DO STOCK MARKETS VALUE INNOVATION?

A META-ANALYSIS

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ABSTRACT

We analyze whether stock markets value innovation by performing a meta-analysis of the empirical literature linking R&D investments and firms' market value. While there is an increasing interest in the attention paid by financial markets to firm level innovation activities, the theoretical debate and the empirical results presented by a growing number of studies performed within different disciplinary domains still oscillate between markets myopia and markets efficiency. We contribute to resolve this indecision applying Hunter and Schmidt (1990) correction procedures on existing studies estimating the impact of different corporate assets on the market value of the firm. After correcting for random sources of variations and possible problems with the reliability of the independent and the dependent variables, we show that the R&D-market value relationship is consistently positive and that the market values one currency unit invested in R&D activities as much or more than one currency unity invested in tangible assets. Moreover, we use a fully factorial regression model to assess the magnitude of the reported coefficients against a set of sample specific and design specific variables. Our results show that, when other intangible assets are considered, the market valuation of firms' R&D investments generally lowers. Moreover, whereas adding industry-level controls seems to better specify the relationship between R&D investment and market value, firm-level variables do not substantially affect the results. Implications for research and practice are presented and discussed.

INTRODUCTION

Economics and strategy literature has extensively recognized that innovation represents the engine of economic growth for the firm and the economic system in general. In spite of such attention to the role technological innovation, however, we are still lacking adequate schemes for its measurement and valuation (Lev, 2001). A main problem is that expected results from R&D investments or other innovation activities are subject to a very high degree of uncertainty (Mansfield et al., 1977). As a consequence, it is often hard to predict how investments in innovation will impact on firm value as determined by stock markets (Oriani and Sobrero, 2002). Clearly, this shortcoming is relevant to critical decisions of managers seeking shareholder wealth maximization, such as resource allocation to corporate innovative activities or the recourse to capital markets for R&D financing.

Indeed, some interesting indications to understand how stock markets evaluate firms' innovation activities can be drawn from a broad stream of empirical literature in the fields of industrial organization and financial economics that has investigated the relationship between several firm-level measures of technological innovation and stock market indicators. Different approaches have been adopted. Some studies have analyzed the relationship between the stock of R&D investments or patents and a firm's market value at a given time (Griliches 1981; Jaffe 1986; Hall 1993a, 1993b, among others), whereas others have observed the long-run stock returns associated with R&D-based measures (Pakes, 1985; Lev and Sougiannis, 1996; Chan et al. 2001, among others) or short-term market value adjustments following corporate announcements on R&D activity (Chan et al. 1990; Woolridge and Snow 1990, among others).

However, the interpretation of these studies for the strategic management of innovation is complicated by several difficulties. First, the concept of innovation itself is very broad and hard to precisely define from an empirical point of view (Griliches, 1995). Consequently, the abovementioned studies have adopted different variables to measure this construct. Second, it is not ascertained if the market valuation fully reflects future benefits from innovation. In this respect, some authors have found evidence for a systematic underestimation of firms' R&D investments by the stock market (Lev and Sougiannis 1996, 1999; Chan et al., 2001). Third, the application of different methodologies and research designs to the problem of the market value of innovation has led to results that not always coincide. In fact, even though all analyses generally show a positive valuation of innovation, this has proved to be very erratic. In particular, several studies have shown how the market valuation of R&D investments is volatile over time (Lustgarten and Thomadakis, 1987; Hall, 1993a, 1993b) and across industries (Jaffe, 1986; Cockburn and Griliches, 1988) or countries (Hall and Oriani, 2004).

Considering the amount of available empirical evidence, the practical and theoretical importance of the subject, and the evolution of financial markets all over the world, a formal cumulative analysis of the results can offer several insights. First, it can give an informative assessment of the level of agreement or not among the studies conducted so far. Second, it can partial out from the various estimates the effect, if any, of several measurement problems usually discussed. Third, it can test whether the variance among the results is random or due to some moderating effect. Fourth, it can assess whether and how different choices related to the research design, such as sample characteristics or the inclusion of control variables accounting for alternative hypotheses, affect the empirical estimate of the market value of innovation. Finally, it can offer specific and stimulating insights not only to scholars interested in continuing this line of research, but also to researchers in other fields of study, by suggesting unexplored paths and raising possible inconsistencies, while avoiding inefficient replications on findings already robust and systematic.

To move in this direction, we conducted a meta-analysis of the empirical literature linking R&D investments and firm market value. We assessed the magnitude of the reported coefficients against three broad classes of potential moderating factors: the reliability of the independent and the dependent variables; the inclusion of firm- and industry-level control variables; sample characteristics. Applying Hunter and Schmidt (1990) correction procedures on all published studies using empirical models to estimate the impact of different corporate assets on the market value of the firm we show that the relationship between R&D-based measures of innovation and firm value is consistently positive. Significant differences in the size of the effect emerge, however, depending on the different variables considered in the meta-analysis.

The paper is organized as follows. In the next section we will discuss the main theoretical and empirical issues of the models reviewed in the meta-analysis. In the third section the meta-analytic procedure is described, with specific attention to the selection of the studies, the data coding and the statistical tests. In the fourth section the results of the meta-analysis are presented, while in the final section the main implications for future research are discussed.

THEORETICAL BACKGROUND

The study of the relationship between innovation and firm market value is characterized by some specific problems related to the research designs adopted so far. Such problems are strictly connected with the resolution of wider theoretical issues. The use of market-based measures of performance clearly requires some assumptions on the way financial markets work. In particular, it builds on the statement of stock market informational efficiency, implying that security prices fully

reflect all available information (Fama, 1970). The assumption of market efficiency has several important implications for our analysis. First, the market capitalization of the firm can be considered a reasonable proxy of its value. Second, it should change if and only if the stock market receives new general or firm-specific information that modifies investors' expectations about the cash flows form current and future assets (Pakes, 1985; Woolridge and Snow, 1990).

