catalogued the various results and others have discussed the many analytical problems that confront a researcher in this area. The first and pioneering analytic survey was that by Griliches (1979) in the *Bell Journal of Economics*. In that article Griliches laid out the structure of the problem in the production function context and discussed two major measurement difficulties: the measurement of output when a great deal of R&D is devoted to quality improvement and nonmarket goods and the measurement of input, specifically, of the stock of R&D capital. He returned to these themes in Chapter 4 of the Kuznets lectures of 1996, published posthumously (Griliches, 2000).

Hall 1996 (In *Barfield and Smith, AEI/Brookings*)

Hall 2007 – *Annales d'Economie et de Statistique*

In progress: Hall, Mairesse, and Mohnen for the *Handbook of Economics of Technical Change*

2. R&D as investment

R&D spending is both similar to and different from ordinary investment. The similarity is that it is expenditure undertaken today to secure (uncertain) returns in the future, which is why it is sometimes referred to as "R&D investment" and why analysis of the R&D decision frequently uses to the tools of investment analysis. The differences are substantial, and are mostly related to the factors identified long ago by Arrow (1962) as affecting the allocation of resources for invention.

Hall (1992, 2002) discusses the important differences between R&D and ordinary capital investment. Most of them arise directly from the fact that the asset created is an intangible, the knowledge of how to do something. First, the composition of R&D spending is different, with more than half being spent on the wages of highly trained scientists and engineers. Because of this, much of the knowledge thus created may be tacit, and embedded in those scientists and engineers. This fact has two related consequences: ownership of such knowledge may not reside entirely with the firm, and it creates an incentive for smoothing expenditure on R&D, due to the need to keep employees that own valuable firm assets (knowledge).

The second major difference between the two types of investment is the level of uncertainty in their returns, which has a number of implications. First, the economic depreciation (private obsolescence) of the asset created by R&D can be highly variable and will depend to a much greater extent on the actions of competitors. Related to this is the fact that R&D assets typically have a low salvage value, in that their second best use is valued much less than their first best use in the ongoing firm. Finally, the combination of intertemporal production of the R&D asset and the uncertainty of its returns makes investment strategy look like a real options problem, where the decision at any moment is to continue an investment project or cut it off, depending on the movement of expected future returns and their variance.

2.1 Corporate returns to R&D

Contrary to what one might read in the newspaper and some of the economic literature, the corporate returns to R&D are expected to be a rather uninteresting number, essentially given by the cost of capital. However, the realized return will often differ from this number for a variety of reasons.

It could be *higher* for systematic reasons such as a risk premium due to the greater uncertainty of R&D investment outcomes or because there is a lemons' premium due to asymmetric information between investors and firms and the associated moral hazard of firm managers (Hall 2002). It can also be higher because of unexpected positive demand shocks *ex post.* Most importantly it can be higher because the portfolio of R&D projects was more successful than average.

The only systematic reason that the rate of return to R&D can be *lower* than the cost of capital is the various government policies such as matching subsidies and tax credits designed to lower the cost of the firm's own R&D spending on the margin. However, it is also subject to the downside shocks *ex post* from demand and from other forms of innovation failure, such as unexpected entry by competitors.

3. Measuring firm level returns to R&D

3.1 Accounting approach

Given the standard accounting data available for public firms, a number of *ad hoc* approaches to evaluating R&D suggest themselves, mostly based on computing the relationship between standard accounting-based performance measures and R&D investments. For example, this was the approach taken by the Booz-Allan-Hamilton reports on R&D performance around the world (BAH 2006, 2007). The accounting measures they chose were the following: market capitalization growth ratio, the shareholder return to common stock, gross profit margin, gross operating margin, and three growth rates: sales, profit margin, and operating margin. What would we expect to be the empirical relationship of these measures to R&D spending at the firm level?

Assume that there are a number of firms, each of which is pursuing an optimal R&D investment strategy as far as they can, but under considerable uncertainty about the market, the competition, and future prices. Assume also that entry into the relevant sector is not restricted. Both of these assumptions are plausible and rather weak, but they have clear implications for the relationship between the various performance measures and R&D. First, on average we would expect the risk-adjusted returns to R&D to be the same as the returns to any other investment activity. That is, if R&D is expensed and is not fluctuating a great deal over time within firm (as is usually the case for large firms), we would not observe much of a correlation between profits (properly accounted and net of R&D) and R&D. On average the firms get what they pay for and do not earn supranormal returns to R&D. There will be winners and losers, but winning will not be especially related to the level of R&D spending. Note that this does not mean that firms should not spend on R&D, simply that if all firms pursue what appears to them to be a good policy, in equilibrium we would not expect to see a strong relationship between firm profitability net of R&D and R&D spending itself.

