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Back to Basics: Heterogeneity in Scientific Disclosure and Firm Value in the Semiconductor Industry

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Abstract

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Keywords: Corporate science, firm value, semiconductors

1. Introduction

Research and Development (R&D henceforth) stands at the core of corporate competitiveness and sustainable growth (Aghion et al., 2008; Rosenberg, 1990; Schumpeter, 1942, 84). R&D entails heterogeneous activities, ranging from the fundamental questioning of natural phenomena to the application of scientific knowledge for the development of new materials, processes or product/services, each having definite peculiarities with respect to the nature of activities carried forward and the norms regulating the functioning of the respective communities (Dasgupta and David, 1994).

In particular, Research proves to be a problematic activity to be performed within firms. It is an uncertain activity whose results can fall beyond the scope of the firms' businesses (Nelson, 1959). The results of Research can be used from other parties at little cost, resulting in appropriability problems for the performing firms (Arrow, 1963). Moreover, embedding research results in new products and processes, finally, is a lengthy process which firms might not be prepared to undertake (Rosenberg, 1990).[1] Therefore, firms focus on development activities and seek control on the diffusion of their invention through secrecy or patent protection, leaving research mostly confined within the realm of Science, regulated by a set of incentives based on the open publication and diffusion of research results (Dasgupta and David, 1994).

Despite the costs associated to information leakage and risks of imitations arising from the open disclosure of scientific knowledge, there is evidence of corporate scientists actively contributing to the pool of public knowledge through publications in scientific journals; and the contribution is non-trivial. Examples span from firms such as IBM, Intel, Siemens, Xerox among

[1] According to the National Science Board (2014), For instance, businesses were responsible of 69.3% of the US's R&D expenditures in 2011, amounting to 263 billion USD (National Science Board, 2014). Expectedly, only 20% of national basic research was financed by the business sector, most of which is indeed run in public laboratories. Businesses are responsible for 87.6%, 57.3%, and 17.4% of investment in respectively development, applied research, and basic research.

others managing and distributing corporate journals to corporate scientists actively participating at international conferences and submitting articles to peer-reviewed journals (Penin, 2007).

In this paper, we set out to quantify the effect of corporate involvement in the publication of research results in scientific journals on the valuation of the firms' intangible assets. On one hand, engaging in science critically contributes to the knowledge base of the firm (Cassiman, Veugelers, & Zuniga., 2008; Cockburn and Henderson, 1998; Klevorick, Levin, Nelson, & Winter, 1995), enabling more efficient innovation and concordant first-mover advantages (Fabrizio, 2009; Fleming & Sorenson, 2004; Rosenberg, 1990). It also allows firms to better monitor, identify, absorb, and integrate external sources of knowledge (Arora and Gambardella, 1994; Cohen & Levinthal, 1990). On the other hand, the decision to publish research results in a scientific format is a strategic choice which implies costs associated to the loss of control on the disclosed contents. [2] Scholars have highlighted several potential benefits from publishing (Pénin, 2007). In particular, scientific publications generate a strategic signal that firms perform rigorous research and adhere to the scientific norms of openness (Cockburn & Henderson, 1998; Gans, Murray, & Stern 2013; Hicks, 1995); this proves especially useful to persuade academic scientists to collaborate with them (Ding, 2011; Gittelman & Kogut, 2003; Cockburn & Hendserson, 1998; Perkmann, King, & Pavelin. 2011; Zucker, Darby, & Armstrong 2002).[3] More generally, allowing R&D workers to publish research findings can be an effective way to attract and motivate academically trained researchers (Sauermann & Roach, 2014; Stern, 2004; Roach & Sauermann, 2010). Despite bridging with the academic community, corporate involvement in scientific publications can influence the direction of innovation activities among third parties. It

[2] A recent contribution by Bhaskarabhatla & Hegde (2014) shows how IBM adopted a pro-patent policy which discouraged publishing, stressing how publishing is a strategic decision rather than the genuine outcome of research activities.
[3] Within an IP framework, publications can prevent third parties from obtaining intellectual property rights by creating prior art (Baker & Mezzetti, 2005; Della Malva & Hussinger, 2012)

can increase the understanding of in-house technologies and thus facilitate the supply of complementary goods (De Fraja, 1993; Harhoff, 1996). Scientific publications can also be used to slow down innovation among competitors, as in the case of network goods (Pacheco-de-Almeida & Zemsky, 2012), or inform stakeholders about the nature of novel technologies (Polidoro & Theeke, 2012).

