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Corporate Science, Innovation and Firm Value

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Abstract

It can be observed that many R&D performing firms disclosure knowledge in scientific journals. At the micro-level, prior work identified several potential benefits of such a strategy like superior access to informal information networks or to the best PhD graduates. However, scientific research is costly and subject to considerable uncertainty with respect to the outcomes, and the disclosure may lead to spillover effects that decrease the ability of firms to generate returns of their R&D investments. Overall, it remains unclear if and under what conditions a greater scientific orientation in firm?s R&D and in the second step, voluntary disclosure of the outcomes, is a winning strategy. We address this gap and examine the impact of scientific activities on the firm?s market value, using accounting data for US firms from Compustat and matched patent and scientific publication data. In addition to the impact of scientific activities, we consider the heterogeneity of inventive outputs in a more detailed way than it has been done in previous studies. We find evidence for a positive impact of scientific contributions on firm?s Tobin?s Q beyond the effects of R&D and patent stocks.

Jelcodes:O31,-

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Abstract

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Keywords: R&D, Industrial Science, Market value, Tobin's Q, Econometric evidence

JEL classification: G32, O31, O34

1 Introduction

The effect of firm's Research and Development (R&D) activities on firm performance is an interesting question both for innovation scholars and managers and received consequently considerable attention in the literature. Whereas investments into R&D are costly, R&D can also be the source of sustainable competitive advantages based on innovative products and processes (Nelson 1959; Griliches 1981). Although R&D expenditures do typically not find immediate expression in firm performance, they may have a direct impact on the stock market appraisal of firms since financial markets do not only evaluate the current success but also the anticipated future returns. From a firm perspective, it is obviously an important question how the stock market responds to the firm's investment decisions, since also the re-financing costs depend on the external evaluation of shareholders. Acknowledging the relevance, many scholars have addressed the question of the impact of knowledge assets on market value (e.g. Griliches 1981; Jaffe 1986; Hall 1993; Blundell et al. 1999; Bloom and van Reenen 2002; Toivanen et al. 2002; Hall et al. 2005; Nesta and Saviotti 2006; Hall et al. 2007; Ceccagnoli 2009). In the vast majority of these studies, knowledge assets have been operationalized and proxied by R&D investments and patent measures. The typical and quite consistent findings reveal a positive effect of R&D knowledge stocks on the market valuation of firms, and inventive outcomes are found to generate a premium in the firm valuation.

However, beyond the consideration of R&D investments, patent counts and patent quality, there have been only a few attempts to examine the nature and heterogeneity of knowledge stocks and its impact on market valuation. Moreover, it has been widely neglected that the openness of firms with respect to the communication of their research outcomes may impact the shareholders expectations as well. We address this gap by examining the impact of corporate scientific activities and the dissemination of research outcomes on the market value of firms. With the exceptions of Deng et al. (1999) and Belenzon and Patacconi (2010), our study is the first one which considers the role of scientific research in firms. The starting point of our interest is the observation that many R&D performing firms are not only relying on scientific information as a privileged source for their innovation activities but are also active contributors to the stock of scientific knowledge (Hicks 1995; Stephan 1996; Simeth and Lhuillery 2012).

Although generic research potentially allows for creating highly innovative outcomes that are of a high commercial value, such fundamental research is also more uncertain concerning the achievable outcomes, costly in its execution and more difficult to appropriate (Nelson 1959; Rosenberg 1990; Aghion et al. 2009). Apart from the performed research, the disclosure of research findings in the form of scientific publications, which is not only bounded to pure generic research, is recognized as a signalling and appropriation device. Scientific disclosure may target multiple stakeholder groups like academic scientists or professional costumer groups (Hicks 1995; Stern 2004; Penin 2007; Polidoro and Theeke 2011; De Fraja 1993; Pachomovsky 1993; Della Malva and Hussinger 2012). However, the disclosure implies additional costs due to potential knowledge spillovers, incentive schemes for scientists that reward publication success, the potential need for retention strategies to keep successful and visible firm scientists, and opportunity costs based on the necessity to codify the knowledge in a structured format (Cockburn et al. 1999; Kinney et al. 2004; Kim and Marschke 2005; Liu and Stuart 2010; Simeth and Lhuillery 2012).

Our study addresses the question of the net benefits from scientific openness strategies and provides a comprehensive view on the impact of firm's knowledge assets on their stock market valuations. We are particularly interested in analysing the impact of scientific activities of firms and aim to distinguish between the effects that derive from the created knowledge itself (i.e. the basicness of firm's R&D) and effects that are based on the voluntary disclosure of the research results. For doing so, we exploit detailed information about the nature of the inventive and scientific outcomes. With respect to the used data, our empirical analysis relies on firm-level information from the US Compustat edition and matched scientific publication and patent data for a sample of 1,568 firms (7,012 firm-year observations) from sectors that are classified as "High-Tech" according to the OECD definition. The results of our econometric analysis suggest a positive relationship between scientific contributions of firms and their Tobin's Q evaluation.

The remainder of this paper is organized as follows: In Section 2, we briefly review the most important studies that examine the impact of knowledge assets on market valuation. In Section 3, we discuss the mechanism why scientific research in firms and the voluntary disclosure of results may impact the market evaluation. We present data, variables and the econometric design in Section 4, before we show and discuss our results in Section 5. We conclude in Section 6.

2 Knowledge assets and stock market valuation

Based on its high relevance, the relationship between knowledge assets and firm value has received considerable attention by innovation scholars[1]. Early work (e.g. Griliches 1981; Jaffe 1986; Connolly and Hirschey 1988; Hall 1993) measures knowledge assets by R&D stocks and the quantity of inventive outcomes as reflected by patent stocks. More recent studies built on this work and accounted for the expected commercial value of patents by adding quality indicators that are based on forward citation counts or patent family size (Lanjouw and Schankermann 2004; Hall et al. 2005; Hall and Oriani 2006; Hall et al. 2007). All studies have in common that a positive effect of R&D and intensive outcomes is found and quality-adjusted patent measures reveal a premium for the stock market evaluation whereas the effects are from moderate strength given the presence of R&D and patent stocks.

[1] In Appendix table A.1, we provide an overview about the most important studies.

Some studies analyse the relationship between knowledge assets and firm valuation with special attention on environmental factors, moderating influences and specific sector contexts. Using information from the Yale and Carnegie Mellon surveys about the effectiveness of various channels of knowledge protection, Cockburn and Griliches (1998) as well as Ceccagnoli (2009) found that knowledge assets are valued higher if patents are considered as important protection instrument. In related work with respect to these two studies, McGahan and Silverman (2006) provide evidence that spillover effects from competitors lead to a higher market evaluation of firms. Furthermore, recent work analyses the relationship between knowledge assets and market value specifically for the software (Noel and Schankermann 2009; Hall and MacGarvie 2010) and biotechnology sectors (Decarolis and Deeds 1999; Nesta and Saviotti 2007).