At the same time, the level of R&D investment or R&D intensity will be correlated with the firm's future growth, because firms that invest greater amounts given their current size are those that expect (or desire) growth in the future. In this respect, R&D investment is like ordinary investment. Summing up, we expect normal but not supranormal returns to R&D in equilibrium.

Define the following variables, all directly obtainable from firm accounting data: total market value V, the price of common stock P, dividends per share D, net sales or turnover S, total book value A, cost of goods sold CGS, and R&D spending R. Then the performance measures used by BAH and their expected relationship to R&D intensity are given in Table 1.

Table 1: Accounting-based performance measures

Variable	Symbol	Formula	Expected Relationship to R/S
Market cap growth	gval	(V-V(-1)) / V(-1)	Positive
Shareholder returns	r	(P-P(-1)+D) / P(-1)	Zero
Gross margin over sales	gm	(S-CGS) / S	Positive (≈1)
Operating margin over sales	go	(S-CGS-R) / S	Zero
Gross margin growth	ggm	(gm-gm(-1)) / gm(-1)	Weakly positive
Operating margin growth	ggo	(go-go(-1)) / go(-1)	Weakly positive
Sales growth	gs	(S-S(-1)) / S(-1)	Positive

Market capitalization growth

The proper measure of market capitalization is the market value of all claims on the firm's assets, which includes debt and any preferred or convertible stock. If the firm's investments in R&D are creating intangible assets, market value itself will be correlated with R&D, once we control for the book value of the tangible assets. The growth of market cap or market value is an indicator of the growth of the firm, and as such, is expected to be correlated with the rate of past investment, either ordinary tangible investment or R&D investment. However, the magnitude of the correlation is difficult to predict, and the relationship may be somewhat volatile due to the fact that market cap is dominated by the value of common stock.

Shareholder returns

This is the one period return to holding one share of the firm's common stock, defined as the current price less the price last period plus any dividends paid during the period, divided by the price last period. The usual efficient markets hypothesis tells us that there should be little relationship between (lagged) R&D or R&D intensity and shareholder returns: if there were such a systematic relationship, then there is a clear profit opportunity because R&D intensity could be used as a trading rule. This does not mean that we will not experience periods or episodes where R&D systematically leads to higher or lower returns, but it does mean that these periods will not be predictable on the basis of past information and therefore that we do not expect a systematic relationship over time.

Gross margin percentage

Gross margin percentage is the gross profit to sales ratio, where gross profits is sales less the cost of goods sold, and is therefore gross of R&D expenditure. This fact implies that there will be a simple accounting correlation between the gross profit to sales ratio and the R&D to sales ratio and that we expect the relationship to be roughly one for one, with any increase in R&D matched by an increase in gross profits.

Operating margin percentage

Operating margin percentage is the operating income to sales ratio, where operating income is a measure of profits that is net of R&D expenditure. By the arguments given earlier, we do not expect much if any correlation between R&D intensity and the operating income to sales ratio if the firms are behaving in a profit-maximizing way in competitive markets.

Gross margin growth (gross profit growth)

We do not expect the growth in gross profit to be systematically related to the level of R&D intensity, although it might be related to growth in R&D or R&D intensity. However, if gross profit growth reflects overall firm growth, there may be a weak relationship to the level of all investments, R&D and tangible.

Operating margin growth (operating income growth)

As in the case of gross profit, there may be a weak relationship between the growth in operating income or profits and the level of R&D intensity due to the fact that profit growth is related to the overall growth of the firm.

Sales growth

As in the case of market capitalization, sales growth is an indicator of firm growth and we expect that this will be correlated with R&D investment intensity.