We follow an established tradition in the estimation of the value of intangible assets and knowledge capital within the framework of a market value setting (Griliches, 1981; Jaffe, 1986). Existing contributions have focused on investments in R&D, and patents as measure of the knowledge capital of the firm, later incorporating patent citation indicators to correct for expected commercial value (Hall et al., 2005; Belenzon, 2012). In this respect our study extends this line of research to include corporate articles in scientific journals as novel form of knowledge assets, in line with the recent study by Simeth and Cincera (2013). From a scholarly point of view, much of the discussion so far has rested on the assumption that Science, and the outcome published in journals, are basic; whereas a considerable bulk of scientific activities covers investigations which are closer to applications (Kline and Rosenberg, 1986).[4] Therefore, we additionally examine the heterogeneity in the nature of the knowledge disclosed in publications by examining how basic and applied science respectively affect the stock market valuation of the firms.[5] The two types of publications report findings which vary in their generalizability as well as applicability. Specifically, with the first, we refer to a quest for understanding the fundamental aspects of phenomena and observable facts without specific immediate commercial applications

[4] Previous studies have mostly distinguished between "Research" and "Development" and operationalized the first with scientific publications and the second with patents.

[5] Stokes (1997) provides an alternative classification along two definitions: whether the research aims to contribute to fundamental understanding, and consideration of use. The intersection of these two dimensions, also referred to as Pasteur's Quadrant, defines basic research with clear immediate applications.

in mind, whereas by the latter we imply the systematic study to gain knowledge to determine the means by which a recognized and specific need may be met (NSF, 2009).[6]

Our empirical analysis is based on the semiconductor industry in the United States over almost three decades (1980 to 2007). As many previous studies have focused on the life sciences, the semiconductor industry makes for an interesting case. While scientific discoveries play a direct role in new product development in the former, science serves a more indirect role in the latter by providing a map to maneuver a complex landscape of technological possibilities (Fleming & Sorenson, 2004). The semiconductor sector is further characterized by high levels of R&D expenditures and high propensity to scientific publishing (Lim, 2004), and a strong reliance on scientific discoveries for fundamental technological progress (Breschi & Catalini, 2010; Cohen, Nelson, & Walsh, 2002). We infer scientific output through publications in Thompson Reuters Web of Science, and make use of the journal classification in use at the National Science Foundation to tell apart basic and applied research outputs (Hamilton,2003).

In line with earlier evidence (Simeth & Cincera, 2013), we find that scientific publications associate positively to the valuation of firms' intangible assets, highlighting the positive role of corporate engagement in scientific publishing for performance. Moreover, the results indicate that the supposed positive association is driven by publications in basic journals, while publications in applied research do not show a significant effect. We then investigate two possible drivers of this positive relationship: basic science contributing to better inventions, and basic science attracting inventors from Academe. While we cannot formally test which explanation holds using our data,

[6] Notwithstanding alternative definitions of basic and applied science such as the one provided by the OECD (2012), we report the one by National Science Foundation (NSF) as our operationalization of articles in basic and applied journals is based on the latter.

the preliminary evidence provided in this article speaks in favor of basic publications as signal of rigorous research environment to academic inventors.

The remainder of this paper is structured as follows. Section two sheds light on the specific nature of science and publishing practices in the semiconductor industry. Section three expands on the econometric methodology, after which section four describes the data and variables. Section five presents the empirical results, and section six concludes with a discussion of our results.

2. Science in the Semiconductor Industry

To understand the science-value relationship, it is important to understand the role of science in the sector. Much of the empirical research on the importance of science for innovation is confined to the pharmaceutical sector (i.e. Leten et al. 2013; Cockburn and Henderson, 1998), where the traditional linear model of innovation applies, science can be considered a prerequisite for any applied research or product development. The semiconductor sector has developed in a more cumulative fashion, with a strong role played by experimentation in theory testing and several components and equipment developed by a multitude of firms in parallel research lines. This is characterizing of research in complex technologies, where applied research and basic research tend to be highly intertwined and basic research rather offers a more accurate appraisal of applied findings (Rosenberg, 1990). In the accounts of the development of copper interconnects, Lim (2009) illustrate the intertwining of basic and applied research. When IBM researchers tried to replace aluminum with copper, they found that electroplating created the most pure devices, even though this method was the most counterintuitive from a theoretical perspective. The development of copper interconnects was taken further by researchers at Cornell University who used data generated by IBM.