With particular relevance for our work are the related studies by Deng et al. (1999) and Belenzon and Patacconi (2010), which are to our best knowledge the only studies which investigate the impact of scientific activities of firms on their market value. More specifically, Deng et al. (1999) examine whether more science-based patents lead to a positive impact on the market valuation, where the authors document a positive effect. While not accounting for R&D inputs, Belenzon and Patacconi (2010) evaluate the informational value of patent and publication stocks for the firm's market value in the context of Mergers & Acquisitions, where both types of knowledge outcomes are found to have a positive impact. However, the authors suggest that the informational value of scientific publications is decreasing over time, indicating that investors tend more and more to focus on patent information.

3 Scientific research, publications and firm value

Although prior literature documents the positive impact of knowledge assets on the market valuation of firms using R&D and patent information, there is only very limited evidence about the effects of scientific research activities and the dissemination of research outcomes on the firm value. In this section, we discuss the reasons to assume an impact of scientific activities and propose to distinguish conceptually between the orientation of the firm's research activity and the dissemination of research outcomes.

With respect to the orientation of research, there is evidence at the micro-level that generic research allows, on average, for superior innovative performance. The main theoretical reason rests on the absorptive capacity argument (Cohen and Levinthal 1990; Fleming and Sorensen 2004). Beyond the creation of firm-internal capabilities to generate innovative outcomes, companies performing generic research also develop capabilities that allow for a better identification, assimilation and exploitation of external knowledge. Such ability increases the possibilities of firms to create ground-breaking innovations and superior financial returns. In other words, firms engaging in fundamental research activities may be able to re-combine more distant knowledge (in a technological sense) and to create more valuable innovations than other firms. Empirical studies testing this argument indeed show that firms with scientific outcomes produce more innovations (Lim 2004; Cockburn and Henderson 1998), innovations from a higher quality, and in shorter development cycles (Fabrizio 2009). These findings suggest indirectly a positive relationship between generic research and market value, but it has to be considered that generic research is typically associated with specific costs. The execution of fundamental research often requires specific research equipment and human resource management (Cockburn et al. 1999; Simeth and Lhuillery 2012), and the research is subject to higher uncertainty leading to frequent failures (Nelson 1959; Rosenberg 1990). Moreover, the appropriation of outcomes can be more challenging, since outcomes from fundamental research cannot always be patented (Rosenberg 1990). Beyond the decision of firms to be engaged in fundamental research activities that may lead to future successful returns, there is the question of whether firms disclose their research outcomes in a scientific format.

Whereas more research should be eligible for scientific publication the more generic it is in its nature, publication in scientific peer-reviewed journals is not restricted to fundamental research (Stokes 1997; Murray 2002; Simeth and Lhuillery, 2012). The disclosure in a scientific format itself may act as a valuable information device to firm's stakeholder due to two main reasons. First, scientific publications can reflect promising intermediate research outcomes and reduce uncertainty about the success of the R&D program. Considering a timeline, scientific publications could provide information between R&D expenditures as an input factor and the realized inventions represented by patents. Alternatively, in cases where patents and publications derive from one single research project[2], publications may offer additional information with respect to the quality and the novelty of the research outcomes and therefore act as valuable signal for the likelihood that the corresponding patent application gets granted. Since publication in scientific journals requires novelty too, a successful publication may indicate that the novelty requirement is also fulfilled in the patent application, and therefore represent a signal that a positive examiner feedback can be expected. In contrast to the European Union where the patent application has to be filed first to fulfil the novelty requirement, the scientific equivalent can be published 12 months before the patent application in the United States [3]. Second, scientific publications can indicate act as signals concerning the access to external knowledge and the successful diffusion of innovative outcomes. Contributions to the scientific community can serve as entry ticket into informal information channels, indicate capabilities to potential academic collaboration partners (Hicks 1995; Cockburn and Henderson 1998; Simeth and Raffo 2012), or lead to advantages in hiring the best PhD graduates (Stern 2004; Sauermann and

[2] See the literature on "Patent-Paper Pairs" (Murray 2002).

[3] One has to keep in mind that the usual time lags between first submission and acceptance are much shorter in many academic disciplines than in economics or management research, which makes it likely that the scientific equivalent is published before the patent gets granted if the corresponding publication is not submitted much later than the patent application.

Roach 2011). Moreover, the disclosure of outcomes may encourage adoption of science-based products like medical drugs (Polidoro and Theeke 2011) or hamper patenting activities of competitors by establishing new prior art (Parchomovsky 2000; Della Malva and Hussinger 2012) and therefore represent an indirect instrument to appropriate returns from R&D activities.

However, there are also specific costs associated with the publication process which could outweigh the benefits. The most obvious aspects are potential spillover effects which let competitor benefits from the voluntary knowledge disclosure (Arrow 1962). Although a parallel patent application may reduce the threats from spillovers, it is unlikely to prevent additional spillovers completely, particularly if high-quality journals are targeted. High-impact journals should enable stronger signalling benefits but at the expense of fulfilling additional documentation requirements. Moreover, the publication process itself may lead to opportunity costs since the firm researchers have to prepare the documents to fulfil the respective journal requirements, to interact with referees or to codify knowledge that could have remained tacit (see Kinney et al. 2004). In addition, firm scientists that achieve to publish successfully are more visible to other potential employers, which may impose the need for costly retention strategies (see Liu and Stuart 2010; Kim and Marschke 2005).

4 Methodology

4.1 Data sources

Our analysis is based on a sample of large US-American firms from high-technology sectors according to the definition of the OECD. More specifically, we considered the sectors of pharmaceuticals and biotechnology, telecommunication equipment and semiconductors, aircraft, and scientific and medical instruments. Additionally, we also included the chemicals sector since it is often recognized as a science-oriented sector. Our dataset covers the time period 1996-2003 and firms got sampled if they invested into R&D at least in one year during this period[4]. The firm-level information comes from the Compustat US edition, the patent data from EPO PatStat (which includes the entire USPTO collection), and the publication data from Elsevier's Scopus database.

The matching process of the firm-level data with publication and patent information deserves further discussion since name-based matching procedures are potentially subject to errors[5]. To achieve high-recall rates of the publication and patent numbers, we carefully pre-cleaned all firm names by correcting misspellings and removing legal firm identifier ("Inc.", "Corp."). The technical implementation of the publication and patent matching process differed in the sense that scientific publications have been retrieved manually from the Scopus online database whereas the patent data

[4] The period of analysis is determined by data availability constraints, since SCOPUS extended its journal coverage considerably in the year 1996.

[5] See Thoma et al. (2010) for a general discussion on the matching process of firm-level data with other sources.

was matched using an offline source. The former leads to a much more time-consuming gathering process than the "automatic" offline matching, but the latter requires an extensive manual cleaning of the algorithm-based matching results. The manual retrieval from Scopus allowed for a direct inspection of the hits, including an immediate exclusion of incorrect affiliations that are based on institutions with an identical name component, resulting in a highly accurate matching. The offline-matching procedure with patent data from EPO Patstat required specific steps. First, all names were pre-tested online in the EPO Espacenet search module to detect problematic name components. Subsequently, firms with very ambiguous names have either been excluded directly or marked for a detailed manual inspection once the actual matching was executed. Second, after pre-testing several matching algorithms, we could identify a powerful algorithm that achieves a high recall rate while simultaneously limiting false positive hits (see Raffo and Lhuillery, 2009). Afterwards, the resulting matches have been checked manually with particular focus on firms with atypical input-output ratios (i.e. patents/R&D) and those that have been identified in the pre-tests as problematic[6]. In order to provide further evidence on the quality of our patent matching process, we have matched our data also with the Compustat-NBER dataset by Bessen (2009). We performed regressions with the patent numbers based on our matching and the Compustat-NBER matching (see Appendix A.2), and the results are fully consistent with the coefficients almost being identical. Since in the Compustat-NBER matching also considers statically the ownership structure for one period, this exercise provides also evidence that our results are not affected based on the non-consideration of affiliates in our study[7].

