Killing the Golden Goose? The Decline of Science in Corporate R&D

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Abstract

Scientific knowledge is believed to be the wellspring of innovation. Historically, firms have also invested in research to fuel innovation and growth. In this paper, we document a shift away from scientific research by large corporations between 1980 and 2007. We find that publications by company scientists have declined over time in a range of industries. We also find that the value attributable to scientific research has dropped, whereas the value attributable to technical knowledge (as measured by patents) has remained stable. These effects appear to be associated with globalization and narrower firm scope, rather than changes in publication practices or a decline in the usefulness of science as an input into innovation. Large firms appear to value the golden eggs of science (as reflected in patents) but not the golden goose itself (the scientific capabilities). These findings have important implications for both public policy and management.

Keywords: innovation, basic research, scientific capabilities, technical capabilities, globalization, competition.

JEL Classification: O31, O32, O16.

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1. Introduction

There is an extensive literature in strategy on corporate engagement in scientific research (e.g., Rosenberg, 1990; Gambardella, 1995; Henderson and Cockburn, 1994; Fleming and Sorenson, 2004; Pisano, 2006; Durand et al., 2008). Despite the well-known problems of appropriability, many leading American and European firms have invested in science, and such investments have resulted in some major scientific and technological breakthroughs. Corporations invested in science primarily to develop significant new products and processes, but also to help absorb external knowledge, and perhaps to attract talented workers (Griliches, 1986; Gambardella, 1995; Cockburn and Henderson, 1998).

Since the 1990s, however, many leading firms have reduced their investments in science.[1] Articles in the popular press lament the demise of top-flight corporate labs, crediting the rise of small research-intensive start-ups, often fuelled by venture capitalists (e.g., Economist, 2007). Other accounts blame the growing financial considerations that cloud the judgment of managers (Lazonick, 2013). Data from the National Science Foundation show that the share of basic and applied research in corporate R&D in the United States has declined from 28% in 1985 to 21% in 2009.[2] However, classifying expenditures as either "research" or "development" is difficult. Furthermore, firm-level data are not publicly available, making it difficult to assess whether the aggregate trends reflect changes in the behavior of existing firms or other factors, such as a change in the industrial mix of reporting firms.

We develop publication-based indicators of scientific research at the firm level. We link scientific publications in "hard science" journals (including engineering science) from the Web of Science to publicly traded firms in the United States, using the affiliations of the authors. Our primary firm sample consists of 1,014 companies with at least one patent over the period 1980-2007. Collectively, these firms account for 312,000 "firm publications" – scientific articles where at least one of the authors is a company employee. In addition, we use firm-level information on variables such as patents, stock market value, book value of capital, and R&D expenditures.

Using these data, we document how corporate research has changed in large firms, and provide important clues about what has driven these changes. Over the period 1980–2007, we find that investments in scientific research by publicly traded American companies have diminished. More-

[1] For simplicity, we use the terms "science" and "basic research" interchangeably. This usage is not universally agreed upon, and with good reason. However, our choice is with an eye to the difficulty of empirically successfully distinguishing between scientific and basic research. When not likely to create confusion, we sometimes simply use "research" for brevity.

[2] See NSF Science & Engineering Indicators 2012, Appendix Tables 4-3, 4-8 and 4-9.

over, the implied value of scientific capability, as measured by stock market valuations or by the acquisition price in M&A deals, has also declined. Specifically, we show: (i) a decline in publications by large American firms; (ii) a decline in the market value premium of the stock of publications; (iii) a fall in the acquisition premium paid for publications in M&A deals; and (iv) a decline in post-acquisition publication activity by target-firm scientists. By contrast, over the same time period: (v) patenting by large American firms has increased and (vi) the implied value of patents, including the premium paid for patents in M&A, has not decreased. These patterns are present across a range of industries, except perhaps biotechnology. We find similar results for European firms (both public and private) that we matched with our patent and publication data, indicating that these trends are not just confined to American firms.

A concern is that our results may merely reflect changes in how firms protect their knowledge. Large firms may still invest in science but simply publish less, perhaps in order to patent or better protect their research findings. In principle, the strengthening of intellectual property, particularly patents, should encourage rather than discourage firms from publishing (Gans et al., 2013). But if the firms are eschewing publication to avoid inadvertent disclosure of commercially valuable findings, they should particularly avoid applied scientific journals, which are more likely to contain findings close to commercial applications. We find, instead, that the decline in firm publications is especially marked for publications in journals dedicated to basic rather than applied research. Moreover, provided that science remains valuable, changes in publication behavior should not affect the premium for scientific capability paid by acquiring firms in M&A, contrary to what we find. Overall, our results suggest that large firms are withdrawing from investing in science internally and focusing more on development (less "R" and more "D,") rather than simply changing their publication behavior. Large firms continue to value the golden eggs that science can produce but are unwilling to invest in the golden goose itself.

Firms would reduce investment in science if science itself becomes less useful for innovation (Jones, 2009; Gordon, 2012). However, we do not see any decline in the number of patent citations to science over time, nor do we find any evidence that the science used in inventions is growing older. Thus, the decline in private investments in science cannot be explained away by a reduction in the usefulness of new science. Similarly, although problems of appropriating the benefits of scientific research are well known, there is no evidence that these problems have worsened over time. If anything, stronger patent and copyright laws appear to have made scientific knowledge easier to protect.

We interpret these patterns as part of a longer historical process wherein firms are specializing in different parts of the innovation value chain. Large firms are relying more upon external inventions and less upon internal research. This withdrawal of large firms from science has been accompanied by a growing division of innovative labor in which large firms focus on development and commercialization, leaving universities and small firms to generate new ideas (e.g., Arora and Gambardella, 1994; Arora et al., 2001; Higgins and Rodriguez, 2006; Mowery, 2009). The present paper also highlights two important correlates of this historical process: increasing global competition and changes in firm scope. We find that both global competition and a narrowing of firm scope are associated with a shift away from the creation of new knowledge and toward the commercial application and protection of existing knowledge. These findings suggest that competition has nuanced effects on a firm's innovation strategy; most importantly, however, competition appears to shift managerial focus towards short-term results.

The remainder of the paper is organized as follows. Section 2 provides some historical and conceptual background for the empirical analysis, and relates our work to the existing literature. Section 3 discusses our data sources. Sections 4 to 7 describe our econometric specifications and present our estimation results. Section 8 discusses some of the implications of our findings, while Section 9 concludes.

2. Conceptual background and contribution to the literature

2.1. Evolution of corporate research

Corporate investments in science began modestly. The leading firms of the 1870s and 1880s, such as the railroad companies and Western Union, mostly relied on external inventions and established industrial labs to evaluate the quality of inputs (Mowery, 1995; Carlson, 2013). Growing competition, anti-trust pressures, and the increasing output of university-trained PhDs led companies such as GE and DuPont to invest in internal research to generate new products and processes to fuel growth (Reich, 1985; Hounshell and Smith, 1986). The process gained momentum during the inter-war years, as corporations grew larger and more anxious to control and "routinize" innovation. Landmark discoveries (e.g., vacuum tubes, radio, synthetic rubber, nylon), the growing practical applicability of recently discovered scientific principles, and the rapid increase in government funding in the United States led to more companies investing in internal research after World War II.

But corporate research often failed to deliver returns to shareholders. Discoveries such as nylon and the transistor were few and far between. And even when fundamental advances in science or technology were made, the sponsoring firms often failed to profit from these advances. The graphical user interface, for instance, was invented in Xerox's PARC, but other firms, most notably Apple and Microsoft, reaped the rewards. By the 1980s, firms began to look to universities and small start-ups as sources of ideas and new products, using a mix of contracts, licenses, alliances, and outright acquisitions. Many corporate labs were closed, downsized, or redirected toward more commercial applications (Pisano, 2010).

NSF data indicate that firms with more than 10,000 employees accounted for 73 percent of non-federally funded R&D in 1985. By 1998, this share had dropped to 54 percent, and to 51 percent by 2008 (Mowery, 2009). An additional indicator of the decline in the relative importance of large firms is the sharp drop in share of large firms in the R&D 100 awards winners: whereas 41 percent of the awards went to Fortune 500 firms in 1971, only 6 percent went to Fortune 500 firms in 2006 (Block and Keller, 2009).