Despite the pervasiveness of application-oriented research, semiconductor firms have critically contributed to the fundamental understanding of conductivity (Langlois and Steinmuller, 1999; Lim, 2004): companies such as AT&T, IBM, GE, and Texas Instruments have had Nobel laureates among their employees. Basic research in semiconductors has backed fundamental shifts in dominant designs and production processes throughout the whole industry. One pertinent and timely example is the development of the blue light-emitting diodes (LEDs), which started with the discovery that indium gallium nitride (InGaN) was more efficient in reflecting short-length waves than zinc selenide (ZnSe), the current standard at the time. Leveraging on intuitions from Material Science, Nakamura from Nichia Corporation developed a process to use InGaN for mass production of blue LED and demonstrated its superior performance with respect to ZnSe (Johnstone, 2007). Indium Gallium became the new standard for the production of short-length wave devices such as (blue) beams and lasers. Growth in size at Nichia was more than tenfold in just a few years.

Basic science has helped the semiconductor industry to clear fundamental hurdles to progress. In the current industrial context, nanotechnology and quantum computing are proving essential to overcoming the limitations of the dominant CMOS technology on sub-100 nanometer manufacturing scales. The process of miniaturization is likely to change CMOS in production as well as materials (Jiang, Tan, & Thursby., 2011). Public research is in particular important for fundamental progress: Cohen et al. (2002) report that 36% of R&D projects made use of research findings from Academe, which puts the sector among the most intense users of scientific findings. However, learning-by-hiring is also important in the sector due to the diffusion and tacitness of most expertise (Almeida & Kogut, 1999).

Another relevant aspect of the industry is its stance with regard to various forms of intellectual property (IP). Formal IP such as patents is not seen as particularly effective for appropriating the returns to R&D in the industry (Cohen et al., 2000). Rather, patenting is mainly used in cross-licensing negotiations and to secure the freedom to operate own technologies, usually characterized by high sunk costs (Hall and Ziedonis, 2001). With respect to publishing, Lim (2004) reports a higher concentration of publishing activities in the semiconductor industry, as compared to the Pharmaceutical sector, where a handful of companies are responsible for the bulk of corporate publications. A division of labor seems to exist among corporate scientists: Lim (2000) reports a negative relationship between basic publication and patents among researchers employed at IBM, Intel and AT&T. Firms allow their researchers to publish also to earn an entry ticket to the academic community and connect to external sources of scientific information in order to gather unpublished information. For example, the inventor of the Blue LED and 2014 Physics Nobel Laureate, Nakamura, reported the problems he initially faced in interacting with the scientific community due to his lack of publications as corporate scientist. Similarly, accounts on the development of the laser technology report that researchers were not able to replicate the findings reported in published articles and face-to-face interaction was needed to access the tacit knowledge to replicate the experiments (Hicks, 1995). Henkel and Pangerl (2008) report an increasing use of strategic disclosure in scientific articles for defensive publishing purposes. Anecdotal evidence points to publications as complementary strategy to patenting to disclose and protect research results, such as minor improvements on core technologies as well as intermediate results (Baker and Mezzetti, 2005; Della Malva and Hussinger, 2012).

3. Method

Much in line with extant literature (e.g. Belenzon, 2012; Simeth and Cincera, 2013; Hall et al. 2005; Griliches, 1984), our empirical strategy is based on the stock market valuation of firms with respect to its physical assets (Tobin's Q). This approach draws from the hedonic price model in that it considers firms as bundles of assets and capabilities, from plants and equipment to intangible assets such as brand names, good will and knowledge. Such approach assumes that financial markets attach a valuation to firms' asset bundles which equals the discounted value of firms' future cash flows.