To avoid biases that origin from M&A activities, measurement errors and "atypical" firms (e.g. specialized R&D firms with majority of shares owned by business groups), several filters have been applied. First, to limit potential biases from Merger and Acquisitions events, firms with large book value changes were identified based on the criteria of an increase of more than 300% or decrease of 75% between two subsequent years (see also Griliches 1981; Hall and Oriani 2006; Aldieri and Cincera 2009). We dropped only the firm-year observation where the large change occurred and treated the firm in years after the event as new firm (see Mairesse and Griliches 1984). An entire exclusion could lead to a selection bias since M&A activities are likely based on successful R&D operations and knowledge outcomes given that our sample includes only firms from high-technology sectors. In addition, we excluded the top 1% centile of firm-year observations with the most drastic market value changes between two periods. To address particularly potential measurement errors and inaccurate initial knowledge stock computations, we dropped in addition those observations with extremely high (top 1%) knowledge stock/asset ratios[8]. Finally, we excluded firms with an R&D/Sales

[6] A direct download from *EPO Espacenet* was not feasible due to the limited export functions.

[7] An ideal approach would be to consider the affiliation structure of firms in a dynamic manner, i.e. to consider yearly updates. However, this is hardly feasible from a practical viewpoint given the large sample used in our study.

[8] The three measures concerned are R&D/A, PAT/A, PUB/A which are explained in detail in the next section.

ratio>1 and those with less than 10 employees. Based on these filters, the available sample size for our regression analysis decreased from 10,191 to 7,012 firm-year observations[9]. All used financial amounts have been adjusted for inflation using the Gross-Domestic Product (GDP) deflator.

4.2 Variables

To construct our dependent variable, we follow prior work and use the standard "Tobin's Q" indicator, which represents the ratio of the firm's market value over book value. The market value is composed by the market value of the equity plus the market value of the debts. The first is calculated by the number of outstanding shares multiplied by the stock price at the end of the fiscal year whereas the market value of debts is approximated with the book value of liabilities (see Blundell et al. 1999; Hall and Oriani 2006, Ceccagnoli 2009). The firms' book value is represented by the firm's total assets at the end of the fiscal year.

With respect to the independent variables, we computed several indicators in order to represent the firm's knowledge stocks and their heterogeneity. A core measure is the firm's R&D stock which reflects the overall investment into knowledge production and potential future returns. Since knowledge gets obsolete over time due to the on-going technological development and (re-)actions by competing firms, we used the frequently used perpetual inventory method to construct this variable and assume the usual 15% depreciation rate (see e.g. Griliches and Mairesse 1984; Hall 1990). Therefore, the R&D stock as well as the other knowledge stock indicators explained below are computed as follows:

$$R\&D\ STOCK_t = R\&D_t + (1-\delta)R\&D\ STOCK_{t-1} \quad \text{(1a)}$$

Although the computation of the R&D stocks is basically straightforward, one has to make assumptions about the initial R&D stock ($R\&D\ STOCK_{to}$) which remains unobserved to the econometrician. In our study, we apply a standardized growth rate for R&D and the other knowledge stock measures of 8% (Hall and Oriani 2006; Hall et al. 2007)[10]. The initial unobserved R&D stock is approximated as follows[11]:

[9] See Appendices A.3 and A.4 for details on the impact of the filters on the observation numbers and the sample composition.

[10] As an alternative, we computed the initial stocks using a combination of firm-level and industry level growth rates. However, this approach leads partly to extreme values and an extrapolation imposes assumptions about the persistence of trends particularly with respect to the additional patent and publication indicators.

[11] This applies especially to firms that do not have a long pre-sample record in Compustat.

$$R\&D\ STOCK_{to} = R\&D_{t0} / (\delta + g) \qquad (1b)$$

Concerning the firm's inventions, we include several measures that aim to capture the amount of inventive outputs, their scientific orientation, quality and scope. The absolute amount of inventive outcomes is represented by patent stocks (*PAT*). This measure captures the overall dimension of firms' inventive activities but does not reflect any heterogeneity in the inventive output. A core measure on the side of the inventive outcomes is its science orientation (*SCIPAT*). This measure reflects the use of scientific information sources and indirectly the potential to create scientific outcomes which can potentially be published in a scientific format. To proxy the science orientation, we assume that the existence of a scientific document in the backward references of the firm's patents indicates a science-based patent (see also Deng et al. 1999; Della Malva and Hussinger 2012; Chatterji and Fabrizio 2012). We were able to identify scientific documents in the Non-Patent-Literature (NPL) section of the patents' backward references with a high precision using specific keywords and character combinations that have been collected through an extensive screening of the NPL information in the EPO PatStat database. We believe that this variable allows to some extent for a differentiation between the research orientation (i.e. the degree of generic research) and disclosure effects, since it points to generic research outcomes within firms but does not depend on a real contribution to the public knowledge stock, which we measure through the absolute number of scientific publications. Moreover, the quality of the inventive outcomes (*FWDCIT*) is measured using forward citation counts (Hall et al. 2005). To deal with the obvious truncation problems, we considered only those citations that occur within a five-year window after the priority date of our focal patents (Lanjouw and Schankerman 2004; Marco 2007). Finally, we control for the scope of inventive outcomes which reflects the boundaries of the desired patent protection (*CLAIMS*). A broader protection should increase the likelihood that competing firms are negatively affected in their freedom to operate. As a result, an increasing scope should be positively associated with patent quality and is measured by the number of claims (Lanjouw and Schankerman 2004).

Our core interest in this paper lies in the impact of voluntary scientific contributions of firms on their market value. To assess the potential informational value of scientific contributions and their heterogeneity on market evaluation, we construct three measures. First, equivalent to our measure on the amount of inventive outcomes, we capture the amount of scientific contributions by computing a stock measure based on the number of scientific papers published by the firm (*PUB*). Second, to capture the academic quality, we rely on journal impact factor information. Since our sample period captures also relatively recent years and our data does not contain information about the exact citation year, citation analysis cannot be applied due to connected data truncation problems. Instead, we use information about the journal quality. Since the absolute journal impact depends on the field size and journal impact factors are not completely adjusted, we identify the best journals by five scientific disciplines (Life Sciences, Physical Sciences and Engineering, Social Sciences, Health Sciences and General) and take the 10% best journals based on the impact factors within these disciplines. Afterwards, we include a variable that captures the share of scientific publications that belong to those top-journals (*TOPPUB*) and build equivalently to all other knowledge stock measures a separate stock of these publications. Third, we account for academic co-authorship by identifying the share of co-authored publications with academic institutions on all publications (*ACADPUB*). Such a measure captures the degree of connectedness to the scientific community.