In this section we start by presenting the different classes of models used by empirical studies to test these theoretical assumptions, focusing in particular on the subset whose evidence will be cumulated in the empirical section. This is represented by the studies that analyze the relationship between different measures of technological innovation and firm market value at a given time. We then discuss the theoretical reasoning behind alternative measurement choices of technological innovation and the consequences for our meta-analysis.

Models

A large group of studies has focused on the analysis of the relationship between different measures of innovation and firm market value at a given moment in time. These studies were particularly appropriate for a meta-analysis because of the large amount of empirical evidences available and the high comparability of the results obtained. Therefore, this is the stream of literature we decided to concentrate on.[1]

These studies implicitly or explicitly assume that the firm is evaluated by the stock market as a bundle of tangible and intangible assets (Griliches, 1981). In this perspective, firms' innovation activities create a stock of technological assets that should be consistently evaluated by the stock market. In equilibrium, the market valuation of any asset results from the interaction between firms'

[1] Other alternative research designs have been adopted in literature. A first group has examined the relationship between R&D investments and the contemporaneous or subsequent stock returns, trying to verify whether the stock market correctly evaluates corporate innovation activities (Lev and Sougiannis 1996, 1999; Chan et al., 2001). A second group is based on the event study methodology relating corporate announcements on R&D programs with the stock returns in the days preceding or following the announcement (e.g. Chan et al., 1990; Woolridge and Snow, 1990). However, both the groups present a lower number of studies than the one we selected. Moreover, the studies of these groups are scarcely comparable because of the differences in the empirical methods and the measures of innovation adopted.

demand for investment and the market supply of capital for that specific asset (Hall, 1993b). It is then possible to represent the market value V of firm i at time t as a function of it assets:

$$V_{it} = V\,(A_{it}, K_{it}, \Sigma I_{\mathrm{it}}) \qquad [1]$$

where A_{it} is the book value of tangible assets, K_{it} is the replacement value of a firm's technological assets and ΣI_{it} is a set of control variables, including the replacement value of the other intangible assets.

If single assets are purely additive, it is possible to express the market value of a firm as a multiple of its assets. Two main functional forms have been adopted by the studies examined. Those following the seminal contribution of Griliches (1981) have modeled the relationship as follows:

$$V_{it} = b\,(A_{it} + \gamma\, K_{it} + \Sigma\lambda I_{it}) \qquad [2]$$

where b is the market valuation coefficient of a firm's total assets reflecting its differential risk and monopoly position, which in equilibrium should be equal to one, γ is the relative shadow value of technological to tangible assets, and the product $b*\gamma$ measures the total effect of the technological assets on firm market value (absolute shadow value). The expression [2] is the base of the model known in literature as *hedonic model*. Dividing both the members of [2] by A_{it} and taking the natural logs, we obtain the following expression:[2]

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

[2] Some studies do not subtract A_{it}, obtaining a slight different estimation model. Also in this case, however, the aim of the estimation is the determination of γ, which is the differential valuation of K_{it} relative to $A_{it.}$

The ratio V_{it}/A_{it} can be considered a proxy of Tobin's q, which is the ratio of the market value of a firm's assets to their replacement cost.[3] The estimation of [3] allows us to assess the average effect of a currency unit invested in technological assets on the market value of the firm. Hall and Kim (2000), Hall et al. (2000), Bloom and Van Reenen (2002) estimate equation [3] through Non-Linear Least Squares. Other authors applying the same model use the approximation $\log(1+x) \approx x$ obtain a linear equation estimated through Ordinary Least Squares (e.g., Griliches, 1981; Jaffe, 1986; Cockburn and Griliches, 1988; Hall, 1993b). The recent study of Hall and Oriani (2004) estimate both functional forms without finding substantial differences between the results reported.

A second additive function that has been adopted is based on the work of Hirschey (1982) and can be expressed as follows:

$$V_{it} = \alpha + \beta A_{it} + \gamma K_{it} + \sum \lambda I_{it} \qquad [4]$$

Dividing both the terms of [4] by A_{it}, we have the following general functional form in which the dependent variable is again a proxy of Tobin's q (Chauvin and Hirschey, 1993):

$$V_{it}/A_{it} = \alpha\ 1/A_{it} + \beta + \gamma\ K_{it}/A_{it} + \Sigma\lambda\ I_{it}/A_{i} \qquad [5]$$

In this case, the absolute shadow value of the technological assets is measured by the coefficient γ, whereas in the models based on expression [2] it is represented by the product $b*\gamma$. Therefore, in order to compare the results of the two functional forms we will assume b equal to 1. This is a theoretical assumption of the models described and is normally confirmed by empirical

[3] Tobin's q has often been used by studies in industrial organization as a performance measure because of its attractive theoretical properties: it implicitly uses the correct cash flow risk-adjusted discounted rate, imputes equilibrium returns

results (Hall, 2000). It is also worth noticing that in equilibrium, if a firm is investing optimally in all its assets, all the coefficients of both tangible and intangible assets should be equal to 1.