Several factors contributed to the growing importance of small firms' research. Encouraged by the 1980 Bayh-Dole act, universities and other research institutions began to commercialize their discoveries more actively. University scientists found increasingly attractive to start their own businesses, whose high-powered incentives and nimble ways are difficult to replicate in large, established firms encumbered by bureaucracy, politics, and the burden of past legacies (Christensen and Bower, 1996; Sull et al., 1997). Changes in the institutional and legal environment have complemented these trends. Start-ups can get financing from venture capitalists and SBIR and other government programs (Kortum and Lerner, 2000; Mazzucato, 2013). Intellectual property rights have been significantly strengthened starting from the early 1980s, first in the U.S. and subsequently in other countries (Jaffe and Lerner, 2004; Guellec and van Pottelsberghe de la Potterie, 2007).

These developments have promoted a new division of labor, where small start-ups specialize in scientific research and larger, more established firms specialize in product development and commercialization (Arora and Gambardella, 1994; Arora et al., 2001). In this view, smaller firms have a comparative advantage in generating ideas whereas larger firms have an advantage in exploiting them. Large firms may invest in scientific capability to be effective buyers of knowledge.

2.2. Changing value of investments in scientific research

Typically, investments in scientific research are undertaken by firms to create new products or processes and to absorb outside technology. Innovations sometimes arise directly from scientific advance (e.g., new drugs) and sometimes as indirect outputs of scientific research (e.g., laser). In other cases, scientific research enhances the productivity of technical search, by guiding it toward more fruitful pastures (Evenson and Kislev, 1976, Gambardella, 1995; Fleming and Sorenson, 2004). Investments in scientific research also help firms absorb outside technology (Cohen and Levinthal, 1989; Gambardella, 1992; Arora and Gambardella, 1994). Company scientists can help identify promising new inventions, engage with the relevant outside researchers, and help assimilate and adapt outside technology. Publishing in academic journals and attending conferences, in particular, may be the most effective way to remain "plugged in" to the external scientific network (Rosenberg, 1990; Cockburn and Henderson, 1998).

Narin et al. (1997) propose using citations by patents to scientific publications to measure the use of science in innovation. Van Looy et al. (2003) find a positive relationship between the science intensity of patents (i.e., the citations to the scientific, non-patent literature) and technological productivity, in ten science-intensive technological domains. We find that patents by our sample firms continue to cite science at the same rate as before, and the age of the cited publications is constant over time, indicating that new scientific discoveries continue to be relevant for innovation. Moreover, publishing firms cite more recent science than non-publishing firms, indicating that scientific capability continues to bestow an advantage in terms of being able to absorb more recent scientific findings.[3]

Many scholars have documented the financial benefits of investment in science. Griliches (1986) analyzes the drivers of productivity and profits for a sample of the 1,000 largest manufacturing firms in the U.S. For the period 1957–1977, he finds that the share of basic research in the firm's R&D expenditure was positively related to measures of productivity growth. We follow Griliches in linking market value to research but use citation weighted publication stock, consistent with Gambardella, (1992) and Cockburn and Henderson (1998). Hall et al. (2005) use a market value approach to measure the return to R&D investment for U.S. firms in the 1980s but do not distinguish between research and development. A positive relationship can also be found between the market valuation of firms and the science intensity of their patents (Deng et al., 1999) or their stocks of scientific publications (Simeth and Cincera, 2013).

These studies do not examine how the value of investments in science has changed over time, and

[3] Engaging in scientific activities also enhances the reputation of the firm and certifies the quality of its research to prospective investors, employees, government agencies, and sophisticated customers (Hicks, 1995; Audretsch and Stephan, 1996). Clinical studies, for instance, are routinely used by firms in the pharmaceutical industry to advertise the effectiveness of their drugs to doctors and hospitals (Azoulay, 2002). Also, to the extent that allowing employees to publish helps firms recruit more talented researchers, participating in the process of advancing science can be a profitable strategy for some firms (Stern, 2004; Roach and Sauermann, 2010). Our findings do not speak to these possible reasons for engaging in scientific research.

why. Yet, understanding the trade-offs involved in managing science within corporate boundaries is of fundamental strategic importance for technology firms.

Firms face a number of challenges in generating returns from scientific research. The well-known appropriability problem is only one of these. For even when patents are effective, managing research is challenging. Research, as opposed to development, tends to involve projects with long time horizons and uncertain outcomes. Choosing suitable research projects, providing researchers with appropriate goals, and monitoring their performance is difficult, especially for managers whose expertise is commercial rather than scientific (Kay, 1988). Investments in research are more productive when researchers have creative freedom and operate in an "open", university-like institutional arrangement (Dasgupta and David, 1994). Often this requires insulating research from the rest of the business. Such isolation from the business can result in corporate research diverging from the firm's strategic needs, making it less relevant to the firm (Hounshell and Smith, 1986; Argyres and Silverman, 2004, Arora et al., 2014).

A fundamental challenge firms face in appropriating the returns from research is recognizing its commercial value. In part, this can attributed to a natural tendency of both individuals and organizations to search locally (March and Simon, 1958; Stuart and Podolny, 1996). Firms are most likely to invest in innovation projects that are related to their existing operations (Leonard-Barton, 1992; Ahuja and Lampert, 2001; Chesbrough, 2002). This implies that diversified firms may be the ones best positioned to exploit the unpredictable outcomes of scientific research. As Nelson (1959: 302) notes, "[a] broad technological base insures that, whatever direction the path of research may take, the results are likely to be of value to the sponsoring firm". Using firm-level data on sales concentration to measure firm scope, we provide support for these ideas. We find that decreases in firm scope are associated with a reduction in publications, and a decline in the stock market value of publications.

A second, possibly interrelated reason for the decline in investments in science by large firms is increasing global competition. Theoretically, greater competition has ambiguous effects on the propensity of leading firms to develop innovations internally. On the one hand, competition drives price-cost margins down and thus discourages investments in R&D, but on the other hand, successful innovation may be the only way to "escape" competition and low price-cost margins (Aghion et al., 2005). Empirical work on the topic, while extensive, has been largely inconclusive (see Cohen 2010 for a survey). Bloom et al. (forthcoming) use a panel of up to half a million firms over 1996–2007 across twelve European countries, and find that Chinese import competition led to increases in patenting, IT, and TFP. For a smaller sample of 459 R&D-performing firms, they also find that Chinese import competition led to an increase in R&D. We too find that greater Chinese import penetration is associated with an increase in patenting. However, we also find that competition from China is associated with *reductions* in investments in science, R&D expenditures, and physical investment. These findings suggest that low-cost competition may have different effects depending on the type of activity. It may encourage incremental and appropriable (i.e., patentable) research, but may discourage more long-term, basic research.

3. Data and results

We combine data from four main sources: (i) U.S. Compustat, (ii) M&A data from Thomson SDC Platinum, (iii) scientific publications from ISI Web of Knowledge, and (iv) patent data from PatStat (USPTO and EPO). We use three different firm samples. Our principal results pertain to publicly traded firms in the U.S. We also provide additional evidence using a large sample of M&A deals, and a sample of European firms that either patent or publish. The latter two samples are described in more detail along with the corresponding empirical results.

We focus our econometric analysis on U.S. Compustat firms with at least one patent over the period 1975–2007, leaving us with 1,014 firms and 11,304 firm-year observations. To capture their investment in science, we match these firms to ISI Web of Science (matching firm name with the affiliation field for each publications record). We identify approximately 312 thousand articles with at least one author employed by a Compustat firm in our sample. We select only articles in "hard-science" journals (natural sciences and engineering), and unless noted otherwise, we weight articles by citations. To measure investment in technology, we match our firm sample to patents granted by U.S. and European patent offices from PatStat. To avoid double counting of patents on the same invention, we exclude European patents that belong to the same family as an already matched U.S. patent. We also weight patents by citations. For both patent and article citations, we use all citations received, normalized by the mean number of citations received by the cohort.

The main variables used in the analysis of Compustat firms include market value, book value of capital, R&D stock, publications stock, and patents stock.[4] Panel A in Table 1 summarizes

[4] Following Griliches (1986), market value is defined as the sum of the values of common stock, preferred stock, and total debt net of current assets. The book value of capital includes net plant, property and equipment, inventories, investments in unconsolidated subsidiaries, and intangibles other than R&D. R&D stock is calculated using a perpetual inventory method with a 15 percent depreciation rate (Hall et al., 2005). So the R&D stock, GRD, in year t is $GRD_t = R_t + (1-\delta)GRD_{t-1}$ where R_t is the R&D expenditure in year t and $\delta = 0.15$. Publications stock in year t is calculated in the same way as $Publications\ stock_t = Pub_t + (1-\delta)Publications\ stock_{t-1}$ where Pub_t is the citations-weights flow of publications in year t. Citation weights are the ratio between the number of citations an

descriptive statistics for Compustat firms. The mean market value of the firms in our sample is $5.9 billion (of which $3 billion are in physical assets), and mean R&D spending is $129 million. Their mean scientific publications stock is 58 and patents stock is 174. Approximately 28 percent of our sample firms publish a scientific article at least once during the sample period.