Finally, we control for the amount of sales (Hall and Oriani 2006; Belenzon 2011) and include sector and year dummy variables into our models to account for heterogeneous market evaluations across industries and time (see Cockburn and Griliches 1988; Nesta and Saviotti 2006; Hall et al. 2005).

4.3 Model and estimation techniques

In this paper, we analyse the relative market evaluation of firms (Tobin's Q) as a function of their knowledge assets. Following our theoretical discussion, we separate the knowledge stock of firms into R&D investments, inventive, and scientific outcomes. We rely on the classical market value function which is well established in the literature (Griliches 1981; Hall et al. 2005) and which regards tangible (A_{it}) and intangible assets (K_{it}) as additive ("hedonic model"). The function can be formalized as follows:

$$V_{it}(A_{it}, K_{it}) = q_{it}\ (A_{it}\,, \gamma K_{it})^{\sigma} \quad (2)$$

In this equation, q_{it} represents the valuation coefficient of the firm's assets, and the parameter γ in the model allows for a different valuation of knowledge assets in comparison to the physical assets. The valuation coefficient q_{it} may vary across time, industries and also contains a firm-specific component. The factor σ represents scale effects and is assumed to equal one[12] (e.g. Hall et al. 2005). Taking logarithms on both sides and moving tangible assets to the left hand side of the equation yields the following expression:

$$\mathrm{Log}\left(\frac{V_{it}}{A_{it}}\right) = \log Q = \log q_{it} + \log\left(1 + \gamma\frac{K_{it}}{A_{it}}\right) + e_{it} \quad (3)$$

As mentioned above, the knowledge stock of the firm is measured using R&D investment, patent and scientific publication stocks. To examine whether R&D, patent and particularly publication stocks

[12] We tested formally for scale effects by regressing log (Market value) on log (Assets) and industry/time controls, and the coefficient on log (Assets) is 0.98, supporting the assumption of constant scale effects.

lead to heterogeneous market evaluations, we introduce correspondingly our variables as ratios of accumulated knowledge over physical assets into the model, which is formalized in equation (4). From a theoretical point of view, R&D, publication and patents stocks likely represent different stages of knowledge transformations, and scientific and inventive outcomes may not only derive from firm's R&D investments but also through interactions with the environment (see the literature about Open Innovation, Laursen and Salter 2006). Such reliance on external knowledge might only be imperfectly captured by the R&D expenditures of firms. These considerations advocate for including R&D, scientific and patent knowledge stocks independently into the equations and to relate them to the size of the physical assets. An alternative approach to model scientific and inventive outcomes would be to introduce them as stocks denominated by R&D stocks, resulting in an outcome productivity measure (e.g. Hall et al. 2005; Hall and Oriani 2006; Hall et al. 2007)[13].

$$\text{Log}\left(\frac{V_{it}}{A_{it}}\right) = \log Q = \log q_{it} + \log\left(1 + \gamma_1 \frac{RD_{it}}{A_{it}} + \gamma_2 \frac{PAT_{it}}{A_{it}} + \gamma_3 \frac{PUB_{it}}{A_{it}}\right) + e_{it} \qquad (4)$$

In the empirical setting, R&D, PAT and PUB represent the respective stock measures that have been computed using the perpetual inventory method with an assumed depreciation rate of 15%. In addition, we are interested to capture the nature of firm's knowledge stocks in a more detailed way and aim to differentiate between research orientation and direct disclosure effects, which requires further measures. To detect if these additional variables lead to a different market evaluation given the presence of the knowledge stocks of equation (4), we introduce them as ratios that are orthogonal to the main variables. Consequently, the extended model to equation (4) can be written as:

$$Log\left(\frac{V_{it}}{A_{it}}\right) = \log Q = \log q_t + \log\left(1 + \gamma_1 \frac{RD_{it}}{A_{it}} + \gamma_2 \frac{PAT_{it}}{A_{it}} + \gamma_3 \frac{PUB_{it}}{A_{it}} + \gamma_4 \frac{SCIPAT_{it}}{PAT_{it}} + \right.$$
$$\left. + \gamma_5 \frac{FWDCIT_{it}}{PAT_{it}} + \gamma_6 \frac{CLAIMS_{it}}{PAT_{it}} + \gamma_7 \frac{TOPPUB_{it}}{PUB_{it}} + \gamma_8 \frac{ACADPUB_{it}}{PUB_{it}}\right) + e_{it} \qquad (5)$$

As explained in the preceding section, these measures reflect the science orientation of the firm's

[13] Under the assumption that scientific publications and patent represent the same knowledge pieces (see literature on Patent-Paper Pairs, e.g. Murray 2002), scientific publication stocks could also be modelled orthogonally to patents: $\text{Log}\left(\frac{V_{it}}{A_{it}}\right) = \log Q = \log q_{it} + \log\left(1 + \gamma_1 \frac{RD_{it}}{A_{it}} + \gamma_2 \frac{PAT_{it}}{RD_{it}} + \gamma_3 \frac{PUB_{it}}{PAT_{it}}\right) + e_{it}$. However, this would be a rather strong assumption in the absence of systematic empirical evidence on the nature of published and patented outcomes in the private domain. Moreover, even in the case of a sufficient knowledge overlap, there is not necessarily a one to one relationship between patents and publications and one has also to consider the heterogeneity in the propensity to patent not only between but also within sectors.

patents (*SCIPAT/PAT*), their quality (*FWDCIT/PAT*) and the scope of the desired protection (*CLAIMS/PAT*). Concerning scientific outcomes, information about the academic quality of the scientific output (*TOPPUB/PUB*) as well as the connectedness to academic institutions is of interest (*ACADPUB/PUB*).

Whereas the equations (4) and (5) can be directly estimated using Non-Linear Least Squares (NLLS), an approximation with log (1+x) ~ x may allow for applying standard OLS as well as techniques that take the Panel structure of our data explicitly into account. Since the approximation quality depends on the realized values of the independent variables, we tested it explicitly and detected a bias of around 10% at the mean values of our knowledge measures. This makes us believe that the approximation can be used while acknowledging that the reported magnitudes are only of limited precision in the light of the additive market value function[14]. The linearization of the market value function implies to include the knowledge stock variables as log-level specifications into the regression models (see Hirsch and Seaks 1993, for an explicit discussion). Therefore, all knowledge stocks variables are included correspondingly.