Table 2 shows the results of our estimation of the following simple model using data on US firms:

$$y_{it} = \beta r_{it} + \lambda_t + \delta_j + \varepsilon_{it}$$

where y is one of the seven performance measures, r is the R&D to sales ratio lagged two years earlier to avoid simultaneity bias, the λ's are time (year) means, the δ's are industry means (included in the second columns), and ε stands for "errors" in the model, mainly related to omitted variables and measurement errors in the included variables. That is, we control for the average performance in each year and two digit industry, but not for capital, labor and other relevant factors such as quality of organization and management. We estimated this relation for two time periods: the 4 years 1996-1999 and the 4 years 2002-2005, to illustrate how things can change over time. Note that these two periods bracket a period in which the technology part of the stock market experienced a large rise and fall due to the dotcom boom and year 2000 investment.

Table 2: Impact of lagged R&D intensity on various performance measures

Dependent variable	**1996-1999**		**2002-2005**	
Market cap growth	.28 (.16)	.30 (.22)	-.04 (.01)	-.00 (.12)
Shareholder returns	.05 (.15)	.06 (.18)	-.29 (.11)*	-.17(.11)
Gross margin percentage	1.82 (.08)*	1.53 (.09)*	1.45 (.05)*	1.34 (.06)*
Operating margin percentage	.14 (.03)*	.14 (.03)*	-.09 (.03)*	-.06 (.03)*
Gross margin growth	.14 (.06)*	.16 (.08)*	.17 (.06)*	.19 (.06)*
Operating margin growth	.34 (.15)*	.37 (.15)*	1.10 (.13)*	1.05 (.14)*
Sales growth	.30 (.08)*	.21 (.07)*	.14 (.03)*	.16 (.04)*
Year dummies	yes	yes	yes	yes
2-digit industry dummies (25)	no	yes	no	yes
N of observations (firms)	5688 (1422)		5800 (1450)	

Source: S&P Compustat annual industrial file, authors' computations.
Sample is manufacturing plus oil and gas, communications, wholesale trade, and business services (R&D-doing firms only)
Method of estimation is Least Absolute Deviations. * significant at the 5% level.
R&D intensity = R&D to sales ratio, lagged two years
Gross margin = sales less cost of goods sold (gross of R&D)
Operating margin = operating income (net of R&D)
Percentages are relative to sales
Shareholder returns are holding period capital gains plus dividends per share
Market cap is the total market value of the firm, including long term debt

Our discussion above had two clear predictions of a relationship, which are partially confirmed by Table 2. First, the growth in gross margins, operating margins, and sales are positively related to R&D intensity. Second, gross income to sales is correlated slightly more than one for one with the R&D to sales ratio, as we would expect given that it is gross of R&D.

The remaining results are more equivocal although not inconsistent with the arguments presented earlier. Shareholder returns are largely uncorrelated with R&D intensity, with the exception of a slightly negative relationship during the 2002-2005 period when we do not control for two-digit industry. Operating margins are correlated with R&D intensity, but with opposite signs during the two periods. Because there is no reason to expect stable relationships between R&D and the profit rate, this result is not as surprising as it might first appear to be. The most striking result is that the growth in market capitalization is insignificantly (although positively) related to R&D intensity during the first time period and unrelated during the second. As we will see in subsequent tables, somewhat unstable estimates for the market cap growth-R&D relationship arise partly from market volatility during this period, and the so-called "dotcom" bubble during the late 1990s.

Table 3 looks at the same relationship in a slightly different way, to focus on more long term relationships and average out some of the year-to-year volatility. The results in this table are based on a single cross section of average performance over a four-year period (1996-1999 and 2002-2005) as it relates to R&D performed two years prior to the beginning of the period (1994 and 2000). With one exception, the results are now somewhat clearer. Those for the gross margin and sales growth are essentially the same as in Table 2. None of the other income measures are very significantly related to R&D, although what relationship there is is positive. The growth in market capitalization is now quite positively related to R&D, as expected.