[Insert Table 1 here]

Figures 1-2 plot how the shares of publishing and patenting firms in our sample have changed over time. We consider Compustat firms with positive yearly R&D expenditures for the period 1980–2007. Later in the econometric analysis we present the within-firm analyses that account for changes in sample composition.

Figure 1 shows that the share of firms that publish each year has dropped over time, from a high of 18 percent in 1980 to a low of about 5 percent in 2007. By contrast, the share of patenting firms has increased over time, from 15 percent in 1980 to just under 25 percent in 2007. R&D intensity, the ratio of R&D to sales, has remained stable over time at about 3 percent. Importantly, the share of patent citations to science (the ratio between patent citations to scientific journals and total number of citations the patent makes) has remained stable over time. This finding, which we explore more carefully in Section 4.1, suggests that a decline in the use of science in innovation is not likely to explain firms' withdrawal from science.

Figure 2 plots the share of publishing firms by selected industries. The main takeaway here is that decline in publications is found in virtually every technology domain. Section 3.1.3 shows that this pattern is robust to controlling for changes in sample composition over time.

[Insert Figures 1-2 here]

3.1. Econometric Results

3.1.1. Internal investments in science

Columns 1–4 in Table 2a present the estimation results of time trends in investments in science using within-firm specifications. We report robust standard errors and cluster by firm. Publications (weighed by citations received) fall over time. The coefficient of the time trend implies that publications fall at about 1% per year, or by about a quarter over the sample period. However, this is the average for all firms in the sample, not just firms that engage in research. Column 2 includes

article receives and the average number of citations received by all articles published in the same year. Patents stock is computed in an equivalent way using patents data. Yearly observations with missing values are set to zero.

only firms that published at least one publication during the period 1970-2007. The coefficient estimate on the time trend has a greater absolute value (-0.03, as compared to -0.01). This estimate implies that between 1980 and 2007, publications by firms that publish fell by close to three quarters. Columns 3 and 4 examine trends in patenting and R&D intensity (R&D expenditures over sales). Both patenting and R&D intensity remain stable over time. While our within-firm estimation controls for changes in the sample composition over time, our results can still be driven by younger firms that entered the sample in the second half of our sample. Our results are largely unchanged if we restrict the analysis to firms that are present in both early and late sample periods. In unreported results we find that for firms that are in our sample for at least 20 years, the coefficient estimate on the time trend is -0.03 (standard error of 0.01), and -0.04 (standard error of 0.01) for firms that are present for at least 10 years.

These changes in publication output could reflect either a reduction in the private value of scientific capability or an increase in its marginal cost (or both). An increase in marginal cost would reduce the quantity of research but also increase its average value. To distinguish between shifts in value and cost, we examine how the elasticity of market value with respect to publication and patent stocks has changed over time. Columns 5-7 report on estimates where the dependent variable is the natural log of stock market value. Column 5 includes interactions between publication stocks with a time trend, as well as between patent stocks and time trend. We cluster standard errors by firm, and include 248 four-digit industry fixed effects. The coefficient estimate on the interaction between publication stock and time trend is negative and statistically significant. These estimates imply that the elasticity of market value with respect to publication stock dropped from 0.07 to 0.02 between 1980 and 2007. For patents, the elasticity rose from 0.07 in 1980 to 0.18 in 2007. Columns 6–7 split the sample at its median year to allow for a more flexible analysis of how the coefficient estimates change over time. The same pattern of results holds. In unreported specifications, we find that our results are also robust to the exclusion of the dot com bubble years. Specifically, the exclusion of the period 1998-2000 does not materially change our results.

Interpreting estimates from market value regressions is not straightforward. Our interpretation is that the decline in publishing output reflects a reduction in the derived demand for private investment in scientific research. Taken together, the results in Table 2a imply that the decline in publication output is not merely a matter of possibly higher marginal cost of research but instead reflects a reduction in the "demand" for scientific capability. The results imply that whereas the private value of technical capability has increase (or, at a minimum, has not decreased), scientific capability has become privately less valuable.

[Insert Tables 2a-2b here]

3.1.2. Publication output as a measure of investment in science?

Scientific publications are a common measure of investments in basic research. However, it is possible that our results simply reflect changes in publication behavior. If firms have, for some reason, changed practices such that there is a greater emphasis on secrecy, scientific publications may become a less accurate measure of investment in research or of scientific capability. On conceptual grounds, Gans et al. (2013) argue that patenting and publishing are complements rather than substitutes. Stronger patent protection ought to increase rather than decrease publication. However, scientists with limited time may allocate more time to patents and less to publications if firms are increasing the rewards for patents as compared to publications. This would make patenting and publishing substitutes rather than complements (Bhaskarabhatla and Hegde, 2014).

Insofar as companies are reducing publications to avoid information leakage, we would expect publications in applied journals to decline faster than those in basic research journals. This is because applied journals are more likely to contain commercially sensitive and patentable information. As Table 2b shows, we find the opposite.

For the results reported in Table 2b, we match the journals in our data to the CHI journal database (Leten, Kelchtermans, and Belderbos, 2010). The complete CHI database includes a list of 17,753 journals which have been classified by their level of research "basicness". About 40 percent of the publications in our sample were matched to CHI journals. Columns 1 and 2 in Table 2b distinguish between firm publications in basic and applied journal. A publication is classified as *basic* if it is published in a journal with a CHI level of 4 (the highest value), and as *applied* if it is published in a journal with a CHI level of 1 (the lowest level). We find that the decline in publications over time (within firms) is strongly evident for basic publications, but not for applied publications. The decline in publications is also not evident for publications in low impact factor journals (column 3). This suggests that the decline in publications documented in Table 2a is driven by a decline in basic research. Column 4 examines the time trend in the share of firm publications in basic journals (CHI level of 4), for the subsample of publishing firms. We find that the share of basic publications in total firm publications has fallen over time.

Columns 5–6 present the corresponding results for stock market value. Column 5 includes separate measures for basic and applied publication stocks. The decline over time in the elasticity of value with respect to publications is evident for basic publications (an estimate of -0.02), but not applied publications (estimate indistinguishable from zero). Column 6 focuses on the subsample of publishing firms and shows that the elasticity of firm value with respect to the share of firm publications in basic journals is positive and quantitatively large (an estimate of 0.05), and that this elasticity has fallen in value over time. Finally, in unreported regressions we find that all these results hold also when we use the journal impact factor to distinguish between publications, instead of classifying publications by the CHI index.

In sum, Table 2b shows that firms are publishing less largely because they are publishing less basic research rather than publishing less applied research. Further, the decline in the value of scientific capability is largely because basic scientific capability is less valuable. These patterns are inconsistent with the notion that the decline in publication reflects mere changes in publication behavior or greater emphasis on secrecy. Rather, large firms appear to have changed their R&D composition—they have been moving away from basic research and toward more applied and patentable research.

3.1.3. Patterns within technology domains

Tables 3 and 4 explore how the above pattern of results varies across technology domains. We classify firms into technology domains based on the distribution of their patents across the following technology fields: biotechnology, chemicals, pharmaceuticals, electronics, information technologies, semiconductors, and telecommunications. Overall, we find that the trends reported in Table 2a are present in all technology domains. In Table 3, we interact a time trend with technology domains dummies. Column 1 shows that publications fell in all technology domains. Table 4 examines the relationship between scientific capability (measured by the stock of publications) and market value, within technology domains. For this analysis, we assigned firms to technology domains using patenting classes where the plurality of the patents are classifed. As in Table 2a, it shows that the implied private value of scientific capability has declined in all technology domains except biotechnology. The principal takeaway from Tables 3 and 4 is that the decline in research that we have documented is broad based, and not driven by any particular technology domain.

[Insert Tables 3–4 here]

3.1.4. Value of scientific capability in M&A

Our estimates of the private value of scientific capability rely upon stock market values. These reflect the collective judgment of investors. The prices that firms in our sample pay to acquire other firms, and its relationship to the scientific ability provide an estimate the implied value that managers put on scientific capability. For this analyis, we use the set of acquisitions by our sample firms where data on acquisition price, percentage of acquired equity, assets and sales is available in SDC Platinum. We further restrict the sample to targets from OECD countries. We match the acquired firms (targets) to ISI and PatStat to develop measures of the publication and patents of the target firms. Our sample includes 26,884 acquisitions by Compustat firms. Nearly half (46%) of the deals involve American targets, 19% British targets and 6% Japanese targets. At the time of their acquisition, 836 target firms have at least one scientific publication and 4,852 firms have at least one patent.