The market value of a firm is therefore a function of tangible and intangible assets, which enter additively, and is formalized as follows:

$$V_{it} = q(A_{it}, \theta K_{it})^{\sigma}$$

Where V_{it} represents the stock market valuation of firm i, A_{it} represents its physical assets, and $\mathbf{K}_{i1}$represents its intangible or knowledge capital. θ is the shadow price of knowledge assets and allows the latter to be valued differently from tangible assets. σ allows for scale effects, and it is assumed to be one (constant returns to scale). Taking logs and moving physical assets to the left-hand side, the equation to estimate becomes:

$$\ln\left(\frac{V_{it}}{A_{it}}\right) = \ln q + \ln\left(1 + \theta \frac{\boldsymbol{K}_{it}}{A_{it}}\right) + \varepsilon_{it}$$

We operationalize $\mathbf{K}_{i1}$ to include measures of R&D expenditure, patents and publications. We hence specify $\mathbf{K}_{it}$ as:

$$\mathbf{K}_{it} = \text{R\&D stock}_{it} + \text{Patent stock}_{it} + \text{Publication stock}_{it}$$

All stocks are calculated using perpetual inventory methods, applying a 15% depreciation rate from the first available data point.[7] Therefore the equation above reads as follows:

$$\ln\left(\frac{V_{it}}{A_{it}}\right) = \ln \mathrm{q} + \ln\left(1 + \theta_1 \frac{\boldsymbol{R\&D}_{it}}{A_{it}} + \theta_2 \frac{\boldsymbol{PAT}_{it}}{A_{it}} + \theta_3 \frac{\boldsymbol{PUB}_{it}}{A_{it}}\right) + \varepsilon_{it}$$

Whereas R&D expenditures are an input of the knowledge generating process, and usually with very uncertain outcomes, patents and publications represent two channels through which firms disclose the results of R&D. The distribution of importance or significance of these two measures is however highly skewed. Therefore we weigh patents and publications by the forward citations received respectively in the patent and scientific literature. [8] We further control for other factors affecting firm value, such as the log of sales and sales growth as larger and faster-growing firms might show different abilities to benefit from the publication of research results. We also include a set of time dummies as well as dummies for instances in which firms show patent stocks and publication stocks equal to zero. We estimate this equation using non-linear least squares, lagging the explanatory variables by one year to mitigate endogeneity.

4. Data

The analysis is based on the universe of U.S. listed firms whose primary activity is classified under SIC code 3674 (Semiconductors and related devices), operating between 1980 and 2007.[9] We used Compustat North America to extract all necessary pieces of information

[7] We estimated the starting value of R&D stocks assuming a 7% pre-observation growth rate and a 15% depreciation rate.

[8] See Van Raan (2005) for an overview of the use of forward citations in the scientometric literature and Trajtenberg (1990) for the importance of forward citations in patents.

[9] Firms needed to be listed at least three years in that period to be included in the sample. Some firms were removed that were active in markets which we deemed as not part of 'core' semiconductors (specifically, firms who focus purely on consumer products or solar photovoltaic panels), or who were subsidiaries of an international group. The first group is likely to be subject to market dynamics outside of the semiconductor market as defined above, and the second is likely subject to strategic reporting of earnings and other information, thus distorting findings. The

regarding accounting figures, including market value, R&D, and capital among others. We deflated accounting figures using GDP deflators. We calculate Tobin's Q as the market value of equity plus the book value of debt, divided by book value of assets.[10] We identified firms' scientific publications using data from Thompson Reuters Web of Science.[11] Web of Science is among the largest collections of scientific publications, including outlets in natural and physical sciences. It thus constitutes an adequate source to quantify semiconductor firms' scientific outputs. We used the journal-level classification created by Hamilton (2003) to differentiate between basic and applied research. Level 4 journals were deemed basic, while others were labeled as applied.[12] We similarly matched these firms to USPTO patents using the Fall 2011 edition of Patstat and the name disambiguation exercise by Magerman, Van Looy, & Song (2006).

Insert Table 1 about here

Our final sample is an unbalanced panel of 164 firms. The average firm was observed for 12 years. Table 1 shows descriptive statistics for the accounting, patent, and publication variables. The mean firm-year is valued at 2.31 times book value. It has 652 million 1992 USD in

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remaining 158 firms are involved to large degree in the design and production of integrated circuits, which we define as the 'core' of the semiconductor industry. One firm was further dropped for which we found extremely high numbers of held patents combined with extremely low R&D expenditures. These observations, which were in all likelihood not representative of reality, significantly biased the results.