A further econometric concern is related to the potential presence of unobserved firm-specific effects. Surprisingly, this aspect has only received little attention in studies which deal with market value estimations (see Griliches 1981; Jaffe 1986; Blundell et al. 1999 for exceptions). The standard specification tests on the linear models suggest that OLS and Random Effect models are indeed inconsistent. Therefore, there is rationale to rely on estimation procedures that take firm-fixed effects into account. However, this is not straightforward in our context due to the potential pre-determination of our variables. To achieve consistent estimates, a "within" estimation strategy requires strict exogeneity of the independent variables, however this assumption might be too strong since market valuations may influence investment decisions into R&D, the patenting behaviour or the scientific openness of firms. Although a sufficiently long time period can mitigate the problem of pre-determined variables, we tested additionally dynamic panel models by means of system-GMM estimators (Blundell and Bond 1998) where we regard our knowledge stock measurements explicitly as pre-determined or endogenous and adapted the instrument lags correspondingly. Unfortunately, the model specification tests rejected the validity of the instrument sets which prevented us to report these regression outputs. Consequently, we focus on non-linear and linear estimations that use the cross-section variance and additionally on "within" and non-dynamic first-difference estimations.

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[14] Hall and Oriani (2006) tested also the appropriateness of the approximation and found that it is not problematic if the R&D stock/Asset ratios do not exceed the value of 1, which applies to 85% of the firm-year observations in our sample. Afterwards, the non-linear estimation strategy can be somewhat superior.

4.4 Descriptive statistics

In Table 1, we provide an overview about the mean and median values as well as standard deviation of the regression variables and additional measures that are informative to describe firm characteristics. Since all firms are stock-market listed, the sample consists predominantly of medium and large sized firms. However, the median values suggest a considerably heterogeneity among our sample firms. The median values are 7.43 million USD for the annual R&D expenditures, 73.89 million USD for sales and 334 for the number of employees whereas the mean values are much higher, indicating both the presence of very large but also medium sized and small firms. Overall, our sample firms account for more than 40% of all business R&D expenditures in the United States[15]. With respect to the firm's Tobin's Q, the average ratio is quite high with 2.64, whereas in 15.5% of the firm-year observations, the market valuation is below the book value.

-- Insert Table 1 about here --

Trends of publication outcomes within the sample period are shown in Table 2. The share of publishing firms increases from 40% in the year 1996 to 50% in 2003. This share is only marginally lower than the percentage of patenting firms, which reaches 61% in the year 2003. When considering both patenting and publishing simultaneously, it can be seen that both output types are complementary since a majority of publishing firms in a given year also files a patent application. However, 29% of the firms do neither patent nor publish in the year 2003. With respect to aggregated output numbers of our sample firms, the total number of patents increases considerably over time from 16,443 in 1996 to 26,378 in 2003, while the total publication output stagnates. Although the patent numbers exceed the publication outputs by the factor 2 in the year 2003, the publication amounts can nevertheless be regarded as impressive given that firms are by mission not concerned with contributions to the stock of scientific knowledge as sake of its own.

-- Insert Table 2 about here --

In Table 3, we display the bivariate correlations of our regression variables. Not taking multivariate interactions into account, we see a moderate positive correlation between all knowledge stock measures and the firm's Tobin's Q. The parallel inclusion of R&D, patent and publication stocks

[15] This percentage is based on the reference year 2005. The business sector R&D includes both manufacturing and service sectors and amounts to 226,159 Mio USD (see OECD 2011, page 46).

may raise concerns about multi-collinearity. Not surprisingly, we find notable but not problematic correlations ranging from 0.28 to 0.37 between our core measures R&D/A, PAT/A, and PUB/A.

-- Insert Table 3 about here --

Stronger concerns may arise from the variables that are additionally used in the extended model. The patent (publication)-based measures share those zeros that are originating from zero patent (publication) stocks, which implies by construction some correlation. Consequently, we detect relatively high correlations between publications with academic co-author and top-journal publications (0.62) or between science-based patents and broader patent scope (0.48). In the former case, one can also assume a positive impact of co-authorship with academic institutions on academic quality (see also Simeth and Lhuillery 2012). Despite these relative high correlations between some explanatory variables we believe, also thanks to the size of our dataset, that we can still provide valid statements on the impact of these measures.

5 Econometric results and discussion

5.1 Main models

The results of our econometric analysis are depicted in Table 4. Following our considerations in the preceding section, we have estimated the Tobin's Q both with non-linear and linear regression models. When comparing the non-linear with the equivalent linear models, it is visible that the tendencies with respect to signs and significant variables are very consistent, which is in line with our argument that the linearization of equation (4) is a valid approximation and can therefore be used. In the columns 1-5, we estimate the baseline specification using NLLS, OLS, fixed effects ("within" and "first-difference") and random effects estimators. Whereas the standard specification tests propose that random effects and OLS regressions are inconsistent, the results of all estimation procedures are very similar. With the exception or R&D stocks in the NLLS estimation, the three knowledge stock measures representing R&D (*R&D/A*), patent (*PAT/A*) and publications (*PUB/A*) stocks have a significant and positive effect on the Tobin's Q indicator. This robust finding across all estimation procedures provides a first indication that scientific publications indeed provide additional information to the shareholder of firms.

-- Insert Table 4 about here --

In order to obtain a more detailed picture, we introduce our additional measures that aim to capture the heterogeneity of scientific and inventive outcomes. In columns 6-10, we added them first independently to the baseline specifications using the NLLS estimator. It can be seen that all measures provide additional information and are all positive and significant. Not only the main patent stock variable continues to show a positive and significant impact but also the publication measure is relatively stable. Specifically, publication stocks (*PUB/A*) remain significant at the 5% level when controlling for patent quality (*FWDCIT/PAT*), patent scope (*CLAIMS/PAT*) or science-based patents (*SCIPAT/PAT*). However, when including the additional publication measures that reflect the heterogeneity of scientific outcomes, the main effect gets weaker and turns insignificant in model (9). The positive and significant impact of publications in top-journals (*TOPPUB/PUB*) and those co-authored with academics (*ACADPUB/PUB*) propose that there is heterogeneity in the informational value of publications for firms' shareholders.

In columns 11-14, we display the regression results with the full variables set using NLLS, OLS, and fixed effect estimators. Starting with the models not accounting for firm-fixed effects, it can be seen that R&D stocks (*R&D/A*), patent stocks (*PAT/A*) and patent quality (*FWDCIT/PAT*) are found to be significant which is in line with the findings of previous studies (e.g. Hall et al. 2005). However, publication stocks (*PUB/A*) are not significant anymore in model (11) but only the additional measure of publications in top-journals (*TOPPUB/PUB*). When testing the two measures for joint significance, the Null-hypothesis of a zero-impact is rejected at the p-value 0.025. This suggests that there is still an impact of scientific contributions on the Tobin's Q indicator while controlling for the nature of inventive outcomes and R&D. However, in the specifications that take firm-fixed effects into account, the main effect (*PUB/A*) is positive and significant beyond the effect of R&D, patent stocks and patent quality but publications in top-journals do not provide any premium. Hence, while overall the estimation models are consistent in suggesting a positive and significant effect of scientific publication stocks, the alternative estimation procedures suggest some subtle differences depending if they take the cross-section variance into account or not. In other words, publication quality seems to matter for the determination of differences in the market evaluation across firms whereas the publication quality does not matter when controlling for unobserved firm-specific characteristics (like potentially relatively time-invariant research capabilities) but the absolute amount of scientific contributions. Interestingly, the relative stock of science-based patents does not provide much information in the full specification anymore.