Panel B in Table 1 above summarizes the descriptive statistics for target firms. The average target firm is valued at $162 million, has $79 million in assets, generates $138 million in annual sales, and makes $17 million in profits. Of the target firms that have at least one publication, the mean stock of publications is about 4 with a median value of 0.2. Of the target firms with at least one patent, the mean stock of patents (the sum of USPTO and EPO patents) is 30 with a median value of 3.6.

Table 5 presents the estimation results for the value of scientific capability based on acquisition price. The estimation results are consistent with the stock market value regressions and show that the implied value of scientific capability has indeed fallen. Column 1 interacts publication and patent stocks with time trend. Consistent with our previous findings, the elasticity of acquisition price with respect to publication stock is falling over time. On the other hand, the elasticity of acquisition price with respect to patent stock is rising.

Columns 2–3 use more flexible specifications which split the sample at the median year value. As before, the coefficient estimate on publication stock is very large and statistically significant in the early sample period (0.17), and falls nearly to zero in the later sample period (-0.04). We easily reject the null hypothesis that these two coefficients are statistically identical. Column 4 shows that the same pattern of results continues to hold when we restrict the sample to target firms that either patent at the USPTO or EPO or publish. Column 5 shows that the results are not driven by the 1999–2001 IT bubble.

The main takeaway from Table 5 is that the value managers place on scientific capability of their target firm (as proxied by its stock of publications) has fallen over time whereas the value they place on the technical capability of their target firm (as proxied by its stock of patents) has not decreased. This is broadly consistent with the suggestion that large firms are shifting their focus away from basic research and toward more applied activities.

[Insert Table 5 here]

3.1.5. Post-acquisition publication behavior

If the value of scientific capabilities has declined and acquiring firms are becoming more reluctant to invest in science, we would expect to see a decline in publication activity by researchers of the target firms after the acquisition. A few papers stress the difficulties acquiring firms face in making productive use of the human capital they acquire in the form of inventors and researchers. For instance, Valentini (2012) concludes that acquisitions in medical devices and photographic equipment between 1988 and 1996 resulted in a greater focus by the acquirer on short-term results.

Measuring post-acquisition publication activity is challenging because the acquired firm may cease to exist as an independent unit following the acquisition. To account for publications of potentially dissolved units, we include publications by acquiring firms in the post-acquisition period where the authors also appear on pre-acquisition publications belonging to the acquired firm.[5] If large firms are withdrawing from science, then the scientists who are hired through acquisitions should reduce their publication activity post-acquisition, and the reduction should be larger for more recent acquisitions.

Table 6 presents the estimation results of a within-firm variation in publication behavior post-acquisition. For each firm, we examine a three-year window around the acquisition year and estimate the effect of a post-acquisition dummy—a dummy that receives the value of one for the three post-acquisition years and zero for three pre-acquisition years. Columns 1–6 present the estimation results for the flow of publications. Column 1 shows that publications tend to drop post-acquisition. Comparing columns 2 and 3, we see that the drop is especially marked for acquisitions in the second half of our sample period: The coefficient on the post-acquisition dummy falls from 0.01 for acquisitions between 1985 and 1996, to -0.20 for acquisitions between 1997 and 2004. The difference is statistically significant and meaningful. Whereas there is very little decline in publication post-acquisition in the early part of the sample period, for later deals, after-acquisition publications

[5] We use a three-year window to track publications after acquisition by the target firm. Around 90 percent of the publications continue to carry the name of the acquired firm, but about 10 percent of the post-acquisition publications are in the name of the acquiring firm but with an author who appears on a previous publication of the target firm.

drop by about 33 percent of the sample mean. This pattern of results also holds when we weigh publications by citations (the coefficient estimate on publications flow drops from a positive 0.9 in the first sample period, to a negative -1.8 in the later sample period). For deals after 1997, the post-acquisition publication decline is 27 percent.

We repeat this exercise, this time with patents. We check whether inventors from acquired firms also reduce patenting after acquisition. Instead, as we can see in columns 7–9, on average, patenting activity *rises* after the firm has been acquired, although this rise takes place mostly in the first half of the sample, while in the second half there is no change in patenting activity post-acquisition.

In sum, Table 6 provides additional support for the conjecture that firms have lowered their willingness to pay to acquire external scientific capability over time. In part, at least, this is because the acquiring firms are less willing to invest in science internally. The fruits of science, here proxied by patents, continue to be valued but not science itself.

[**Insert Table 6 here**]

4. Mechanisms

4.1. The use of science in innovation

Firms invest in science for several reasons. First, scientific discoveries may themselves lead to innovation. If new scientific knowledge is becoming less relevant for commercial innovation, firms will be less likely to invest in research. Tracing the application of science to commercial ends is very difficult. One proxy, admittedly highly imperfect, is the citations patents make to scientific publications. Narin et al. (1997) found that, of the papers published in 1988 cited by patents issued in 1993, over 40 percent were from public research institutes, while nearly 27 percent were produced by firms. If applying scientific knowledge to industry is becoming much harder or more costly, there ought to be fewer citations to science by patents.

In Table 7 we examine trends in the citations to scientific publications by patents produced by our sample firms. Because we are interested in patent citations to science, we purged the "non patent references" of trade journals, news articles, press releases and the like. Visual inspections indicate that the remaining references can reasonably be considered to be references to scientific publications. As shown in column 1, patent citations to science remain stable over time. Columns 2 and 3 split the sample by firms that invest in science and firms that do not. For both subsamples we find an insignificant coefficient estimate on time trend. Columns 4–7 explore variation across broad technology fields. No field experiences a decline in the number of citations to science over time. Consistent with this, NSF data show that whereas about 10.6 percent of U.S. utility patents cited scientific publications in 1998, the share had increased to 11.9 percent by 2010. Over the same period, the share of scientific publications cited in a patent had largely remained unchanged, at around 1.7 percent (NSF S&E Indicators, 2012, Table 5-49).

In unreported robustness checks, we reran the analysis only counting references to articles published in journals in the CHI journal database. In the "clean" sample, mean patent citations to science at the firm-year level is 2.4 (a median of 0.5). As an additional robustness check, we reran estimates restricting our attention to citations to journals with a high (above median) ISI impact factor. We find results very similar to those reported in the paper.

[Insert Tables 7–8 here]

Though patents may continue to cite science, they may be citing older science. If innovation is less likely to require new scientific knowledge, firms may reduce their own investment in creating such new knowledge. Further, investments in scientific capability may serve to absorb and use existing scientific knowledge, the vast bulk of which is external to the firm. If, over time, external scientific knowledge has become more accessible to firms due to developments in markets for technology and improvements in information technology, the need to invest in scientific capability may have fallen.

We examine whether innovations rely upon increasingly older scientific knowledge, and how this differs with the scientific capability of the firm. Specifically, we ask if the average age of scientific publications cited by patents has changed over time, and whether these trends differ between firms that do publish and those that do not. We expect that if innovation is less reliant upon recent scientific knowledge, the average age of the publications cited by patents should increase. If scientific capability enables firms to use more recent science in their innovations, this should be reflected in a lower average age of publications cited by their patents. That is, publishing firms should cite more recent publications in their patents than non-publishing firms. However, if scientific capability becomes less relevant for absorbing external knowledge, the difference in the vintage of articles cited by publishing and non-publishing firms should shrink over time.

Table 8 presents the results where we use firm-year observations with at least one patent citation to science. This leaves us with 850 firms and 6,251 observations. Our dependent variable is the average publication year of articles by all patents of the focal firm in a given year. Our results are remarkably insensitive to whether we use industry fixed effects (columns 1 and 2) or firm fixed effects (columns 3 and 4), and they are very similar across major technology fields (columns 5–8).

The first point to note is that the coefficient of the time trend ranges between 0.97 and 1.01, and it is statistically indistinguishable from 1. In plain words, patents that are a year younger cite papers that are on average published one year later than papers cited by one year older patents. The vintage of science used in innovation, as measured by the relative average age of the scientific literature cited by patents, has remained unchanged.

Second, the coefficient of the log of publications ranges from about 0.22 to 0.35. Thus, a doubling of publication stock is associated with a reduction of about three months (column 1) to four months (column 3) in the average age of the cited scientific publications. This suggests that scientific capability is important in enabling firms to absorb more recent scientific knowledge, although of course it is also likely that firms that publish also work on more cutting-edge innovation.