Table 3: Impact of lagged R&D intensity on various performance measures, 4 year averages

Dependent variable	1996-1999 LAD estimates		2002-2005 LAD estimates		1996-1999 Approximate impact of an increase in R&D†	2002-2005 Approximate impact of an increase in R&D†
Market cap growth	**1.02 (.21)***	**.81 (.26)***	**.43 (.12)***	**.41 (.13)***	6%	3%
Shareholder returns	**2.36 (.47)***	**2.04 (.64)***	.22 (.13)	.27 (.16)	14%	0
Gross margin percentage	**1.57 (.18)***	**1.33 (.19)***	**1.36 (.15)***	**1.27 (.15)***	9%	9%
Operating margin percentage	.16 (.07)	.08 (.09)	-.08 (.05)	-.03 (.06)	0	0
Gross margin growth	.24 (.12)	.19 (.18)	**.14 (.06)***	**.18 (.07)***	0	1.5%
Operating margin growth	.42 (.22)	.35 (.18)	.34 (.26)	.41 (.27)	3%	3%
Sales growth	**.28 (.07)***	**.23 (.08)***	**.15 (.04)***	**.17 (.05)***	1.5%	1.3%
2-digit industry dummies (25)	no	yes	no	yes		
N of observations (firms)	1427		1454			

Source: S&P Compustat annual industrial file, authors' computations.
Sample is manufacturing plus oil and gas, communications, wholesale trade, and business services (R&D-doing firms only)
R&D intensity = R&D to sales ratio in 1994 (first 2 columns) or 2000 (last 2 columns)
Gross margin = sales less cost of goods sold (gross of R&D)
Operating margin = operating income (net of R&D)
Percentages are relative to sales
Shareholder returns are holding period capital gains plus dividends per share
Market cap is the total market value of the firm, including long term debt
†These columns show the expected increase in the dependent variable when R&D intensity increases from the 25th percentile to the 75th percentile.

The surprising result is that shareholder returns are now very positively related to R&D during the first period, although still not at all related to R&D during the second period. What this means is that firms with high R&D intensity relative to their two-digit industry in 1994 experienced substantial positive returns between 1996 and 1999, but that firms with high R&D intensity in 2000 experienced no higher returns than other firms in 2002-2005. A likely explanation of this finding lies in the growth and then bursting of the dotcom bubble, which did impact a number of firms in various ICT sectors. It would be misleading without further evidence to draw strong conclusions from the finding, as transitory variations in returns to R&D over time are to be expected and indeed, have been observed during other periods (Hall 2007).

The last two columns of Table 3 show the expected impact of changes in R&D intensity for these firms. The R&D-to-sales ratio for our sample ranges from 0 to 100 per cent with a median of 1.2 per cent and an interquartile range of 7 per cent. In the table we show the impact for a firm whose R&D intensity moves from the 25th percentile to the 75th percentile of the distribution. Because all of the performance measures are effectively in per cent (either growth rates or shares), what is shown in these columns is the absolute change in the value. For example, increasing R&D from the first the third quartile implies that sales growth is higher by 1.5 per cent in both periods, and that the gross margin percentage is higher by 9 per cent.

Table 4 breaks down our sample of firms into those in the Information and Communication Technology sector and the other sectors, in order to probe a bit further the reasons for differences across the two periods. There are relatively few differences between these two sectors: the only significant ones are that the relationship between gross margin growth and R&D intensity is substantially lower in the ICT sector in both periods and that between operating margin growth and R&D intensity is lower in the second. Although the relationship between shareholder returns and R&D intensity fell substantially in ICT and much less in the non-ICT sector, the differences are not significant.

Our conclusion is that for the sample as a whole, the predictions of the simple theory outlined earlier are supported: gross margins are roughly proportional to R&D intensity, shareholder returns are not, and the growth rates of market capitalization, sales, gross margins, and operating margins are weakly related. Looking within sectors, we see some support for the idea that R&D intensity and performance have little relationship during the second period in ICT (as was argued by the BAH report), but that the relationship in non-ICT firms is the fairly positive. We want to emphasize that this kind of inconsistent result is to be expected, given the level of uncertainty when undertaking R&D.

3.2 Econometric approaches

The econometric measurement of the private returns to R&D is grounded in the same model used to measure the returns to other investments. R&D spending is thought of as a decision made today based on the firm's current set of assets and skills and its expectations about the future returns to that spending. There are essentially two methods available to measure returns: e*x post* evaluation, which looks at the output which resulted from the R&D investment input, and e*x ante* evaluation, which uses the firm's market value to infer the market's expectations about the returns to current and past R&D investments. We discuss each of these two approaches in the next two sections of the paper.