Following our discussion in section 3, the questions arise whether the found effects represent (i) an impact of generic research or the disclosure itself (ii) signalling benefits to academic audiences or the use of publications as appropriation device like in the case of defensive publication. Unfortunately, we cannot provide detailed insights concerning these mechanisms but only provide some indications that have to be treated cautiously. Our measure that captures science-based patents (*SCIPAT/PAT*) is not significant in the full variables specifications, suggesting that our regression results reflect mainly a positive impact of the disclosure. Admittedly, this measure can only serve as proxy since it can indicate scientific activities without observing active scientific contributions, but is on the other hand based on observed inventive outcomes. With respect to the second question, our results suggest that both aspects could be valid. As mentioned in the previous paragraph, the absolute amounts have an impact in the fixed effect models but not the quality of the scientific contributions or the connectedness to academic institutions, providing some support for the appropriation aspect. Given the limitations of our measures, we have to leave more detailed insights on the underlying drivers to future research. In fact, even the found effect on patents leaves space for interpretation. It could either reflect the successful creation of inventive outcomes or the protection of these outcomes based on the granted patent right. This ambiguity is not straightforward to address, even with additional measures to reflect patent scope, since they may also reflect both mechanisms. In our regressions, the corresponding variable (*CLAIMS/PAT*) is found to have surprisingly little impact when controlling simultaneously for patent quality. In addition, we tested interaction-effects between publication and patent stocks (*PUB/A* x *PAT/A*) as well as between publication stocks and science-based patents (*SCIPAT/PAT* x *PUB/A*), but there is no indication of a complementary or substitutionary relationship of these measures with respect to the Tobin's Q valuation[16].

With respect to our estimation strategy in general, our relatively consistent regression results indirectly indicate that there is no tremendous bias originating from pre-determined variables and firm-fixed effects. However, one may still be concerned about unobserved time-varying factors that are correlated with the error term and our explanatory variables. As mentioned in the methodology section, we tested dynamic panel specifications using appropriate lags of our independent variables as instruments. Unfortunately, we could not obtain valid estimates due to problems with second-order autocorrelation and lags of explanatory variables that turned out being invalid instruments. Therefore, we could not address potential endogeneity sufficiently and acknowledge corresponding concerns. Nevertheless, although our results are not conclusive and conditional upon further validation and robustness tests, we believe that our findings provide a valuable first indication about an additional impact of scientific publication stocks on the firms' market valuation beyond the effects of R&D, patents and patent quality.

5.2 Robustness tests

In order to test the robustness of our results and to detect heterogeneous impacts of the knowledge asset variables on the Tobin's Q indicator, we performed several robustness tests. These include flow

[16] Results available upon request.

instead of stock measures, alternative functional forms or dynamic Panel models. We did not detect notable differences or had concerns with respect to the validity of our findings (e.g. when modelling both patent and publication stocks orthogonally to R&D) and consequently do not report them. In the following, we focus on subsample regressions distinguishing (i) the three most important meta-sectors, (ii) firm size, (iii) sub-periods, and (iv) alternative knowledge depreciation rates. The relative differences between the subsample regressions are not found to be very sensitive on the estimation procedure and therefore, we display and comment the results of the NLLS estimations in Table 5.

-- Insert Table 5 about here --

First, we run separate regressions with the three meta-sectors biotechnology & pharmaceuticals, ICT's, and instruments as reported in the columns (1)-(3). We find some differences of the impact of knowledge assets on the Tobin's Q indicator. R&D stocks (*R&D/A*) are found to have a positive and significant impact in the pharmaceutical and instrument sectors but not in the ICT domain. However, patent stocks (*PAT/A*) are strongly significant and with a remarkable magnitude in ICT but less in the other sectors, with patent stocks not being significant for pharmaceuticals and only at the 10% level for instruments. These results suggest that R&D investments are a highly uncertain predictor for future commercial success in ICT's, whereas patent protection clearly provides a positive signal to the shareholders. With respect to scientific publications *(PUB/A)*, we only see a positive and significant sign for scientific and medical instruments. Interesting is the finding that publication stocks do not seem to be a predictor for market value in the pharmaceutical sector. This sector is traditionally regarded as science-based, with close interactions between firms and universities and some firms being on the frontier of science. The result could point to a limited informational value of scientific publications given the extensive publication activity in this sector and a relatively focus on publishing fundamental research which is more uncertain with respect to future commercial returns.

Second, we distinguish between small and large firms based on the median workforce number (312 employees). In the subsample with the small firms, R&D and patent stocks are positive and significant at the 1% level while publication stocks are significant on the 10% level. In the sample with the larger firms, R&D stocks are not significant anymore and even have a negative sign, whereas both patent and publications stocks have a positive sign but only the publication variable is significant at the 1% level. Given the evidence provided by earlier work that firms signalling scientific capabilities achieve higher IPO placement amounts (Higgins et al. 2009), the result of a larger impact for larger firms is somewhat surprising.

Third, we split our sample according to an early (1996-1999) and late (2000-2003) period. Although the two sub-periods are relatively short, a difference in the evaluation of knowledge assets would not be surprising given the "Dot-Com" Hype in the late 1990s years and the subsequent consolidation. Interestingly, our results propose that the impact of R&D declines, while we do not find a difference in our publication measure which is in both sub-periods positive and significant.

Fourth, we tested alternative knowledge depreciation rates with 10% and 25%. The results reported in the columns (8) and (9) do not indicate notable differences with the exception that R&D gets significant if a higher rate of 25% is assumed. Overall, these robustness tests indeed suggest some heterogeneity concerning the impact of scientific publication stocks but not with respect to every dimension. In particular the results of our tests suggest some sector differences.

6 Conclusion

This study examines the impact of scientific activities of firms on their market evaluation. Although scholars have started to address the determinants of scientific disclosure, there is very little evidence on the payoffs and performance effects of scientific openness strategies. We address this gap and provide novel empirical evidence using a rich dataset with firm-level information for US-American high-tech companies and matched scientific publication and patent data. Our analysis is not conclusive, but the econometric results suggest that scientific contributions provide a positive effect on the stock market value of firms beyond the impact of R&D, patents and patent quality. Thanks to our comprehensive set of variables that captures the heterogeneity of scientific and inventive outcomes, we find also some indication that the positive effects of scientific contributions may not only represents benefits of doing generic research (like obtaining superior absorptive capacities) but at least partially reflect benefits that are based on the disclosure itself.

It has to be stressed that our results have to be interpreted cautiously since our measures do not allow for separating the underlying cause-effect mechanism. Moreover, we could not address endogeneity concerns with respect to unobserved time-varying factors. However, given that we controlled for several characteristics of inventive outcomes and the application of alternative estimations procedures, our results provide a first indication that scientific disclosure offers some information to the stock market. If this finding is found to be robust in further validation, it represents an important insight for managers in firms, since it indicates that scientific openness strategies can indeed be valuable. It could encourage managers to consider corresponding openness approaches (e.g. to grant all scientists the right to publish) which would be desirable from a social welfare point of view since many technologies and innovations are of a cumulative nature. However, our analysis also suggests that the impact of scientific contributions is heterogeneous depending on the firm's context as some of our subsample regressions suggest. In future versions of this paper, we intend to extend the sample period by two years due to the consideration of updated patent data, further attempts to address endogeneity concerns, and additional robustness tests.