Finally, there is very little evidence to suggest that investments in science have become less effective over time in helping firms absorb external science. Columns 2 and 4 include an interaction between the stock of publications and a time trend. The coefficient of the time trend is small and insignificant. It is similarly small and insignificant when we look across technology domains, with the exception of chemicals.[6] To sum up, we find no evidence that science has become less relevant for innovation, or that the relevant scientific knowledge is of older vintage. We also find no evidence that internal scientific capability is becoming less effective in helping firms absorb scientific knowledge.

4.2. American regulatory changes

Changes in the U.S. regulatory environment such as the Sarbanes-Oxley Act of 2002 and the Bayh–Dole Act of 1980 are said to have discouraged large American firms from making longer-term investments, including investments in scientific capability. To test the conjecture that our results are driven by American regulatory changes, we expand our data to European firms. We match publication and patent records to all European firms from Amadeus (private and public firms). We identify about 58,000 publications by 3,642 firms, and 210,000 patents by 10,053 firms. Lacking data on R&D expenditures for European firms, we restrict attention to firms that either patent or publish at least once during the sample period of 1997–2007, the period for which financial data are available. Of these firms, about 31 percent publish at least once, and the vast majority, over 90 percent, patent at least once between 1997 and 2007.

[6] Of course, there are additional dimensions of absorptive capacity other than a faster absorption of external knowledge. For example, absorptive capacity may allow firms to identify relevant knowledge that is geographically distant from the firm, or assess the quality of this knowledge, or how close it is from a technical standpoint to the firm core knowledge. It would be interesting to examine these additional dimensions in future work.

Table 9 presents the estimation results for within-firm changes in number of publications and patents. We observe a very similar pattern of results for the European firm sample. Publications decline over time (column 1), even after controlling for firm sales, which are available only for a subsample of firms for 1997–2007 (column 2). Publications decline at about the same rate for private as for public firms (column 3), which makes it less likely that short-termism, sometimes attributed to public equity markets, is the reason for the decline in scientific research by firms. The rate of decline is similar when we restrict attention to firms that are present in the sample for longer than 10 years (column 4), and is even greater when we focus only on firms that started to invest in science prior to 1980 (column 5). Finding that European firms display similar reductions in investment in science as American firms is not consistent with the idea that specific regulatory changes in American institutions drive the results of this paper. Nor do they provide support for the argument that short-termism in stock markets is responsible for the decline.

[**Insert Table 9 here**]

4.3. Globalization

Another possible explanation for why large firms have reduced their investments in scientific capability is increased competition from overseas, particularly from low-wage countries. To explore this mechanism, we follow Bloom et al. (forthcoming) and calculate the level of Chinese import penetration as the share of the value of imports originating from China in the total imports in an industry from 1998 to 2008.[7] For each industry we compute the change in Chinese import penetration from 1998 to 2008. We observe a significant rise in imports from China over time across industries: import penetration rates more than double, from an average of 2 percent in 1998 to 5 percent in 2008. We use *changes* in Chinese import penetration as our measure of increased globalization.

Columns 1–2 of Table 10 show a strong negative relationship between increased imports from China and the number of citation weighted scientific publications. The dependent variable is the three-year change in publications, and the regressors are also computed as three-year changes, with the obvious exception of the time trend. The standard errors are adjusted to allow for the serial correlation and are clustered at the firm level. Controlling for changes in Chinese import penetration explains the within firm decline in publications over time. Without controlling for Chinese imports

[7] The import data is from the UN Comtrade database that tracks annual bilateral import and export trade volumes between pairs of countries. We aggregate the trade value between China to industry four-digit SIC level from the six-digit product level, and normalize the Chinese imports by domestic production figures from Eurostat's Prodcom database. Please see Bloom et al. (forthcoming) for more details.

(column 1), the coefficient estimate on time trend is negative and statistically significant from zero (-0.01 with a standard error of 0.01). After controlling for Chinese imports (column 2), the coefficient estimate of the time trend in publication is small and insignificantly different from zero.

Columns 3–5 presents the results for the relationship between three-year changes in Chinese import penetration and corresponding changes in patent output, R&D expenditures, and physical investment. As with publications, we find a negative relationship for R&D and physical investment. It appears that increases in import competition from low-wage countries (proxied here by imports from China) tend to reduce forward-looking investments in both tangible and intangible capital. Interestingly, however, and consistent with Bloom et al. (forthcoming), the propensity of our firms to patent increases in sectors that experience an influx of Chinese imports over time.

Table 11 presents the estimation results for stock market value. Column 1 includes interactions terms between changes in Chinese import penetration and publication and patent stocks. We find that the stock market value of publications declines with an increase in Chinese imports, but the value of patent stock does not. Columns 2 and 3 report results for industries which experienced a sharp rise in Chinese import penetration and those that did not. As shown in Column 2, the decline in the value of publications and the increase in the value of patents over time are strongly evident in the industries facing high competition from China, but not in those insulated from Chinese imports (column 3). For industries insulated from Chinese imports, the value of publications and patents remains stable over time.

Overall, therefore, our evidence suggests that growing globalization is a plausible mechanism for why large firms in advanced economies are withdrawing from science. It is important to stress that, as with other analyses, we are measuring association rather than causal structure. For instance, it is possible that industries where opportunities for radical innovation—innovation drawing upon scientific knowledge—are declining are also those which face greater import competition from China. Our objective here is not to provide definitive results but to see whether the data provide prima facie support for some mechanisms relative to others. We also emphasize that the decline in the value that large firms attach to scientific capability predates 2001, the year China entered the WTO. Thus, China should be seen as an instantiation of a broader trend, not fully captured in our empirical analysis, wherein growing competition from lower-wage countries is pushing firms away from science and toward more applied research.

[Insert Tables 10–11 here]

4.4. Firm scope

Large firms may also be withdrawing from science because they are becoming less diversified. We use firm-level data on sales concentration from the Compustat line of business database to test the idea that firms with an increasingly narrower product base are most likely to reduce their investments in science. The results of Table 12 are effectively within-firm estimates, relating changes research to changes in the firm's scope. The dependent variable in Column 1 is the three-year change in the output of scientific publications, and the key independent variables are also computed as three-year changes. As before, the standard errors are robust to serial correlation and clustered at the firm level. We see that there is a strong negative relationship between changes in firms scope and publications, controlling for size and changes in the R&D stock. Based on the estimates from column 1, we find that moving from the lowest to the highest decile of decreases in firm scope is associated with a drop of 87 percent of sample average decline in publications. However, as columns 2 and 3 show, the decline in patents and R&D investment is much smaller and we cannot reject the null hypothesis of no decline.

Columns 4–5 examine whether the decline in the stock market value of publications is more pronounced in the subsample of firms that have become more focused over time. Column 4 shows that for firms which have narrowed their scope, the implied stock market value of publications declines over time. By contrast, as Column 5 shows, for firms whose scope has widened, there is no such decline. Also consistent with the general trends reported earlier, the implied stock market value of patents increases rather than decreases, for both types of firms. Moreover, the implied value of patent for firms with narrowing scope grows at least as fast as that of firms whose scope has not narrowed over time. Overall, our results are consistent with the conjecture that investments in science benefits mostly diversified firms. Firms that have narrowed their scope derive less value from scientific capability and have accordingly reduced their investments in science.

[Insert Table 12 here]

5. Discussion

The discourse among managers and strategy consultants often centers on how firms can grow. Innovation features prominently in such discussions. Innovation has many sources but in the ultimate analysis, without advances in the stock of scientific knowledge, technical progress will eventually falter, as will the rate of innovation. Of course, firms have drawn upon the stock of public scientific knowledge to fuel their innovation efforts, but they also invested in developing and maintaining internal scientific capability as well. In so doing, they hoped for new goods and services to emerge from research labs, but also banked on in-house scientists to guide technical search, acquire relevant external technology, and serve as talent magnets. They did so understanding that investments in internal scientific capability would not pay off right away but would take time to materialize. Only firms willing to take the long view would invest in internal science.

While a few papers have attempted to quantify the size of the private returns to investments in science, to the best of our knowledge no previous work has examined how the value of such investments has changed over time. In addition, few studies jointly analyze changes in both the value and the quantum of investment in science.[8] We use data on both publication output and the implied stock market value of publications for all publicly traded American firms, for over a quarter century. We verify that similar patterns hold for European firms. We additionally analyze acquisitions of small, research-based firms to infer the implied value managers place on scientific capability in the target firms, and we examine the publication behavior of target-firm scientists following the acquisition. By piecing together these complementary pieces of evidence, we provide the most comprehensive evidence to date on the changing structure of corporate R&D in large firms.