3.2.1 Production function

The framework used by Griliches (and a host of subsequent researchers) to estimate the productivity of R&D or the private returns to R&D relies on the usual Cobb-Douglas production function augmented to include an additional input that he called "knowledge" capital.[4] A survey of results obtained using this model is given by Mairesse and Mohnen (1990) and the econometric issues that arise in estimating production functions in general have been reviewed in Griliches and Mairesse (1997). This section of the paper presents the model and discusses the problems with using it to measure the rate of returns to R&D.

The Cobb-Douglas production function augmented with a knowledge capital term takes the followng (stylized) form:

$$Y = AL^{\alpha}C^{\beta}K^{\delta}e^{u} \tag{1}$$

where L is a measure of labor input, C is ordinary (tangible) capital, K is knowledge (intangible) capital, and u is a disturbance. To implement this equation for estimation using a panel of firms followed over time, take logarithms and write it using i to denote firms and t to denote time:

$$y_{it} = \eta_i + \lambda_t + \alpha l_{it} + \beta c_{it} + \gamma k_{it} + u_{it} \tag{2}$$

The lower case letters denote logarithms of the variables in the original model, η_i denotes a firm specific effect that is constant over time and λ_t denotes a time-specific effect that is constant across firms. The shock u_{it} and the firm effect η_i may possibly be correlated with the current (and future) input levels. In principle, both of these econometric problems can be solved by estimating with GMM on first differences of the equation, provided appropriate instruments are available (Blundell and Bond 1998).

Although equations (1) and (2) are usually labeled production functions, in the case of individual firms they are more properly called revenue production functions. That is, in the absence of firm-specific price deflators, the measure of output Y is the firm-level price multiplied by the quantity sold (or a sum of such terms in the usual case where there is more than one product). This fact implies that γ measures the joint contribution of R&D to productivity and to the prices charged by the firm (which could be declining if R&D makes the firm more efficient in a competitive market or increasing if R&D is primarily used to improve quality). But from the perspective of measuring private returns, this is not a problem, because either (cost reduction or product improvement) are outcomes that end up in thebottom line. Nevertheless, it is important that we not confuse these measures with *true* productivity measures, which remove the effects of R&D on price. The latter are the relevant concept for social welfare.

Implementing estimation using equation (2) requires construction of a measure of knowledge capital K. Beginning with the work conducted during the large NBER project on R&D, patents, and productivity, Griliches and his co-authors used a conventional declining balance formula for the construction of (real) K, by analogy with ordinary investment and capital:

$$K_{it} = (1-\delta)K_{i,t-1} + R_{it} \tag{3}$$

[4] Occasionally researcher have used a more complex form of the production function, such as the trans-log (e.g., Bernstein and Nadiri, 1986, 1989)

Although a variety of choices for the depreciation rate have been explored in the past, the choice makes little difference for estimation, and most researchers use the 15 per cent that Griliches had settled on in his work (see Hall and Mairesse 1995 for some experiments with different rates). It is easy to see why this might be the case: assume that R&D grows over a sufficiently long period at a constant (firm-specific) rate g_i and that the knowledge capital K depreciates at a firm-specific rate δ_i. Then one can show that

$$K_{it} \cong \frac{R_{it}}{\delta_i + g_i} \text{ or } \log K_{it} = \log R_{it} - \log(\delta_i + g_i) \tag{4}$$

where R denotes real R&D investment at time t and δ is a suitably chosen (private) depreciation rate.[5] As long as the growth rate and depreciation do not change very much within firm over time, they will be incorporated into the firm effect in equation (2), and the estimated elasticity of output with respect to either K or R will be the same, and that for K will not depend on the choice of depreciation rate.

However, although the elasticity of output with respect to R&D may not be affected by the choice of the depreciation rate, the same is not true of the rate of return derived from the elasticity. To see this, note that the gross and net rates of return to K are:

$$\rho^G \equiv \frac{\partial Y}{\partial K} = \gamma \frac{Y}{K^*} \text{ and } \rho = \gamma \frac{Y}{K^*} - \delta \tag{5}$$

Therefore the production function approach to measuring returns requires knowledge of δ both to compute the correct level of K and also to convert gross returns to net returns.

