College of Management of Technology

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

FORAY Dominique, HALL Bronwyn H., MAIRESSE Jacques

Pitfalls in Estimating the Returns to Corporate R&D Using Accounting Data

CEMI; UC Berkeley, Uni. Maastricht, NBER, IFS;
CREST-ENSAE, Uni. Maastricht, NBER,

CDM Working Papers Series

Sept. 2007 **CEMI-WORKINGPAPER-2007-003**

Submission to the First European Conference on Knowledge for Growth, October 8-9, 2007

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Challenged by the results and recommendations of the BAH report, in this paper we assess some of the pitfalls to be avoided in using accounting data to estimate corporate R&D returns and illustrate a proper use of such data. We first offer a critique of important aspects of the methodology and of some of the main conclusions in the BAH report. Using similar data and a comparable approach, we then present our own estimates of the impact of R&D on the growth, profitability, and market value of public corporations, and contrast our interpretations and conclusions with that of the report.

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Dominique Foray, Bronwyn H. Hall, and Jacques Mairesse[1]

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Our critique takes three parts: first, the data normally available in the financial accounts of firms is not well-suited to assessing the returns to R&D. Such expenditure is an investment in the future, but is generally treated by accountants as immediately expensable. There are also a number of issues in the interpretation of results based on gross versus net profits and in the robustness of estimates to the presence of extreme outliers in the data. Second, we discuss the difficulties arising from the fact that the theory that posits a relationship between R&D investment and subsequent returns is difficult to test if all firms make the "correct" investment decisions in an expected value sense. In the absence of substantial out of equilibrium behavior, we do not expect supranormal or subnormal returns to R&D. Third and last, there are a number of statistical and interpretive problems in drawing conclusions from the results of regressing output indicators on R&D. Chief among these is the confusion of low explanatory power with lack of impact -- in the presence of highly variable outcomes, the two are not the same.

We then turn to our own analysis. Using data on approximately 1500 large public firms in R&D-intensive sectors from a number of OECD countries, we outline the underlying model that is used to measure returns to these kinds of investment, touching briefly on the measurement of depreciation that is needed to go from gross to net. We show that there are indeed strong relationships between investment in R&D and the market value and subsequent growth of firms on average. The relationship between R&D and current profitability is more

[1] EPFL; UC Berkeley, University of Maastricht, NBER, and IFS; CREST-ENSAE, University of Maastricht, and NBER.

variable, as one would expect given our earlier discussion of the pitfalls in using accounting data. Our results thus confirm the average productivity and economic profitability of R&D investment, in spite of their expected intrinsic uncertainty, both across firms and across time.

The paper concludes with a review and best practice summary for the problem of evaluating R&D performance as well as the performance of other innovation investments using accounting data, which is often all that is available to analysts and policy makers.

Introduction

Does R&D have an impact on firm growth, profits, and value? Anyone reading the recent report by Booz-Allen-Hamilton (2006, the "BAH Report") might conclude the contrary. This report seems to offer support to skeptics, those who believe that it is possible to compete successfully in the modern economy without investment in R&D and that the share of spending devoted to research has no relationship to the economic performance of an enterprise (or a country).

But this conclusion would not be warranted by the vast bulk of evidence in the economic and business management literature. Although it is certainly true that firm success is highly unpredictable and depends on many factors other than R&D investment and patenting, it is nevertheless the case that there is a strong relationship between these activities and the growth and profitability of firms, and it is extremely misleading to argue that there is not.

In this brief we offer a critique of the analysis in the BAH report, bringing the considerable body of evidence in the research literature to bear. We discuss the ways in which BAH use their evidence to draw misleading conclusions which they then translate into recommendations that if they were followed, would leave most firms worse off than they are now.

Perceptive readers and analysts may ask why we focus on the BAH report, as they will see immediately the weakness in its recommendations and conclusions. Our motivation is that the report has had some impact in business and policy communities via its appearance in summarized form in newspapers, business magazines and on the WEB. While we have nothing against "a report having a big impact," if it were evidence-based and did not oversimplify the issues, we are concerned about the wide and rapid dissemination of a message relayed and amplified by well-read newspapers, which ultimately turns out to be largely wrong and misleading. There is risk that many readers will be at a minimum confused and at worst will take away mostly what is written in bold or italics: "*firms that spend less on R&D than their competitors have superior financial performance,"*[2] or *"Innovation champions show a ratio of R&D expenditures to sales that is below the average,"*[3] or "*All these companies spend less than their competitors on research and development, yet outpace their industries across a wide range of performance metrics.*"[4]

[2] The title of the web page presenting the report.: www.boozallen.com/capabilities/services_article/18054973

[3] *Le Temps*, 8 December 2006.