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Table 1: Summary statistics

Variable	N	Mean	Std. Dev.	Median	Min	Max
TOBINS Q	7,012	2.64	3.03	1.79	0.26	96.73
A (BOOK VALUE)	7,012	1453.86	7138.22	82.91	0.55	273007.30
R&D EXP	7,012	93.89	417.13	7.43	0.00	12942.19
R&D STOCK	7,012	447.81	1855.52	35.72	0.00	30878.81
R&D/A	7,012	0.61	0.72	0.38	0.00	7.47
PATSTOCK	7,012	114.61	534.93	5.65	0.00	10012.23
PAT/A	7,012	0.17	0.33	0.06	0.00	3.13
SCIPAT/PAT	5,346	0.38	0.31	0.33	0.00	1.00
FWDCIT/PAT	5,346	7.19	6.25	5.88	0.00	81.63
CLAIMS/PAT	5,346	20.12	8.79	18.96	1.00	102.00
PUBSTOCK	7,012	66.15	330.24	1.55	0.00	5814.05
PUB/A	7,012	0.09	0.23	0.01	0.00	2.63
TOPPUB/PUB	4,359	0.30	0.31	0.24	0.00	1.00
ACADPUB/PUB	4,359	0.35	0.33	0.30	0.00	1.00
SALES	7,012	1170.28	5011.15	73.89	0.50	77613.83
EMPLOYEES	6,892	4016.29	14272.49	334.00	10.00	238000.00

financial amounts in Mio USD (2005, GDP deflated)

Table 2: Publication trends over time

Year	1996	1997	1998	1999	2000	2001	2002	2003
Perc. Patenting firms	50%	53%	55%	57%	57%	60%	60%	62%
Perc. Publishing firms	40%	41%	42%	44%	43%	43%	45%	50%
… only publishing	9%	9%	10%	9%	8%	6%	8%	10%
… patenting & publishing	31%	32%	32%	35%	34%	38%	37%	41%
… only patenting	19%	21%	24%	22%	23%	22%	23%	21%
… neither pat./publ.	41%	38%	35%	34%	34%	34%	32%	29%
Observations per year	*925*	*949*	*939*	*864*	*830*	*851*	*844*	*810*
Total Publications	12,506	12,704	12,393	11,132	10,646	10,277	11,345	13,277
Total Patents	16,443	20,482	20,347	20,426	23,389	25,880	27,136	26,378

Table 3: Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) LTOBIN'S Q	1												
(2) R&D/A	0.105	1											
(3) PAT/A	0.126	0.321	1										
(4) PUB/A	0.137	0.280	0.372	1									
(5) PAT/R&D	-0.014	-0.057	0.173	0.074	1								
(6) PUB/R&D	0.002	-0.052	0.082	0.277	0.614	1							
(7) FWDCIT/PAT	0.130	0.039	0.184	0.018	0.017	-0.020	1						
(8) SCIPAT/PAT	0.176	0.084	0.180	0.259	0.057	0.094	0.266	1					
(9) CLAIMS / PAT	0.112	-0.003	0.239	0.101	0.056	0.032	0.462	0.476	1				
(10) TOPPUB/PUB	0.198	0.072	0.132	0.311	0.021	0.104	0.032	0.363	0.205	1			
(11) ACADPUB/PUB	0.156	0.062	0.126	0.227	0.029	0.097	0.105	0.325	0.253	0.621	1		
(12) SALES	0.051	-0.092	-0.064	-0.043	-0.014	-0.012	0.044	0.063	0.042	0.105	0.048	1	
(13) EMPLOYEES	0.020	-0.114	-0.072	-0.053	-0.015	-0.015	0.032	0.046	0.040	0.115	0.051	0.909	1

Table 4: Regression outputs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
LOG TOBIN'S Q	NLLS	OLS	WITHIN	FD	RE	NLLS	NLLS	NLLS	NLLS	NLLS	NLLS	OLS	WITHIN	FD
	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)	Coeff (SE)
R&D/A	0.026	0.044***	0.026*	0.065***	0.027**	0.040*	0.028	0.038*	0.026	0.027	0.039*	0.041***	0.027*	0.065***
	(0.020)	(0.016)	(0.014)	(0.017)	(0.010)	(0.021)	(0.020)	(0.021)	(0.019)	(0.020)	(0.021)	(0.016)	(0.014)	(0.021)
PAT/A	0.182***	0.161***	0.087**	0.102**	0.142***	0.122**	0.165***	0.141**	0.186***	0.182***	0.127**	0.114***	0.090**	0.103*
	(0.056)	(0.042)	(0.039)	(0.046)	(0.025)	(0.057)	(0.057)	(0.056)	(0.056)	(0.056)	(0.057)	(0.041)	(0.039)	(0.053)
PUB/A	0.175**	0.142***	0.168***	0.162***	0.146***	0.174**	0.146**	0.171**	0.093	0.123*	0.098	0.088*	0.164***	0.157**
	(0.072)	(0.054)	(0.047)	(0.059)	(0.034)	(0.073)	(0.072)	(0.074)	(0.071)	(0.070)	(0.071)	(0.052)	(0.047)	(0.067)
FWDCIT/PAT						0.013***					0.010***	0.007***	0.006***	0.004
						(0.002)					(0.003)	(0.002)	(0.002)	(0.003)
SCIPAT/PAT							0.132***				0.009	0.012	-0.027	-0.011
							(0.039)				(0.043)	(0.036)	(0.033)	(0.045)
CLAIMS/PAT								0.004***			0.000	0.000	-0.002*	-0.001
								(0.001)			(0.001)	(0.001)	(0.001)	(0.001)
TOPPUB/PUB									0.227***		0.161***	0.123**	0.035	0.027
									(0.050)		(0.060)	(0.049)	(0.039)	(0.047)
ACADPUB/PUB										0.173***	0.064	0.044	-0.028	0.009
										(0.042)	(0.052)	(0.042)	(0.032)	(0.040)
SALES	0.009***	0.033***	0.064***	0.056***	0.024***	0.007***	0.008***	0.008***	0.007***	0.008***	0.006***	0.020***	0.064***	0.055***
	(0.002)	(0.006)	(0.013)	(0.016)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.006)	(0.013)	(0.018)
CONSTANT	0.767***	0.567***	0.908***	0.255***	0.667***	0.727***	0.753***	0.724***	0.757***	0.762***	0.720***	0.612***	0.903***	-0.181***
	(0.049)	(0.048)	(0.061)	(0.013)	(0.225)	(0.048)	(0.041)	(0.046)	(0.041)	(0.040)	(0.038)	(0.047)	(0.062)	(0.016)
INDUSTRY CONTROLS	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
TIME CONTROLS	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm-Year observations	7,012	7,012	7,012	5,370	7,012	7,012	7,012	7,012	7,012	7,012	7,012	7,012	7,012	5,370
Firm-IDs (cluster)	1,568	1,568	1,568	1,294	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,294
R2	0.158	0.164	0.114	0.173	0.157	0.171	0.162	0.164	0.167	0.165	0.179	0.180	0.116	0.172