R&D-based measures of technological innovation

The concept of innovation is very broad and difficult to define from an empirical point of view (Griliches, 1995). Nevertheless, if the definition of comprehensive measures can be too presumptuous, it is possible to assess the contribution of identified investments in advancing the state of knowledge in given areas. In particular, previous studies have referred to a large extent to R&D activity, which is one of the main sources of technological innovation. In this perspective, R&D investments add value if they are able to generate an intangible asset, that is a stock of technological assets (Griliches, 1981). Then, an R&D-based measure of firm's technological assets should be a stock measure. Accordingly, this has been often computed as the capitalization of present and past R&D expenditures. In particular, the following expression has been generally adopted (see Griliches and Mairesse, 1984):

$$K_t = (1 - \delta)\, K_{t-1} + R_t \qquad [6]$$

where K_t is the *R&D capital* at time t, R_t is the annual R&D expenditure 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 accounting principles in all the countries normally require R&D costs to be written-off to expense when incurred because of the lack of a clear link with subsequent earnings (see Lev and Sougiannis, 1996; Zhao, 2002). The use of a depreciation rate is justified by the decay of knowledge over time and the loss of economic value due to advances in

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and minimizes distortions due to tax laws and accounting standards (Lindenberg and Ross, 1981; Montgomery and Wernerfelt, 1988).

technology. Nearly all the studies analyzed in this paper use a constant annual 15% depreciation rate (Jaffe 1986; Cockburn and Griliches, 1988; Hall, 1993a, 1993b).[4]

Alternatively, some studies have used annual *R&D investments* instead of R&D capital (e.g. Cockburn and Griliches 1988; Hall 1993a; Hall and Vopel 1996), because of the persistence of R&D investments at the firm level over time empirically demonstrated by previous research (e.g. Hall et al., 1986). Clearly, the coefficients of the studies adopting R&D capital and R&D investments as alternatives proxies of the stock of technological assets are not directly comparable because of the different scale of the independent variable. For this reason, in the meta-analysis we will treat them as separate groups.

It is anyway worth noticing that the studies using R&D capital are more intuitively interpretable. Since R&D capital is a stock measure consistent with the market value, the coefficient γ has a very clear meaning. It is the market value of one currency unit invested in R&D activities by the firm. Therefore, if the coefficient γ is greater than 1, it means that investing in R&D enhances the firm market value more than proportionally. Moreover, given the functions [2] and [4] and assuming b=1, a value of γ greater than 1 signals that R&D investments are evaluated more than tangible assets by the stock market. Clearly, the contrary holds when γ is lower than 1. This interpretation is not valid, instead, for the studies using the R&D investment proxy.

Finally, it is worth noticing that the use of R&D-based measures does not definitively resolve the questions related to the measurement of technological assets. Some problems still persist. First, the quality of corporate financial reporting on R&D activity and intangibles is often inadequate to economic analysis purposes (Lev, 2001). Second, national accounting laws often do

[4] Other studies adopting a different approach that is not reviewed in this paper use an estimation procedure determining industry- and time-specific economic depreciation rates (Lev and Sougiannis, 1996, 1999). More precisely, the authors run a regression model in which the dependent variable is the annual operating income and the independent variables are the lagged values of total assets, advertising expenditures and a vector of the past R&D investments.

not require the quantitative the annual R&D expenditures.[5] Finally, R&D investments are a not an output, but an input measure of the innovation process. A minority of studies has used patent-based measures either alternatively to R&D-based measures (e.g. Hall et al., 2000; Bloom and Van Reenen, 2002) or along with them in the same regression (e.g. Jaffe, 1986) to overcome these problems. Since patent-based variables are not comparable with R&D-based one, because they are measured on a different scale, we were forced to exclude from the meta-analysis those few studies adopting only the former. Instead, for those studies using R&D- and patent-based variables jointly in the same regression, we controlled for the potential effect of the inclusion of both measures on the coefficient of R&D capital or R&D investments.

EMPIRICAL ANALYSIS

Sample

To review the empirical results on the relationship between R&D investments and market value of the firm we proceeded as follows. First, we identified ProQuest and Econlit as the two most important online literature databases for economics and management related subjects, containing both published works and working paper series. ProQuest provides global access to one of the largest online content repositories, including more than a million dissertations and about 4,000 newspapers and periodicals. EconLit is the American Economic Association's electronic bibliography of economics literature, containing, in addition to published works, working papers and dissertations in economics. As a complementary source and as a way to check for the completeness of our extraction, we also used Google Scholar, a special release of the homonymous

[5] For example, in the European Union, the United Kingdom is one of the few countries where quantitative disclosure of R&D investments is compulsory, while in France, Germany and Italy there exists only an obligation concerning R&D qualitative information (KPMG, 1995; Belcher, 1996).

popular research engine specifically focused on academic contents. We performed a query in each database with the string “market value” or “firm market value”, our dependent variables, always appearing alternatively in logic conjunction (operator AND) with “R&D”, “intangible asset”, “hedonic model” and “Tobin’s q”. Proquest and Econlit returned 236 and 76 papers, respectively, while Google Scholar returned 1122 links.

We then conducted a first review of the identified papers to consider their usefulness for the meta-analysis and eliminate duplicates. In particular, we decided to retain those studies which, in order to estimate firm market value used either one of the functional forms [2] or [4] and, among the independent variables, included R&D investments or R&D capital. This second constraint was required because, as specified above, an R&D-based measure of innovation-related intangibles is not necessarily present in the models described in the previous section. Some authors, for example, focus only on patents to observe their impact on firm’s market value without taking into account a specific measurement of R&D. After applying the above set of restrictions, 40 studies remained.

Finally, as a third step, we refined our retention criteria to both ensure the results comparability across studies and control for some substantial and computational limitations of meta-analytic studies (Hedges and Olkin, 1985; Rosenthal, 1991). This led to the complete exclusion of all the papers that neither specified the functional form, nor presented detailed results. In addition, we did not select those studies using rough proxies for critical dimensions, such as tangible assets or market value.