In addition, the present paper also explores a number of factors that, in recent times, may have induced large firms to reduce their investments in science. One factor is narrower firm scope. At least since the 1990s, many firms have been focusing on their "core competencies," possibly as the result of growing competition. While concentrating on a narrower set of products or a smaller portion of the value chain can have advantages, basic research (and its unpredictable fruits) may be less valuable to narrowly focused firms. This can in principle explain both a reduction in investment in science by less diversified firms, and a lower implied value for basic research investment.

A second factor that may have induced firms to withdraw from science is globalization. Globalization and increased competition may reduce the payoff to innovation, reducing the value of scientific capability. Competition from low-cost countries can also depress private investments in science by reducing cash flows, thereby reducing the amount of internal funds available to fund research. This second financial constraints argument can explain why firms invest less in science, but is hard to reconcile with a decline in the market value premium for scientific capability. If firms that invest in scientific capability are the ones that are able to overcome financial constraints, then the market should respond positively to such investments, not negatively. One possibility is that markets, as well as managers, become more short-term oriented when firm profitability declines (as

[8] However, Simeth and Cincera's (2013) results imply a decline in the value of publications.

a result of global competition). Alternatively, it could be that investment in internal science is an inefficient relic of a past long gone, when big American and European firms could afford to "waste" resources. In this view, large firms are inefficient performers of research and need to be pushed to outsource research to smaller and more nimble partners.

We find little support for other potential explanations for our findings. One is that large firms have merely changed their publication practices rather than reduce their investment in science. A decline in publication output may reflect not changes in R&D composition, but rather a rejection of "open science" in favor of greater focus on patents or secrecy. Were this so, we would expect large firms to reduce publications in applied scientific journals, which contain findings more likely to be commercially relevant. We find instead that the decline in firm publications is most prominent for publications in high-impact scientific journals, as well as in journals dedicated to basic rather than applied research. Furthermore, if changes in publication were simply due to changes in disclosure strategy but firms continued to value scientific capability to the same extent, we would not expect to find any reduction in the premium firms pay to acquire scientific capability through M&A. Instead, we find that the premium for the scientific capability of firms acquired in M&A has declined. This suggests that the decline in publications and the increase in patenting are not merely driven by a change in publication strategy. Rather, large firms appear to be moving away from basic and scientific research and toward more applied and incremental research.

Other mechanisms for which we find little support in our data include a reduction in the relevance of science for innovation, a diminished importance of absorptive capacity, and changes in U.S. regulatory environment. One, admittedly imperfect, way of tracing the application of science to technology is to use the citations patents make to scientific publications. We show that scientific knowledge continues to be relevant for innovation (i.e., patents continue to cite science) and that *new* science in particular remains important (i.e., the vintage of scientific knowledge used in innovation has not changed over time). Thus, our findings suggest that the withdrawal of firms from science is likely to leave an important gap in the relevant scientific base for innovation.

Using patent citations to scientific publications we also show that firms with higher scientific capability are able to draw upon more recent scientific knowledge in their innovations, and that the relatively higher absorptive capacity they so enjoy has not eroded over time. This suggests that the reduction in investments in science is unlikely to be because scientific capability is now less helpful in enabling firms to use external knowledge. Finally, using data on European firms, we show that American regulatory changes are unlikely to drive our results. Needless to say, all these tests have limitations (for instance, absorptive capacity could confer other advantages to firms rather than simply facilitating access to more recent scientific knowledge) and further exploring potential causal mechanisms remains an important avenue for future research.

6. Concluding Remarks

Our results indicate that the willingness of large firms to invest in scientific capability has declined. This is reflected in their behavior (e.g., their propensity to publish), the acquisition price of the science-intensive firms they acquire, and the stock market premium that investors attach to scientific capability of the firms. It is also consistent with other evidence reported in the literature on the increase in alliances and licensing, as well as qualitative evidence on the decline in corporate research.

A pessimistic interpretation of these results is that private research is in decline. Established companies can no longer emulate firms such as DuPont, AT&T, or Merck, whose investments in research in the past have significantly advanced the frontiers of human knowledge. Unless public funding can make up the deficit, technical progress will slacken and eventually reduce productivity growth. Managers in established firms, struggling to satisfy increasingly assertive investors, may be disinclined to make long-term risky bets on internal science. They may look to other means to achieve their growth targets, including international expansion and sourcing inventions and knowledge from outside the firm.

The last option, external sourcing of innovation, points to a less alarming interpretation. It may well be that other organizations—smaller firms and universities—are making up the shortfall in investment in research. According to this interpretation, what is happening is a reallocation of research from large corporate labs to more efficient organizations. To the extent that public support for research falls, external sourcing may be a less viable option because the aggregate production of knowledge falls.

The enhanced efficiency of how research is performed can substantially offset the shortfall in the quantum of investment in research. Even so, scientific entrepreneurs need to heed these trends. Acquisition is a common exit for start-ups. If acquirers will not pay for scientific research, as our results show, it implies that start-ups will have to invest longer, until such time as the research bears fruit and the resulting innovations can be converted into patents and products. Not all organizations that are good at research are also good at converting their research into commercially relevant forms. Requiring all research-intensive start-ups to move downstream will undoubtedly be inefficient. More importantly, it would dissuade some start-ups from investing in research, reducing the overall investment into an activity that is believed to have high social returns.