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 5: Robustness tests

LOG TOBIN'S Q	(1) Pharma NLLS Coeff (SE)	(2) ICT NLLS Coeff (SE)	(3) Instrum. NLLS Coeff (SE)	(4) Small firm NLLS Coeff (SE)	(5) Large firm NLLS Coeff (SE)	(6) Early Per. NLLS Coeff (SE)	(7) Late Per. NLLS Coeff (SE)	(8) D 25% NLLS Coeff (SE)	(9) D 10% NLLS Coeff (SE)
R&D/A	0.187***	-0.019	0.051	0.072***	-0.030	0.053*	0.009	0.057**	0.016
	(0.063)	(0.021)	(0.038)	(0.024)	(0.049)	(0.029)	(0.020)	(0.028)	(0.016)
PAT/A	-0.039	0.311***	0.142*	0.254***	0.013	0.212***	0.161**	0.281***	0.144***
	(0.164)	(0.097)	(0.075)	(0.071)	(0.088)	(0.061)	(0.068)	(0.075)	(0.047)
PUB/A	0.078	0.012	0.377***	0.141*	0.430***	0.140*	0.166*	0.174**	0.155**
	(0.139)	(0.082)	(0.144)	(0.083)	(0.146)	(0.084)	(0.091)	(0.086)	(0.062)
SALES	0.013***	0.007*	0.012	1.214***	0.008***	0.010***	0.007***	0.009***	0.009***
	(0.003)	(0.004)	(0.008)	(0.377)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
CONSTANT	0.697***	0.793***	1.177***	0.661***	0.759***	0.680***	0.745***	0.766***	0.769***
	(0.060)	(0.133)	(0.081)	(0.042)	(0.041)	(0.056)	(0.037)	(0.049)	(0.049)
INDUSTRY CONTR.	yes	yes	yes	yes	yes	yes	yes	yes	yes
TIME CONTROLS	yes	yes	yes	yes	yes	yes	yes	yes	yes
Firm-Year observations	1,390	3,082	2,410	3,502	3,510	3,677	3,335	7,012	7,012
Firm-IDs (cluster)	335	685	523	966	792	1,247	1,086	1,568	1,568
R2	0.207	0.150	0.135	0.175	0.203	0.153	0.184	0.160	0.157

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix A.1: Key literature on the impact of knowledge assets on firm value

	Knowledge measures					
Study	**R&D**	**Patents**	**Patent quality**	**Further distinctive elements (variables, scope, estimation strategy)**	**Sample size**	**Period**
Griliches (1981)	Yes	Yes	No	Within estimation	1,091	1968-1974
Jaffe (1986)	Yes	Yes	No	Technological position, spillovers	432	1973-1979
Hall et al (1993)	Yes	No	No	Advertisting expenditures	24,333	1973-1991
Cockburn and Griliches (1998)	Yes	Yes	No	Appropriability and sector effects	722	1980
Blundell et al. (1999)	No	Yes	No	Innovation stock, industry-level variables	3,511	1972-1982
Deng et al. (1999)	Yes	Yes	Yes	Science-based patents	388 firms (obs. not reported)	1985-1995
Bloom and Van Reenen (2002)	No	Yes	Yes	Market uncertainty	2,138	1968-1996
Lanjouw and Schankerman (2004)	Yes	Yes	Yes	Several patent quality measures; productivity and demand equation	11,464	1980-1993
Hall et al. (2005)	Yes	Yes	Yes	Patent citations	12,188	1963-1995
Hall and Oriani (2006)	Yes	Yes	No	European patents	2,156	1989-1998
McGahan and Silverman (2006)	Yes	Yes	Yes	Competitor spillovers	24,815	1981-1999
Hall et al. (2007)	Yes	Yes	Yes	European patents, quality index	5,312	1991-2002
Ceccagnoli (2009)	Yes	No	No	Appropropriability measures (incl. patent effectiveness)	330	1991-1993
Belenzon and Patacconi (2010)	No	Yes	No	Scientific Publications; Merger &Aquisition context	33,920	1985-2007
Sandner and Block (2011)	Yes	Yes	Yes	Trademarks	6,757	1996-2002
Our study:	Yes	Yes	Yes	Scientific publications, heterogeneity of scientific & inventive outcomes and firms	7,012	1992-2003

Appendix A.2 Comparing own matching outcome with NBER-benchmark

LOG TOBIN'S Q	(1) NLLS Coeff (SE)	(2) NLLS Coeff (SE)	(3) OLS Coeff (SE)	(4) OLS Coeff (SE)
R&D/A	0.026	0.024	0.044***	0.043***
	(0.020)	(0.018)	(0.016)	(0.016)
PAT/A	0.182***		0.161***	
	(0.056)		(0.042)	
PATNBER/A		0.188***		0.155***
		(0.062)		(0.048)
PUB/A	0.175**	0.193***	0.142***	0.158***
	(0.072)	(0.072)	(0.054)	(0.055)
SALES	0.009***	0.009***	0.033***	0.032***
	(0.002)	(0.002)	(0.006)	(0.006)
CONSTANT	0.767***	0.778***	0.567***	0.584***
	(0.049)	(0.054)	(0.048)	(0.050)
INDUSTRY CONTR.	yes	yes	yes	yes
TIME CONTROLS	yes	yes	yes	yes
Firm-Year observations	7,012	7,012	7,012	7,012
Firm-IDs (cluster)	1,568	1,568	1,568	1,568
R2	0.158	0.157	0.164	0.163

Robust standard errors in parentheses;
*** p<0.01, ** p<0.05, * p<0.1

Appendix A.3: Data cleaning

Data cleaning and stepwise filters	N
Total observation number for regression analyis, period 1996-2003	10,191
Firms with atypical (negative) equity values	824
Excluding firms with ambiguous matches (patents, publications)	364
Filter for M&A (firm-year-obs. with annual book value change >300% or -75%	127
Extreme changes in Market value (1%)	68
Excessive R&D/A, PAT/A, PUB/A ratios (1%)	216
Small firms (<10 employees) and firms with Sales < 500.000 USD	608
Firms with R&D/Sales ratio > 1	972
Final sample size	7,012 (69%)

Appendix A.4: Observations by included sectors

Meta-Sector	SIC included	Firm-year observations
Biotechnology & Pharmaceuticals	2834, 2835, 2836	1,116
Chemicals	2800, 2810, 2820, 2821, 2833	274
Telecommunication equipment & Semiconductors	3570, 3571, 3572, 3575, 3576, 3577, 3578, 3579, 3661, 3663, 3669, 3670, 3672, 3674, 3677, 3678, 3679, 4812, 4813, 4822	3,082
Aircraft & Aerospace	3721, 3724, 3728	130
Navigation, Scientific, Medical, Optical instruments	3812, 3822, 3823, 3824, 3825, 3826, 3827, 3829, 3841, 3842, 3843, 3844, 3845, 3851, 3861	2,410
Sum		7,012