[10] In terms of Compustat variables, we calculate $\frac{\text{csho}*\text{prccf}+\text{dltt}+\text{dlc}}{\text{at}}$, where csho represents the number of common shares outstanding, prccf represents the mean average closing share price, dltt is total long-term debt, dlc is total debt in current liabilities, and at represents total assets.

[11] We adopted a conservative approach in collecting publication and proceedings data from Thomson Reuters Web of Science: author address and affiliation fields were searched for generic versions of the firms' names, and the results were manually checked for consistency. Firms were similarly matched to patents using generic firm names and manual cleanup.

[12] The classification has been frequently used in previous studies citated in this paper (i.e. Lim, 2004) as well as by national scientific organziations such as the National Science Foundation in the U.S.A. and the Observatoire des Sciences et des Techniques in France. It differentiates between biomedical research and other fields. For non-biomedical journals, the categories are labelled as follows: 1. applied technology, 2. Engineering science-technological science, 3. Applied research – targeted basic research, 4. Basic scientific research (Hamilton, 2003, p. 5-6). While not all research in our 'applied' group is equally applied, the generalization serves to separate out the basic publications.

sales and 935 million in assets. It spends 87 million 1992 USD on R&D, receives 49 patents, and publishes 13 papers in Web of Science. The vast majority of these come from applied journals: only 3% of publications are in basic journals.

The majority of firms (81%) publish at least at some point. Publishing in basic literature is much more concentrated: only 28% of firms have at least one publication in a basic journal. This is in line with the observations of Lim (2004) and Tijssen (2004) that basic research in semiconductors tends to be concentrated in a small number of firms. Publishing associates positively with Tobin's Q: the market value to book value ratio of publishing firms is 1.26 times that of non-publishing firms, but the median firm with a basic publication is only valued weakly significantly more highly than the median firm without (Table 2).

Insert Table 2 about here
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5. Results

5.1. Main results

Table 3 presents the main results. We estimate Tobin's Q as a function of publication stocks through non-linear least squares (NL-LS) in column 1 and 2, and provide some robustness checks in columns 3 through 5.

As column 1 shows, publishing is associated positively with Tobin's Q in the semiconductor industry at 10% statistical level. Previous studies have found a general positive association between publications and Tobin's Q across different sectors, yet insignificant in the electronic sector at large (Simeth and Cincera, 2013). The coefficient associated to the R&D intensity of the firm is expectedly positive and significant whereas the stock of patents, normalized by physical Assets, is nonsignificant at conventional statistical levels. This last result contradicts previous findings on the valuation of knowledge assets (e.g. Hall et al., 2005), which instead found patents to be positively associated to Tobin's Q. The result can be explained by the fact that patenting in the sector mostly follows strategic reasons (Ziedonis, 2004) as firms use them for bargaining purposes in cross-licensing negotiations or to protect the freedom to operate their technologies. Moreover, they are not ranked as an effective appropriation mechanism (Cohen et al., 2002; Ceccagnoli, 2009).

In column 2 we split publications into basic and applied publications. The results indicate that publishing basic and applied research is valued differently: basic publications are positively associated to firm value, while the coefficient of applied publications is positive but not significant. The semi elasticity of basic publication intensity with respect to Tobin's Q is estimated at 0.15%, ceteris paribus. Column 3 to 5 present the results of different robustness checks, such as excluding non-publishing entities (column 3), focusing only on firms which have published at least one article in basic journals (column 4) and excluding the 5% of largest publishers. The results are consistent across subsamples and confirm the heterogeneous relationship between corporate engagement in scientific publishing and firm value.

Insert Table 3 about here

5.2. What drives the science-value relationship?

The results so far have indicated that most of the higher valuation that firms publishing science receive comes from involvement in basic science. This result is non-trivial as publications in basic journals represent a small fraction of all corporate publications, about 3%. With the support of some descriptive evidence, we discuss the possible reasons that might explain these heterogeneous effects by exploring two mechanisms: scientific origins of technologies and labor market signaling.

In line with a linear model of innovation, the first possibility builds on the assumption that scientific understanding leads to more impactful technological improvements. As basic science deals with problems that are further away from technologies, but more broadly applicable than applied research, (Fleming & Sorenson, 2004; Jaffe, 1989), the value premium to basic science might relate to a stronger or broader impact on subsequent technological developments as in the case of first mover advantages stemming from important technological shifts.