[4] www.strategy-business.com/press/article/0645?gko=c3340-1876-20606671

We would caution such readers that the BAH report completely ignores the previous literature on the returns to R&D, what has been learned from this research, and what the results mean for a firm. If, as been shown long since by economic researchers, the uncertainty inherent in the processes of research and innovation imply an equivalent uncertainty in the profitability of these investment at the level of an individual firm, there is no doubt that such profitability – when it is measured at the aggregate level or for the whole society - has been shown to be as high or higher than the profitability of investment in the physical capital. Econometricians are the first to recognize the great difficulties of measuring the output of the R&D at the firm level and of the interpretation of the results – in particular, difficulties in related to the measurement of the prices in the case of the new products,[5] or to the question of the lag between investment in R&D and its contribution to performance.

Even if taken separately each study seems fragile, the fact that their results agree to a great extent makes the conclusions more convincing. Such an intellectual achievement, to which scholars like Griliches, Mansfield, and Scherer have contributed, cannot be simply discarded without more careful study than has been presented in this report.

The BAH report uses simplistic tools, essentially "cross-sectional" correlations, lacking even controls for industrial sector and country to say nothing of other relevant variables such as firm size and physical capital. It resorts to ex-post endogenous grouping of bad-performing-high R&D firms versus high-performing low R&D firms. It interprets a low correlation value as being economically and statistically insignificant, which is not always the case. In addition, analyzing only R&D firms is a potential source of selectivity bias, which is not even alluded to in the Report.[6] What about those firms that do no R&D? Do they perform better or worse than the firms in the sample? In short, the analysis confuses a group of selected trees with both the forest as a whole (the overall positive impact of R&D) and with each individual tree (the huge heterogeneity, which is to be expected at the micro economic level).

The report misinterprets even its own results. Assume that the sample consists of a number of firms, each of which is pursuing an optimal R&D investment strategy, but under considerable uncertainty about the market, the competition, and future prices. Entry into this activity is not restricted, so on average we would expect the risk-adjusted returns to R&D to be the same as the returns to any other investment activity. What are the implications of these assumptions? First, if R&D is expensed and is not fluctuating a great deal over time within firm, we would not expect to observe much of a correlation between profits and R&D, because on average the firms get what they pay for and do not earn supranormal returns to R&D.[7] 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 imply that firms should not spend on R&D, simply that if all firms pursue what appears to them to be a good policy, we would not expect to see a strong relationship.

[5] When price measurement does not account for the quality improvement from R&D, one obtains an undervaluation of the contribution of R&D to growth. During the past quarter century, this has been an especially severe problem for data from the ICT sector.

[6] For a discussion of the misleading results on firm performance that can be introduced by selectivity bias, see Denrell (HBR 2005).

[7] In making this argument, we assume (as do BAH, in effect) that R&D is not highly variable so that current spending can be used as a proxy for the capital created by R&D, which is the appropriate concept if returns are intertemporal.

A second conclusion from this argument is that we would expect profits gross of R&D to be correlated with R&D, but that is a simple accounting correlation. Finally, we do expect market capitalization to be related to the level of R&D spending, under the assumption that it creates an intangible asset that yields returns into the future. With these observations in mind, let us look at the performance screens used in the report.

The report uses seven performance screens: sales growth, gross profit to sales ratio, gross profit growth, operating income to sales ratio, operating income growth, market cap, and shareholder returns. For subsequent analysis, it is important to understand exactly how these performance indicators are defined. Gross profit is sales less the cost of goods sold, and is therefore gross of R&D expenditure. As indicated above, this implies that there will be simple accounting correlation between the gross profit to sales ratio and the R&D to sales ratio. Operating income is net of R&D expenditure and we do not expect much if any correlation between R&D intensity and the income to sales ratio if the firms are behaving in a profit-maximizing way.

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 any intangible assets, market value will be correlated with R&D, once we control for the book value of the tangible assets. Thus the correct analysis of the relationship between market cap and R&D looks at the relationship between the total market-to-book ratio and a measure of R&D capital (as a proxy for knowledge-related intangibles) rather than focusing only on market capitalization.