3.2.2 Market value

The second major approach to valuing the output of R&D investment considered in this paper is more forward-looking, in that it relies on the financial market's assessment of the value of the firm that has undertaken the investment. The focus is therefore on expected returns, rather than realized profits. This approach has its origins in the seminal work of Griliches (1981) and has been applied to data from a number of countries: US (Cockburn and Griliches 1987, Hall 1993a,b, Hall and Kim 1999, Chan et al. 2001), UK (Blundell et al. 1999, Bosworth et al. 2000, Toivanen et al. 2002), Australia (Bosworth and Rogers 2001), Europe (Hall and Oriani 2006), and Japan (Nagaoka 2006). Most of these studies have found a clear association between firm market value and R&D investment, controlling for other firm assets.

The justification for using firm market value as a proxy for R&D output value is the idea that although on average we might expect that the value of spending another dollar on R&D would be equal to that dollar, therefore allowing the use of R&D input as a measure of R&D

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[5] For future reference, note also that under the assumption of constant depreciation at the firm level, equation (4) implies that the "true" R&D capital K^* (K computed using correct economic depreciation) is given by the equation $K_{it}^* = K_{it} \frac{\delta_i + g_i}{\delta_i^0 + g_i}$, where δ_i^0 is the depreciation rate used to construct the measured K (usually 15 per cent).

value, there are a number of factors that intervene to make this a rather poor measure: first and foremost is the risk of any R&D program, which leads to considerable dispersion in the value of its output ex post even if all R&D input is valued at cost ex ante. In addition, the behavior of competitors in the product market or changes in the prices of inputs or the macro-economy will influence the realized value of an R&D project. At the least, shadow price for R&D output derived from a value regression incorporates all the information currently available about the likely success or failure of the sunk R&D investments in generating future profits for the firm.

Griliches' 1981 approach to the problem of valuing R&D output was grounded in the theory of hedonic prices: the central idea was that a firm could be considered as a bundle of assets, both tangible (physical capital and inventories), and intangible (R&D assets or knowledge stock, reputation, and so forth). To compute the shadow price of an asset at any point in time, one could therefore regress the prices or values of a set of firms on their portfolio of assets of different types, and interpret the slope coefficient of any particular type of asset as its marginal shadow value. When implementing this idea, most researchers have followed Griliches original article and used a first order approximation to the value of the assets, sometimes in logarithmic (Cobb-Douglas) form, but usually in a simple additive specification. The equation estimated looks like this:

$$\log V_{it} = \log\left[\alpha_t p_{it}^I A_{it} + \gamma_t p_{it}^R K_{it}\right] + \varepsilon_{it}$$

$$\text{or} \quad \log Q_{it} \equiv \log\left(V_{it} / p_{it}^I A_{it}\right) = \log \alpha_t + \log\left[1 + \frac{\gamma_t}{\alpha_t}\left(\frac{p_{it}^R K_{it}}{p_{it}^I A_{it}}\right)\right] + \varepsilon_{it}$$

where V_{it} denotes the market value of firm *i* at time *t*, $p^I_{it}A_{it}$ denotes its (nominal) tangible assets, and pRitKit denotes the (nominal) R&D or knowledge asset. The logarithmic form of the equation is often simplified using the $\log(1+\varepsilon) \approx \varepsilon$ approximation to linearize the model.

This methodology allows the measurement of the shadow value of R&D, provided one can construct a measure of the R&D asset. However, nothing in the theory of hedonics suggests that the measured shadow value of R&D capital should be constant across time, or even across industries. In fact, our interest in the exercise is driven by the fact that it will not be constant. In practice, both coefficients (α_t and γ_t) tend to fluctuate a great deal over time and it is not clear how to interpret the fluctuations. αt represents the overall premium or discount in the market for ordinary capital assets and γ_t the relative premium or discount for knowledge (R&D) assets.

When implementing the above methodology, there is an obvious problem in constructing the asset associated with R&D, namely, how should one add up past R&D investments in order to construct this measure? Usually a declining balance formula [equation (3)] is used, with δ set equal to 15 per cent. Although this value may be appropriate on average, in many individual firms and industries, depreciation of past R&D stock in any given year can deviate considerably from 15 per cent and this deviation will show up in the estimated value of γt. Conceptually, the correct measure of the R&D asset in the denominator (the book value) is its replacement cost. But what does this mean? In the case of a machine or tangible asset, the meaning is obvious – it is the cost of acquiring one just like it or of manufacturing a new one. But replacing the knowledge stock created by R&D is quite a different matter: it may be essentially free, if the stock is simply to be duplicated within the firm, that is, spread over more output. It may be low cost, if it is simply to be imitated or rediscovered. It may be high cost, if the corresponding invention is patented and another firm wishes to enter the market and reproduce it, either by taking out a license, or by inventing around the patent.