To the purpose, we traced the citations to the publications in our sample received by subsequent patents. Publications from our sampled firms were therefore linked to the list of non-patent literature in the USPTO patent system.[13] Of 35552 publications in our sample, only 1907 are cited as prior art by patents, 33 published in basic outlets and 1874 in applied journals, resulting in 10236 citations. Given the low numbers of basic publications, the figures reported in Table 4 should be interpreted as suggestive of the phenomenon at hands.

Insert Table 4 about here

Basic publications are significantly less likely to be cited by subsequent patents: 2.9% of articles in basic journals by semiconductor firms are ever cited as relevant prior art, as opposed to 5.4% of publications in applied journals. Conditional on being cited, however, basic publications are not cited less often than applied publications. One might also argue that basic publications – since they are more broadly applicable – have higher degrees of spillovers into other

[13] We build on the results of Callaert et al. (2012) who have developed a machine-learning algorithm to identify scientific references among non-patent literature. From this set of references, scientific references were matched to Non-Patent literature on the basis of a text search algorithm which matched articles' titles and journals' names. The exercise covers the period as of 1993.

organizations. We do find some evidence for this: a smaller share of basic citations (3.1%) comes from a patent owned by the publishing company than that of applied publications (7.8%). Despite the small numbers in Table 4, we cannot conclude that the relationship between basic publishing and firm value in the semiconductor industry occurs because published knowledge contributes to better inventions. This result is in line with previous results in the literature, which has struggled to find direct evidence of a relationship between progress in science and in technology (Cassiman et al., 2008).

The second assumption is that publishing might serve as entry ticket to the scientific community (Perkman et al., 2011). Attracting scientists, in particular, has proven critical to knowledge transfer in the semiconductor industry (Almeida & Kogut, 1999; Lim, 2009). Peer recognition through publishing has been shown to be a critical factor in the career choice of academically trained scientists (PhDs) to the extent that many are willing to trade wage for the possibility to publish (Sauermann & Roach, 2014). Therefore, firms which allow their scientists to publish should be the preferred destination for scientists with the highest scientific potential who choose to leave Academe.

Insert Table 5 about here

We tested this by reconstructing the career history of all inventors listed on the patents of the firms in the sample in the same fashion as Marx, Strumsky, & Fleming (2009). We checked for inward mobility from Academe by taking note of inventors which are listed on the firms' patents and who were previously listed on a patent assigned to a university. Table 5 shows that the share of inventors moving from universities to semiconductor firms is almost twice as large for firms that publish in basic journals than for firms that only publish in applied journals.

Although anecdotal, this descriptive evidence suggests that publishing in basic literature allows firms to establish links with academic inventors.

6. Discussion and conclusion

What are the private economic returns from disclosing science? In this paper we investigated the relationship between scientific publications and firm value of publicly listed U.S. semiconductor firms in the U.S. between 1980 and 2007. The results indicate that the publication of research results in scientific articles is associated to a significant premium in the valuation of intangible. Furthermore, the results suggest that most of the effect is driven by publications in basic journals, which however represent 3% of the the whole sample of publications. We have explored two possible mechanisms behind the observed heterogeneous effect – science-push technological change and (academic) inventor mobility. Descriptive analyses point at a higher attractiveness of firms that publish basic science for academic inventors. Basic scientific publications therefore seem to be the price firms have to pay to attract academic workforce and to keep a foothold in academic laboratories.

Our results have managerial implications. First, they complement the understanding of the valuation of intangible assets by showing that there is informational value in the quantity and nature of scientific disclosure by firms. This goes beyond the use of patent statistics to quantify science (Deng, Lev, & Narin 1999). Because basic and applied science still represent very distinct kinds of knowledge, it is crucial to consider the two when evaluating corporate activity.

A second managerial implication is that the benefits of engaging in and publishing cutting-edge basic research seem to outweigh its costs: our results suggest that semiconductor firms on average disclose too little basic science and too much applied science. Two likely causes of this are the costly nature of publishing in basic or generalist journals (compared to applied journals or technical conference proceedings), due to the highest scientific standards in basic literature, the increased disclosure requirements, and the time spent on revisions, and the discrepancy between the goals of the scientific world and the profit-related goals of firms (Kinney et al., 2004). Nevertheless, firms should be able to profit it they master pursuing the user-driven fundamental questions that align scientists' preference for publishing with the firms' need for business-applicable outcom es.