Finally, the usual efficient markets hypothesis tells us that there should be little relationship between (lagged) R&D ot 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 has been known for some time (see Pakes 1984 and Griliches et al 1991). It does not mean that we will not experience periods or episodes where R&D sytematically 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.

Using data on large publicly traded US firmst from Compustat, we looked at the relationship between these seven performance measures and lagged R&D intensity to examine the findings reported by BAH more carefully and systematically. The first thing to note is that large databases of firm accounting data frequently contain errors and other data problems that can lead to misleading conclusions if the data are not cleaned and if nonrobust estimation methods are used. It is usually not feasible to manually correct the numbers, because the typical database size is on the order of one million numbers. Therefore two approaches are commonly used: ordinary least squares regression with outliers removed from the data or median regression, which is robust to the presence of outliers in the dependent variable. We have used both in this study, after cleaning the data first for the most egregious outliers (stock returns greater than 10,000 per cent, and so forth). We refer the reader to the Appendix A for details and to Appendix B for a comparison of trimmed OLS estimation to LAD estimation using period 2000-2005 data.

Table 1 shows the results of our estimation of the following simple model:

$$y_{it} = \beta r_{it} + \lambda_t + \delta_j + \varepsilon_{it} \qquad (0.1)$$

y is one of the seven performance measures, *r* is the R&D to sales ratio lagged two years earlier to avoid any simultaneity bias, the λs are time (year) means, and the δs are industry means (included in the second columns). That is, we control for the average performance in each year and two digit industry. We estimated the model for two time periods: the 4 years 2002-2005 and the 4 years 1996-1999, 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.

Our discussion above had two clear predictions of a relationship, which are confirmed by Table 1. First, the market to book ratio is highly related to R&D intensity, with a coefficient that implies that the market to book ratio (Tobin's *q*) rises by anywhere from 0.1 to 0.2 for every one per cent rise in R&D intensity. Second, gross income to sales is correlated one for one with the R&D to sales ratio, as we would expect given that it is gross of R&D. Firms that do more R&D have higher gross income to pay for it – no surprise there.

With the exception of sales growth, which is somewhat surprisingly robustly related to past R&D intensity, the remainder of the table is more equivocal, as predicted. Shareholder returns are clearly unrelated to lagged R&D in either period. Operating income is positively related to past R&D in the first period but not the second, whereas the growth in operating income is strongly related to past R&D in the second period and much more weakly in the first. Because there is no reason to expect stable relationships between R&D and these measures, these results are not as surprising as they appear to be. The most interesting result is the relationship between past R&D intensity and contemporary sales growth, which translates into 0.2 per cent more sales growth per annum from a one time increase of R&D intensity of one per cent two years prior.

Table 2 looks at the same relationship in a slightly different way, to focus on more long term relationships. 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 Tobin's q, the gross margin, and sales growth are the same as in Table 1. None of the other income measures are significantly related to R&D, as expected. However, shareholder returns are now very positively related to R&D in 1994, and not at all to R&D in 2000. 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 some firms in other sectors than software/web. 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).

Misleading recommendations

The BAH report mixes the incorrect conclusions obtained from an uninformed and simplistic analysis with some common sense advice (such as the French saying " il vaut mieux etre riche et bien portant que pauvre et malade" or if you prefer "riche et intelligent que ..." . In English, "It is better to be rich and healthy than poor and sick.") We can give here two or

three examples out of the report; such as: it is better to be good (lucky) at doing R&D than bad (unlucky) at it; or ”innovation must be achieved by different departments and business units within the same organization working in parallel rather than in isolation…….it also means looking outside your organization to partners, suppliers and customers for new and innovative ideas.” (BAH 2006, p. 61)

The report conveys the idea that you can "free ride" on R&D done by others, which even at the firm level and even in the short run is unrealistic, and more so at the industry and economy level and in the long run. Firms need to have R&D and innovative activities themselves in order to appropriate efficiently the benefits of other firms' R&D and/or public R&D; and in a world of strong intellectual property rights they also have to buy the knowledge from other firms' R&D or cooperate with them in their R&D activities. It cannot be expected that all R&D spillovers will come from public R&D activities only, freely and in a long sustained way, in all fields and in an increasingly competitive and globalised world economy.