Moreover, within the retained studies, we excluded all the regressions including both R&D investments and R&D capital, because of the multi-collinearity problems associated with the estimates using this approach. Finally, within each study, we accorded preference to regressions based on OLS estimation method, which is the most commonly adopted. On the contrary, only a relatively limited number of studies employ NLLS (Non Linear Least Square) method solely. While we took into account results derived from this last method, we deliberately rejected those obtained through panel data estimators (both fixed and random effects), since their inclusion would have jeopardized results comparability. At the end of this process we retrieved a total of 28 studies and 48 individual regressions for our meta-analysis. Among these studies, 14 were already published in refereed journals, 3 were conference papers, and 10 were still under working paper format, albeit released by primary level research institutions. Fourteen studies (26 regressions) used R&D Investments and fourteen studies (22 regressions) R&D Capital.

For each study, we then recorded the slope coefficient γin the regression equations. However, a standard procedure in economic research is to present and estimate different functional forms associated with the model developed and compare the emerging results. When multiple regressions are present in a single paper, the non-trivial problem of how to treat the entire set of results arises. In order to avoid duplications, multiple regressions (differing only for one or more control variables employed in the model) on the same set of observations, cannot be accounted separately. One solution consists in reporting the average coefficient of the variable of interest. While this choice implicitly includes all the results, it is not statistically orthodox. Since the observation of our meta-analysis is the regression and not the paper, when multiple regressions referred to the same set of observations, we retained only the most complete regression in terms of control variables. On the contrary, analyses on different samples performed within the same study were treated as fully replicated designs and therefore as independent observations.

Meta-analytic procedure

As detailed in the theoretical section, we focus on the effect of R&D investments and R&D capital, as measures of technological assets, on firm market value. While several previous works have shown a positive relationship between both variables and the firm's market value, here we have two distinct objectives. First, we intend to obtain an estimate of the true relationship between R&D investments and R&D capital and firm market value, starting from the slopes reported in the studies examined. Second, we aim at exploring to what extent the inclusion of several control variables accounting for alternative hypotheses and other elements of the research design impact on the R&D coefficient.

Meta-analysis usually focuses on the directionality and significance of the effects or on their magnitude. In either case, a measure of association between the variables of interest from each of the studies analyzed is needed. Bivariate correlation coefficients are normally used, while procedures exist also for dichotomous comparisons relying on d-values. The use of regression slopes and intercepts, on the contrary, is more controversial (Hunter and Schmidt, 1990: 202-206). While the meaning of correlations is attenuated by the unreliability of the measures of both independent and dependent variables, raw score regression slopes and intercepts are attenuated only by measurement error in the independent variable. Moreover, regression slopes and intercepts are usually not comparable across studies, unless all studies used exactly the same scales to measure both variables. Finally, slopes and intercepts can be very difficult to interpret due to arbitrary choices in the scaling of the variables.

All these limitations strongly suggest relying on correlations, even when examining studies using regression models, collecting the relevant information from the correlation matrix that should be normally reported. In our case, however, very few studies reported bivariate correlation coefficients. The very stringent selection procedure used in the definition of the final sample, however, offers the opportunity of overcoming all the abovementioned concerns on the use of regression slopes. In fact, in all the studies selected both the dependent and the independent variables are measured on identical scales. Therefore, the slope coefficient of interest (γ) does not suffer from scaling problems influencing its interpretability. It measures, in fact, the amount of currency units by which the firm's value increases or decreases as a consequence of an investment of a currency unit in R&D activities relative. Moreover, in the functional forms selected, the intercept has its own specific meaning in the estimation model (i.e. the amount of currency units by which the firm's value increases or decreases as a consequence of an investment of a currency unit in any kind of assets). The coefficient γ can then be interpreted as a correlation coefficient and an analysis of the effects of measurement errors in the dependent variable becomes meaningful again. We then conducted all tests in accordance with the procedures presented and discussed by Hunter and Schmidt (1990). Each slope needs to be weighted for the sample size, here measure for the number of observations included in the regression model. The standard deviation of the observed slopes can then be calculated to estimate the variability in the relationship observed.

Such variability, however, could be the sum of different components: true variation in the population, variation due to sampling error, variation due to measurement error. Before proceeding further in the analysis, assessing the impact on true variation of the effects of variables, it is therefore important to eliminate the influence the random variation of the values reported by the studies examined, and then systematic variation due to measurement problems.

We cumulated the results of the studies analyzed in five steps. These steps were common across all different analyses performed, while the calculations changed according to the research question of interest. Table 1 reports and describe the formula used for each calculation. First, we computed the average uncorrected slope coefficient, as the average of all slope coefficient reported by the studies examined weighted by the study's sample size calculated as described above. Second, we calculate the raw uncorrected variance of all the slope coefficients examined. Third, we calculated for each study the attenuation factor to take into consideration the effect of measurement errors in the dependent and independent variables. This third step was repeated four times, considering four levels of reliability: .7, .8, .9 and 1. Fourth, we calculate both the average sample slope and the slope variance, corrected for artifacts' influence. Before any analysis could be made, however, one still has to eliminate from the variance calculated in the previous step the amount of variance due to sampling error. The fifth and last step therefore consisted in the calculation of the slope variance corrected for sampling error, resulting from the difference between the slope variance corrected for artifacts' influence and the sampling error variance, calculated on the average sample slope corrected for artifacts' influence.

We then tried to statistically assess the true relationship between R&D and firm market value and the effect on this relationship of a set of variables through bivariate and multivariate analyses. In the following section we describe these variables and why we chose them.