Finally, firms offering similar non-pecuniary incentives as Academe might be in the position to be considered as an alternative to academic jobs as intellectual freedom and possibility to publish are the main reasons for PhD students to prefer a career in Academe over Industry (Sauermann and Roach, 2010). Non-pecuniary motives such as intellectual challenge and independence have been found to be positively correlated with innovative output (Sauermann and Cohen, 2010). Despite providing access to state of the art knowledge, the organization of Academe as an "invisible college" enables firms to access tap into knowledge developed externally via PhD trained scientists and scholars.[14] From the point of view of the firm, these results suggest that, under some circumstances, minimizing disclosure of scientific information might not be the optimal strategy. Indeed, if inventors with higher ability are more likely to publish, limiting the possibility for scientists to publish might result in sorting of lower ability scientists into these firms or in higher wage premia to convince these inventors to join the firm.

Despite the market failures inherent to Science, our results indicate that firms find profitable to publish scientific research, and in particular engaging in the disclosure of impactful basic research. From a policy perspective, this finding helps to shed light on the incentives that

[14] Anecdotal evidence on the diffusion of copper interconnects across organizations provided by Lim (2009) supports this view: those firms which hired personnel from academic institutions were faster in adopting the new technique as IBM, the original developer, collaborated with several academic institutions in the development of the device.

private parties have in contributing to the stock of public knowledge. It is particularly relevant in periods of decreasing public support for research, when private sponsors, Google, Microsoft, Facebook and the likes represent an increasing share of the research performed and financed at public laboratories (Drake, 2014).

This research has limitations. Firstly, our results are specific to the semiconductor sector and its dynamics and are not representative for the science-value relationship in the economy as a whole. Moreover, we cannot discern between expenditures in applied and basic research and disclosure in applied and basic journals. As published science is likely a selected subsample of all performed research (firms might opt to keep certain knowledge secret, patent other findings, or choose other disclosure channels),[15] the measures in the analysis are subject to selection bias. We could overcome this by incorporating information on firms' expenditures in basic and applied research. To our knowledge, this information is available in some versions of the Community Innovation Survey, but is not available for the universe of public U.S. firms in general. Third, future studies should deal with the firms' strategic choice of disclosure mechanisms – secrecy vs patenting vs publishing – and their antecedents, as this is likely to affect rent distributions between shareholders and scientists (Gans et al. 2010) and influence the kinds of scientists attracted to the company (Sauermann and Roach, 2012). One recent study has highlighted in this regard how firms have redirected their disclosure efforts towards patenting, away from non-protected forms of disclosure (Battacharaya & Hedge, 2014).

[15] An interesting example of this is found in blue LED technology: Nichia kept the technology to work the Gallium secret, patented the processes to develop the components for the blue LED structures and published the results regarding the emitting properties of their products to prove their superiority with respect to Zinc Carbide. Exploring the contents of various disclosure channels could form an interesting topic for future research.

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Figures and Tables

Table 1: Summary Statistics (n=164, t=1980-2007, 2071 obs.)

Variable	Mean	SD	Min	Max
Tobin's Q	2.31	3.33	0.04	90.44
$Sales_{t-1}$, real 1992 million USD	652.12	2157.94	0.00	27877.07
Sales growth	0.37	3.94	-1.00	161.95
$R\&D_{t-1}$, real 1992 million USD	87.01	281.49	0.00	4087.61
$Assets_{t-1}$, real 1992 million USD	934.79	2993.73	0.71	39075.18
$Patents_{t-1}$	48.96	189.80	0.00	2222.00
$Publications_{t-1}$	13.49	49.41	0.00	753.00
Basic $Publications_{t-1}$	0.41	2.14	0.00	33.00
Applied $Publications_{t-1}$	13.08	47.93	0.00	732.00

Notes: Publication indicators: data sourced from Thomson Reuters Web of Science. All publication indicators are citation-weighted.