Another claim is that the lower R&D-to-sales ratio of larger companies relative to smaller is advantageous (BAH 2006, pp. 54-55). But this is comparing apples to oranges: smaller companies tend to be those specializing in the innovative end of the value chain (such as chip design in semiconductors) and will perforce have larger R&D input than large firms, which are often capital-intensive and specialize more in other activities that have scale economies. The question of the relationship of R&D, size, and returns may be of interest, but it cannot be asked in isolation without taking account of other aspects of the firms’s production function.

It is also the case that more than ever, private and public research constitute the constraining “point de passage” for the resolution of the great systematic problems of our time: those of energy and environment in a growth economy; those which relate to the future management of our health systems; those which treat the development of less-developed countries and the response to future demographic shocks, etc. For this reason alone, it might be hoped that out of this report economic decision makers themselves and public opinion do not retain only such ultra-simplistic messages. That would be a shame in the context where it is ever more important that discussions about R&D and knowledge ought to consider the idea of social returns along side that of private returns.

Table 1

Impact of lagged R&D intensity on various performance measures (LAD estimates)

Dependent variable	1994-1999		2000-2005	
Tobin's q (market to book)	**21.5 (1.7)**	**17.0 (1.3)**	**13.19 (.78)**	**9.32 (1.09)**
Shareholder returns	.04 (.15)	.06 (.17)	-.29 (.10)	-.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 (.02)**	-.06 (.03)
Gross margin growth	.14 (.07)	.16 (.08)	**.17 (.05)**	**.19 (.06)**
Operating margin growth	.34 (.15)	.37 (.16)	**1.10 (.14)**	**1.05 (.14)**
Sales growth	**.30 (.08)**	.21 (.08)	**.14 (.04)**	**.16 (.04)**
Year dummies	yes	yes	yes	yes
2-digit industry dummies (25)	no	yes	no	yes
Number of observations (firms)	5684 (1421)		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)

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

Tobin's q is the ratio of total market value to the book value of tangible assets

Table 2

Impact of lagged R&D intensity on various performance measures (LAD estimates using 4-year averages)

	Period			
Dependent variable	**1994-1999**		**2000-2005**	
Tobin's q (market to book)	**27.9 (3.0)**	**20.9 (3.5)**	**14.2 (1.8)**	**10.0 (1.9)**
Shareholder returns	**2.36 (.47)**	**2.04 (.64)**	.22 (.15)	.27 (.16)
Gross margin percentage	**1.57 (.18)**	**1.33 (.19)**	**1.36 (.18)**	**1.27 (.14)**
Operating margin percentage	.16 (.07)	.08 (.09)	-.08 (.04)	-.03 (.05)
Gross margin growth	.24 (.12)	.19 (.18)	.14 (.05)	.18 (.07)
Operating margin growth	.42 (.22)	.35 (.18)	.34 (.25)	.41 (.27)
Sales growth	**.28 (.07)**	**.23 (.08)**	**.15 (.04)**	**.17 (.04)**
2-digit industry dummies (25)	no	yes	no	yes
Number of observations (firms)	1421		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

Tobin's q is the ratio of total market value to the book value of tangible assets

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Appendix A: Data and sample

The sample of firms comes from the 2005 Standard and Poor Compustat Annual Industrial file. Domestic US R&D-peforming firms in SICs 13 (oil and gas), 20-39 (manufacturing), 48 (communications), 50-51 (wholesale trade), and 73 (business services including software) were selected. These are the only SICs with significant amounts of R&D. The distribution of the firms across industry is shown in Table A1. Almost half of the firms are in machinery including computer equipment, electrical equipment, scientific instruments, communications, and software, which can be loosely termed the ICT sector. The reminder are spread throughout manufacturing, with fewer than 10 per cent outside manufacturing.

As preliminary screening to remove clear outliers and observations with incorrectly entered data, the following tests were applied:

- No missing values
- More than 100 employees
- R&D to sales less than 100 per cent
- Gross income positive (i.e., sales greater than the cost of goods sold)
- Operating income to sales greater than -100%
- Growth rates for gross income, operating income, sales, and equity less than 10,000 per cent in absolute value
- Tobin's q (market to book) less than 100
- A full 6 years of data during the relevant period (1994-1999 or 2000-2005)

The net result of these screens reduced the number of firms in 2005 from about 2400 to 1450; this is the sample whose sectoral distribution is shown in Table A1. All these data were used in the LAD (least absolute deviations) regression. Additional screens were applied to choose the OLS sample:

- Growth rates rates for gross income, operating income, sales, and equity less than 150 per cent in absolute value
- Tobin's q (market to book) less than 10

Together, these screens reduced the sample form 1450 firms to 1402 firms in the 2000-2005 sample.