In effect, the knowledge stock that matters for the firm is that which generates privately appropriable returns. From the perspective of *Q* theory, when the depreciation of knowledge assets is high and therefore *Q* is low, either the book value of the knowledge asset should have been lower (implying that *K* should have been constructed using a higher δ) or its market value should be lower (implying that the estimated γ_t will be lower). Although time-varying (and endogenous) depreciation rates can also be a property of ordinary tangible assets, in fact they are much less common because many of these assets trade on a second hand market, which implies that their "market" value is much less volatile and also that it may not vary as much across industries. The problem with the R&D asset variable is that it is often quite specialized and that once past investment has been written off by the emergence of a better competing product, it has little residual private value. Put simply, the lack of data from a secondhand market for R&D assets means that an estimate of the market-to-book value ratio is not enough to inform us about market value or book value separately without further assumptions.

This aspect of R&D capital also implies that valuation of the asset it creates can be highly variable across firms and time. More importantly, it implies that it is not plausible to try to incorporate "true" economic depreciation into the book estimate of R&D capital. It would be far better to try to estimate depreciation from the valuation itself. However, there is a difficulty, because we will need some kind of depreciation to construct a stock from past R&D flows. Simply adding the flows up is not attractive because it places too much weight on R&D done long ago and because the stock then becomes quite sensitive to the number of time periods over which the firm has been observed. So the best we can do is what was originally done by Griliches (1981) and followed by his successors: use a plausible depreciation rate such as 15 per cent and then try to infer the true value from the estimated shadow value of the R&D.

3.3 Depreciation of R&D

The underlying assumption behind the econometric measurement of the returns to R&D is that R&D creates a firm-level stock of knowledge that yields returns into the future. Constructing such a stock from a string of R&D investments requires depreciating the past stock in some way. Therefore, estimating the private returns to R&D using either a revenue production function (flow method) or market value equation (present discounted value of future flows method) requires one to take a position on the magnitude of this depreciation rate. Both confront the same problem: computing the net rate of return or interpreting the shadow value of the R&D stock requires an assumption about the private depreciation or obsolescence of the asset generated by the R&D investments.

But what is this depreciation rate? From the perspective of a firm, it is the rate at which the private returns to past R&D investments decline if no further R&D is undertaken. Determining thus rate is difficult if not impossible, for at least two reasons. First, the appropriate depreciation rate is endogenous to the firm's own behavior and that of its competitors, in addition to depending to some extent on the progress of public research and science. Therefore there is no reason to assume that it is constant over time or across firms, although it will usually (but not always) change slowly in the time dimension. Second, identifying the depreciation rate independently from the return to R&D requires determination of the lag structure of R&D in generating returns. But years of experience with the specification of production functions, market value equations, or even patent production functions (Hall, Griliches, and Hausman 1989) has shown convincingly that this is extremely difficult, because of the lack of appropriate natural experiments. That is, in practice R&D does not vary much over time within firm, so that trying to identify more than one coefficient of R&D is problematic and leads to very unstable results. In the data used in Hall (2007), which is a fairly heterogeneous time series-cross section of firms, the variance of R&D growth rates within firms is only about 4 per cent of the variance of the levels. In addition, as has been observed by earlier authors (e.g., Hall and Mairesse 2005), the log R&D series exhibits close to random walk behavior.[6] The implication of these properties is that including more than one linear function of the (log) R&D series in an equation will be a futile exercise.

[6] The correlogram for the first three lags of the data used here is (0.99, 0.97. 0.96) and the partial correlogram is (0.99, 0.00, 0.00)