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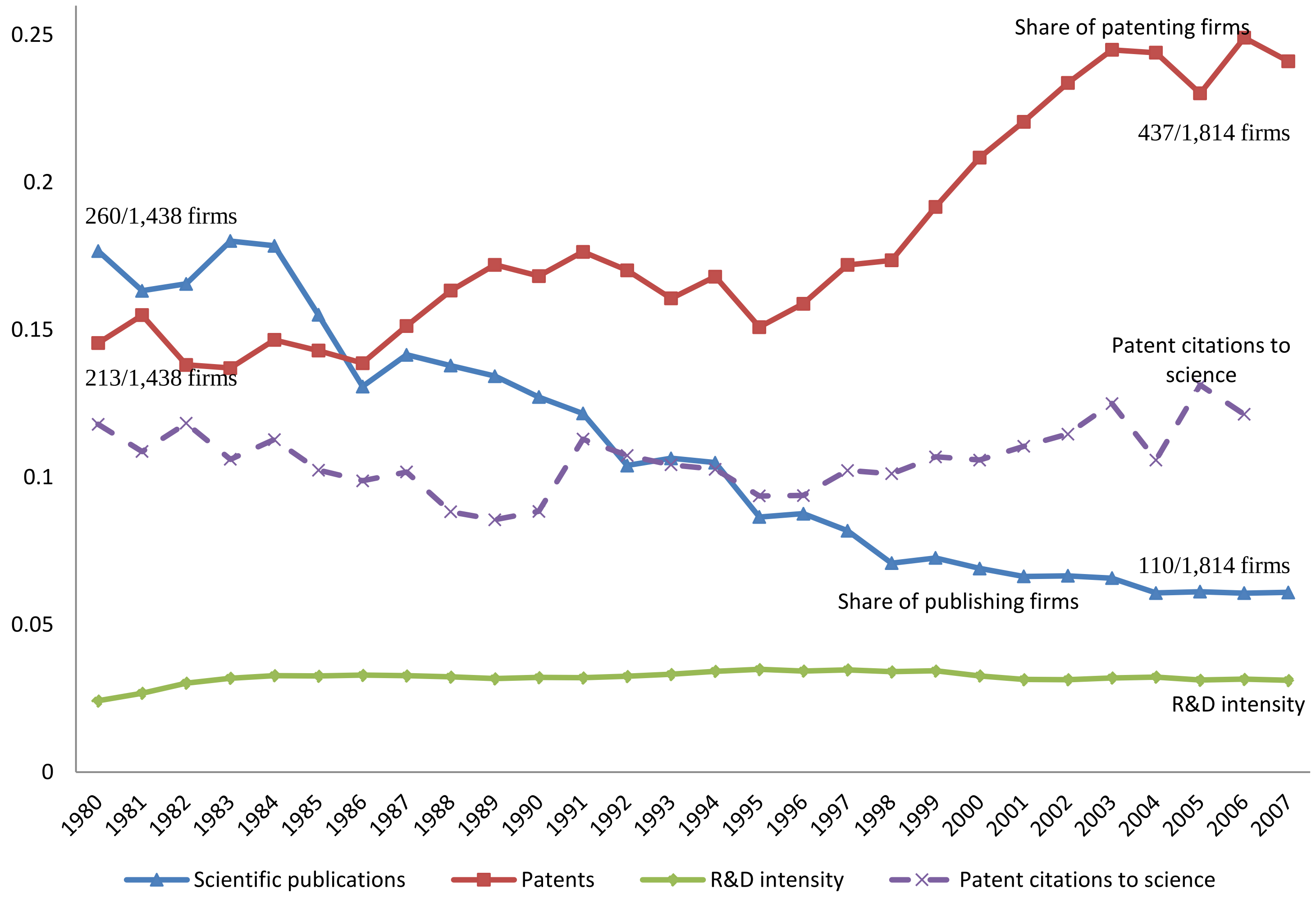
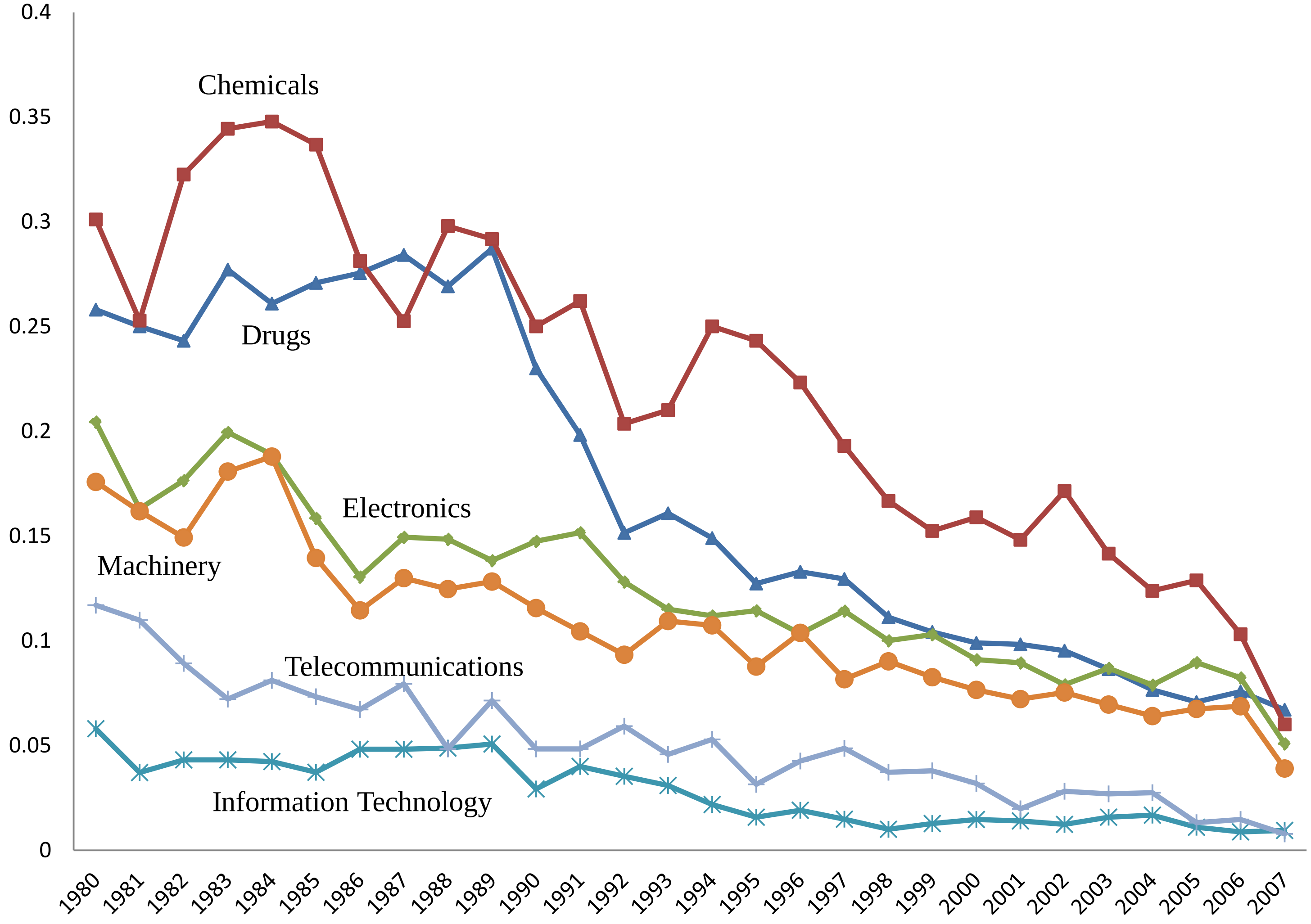
Figure 1: Share of publishing and patenting firms over time



Note: This figure presents the share of publishing and patenting firms of all Compustat firms with positive R&D expenditures, over time. R&D intensity is R&D expenditures over sales. Patent citations to science is the ratio between patent citations to leading scientific journals and the total number of citations the patent makes.

Figure 2: Share of publishing firms over time by selected industries



Note: This figure presents the share of publishing firms of all Compustat firms with positive R&D expenditures over time by selected industries. Industry classification is based on four-digit main SIC code.

TABLE 1. SUMMARY STATISTICS FOR MAIN VARIABLES

VARIABLES	No. Obs.	Mean	Std. Dev.	Distribution 10th	50th	90th
Panel A: Compustat firms						
Market value ($, mm)	11,304	5,920	20,278	33	677	12,208
Assets $_{t-1}$ ($, mm)	11,304	3,017	9,681	24	397	7,328
Sales $_{t-1}$ ($, mm)	11,304	3,410	9,805	35	677	12,208
Publication stock	11,304	58	389	0	0	20
Publication flow	11,304	10	58	0	0	8
Patent stock	11,304	174	664	2	19	314
Patent flow	11,304	26	101	0	2	46
Panel B: Acquisition target firms (SDC Platinum)						
Target value ($, mm)	26,884	155	251	6	57	424
Net assets ($, mm)	26,884	75	116	2	30	209
Sales ($, mm)	26,884	133	51	4	51	400
Publication stock	836	3	13	0	0.2	6
Patent stock	3,767	31	73	0	4	87

Notes: This table presents summary statistics for the main variable used in the estimation for our sample of Compustat and SDC firms. Panel A includes R&D-performing Compustat firms, and Panel B includes all target firms from SDC Platinum in the period 1985–2007 with deal value and assets information.

TABLE 2a. RESEARCH AND THE STOCK MARKET VALUE OF R&D-PERFORMING FIRMS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	ln(Publications)		ln(Patents)	R&D/ Sales	ln(*Market value*)		
Sample:	All	At least one pub	All	All	All	1980–1997	1998–2007
Time trend	-0.011**	-0.029**	-0.004	0.004	0.091*		
	(0.003)	(0.007)	(0.005)	(0.006)	(0.046)		
Time trend ×ln(*Publication Stock*)$_{t-1}$					-0.002**		
					(0.0008)		
Time trend × ln(*Patent Stock*)$_{t-1}$					0.004**		
					(0.001)		
ln(*Publication Stock*)$_{t-1}$					0.074**	0.066**	0.024
					(0.014)	(0.024)	(0.027)
p-value for difference in estimates:						*p-value* <0.01	
ln(*Patent Stock*)$_{t-1}$					0.066**	0.095**	0.153**
					(0.014)	(0.023)	(0.023)
Dummy for Research Lab						0.217*	0.058
						(0.091)	(0.076)
p-value for difference in estimates:						*p-value* <0.01	
ln(*Assets*)$_{t-1}$					0.306**	0.266**	0.372**
					(0.017)	(0.026)	(0.038)
ln(*R&D Stock*)$_{t-1}$					0.066**	0.049**	0.076**
					(0.014)	(0.018)	(0.015)
ln(*R&D expenditures*)$_{t-1}$	0.046**	0.119**	0.186**				
	(0.015)	(0.043)	(0.032)				
ln(*Sales*)$_{t-1}$	0.092**	0.432**	0.109**	-0.167**	0.488**	0.522**	0.422**
	(0.023)	(0.120)	(0.033)	(0.045)	(0.019)	(0.033)	(0.042)
Firm fixed effects	Yes	Yes	Yes	Yes	No	No	No
Industry dummies	-	-	-	-	Yes	Yes	Yes
R^2	0.897	0.879	0.832	0.845	0.842	0.853	0.818
Observations	11,304	4,955	11,304	11,304	11,304	5,288	6,016

Notes: This table presents estimation results for investments in research by publicly listed R&D-performing American firms for the period 1980–2007. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. * significant at 5%; ** significant at 1%.