--- Insert Table 1 about here ---

Data coding

In coding our data we built a set of dichotomous variables accounting for two general aspects of the research design: sample characteristics and control variables. This set of variables is described in Table 2 for the studies using R&D investments and in Table 3 for the studies using R&D capital. Both tables report information on the study, the sample characteristics and the estimation method for each regression included in the meta-analysis along with a list of the variables used in the following analyses.

--- Insert Table 2 about here ---
--- Insert Table 3 about here ---

With respect to sample characteristics, we defined two variables. With *Country* we distinguish the between US and non-US studies, to account not only for the different dynamics of the US stock market as compared to those of the other countries, but also for the fact that the studies on the US are based on the Compustat Database, which can present higher levels of reliability because of its methodological rigor (see Hall, 1990). *Sample Size* indicates whether the sample size is higher or lower than the median value of all the regressions selected. This variable should control for small sample or selection biases in the regression analyzed.

The other variables account for the presence of a set of controls in the regressions examined that we theoretically expect to have a significant impact on the R&D coefficient. In analyzing the papers we then proceeded in the following way. We first kept track of every single control variable employed in the regression, and then we aggregated those variables measuring the same or very similar constructs. While on one hand this choice might lead to a loss of specificity, on the other hand it allowed us to identify the relevant variables at a higher level of aggregation. In addition, from a methodological point of view, it increased the degrees of freedom in the following estimation, which has a fundamental importance for meta-analyses with a limited number of observations.

After this coding procedure, for the studies using R&D investments as proxy of technological assets we identified the following variables:

Intangible assets. This variable is equal to 1 when in the regression analyzed there is a control variable accounting for firm's intangible assets other than R&D. It encompasses two more detailed variables: *Patent and legal protection* and *Other intangibles.* 'Patent and legal protection' includes the presence of the following control variables in the regression: number of patents, patent stock, patent citations, trademarks and industrial designs subjected to some form of legal protection. 'Other intangibles' considers all intangible assets not included in the previous variable, such as, for example, various measures of advertising

Firm Size: This variable indicates the presence in the regression of variables accounting for firm size, measured either by *Tangible assets* or *Total sales*.[6]

Industry: This variable is equal to 1 when in a regression there is an industry-level control. It encompasses two main factors: *SIC-based industry dummies* (SIC2, SIC3) and *Industry concentration* (C4)

For the studies employing R&D Capital instead of R&D Investments we had to make some little changes due to their somewhat different research designs. In particular, the variable Industry accounts for the presence of Industry concentration (C4) and *Technological cluster dummies*, cumulatively present in 4 regressions only, whereas none of the studies selected used industry dummies as a control.

Statistical tests

The slope variance corrected for sampling error calculated as explained above was used to compute confidence intervals for the average sample slope corrected for artifacts' influence. Confidence intervals were then used to statistically test whether the relationship between a firm's market value and R&D investments was different from zero and to assess the univariate effect of a set of variables on this relationship. The first set, aimed at analyzing the effect of different variables on the R&D-market value relationship, includes the following fields: *Patents and legal protection*, *Other intangible assets*, *Industry*, *Firm Size*. The second set includes both *Country* and *Sample Size*

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[6] We also considered two other firm-level control variables: market share and leverage. However, we did not include them in the analyses because they normally appeared in the same regressions where firm size was already controlled. As a consequence, the variables built upon those variables were highly correlated with Size. Moreover, when included in the estimation, they did not substantially change the results.

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control and is targeted to control for specific choices related to the research design made within the different studies.

We also approach the 'file drawer problem' following the procedure recommended by Rosenthal (1991: 103-109). The purpose was to estimate the number of unretrieved studies averaging null results that should exist if the results obtained from the retrieved studies were due to chance alone. Traditionally, meta-analyses consider unretrieved studies as those which have not been published yet. The procedure, however, can logically be extended to consider the generalizability of the results, which might as well be affected by the sampling criteria used. The file-drawer test therefore becomes also a way to control for potential biases introduced by our decisions to exclude some papers, as we explained above and to have not included other journals in our analysis. Technically we needed to calculate the number of unobserved studies averaging null results to bring the magnitude of the effect size observed to a negligible level. In our case, scaling such value according to the metric shared by the variables considered in the analysis, we are interested in computing the number of unobserved studies reporting null results necessary to bring the value of the average corrected slope to less than 1. In this case, in fact, investing a currency unit in R&D activities would destroy value. Given k the number of studies reviewed, β_μ the average corrected slope, and β_c set equal to .8, we use the formula presented in Hunter and Schmidt (1990: 513) to compute x, the number of studies to be exceeded to invalidate the results of the meta-analysis as follows:

$$x = k\,(\beta_\mu / \beta_c - 1) \qquad [7]$$

Finally, we used multiple regression techniques to simultaneously assess the impact of all the different variables of the coefficient γ assessing the relationship between R&D investment or

R&D capital and market value. It is important noticing that within these multivariate estimates, the regression intercept represents the average slope coefficient, while each individual estimate represents the increase or decrease in the average value of the coefficient γ due to the presence of the specific factor in the study considered, after controlling for all other factors. The impact of each single variable on the sample mean is tested by the significance level of the individual coefficient estimates, while the effect of research design choices jointly including a set of predictors is tested through the increment to R^2 test. If the increase in the R^2 is sufficiently large, we can conclude that the predictors in question, when taken together, have an effect on the outcome variable. The formula we employ to make this determination is the following:

$$\frac{\Delta R^2 / \Delta df}{(1 - R^2_{FullModel}) / df_{FullModel}} = \text{F-test } (\Delta df, \text{ df full model}) \qquad [8]$$

RESULTS

Tables 4 and 5 report the results of the meta-analysis of the relationship between R&D Investments or R&D Capital and market value, as well as the changes in the coefficient of interest for different levels of the variables considered. For the R&D Investment studies (Table 4), the overall results indicate a strong support for a systematic positive relationship between the two variables. The average corrected slope is equal to 3.12 and the 95% confidence interval varies between 1.29 and 4.94, indicating that the true population slope is always positive and well above zero. This result confirms that in general stock market positively evaluate firms' R&D investments.