Figure 1

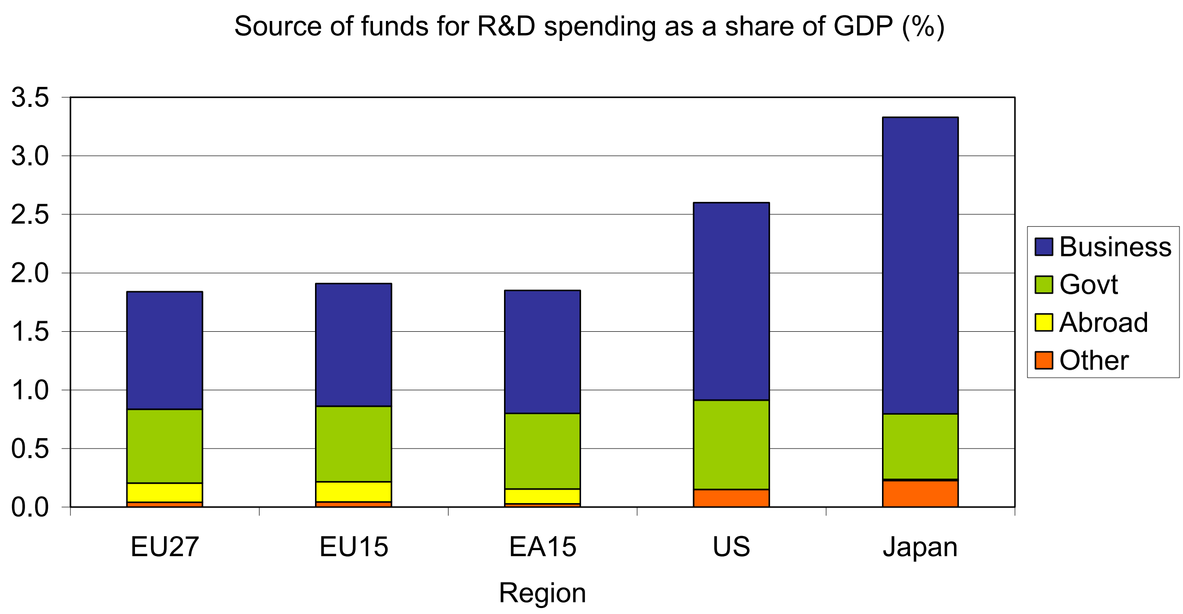
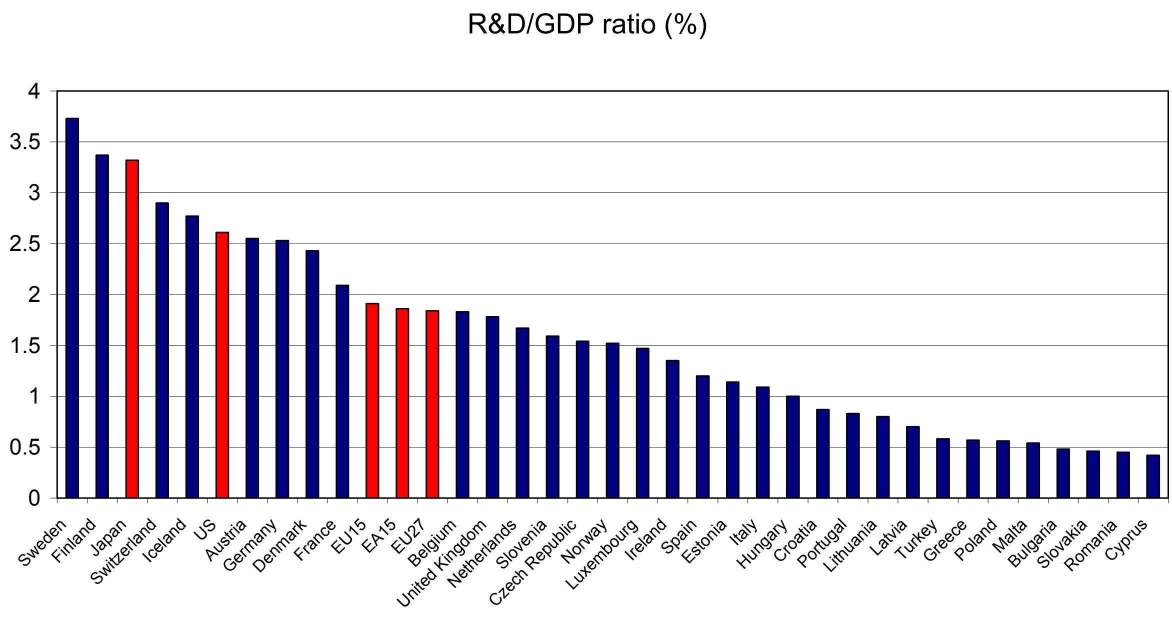


Figure 2



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