Table A1: SIC distribution

SIC	Industry name	# firms	Share
13	Oil and gas extraction	51	3.5%
20	Food and Kindred Products	52	3.6%
21	Tobacco Products	4	0.3%
22	Textile Mill Products	7	0.5%
23	Apparel & Other Finished Prods	26	1.8%
24	Lumber and Wood Prods, ex Furn	8	0.6%
25	Furniture and Fixtures	19	1.3%
26	Paper and Allied Products	31	2.1%
27	Printing,Publishing & Allied inds	34	2.3%
28	Chemicals & Allied Products	128	8.8%
29	Petroleum Refining & Related Inds	18	1.2%
30	Rubber & Misc Plastics Prods	25	1.7%
31	Leather and Leather Products	14	1.0%
32	Stone,Clay,Glass,Concrete Prods	18	1.2%
33	Primary Metal Industries	33	2.3%
34	Fabr Metal,ex Mach,Trans Eq	39	2.7%
35	Indl, Comml Mach,Computer Eq	145	10.0%
36	Electrical Eq, ex Computers	181	12.5%
37	Transportation Equipment	55	3.8%
38	Meas Inst; Photo Goods; Watches	146	10.1%
39	Misc Manufacturng Industries	26	1.8%
48	Communications	75	5.2%
50	Durable Goods - wholesale	51	3.5%
51	Nondurable Goods - wholesale	26	1.8%
73	Business services	238	16.4%
	Total in 2005	**1450**	

Table B1

Impact of lagged R&D intensity on various performance measures (2002-2005)

	Method of estimation			
Dependent variable	**OLS***		**LAD****	
Tobin's q (market to book)	**7.88 (.70)**	**5.23 (.74)**	**13.19 (.78)**	**9.32 (1.09)**
Shareholder returns	**-.60 (.08)**	**-.44 (.09)**	-.29 (.10)	-.17(.11)
Gross margin percentage	**1.31 (.07)**	**1.27 (.08)**	**1.45 (.05)**	**1.34 (.06)**
Operating margin percentage	**-.35 (.07)**	**-.26 (.09)**	**-.09 (.02)**	-.06 (.03)
Gross margin growth	-.06 (.06)	-.00 (.07)	**.17 (.05)**	**.19 (.06)**
Operating margin growth	.09 (.12)	.13 (.14)	**1.10 (.14)**	**1.05 (.14)**
Sales growth	-.04 (.05)	.01 (.06)	**.14 (.04)**	**.16 (.04)**
Year dummies	yes	yes	yes	yes
2-digit industry dummies (25)	no	yes	no	yes

*OLS with all growth rate variables trimmed at 150%, q<10; 4728 observations on 1402 firms; clustered standard errors

**Median quantile regression; 5800 observations on 1450 firms; bootstrap standard errors

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, 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

Tobin's q is the ratio of total market value to the book value of tangible assets

Table B2

Impact of lagged R&D intensity on various performance measures (LAD estimates using 4-year averages 2002-2005)

	Method of estimation			
Dependent variable	**OLS***		**LAD****	
Tobin's q (market to book)	**8.7 (1.2)**	**6.3 (1.1)**	**14.2 (1.8)**	**10.0 (1.9)**
Shareholder returns	.05 (.15)	.11 (.17)	.22 (.15)	.27 (.16)
Gross margin percentage	**1.15 (.13)**	**1.07 (.14)**	**1.36 (.18)**	**1.27 (.14)**
Operating margin percentage	-.17 (.09)	-.08 (.09)	-.08 (.04)	-.03 (.05)
Gross margin growth	.12 (.09)	**.22 (.09)**	.14 (.05)	.18 (.07)
Operating margin growth	.14 (.20)	.23 (.22)	.34 (.25)	.41 (.27)
Sales growth	.06 (.06)	.12 (.07)	**.15 (.04)**	**.17 (.04)**
2-digit industry dummies (25)	no	yes	no	yes

*Ordinary least squares with all growth rate variables trimmed at 150%, q<10; 1203 firm observations

** Least absolute deviations (median) regression with 1454 firm observations; bootstrap standard errors

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 the year 2000

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

Tobin's q is the ratio of total market value to the book value of tangible assets