--- Insert Table 4 about here ---

A change in the reliability of the indicators used to estimate the relationship (i.e. Tobin's Q and the reported level of R&D Investments) has, as expected, an impact on both the average corrected slope and the corrected slope variance. These changes are reflected in the 95% confidence interval which varies between 1.36 and 7.21 at .9 level of reliability, between .02 and 12.23 at .8 and between -2.76 and 21 at .7, while the average corrected slope increases from 4.28 to 9.11.

Splitting our sample on the other variables, and considering a reliability level of .9 (*Patents and legal protection*, *Other intangible assets*, *Industry*, *Firm Size, Country* and *Sample Size)*, we find that the average corrected slopes are quite constant over the split and that the 95% confidence interval is always positive and well above zero. Table 4 reports also a comparison of the different groups of observations based on the average corrected slope only. The differences in magnitude of the coefficients are mostly not significant at conventional levels.

These observations are confirmed by the File Drawer Tests reported in the last column of Table 4, indicating that the number of unretrieved studies reporting null or contrasting results, needed to invalidate the conclusion that γ is positive, is large in comparison to the number of studies actually reviewed, and remains high for all the sample splits performed.

With respect to the studies using the R&D Capital (see Table 5), the average corrected slope for the overall sample is .96. This is very close to the theoretical equilibrium value of 1, indicating that in general stock markets consistently evaluate R&D expenditures. In other words, any currency unit invested in R&D translates on average into about .96 currency units of stock market value. The 95% confidence interval ranges between -.31 and 2.24. This means that several study-specific factors can moderate the value of the coefficient γ, posing greater interest on the analysis of the variables identified in the previous section. As in the case of R&D Investments, changing the reliability of the indicators modifies both the average corrected slope and the corrected slope variance. The 95% confidence interval varies between -.14 and 2.78 at .9 level of reliability, between -.33 and 4.08 at.8 and between -1.03 and 6.64 at .7, while the average corrected slope increases from 1.32 to 2.81.

--- Insert Table 5 about here ---

We then split the overall sample based on the described variables. While for those studies that do not include Firm Size proxies the average corrected slope is equal to 1.63, the ACS coefficient for studies including this variable is relatively smaller (.94). In this case the t-test is statistically significant at the .1% level. Also the presence of Industry controls impacts on the average corrected slope, which changes from 2.13 to 1.13, when studies do not include such controls (the t-test is significant at the .1% level). Similar results are obtained when Patents are considered, with the average corrected slope decreasing from 1.77 to 1.19 when studies do not include such controls (the t-test is significant at the .1% level). Moreover, studies conducted on US data report an average corrected slope smaller (1.27) than studies conducted on non-US data (1.99) (the t-test is significant at the .1% level). Finally, while lower than in the case of R&D investments, the values obtained for the File Drawer Test are generally high, compared to the number of studies reviewed, if we exclude the case of studies including Other Intangibles.

As it can be seen from Tables 2 and 3, though, several of the research design and sample characteristics univariately examined above are simultaneously present within the different studies. Tables 6 and 7 therefore report the multivariate regression analyses for R&D Investment and R&D Capital. For both groups of studies, we constructed a baseline model in which the dependent variable (coefficient γ) is regressed on three main variables: Intangible assets, Industry and Firm Size. Then we enriched the baseline model splitting the variable Intangibles into its more disaggregated constituents: Patent and legal protection and Other intangibles. As a further step, in order to control for specific effects associated with the sample characteristics, we added the sample related variables, Country and Sample Size, to the baseline and the enriched model. In the following regressions, as explained in the previous section, the constant measures the average coefficient γ, whereas the other coefficients represent, *ceteris paribus*, the effect on γ of different decisions related to the research design of the studies investigated (control variables and sample characteristics).

For all studies using R&D Investments (Table 6), the constant is always positive and statistically significant, ranging from 3.48 to 3.59, thus indicating a general positive evaluation of firms' R&D investments by the stock markets and confirming the result already obtained from the previous bivariate analyses. With respect to the moderating effects, in the baseline model (model 1) the variable Intangible assets has a negative (-1.84) and significant coefficient (p-level<.01). This means that when a regression accounts for intangible assets distinct from R&D investments, the coefficient γ shrinks. Therefore, not accounting for other firm-level intangibles could lead to an overestimation of the R&D market value as the value of other intangibles could be at least in part attributed to R&D investments. The Industry variable has a positive (1.02) and significant coefficient (p-level<.1), indicating that in the regressions controlling for industry-level effects the estimate of coefficient γ is higher. This evidence suggests that when industry-level factors affecting firm market value are accounted for, the R&D-market value relationship appears more clearly and is more intense. Interestingly, the common firm-level control Size does not significantly affect the R&D coefficient. When the variables Country and Sample size are introduced (model 2), the results do not substantially change and the R^2 does not significantly improve.

When the Intangibles are disaggregated (model 3), we note that both Patent and legal protection and Other intangibles remain negative. However, only the former is statistically significant (5% level). This indicates that when the studies account for other measures of technological assets, such as patents, the market value of R&D investment results lower. It is then likely that stock markets evaluate a firm's technological referring to multiple indicators, so that an analysis based only on R&D-based measures could only partial reflect the value of a firm's innovation activities. Again when the variables Country and Sample size are introduced (model 4), the results do not substantially change and the R^2 does not significantly improve. The Patent and legal protection coefficient is again positive, although it gets smaller and looses significance at conventional levels. Considering the stability of the directionality of the effect, we interpret this result as a consequence of the loss of degrees of freedom, the absence of any improvement in the R^2, and the limited number of observations available.