Table 2: Comparative Statics

		Obs.	Firms	Tobin's Q
Firm has publications	Yes	1738	133	1.59***
	No	336	31	1.26
In basic journals	Yes	672	46	1.55*
	No	1402	118	1.54
Total		2074	164	1.54

Notes: Author's own calculation based on Compustat and publication/patent information. Publication and citation indicators sourced from Thomson Reuters Web of Science. Median values per firm-year. Firms classified as publishing if it published at least once in 1980-2007. As only a small share of the publications is basic, the statistics of publications in applied journals and firms with citations in applied journals are identical to respectively firms with publications and citations (market value: identical to the unit; Tobin's Q: identical to second digit). Market value: million 1992 USD. Stars indicate significance of Wilcoxon rank-sum test:

* $p < 0.10$
** $p < 0.05$
*** $p < 0.01$

Table 3: Nonlinear Least Squares estimates of basic and applied publications on Tobin's Q

	Ln(Tobin's Q), Pooled Non-Linear LS				
	Full sample		> 0 Publications	> 0 Basic publications	Excluding top 5% Publishers
	(1)	(2)	(3)	(4)	(5)
Publication $Stock_{t-1}$ / $Assets_{t-1}$	0.0001*				
	(0.0001)				
Basic Publication $Stock_{t-1}$ / $Assets_{t-1}$		0.0015**	0.0015**	0.0016**	0.0010***
		(0.0007)	(0.0006)	(0.0007)	(0.0004)
Applied Publication $Stock_{t-1}$ / $Assets_{t-1}$		-0.0001	-0.0001	-0.0000	0.0006
		(0.0003)	(0.0002)	(0.0003)	(0.0009)
Patent $Stock_{t-1}$ / $Assets_{t-1}$	-0.0000	-0.0000	-0.0000	-0.0000*	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
R&D $Stock_{t-1}$ / $Assets_{t-1}$	0.0903***	0.0921***	0.0473**	0.0871	0.0895***
	(0.0291)	(0.0292)	(0.0224)	(0.0793)	(0.0280)
$\ln(Sales)_{t-1}$	0.0000	0.0000	0.0000	0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Sales Growth	0.0291*	0.0292*	0.0203*	0.0600	0.0277*
	(0.0157)	(0.0157)	(0.0112)	(0.0696)	(0.0151)
Observations	2068	2068	1736	672	1917
R^2	0.2094	0.2098	0.2326	0.2983	0.2168

Notes: Regressions additionally include intercept, year dummies, and dummies for observations where the publication stock is zero, or where the patent stock is zero. Heteroskedasticity robust standard errors (in parentheses) allow for serial correlation through clustering by firms. Publication stock, Basic Publication stock, Applied Publication stock: data sourced from Thomson Reuters Web of Science. Stars indicate p-value of coefficient:

* $p < 0.10$
** $p < 0.05$
*** $p < 0.010$

Table 4: Applied publications are more likely to be cited in subsequent patent applications than basic publications

	Observations [Applied; Basic]	Applied	Basic	Difference
Share of publications cited in patents	35552 publications	0.054	0.029	0.025***
	[34423; 1129]	(0.001)	(0.004)	(0.005)
Number of Citations in Patents	1907 publications	5.38	4.82	0.56
	[1874; 33]	(0.28)	(1.09)	(2.15)
Share of citations to Own Patents	10236 citations	0.078	0.031	0.046***
	[10077; 159]	(0.026)	(0.014)	(0.021)

Notes: The first row reports the share of publications from semiconductor firms which are cited as prior art in U.S. patents. The second row reports the average number of citations received from U.S. patents (only of publications that have received at least on citation). The third row reports the share of citations received from U.S. patents assigned to the same organization. Standard errors presented in parentheses. Data about publications are sourced from Thomson Reuters Web of Science. Stars indicate significance level of t-test:

* p < 0.10
** p < 0.05
*** p < 0.01

Table 5: Firms with basic publications experience higher academic inventor attraction rates

	Applied	Basic	Difference
Share of inventors that report inward mobility from Academe	0.012	0.020	-0.008***
	(0.129)	(0.154)	(0.002)

Notes: 35177 Mobility spells: 9078 from firms only publishing applied articles, 26099 from firms publishing basic articles. The first row reports the share of inventors that experience a change of assignee of two consecutive patents of which the former one is a University and the latter one is one of our semiconductor firms. Standard errors in parentheses. Stars indicate significance level of t-test:

* p < 0.10
** p < 0.05
*** p < 0.01