--- Insert Table 6 about here ---

Table 7 shows the results of the regressions on the studies based on R&D Capital. Similarly to the results reported in Table 6, the constant is always positive and statistically significant, and varies between 1.05 and 1.92, clearly indicating that each currency unit invested in R&D capital generally enhances firm market value more than proportionally. Moreover, based on functions [2] and [4] described above, it is evaluated by the stock markets more than an analogous investment in tangible assets. This result would reject then the hypothesis of underestimation of R&D investments by the stock markets advanced elsewhere.

The estimation of the baseline model (model 1) shows coefficients in line with those relative to the previous group of studies. However, none of the coefficients of the variables is significant at the conventional level. The introduction of the variables related to the sample characteristics has interesting effects (model 2). First, the coefficient of Size becomes negative and statistically significant (p-level <.1), indicating that controlling for firm size reduces the coefficient of R&D capital. Positive effects on market value generally deriving form scale economies can be erroneously attributed to the R&D capital if firm size is not controlled for. Second, both the variables Country and Large sample have a statistically significant coefficient. The negative sign of the Country coefficient denotes a lower valuation of the R&D capital by the US stock market. However, this result can not be correctly interpreted if the coefficient of Large sample is not taken into consideration. In fact, most of the US samples are large, so that for several US-based studies the net coefficient γ is the algebraic sum of the constant plus the coefficients of Country and Large sample. The latter is positive, indicating that after controlling for all the other factors, the use of smaller samples can lead to an underestimation of a firm's R&D capital. This evidence has important methodological implications because it suggests that reduced data availability is likely to generate downward biased estimates of the coefficient γ. Third, the significant increase of R^2 (ΔR^2 test p-level <.1) indicates that in this case the two variables jointly increase the overall fit.

Disaggregating the Intangibles into its two components (model 3), we obtain significant results for the variable Other intangibles, which has a negative (-.94) and statistically significant (ten percent level) coefficient, whereas we do not have any significant coefficient for Patent and legal protection. Differently from the previous group of studies, therefore, the relevant control variable for the coefficient γ seems that relative to advertising expenditures and other intangible assets. However, while at least in part due to differences in the research designs of the studies in the two groups, this result confirms that not controlling for neither technological assets nor other intangibles can lead to overestimate the R&D market value. When adding Country and Sample Size (model 4), we obtain again significant coefficients. Moreover, the Industry coefficient becomes statistically significant at the 10% level, confirming the result already obtained for the group of studies using R&D investments.

--- Insert Table 7 about here ---

DISCUSSION AND CONCLUSIONS

The extent to which investments in innovation have a positive effect on firms' market value has attracted scholarly research and practitioners' attention. With the increasing importance of financial markets as a source of financing economic activities, the sensitiveness of investors to firms' investments in innovation has become a critical area of attention for managers and stockholders. This is indeed a critical question jeopardizing managers' decisions on innovation management, such as the amount of resources to allocate to R&D investments or equity-based R&D financing. Empirical analyses have been conducted along the years, using different methodologies and research designs. The relationship between firms' market value and R&D investments has then emerged as a growing research area, where economic, accounting and strategic management perspectives have converged, using a variety of tools and approaches to assess the existence, the directionality and the magnitude of such relationship.

However, two main questions, which made the interpretation of the results difficult to both scholars and practitioners, emerge from a qualitative review of this literature. First, it is not clear whether the investors evaluate the long-tem benefits of the investments in innovation. Several authors have posed severe doubts on this point, suggesting that the returns on R&D investments are systematically underestimated by the stock market (Lev and Sougiannis, 1996; Chan et al., 2001). Second, a high degree of variability was found in the valuation of R&D investments in different country and industry contexts (see Hall, 2000, for a review). Whether this finding depends on different institutional factors or on different choices related to the research design is a question without a clear answer.

In this paper we conducted a meta-analysis of the empirical literature linking R&D investments and firm market value in order to shed some new light on these inconsistencies. We focused in particular on those studies that following the seminal contributions of Griliches (1981) and Hirschey (1982) considered the firm as a bundle of assets and estimated the marginal effect of R&D-based measures of innovation on firm market value. This stream of research is the first one to have pursued empirical tests of the theoretical arguments developed and has attracted a growing attention over the years, with a constant improvement of the research design and an attempt to widen the geographical sources of the data outside the US market. Moreover, such approach is also particularly interesting in the light of the debate on the notion of firm and of the sources of competitive advantage, which has characterized in the last decade the strategic management literature, and is heavily based on the role of intangible assets.

The objective of our meta-analysis was mainly twofold. First, we intended to assess if the cumulated evidence from previous studies was supportive of a systematic positive evaluation of firms' R&D expenditures by the stock markets. Second, we aimed at assessing the magnitude of the relationship between R&D investments and market value against a set variables related to the research design. In this way, we tried to determine if different choices in terms of research design significantly modified the results obtained by the previous studies.

The results presented in this paper move along these lines of enquiry, providing interesting insights. First, they show that an overall analysis of the studies selected offer convergent and robust evidence of a positive relationship between R&D investments and the market value of the firm. More specifically, we can affirm not only that the true population slope is always positive and well above zero, but also that the market values one currency unit invested in R&D activities as much ore more than one currency unity invested in tangible assets.

The consistent valuation of R&D investments by the stock market is an important signal to manager seeking to maximize shareholder wealth, as it suggests that a firm can invest in innovation without fearing negative effects on the stock prices. Measurement errors in the dependent and independent variables, however, might introduce a significant bias both upward and, more importantly in our case, downward, increasing the number of cases in which the market values one dollar (or one Euro) invested in R&D activities less than one dollar (or one Euro) invested in any other tangible assets.

When we account for the effect of variables in the bivariate and multivariate analyses, we find some further intriguing results. First, when the studies control for the presence of other intangible assets, such as patents and advertising, the market valuation of firms' R&D investments generally lowers. This evidence suggests that the investors on the stock market evaluate a firms' innovation activities along different dimensions and referring to multiple indicators of the innovation process, so that an analysis based only on R&D-based measures is at risk to be partial. In this perspective, a more complete disclosure of the different dimensions of their innovation activities could help traded firms to fill the well known R&D information gap with the external investors (see Aboody and Lev, 2000) and have a more transparent and stable valuation on the stock market.

Moreover, whereas adding industry-level controls seems to better specify the relationship between R&D investment and market value, the firm-level variables widely adopted by the previous studies, except measures of intangible assets, do not substantially affect the results. This indicates that if the future work in this field intends to assess the effect of firm-specific characteristics on the market value of innovation should move beyond the traditional control variables and try to define original and innovative variables related to the management of innovation at the firm level. Clearly, this effort will deal with the common trade-off between the depth of the study and the size and generality of the sample. Finally, from a methodological point of view it is interesting to notice that the sample size can matter in explaining the R&D market value. In particular, reduced availability of data, which is typical of non-US countries, is at risk of downward biasing the results obtained.

Our analysis suffers from some limitations, directly connected to some of the results obtained. First of all, we have focused our attention only on one of the three research traditions linking economic performance and R&D investments at the firm level and focusing on financial markets. Future research should address the evidence available from the other research traditions and find appropriate strategies to incorporate all possible models in the meta-analysis, possibly to take a different angle on the questions analyzed in this paper or to answer to different questions. Moreover, while we account for several important moderating factors, we leave out many other factors such as the estimation technique used or the presence of interaction effects involving the R&D coefficient because of the lack of a critical number of studies to perform these analyses. For the same reason, we were also forced to aggregate the variables at a higher level, with a clear loss of specificity. Additional efforts in extending the coding procedures of the studies and extending the sample of studies analyzed will provide important information to further extend the meta-analysis. Finally, since the studies not using a US sample were few, we could code the country variable only as US and non-US. This choice did not allow us to have a clear result on the country effect, although studies based on European data are increasingly being presented at conferences, with results generally aligned with the ones obtained in the US, but also with some differences, usually explained with the specific characteristics of the different stock markets (see Hall and Oriani, 2004). The inclusion of new studies on non-US countries within the meta-analytic framework developed in this paper will allow to more carefully evaluate this issue.

Despite all these limitations, the points raised in the paper are of interest to different research communities and offer important indications on a topic whose relevance is directly connected to the theory and practice of technology and innovation management. Considering the evolution of several decision making tools emphasizing the role of opportunity increasing investments to leverage on existing competencies for enhancing future competitive opportunities, the value attributed to such signals by the market can represent a critical opportunity to raise the funds necessary to grow and commercially exploit the inventions developed. Value increasing or destroying activities therefore cease to a be generic jargon to classify investment decisions and becomes a powerful heuristic to be directly related to the expected evaluation expressed by shareholders and investors also for highly intangible activities such as the ones related to the development of innovation.

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Table 1 - Statistics used and computation methods

Statistic	Computation	Notes
Average observed slope (AOS)	$\sum \beta_{oi} n_i / \sum n_i$ (i = 1-s)	β_{oi} = slope reported by study i n_i = sample size of study i s = total number of studies examined in the meta – analysis
Sampling error variance in uncorrected slope (SEVUS)	$\left(1 - \mathrm{AOS}^2\right)^2 \Big/ \sum n_i \quad \left(i = 1 - s\right)$	Amount of variance among observed slopes due to random error if no correction for artifacts is applied
Uncorrected slope variance (USV)	$\sum n_i \left(\hat{a}_{oi} - \mathrm{AOS}\right)^2 \Big/ \sum n_i \quad \left(i = 1 - s\right)$	Total amount of variance among the study not correcting for artifacts influence
Attenuation factor (A_i)	$a_{i1}\ a_{i2}\ a_{i3}$	Total artifacts correction factor with: a_{i1} = reliability of the independent variable in study i a_{i2} = reliability of the dependent variable in study i a_{i3} = attenuation factor for sample size of study i calculated as 1 – (1/(2 n_i – 1))
Average corrected slope (ACS)	$\sum \left(n_i \hat{a}_{oi} / \mathrm{A_i}\right) \Big/ \sum n_i \mathrm{A_i}^2 \quad \left(i = 1 - s\right)$	Average effect size obtained by meta – analisys after correcting for all artifacts influence
Sampling error variance in corrected slope (SEVCS)	$\sum \left(\mathrm{SEVUS}\, n_i / \mathrm{A_i}\right) \Big/ \sum n_i \mathrm{A_i}^2 \quad \left(i = 1 - s\right)$	Amount of variance among corrected slopes due to random error after correction for artifacts is applied
Corrected slope variance (CSV)	$\sum n_i \mathrm{A_i}^2 \left(\hat{a}_{oi} - ACS\right)^2 \Big/ \sum n_i \mathrm{A_i}^2 \quad \left(i = 1 - s\right)$	Total amount of variance among the slopes after correcting for artifacts influence
Sampling error corrected variance of corrected slope (SECVCS)	CSV - SEVCS	True variance among the slopes after correcting for artifacts influence and random variance