TABLE 2b. PUBLICATIONS AS A MEASURE OF INVESTMENT IN SCIENTIFIC RESEARCH

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Flow of scientific publications			Share basic	ln(Market value)	
Publications:	Basic	Applied	Low Impact Factor	All	All	All
Time trend	-0.005**	-0.001	0.004	-0.023**	0.086*	0.115
	(0.002)	(0.003)	(0.004)	(0.008)	(0.046)	(0.072)
Time × ln(*Basic publication stock*)$_{t-1}$					-0.019*	
					(0.001)	
Time × ln(*Applied publication stock*)$_{t-1}$					0.001	
					(0.001)	
Time × ln(*Share basic publication stock*)$_{t-1}$						-0.003**
						(0.001)
Time trend × (P*ublication stock*)$_{t-1}$						-0.001
						(0.001)
ln(1+*Basic publication stock*)$_{t-1}$					0.071**	
					(0.014)	
ln(1+*Applied publication stock*)$_{t-1}$					-0.024	
					(0.015)	
ln(1+*Publication stock*)$_{t-1}$						0.047**
						(0.013)
ln(*Share basic publication stock*)$_{t-1}$						0.051**
						(0.019)
Time trend × ln(*Patent stock*)$_{t-1}$					0.005**	0.003**
					(0.001)	(0.001)
ln(1+*Patent stock*)$_{t-1}$					0.064**	0.063**
					(0.013)	(0.017)
ln(*R&D stock*)$_{t-1}$	0.013**	0.034**	0.076**	-0.214**	0.071**	0.033**
	(0.006)	(0.011)	(0.025)	(0.055)	(0.005)	(0.007)
ln(*Sales*)$_{t-1}$	0.015	0.032**	0.089*	0.117**	0.489**	0.669**
	(0.009)	(0.013)	(0.043)	(0.067)	(0.019)	(0.028)
ln(*Assets*)					0.308**	0.219**
					(0.017)	(0.026)
Two-digit industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country target dummies	Yes	Yes	Yes	Yes	Yes	Yes
Acquisition year dummies	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.944	0.871	0.705	0.935	0.853	0.891
Observations	11,304	11,304	11,304	4,955	11,304	4,955

Notes: This table presents estimation results when we distinguish between basic and applied scientific publications as indicated by the CHI journal database. Publications are classified as basic if they are published in journals with a CHI level of 4, and as applied if they are published in journals with a CHI level of 1. Column 3 includes only publications in journal with lowest quartile impact factor value. Columns 4 and 6 include only publishing firms. Publications and patents are weighed by citations. Standard errors (in brackets) are robust to arbitrary heteroskedasticity. * significant at 5%; ** significant at 1%.

TABLE 3. INVESTMENT IN RESEARCH BY INDUSTRY OVER TIME

	(1)	(2)	(3)
Dependent variable:	ln(Publications)	ln(Patents)	R&D/ Sales
Time trend	-0.024**	-0.023**	-0.001
	(0.005)	(0.003)	(0.003)
Time trend ×:			
Dummy for Biotechnology	-0.020**	-0.034**	0.028**
	(0.009)	(0.004)	(0.006)
Dummy for Chemicals	0.014*	-0.006	-0.002
	(0.006)	(0.004)	(0.004)
Dummy for Pharmaceuticals	0.003	0.009*	-0.004
	(0.009)	(0.004)	(0.006)
Dummy for Electronics	-0.005	0.022**	-0.007
	(0.006)	(0.003)	(0.004)
Dummy for IT	-0.013*	0.017**	-0.001
	(0.006)	(0.003)	(0.004)
Dummy for Semiconductors	-0.006	0.015**	0.013**
	(0.007)	(0.004)	(0.004)
Dummy for Telecommunications	0.007	0.023**	0.013**
	(0.007)	(0.004)	(0.004)
ln(*R&D expenditures*)$_{t-1}$	0.107**	0.151**	
	(0.022)	(0.014)	
ln(*Sales*)$_{t-1}$	0.322**	0.112**	0.390**
	(0.040)	(0.017)	(0.037)
Firm fixed effects	Yes	Yes	Yes
R^2	0.879	0.854	0.845
Observations	4,955	11,304	11,304

Notes: This table examines time trends in research across industries. Firms are classified into industries based on the distribution of their patents by technology areas. Column 1 includes firms with at least one publication over our sample period. Publications and patents are weighed by citations. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. * significant at 5%; ** significant at 1%.

TABLE 4. RESEARCH AND STOCK MARKET VALUE BY INDUSTRY OVER TIME

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	ln(*Market value*)						
Variables	Biotech	Chemi-cals	Pharma	Elect-ronics	IT	Semicon-ductors	Telecom
Time trend × ln(*Publication Stock*)$_{t-1}$	-0.001	-0.002*	-0.003*	-0.003**	-0.003**	-0.003*	-0.005**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Time trend × ln(*Patent stock*)$_{t-1}$	0.005**	0.004**	0.007**	0.006**	0.007**	0.004*	0.009**
	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)
ln(*Publication stock*)$_{t-1}$	0.134**	0.154**	0.139**	0.114**	0.157**	0.068**	0.136**
	(0.021)	(0.017)	(0.022)	(0.016)	(0.018)	(0.022)	(0.020)
ln(*Patent stock*)$_{t-1}$	-0.035	-0.002	-0.086**	0.034	-0.038	0.148**	-0.065*
	(0.027)	(0.024)	(0.029)	(0.021)	(0.025)	(0.036)	(0.031)
Time trend	-0.009	0.012	0.005	0.024*	0.020*	0.034**	0.013
	(0.013)	(0.009)	(0.015)	(0.008)	(0.009)	(0.012)	(0.011)
ln(*Assets*)$_{t-1}$	0.315**	0.453**	0.320**	0.349**	0.310**	0.274**	0.228**
	(0.041)	(0.028)	(0.041)	(0.023)	(0.026)	(0.034)	(0.031)
ln(*R&D stock*)$_{t-1}$	0.021	0.053**	0.070	0.012	0.007	0.063**	-0.006
	(0.016)	(0.012)	(0.018)	(0.007)	(0.009)	(0.017)	(0.011)
ln(*Sales*)$_{t-1}$	0.418**	0.323**	0.390**	0.543**	0.579**	0.505**	0.677**
	(0.042)	(0.030)	(0.037)	(0.026)	(0.029)	(0.035)	(0.034)
R^2	0.846	0.828	0.833	0.836	0.816	0.851	0.836
Observations	1,465	3,025	1,604	4,590	3,391	2,013	2,064

Notes: This table examines time trends in the stock market value of research across industries. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. * significant at 5%; ** significant at 1%.

TABLE 5. RESEARCH AND TARGET'S FIRM VALUE OVER TIME

Dependent variable: ln(*Target's firm value*)

	(1)	(2)	(3)	(4)	(5)
	All Years	1985-1997	1998-2007	Innovating targets	Excluding IT
Time trend × ln(*Publication stock*)$_{t-1}$	-0.018**			-0.017**	-0.019**
	(0.005)			(0.005)	(0.005)
Time trend × ln(*Patent stock*)$_{t-1}$	0.003**			0.002	0.003**
	(0.001)			(0.001)	(0.001)
ln(1+*Publication stock*)$_{t-1}$	0.292**	0.169**	-0.043	0.266**	0.314**
	(0.064)	(0.040)	(0.069)	(0.062)	(0.065)
p-value for difference in estimates:		*p-value* <0.01			
ln(1+*Patent stock*)$_{t-1}$	0.039**	0.069**	0.072**	0.033*	0.041**
	(0.012)	(0.008)	(0.011)	(0.015)	(0.012)
ln(*Assets*)	0.592**	0.586**	0.595**	0.649**	0.598**
	(0.007)	(0.010)	(0.010)	(0.019)	(0.007)
ln(*Sales*)	0.167**	0.177**	0.157**	0.077**	0.168**
	(0.007)	(0.009)	(0.010)	(0.016)	(0.007)
Time trend	0.018**			0.011*	0.019**
	(0.003)			(0.005)	(0.003)
Two-digit industry dummies	Yes	Yes	Yes	Yes	Yes
Country target dummies	Yes	Yes	Yes	Yes	Yes
Acquisition year dummies	Yes	Yes	Yes	Yes	Yes
R^2	0.654	0.678	0.633	0.646	0.661
Observations	26,884	14,990	11,894	4,684	25,004

stocks. The sample includes all SDC Platinum deals with non-missing information on target firm value, assets and sales. The sample period is 1985–2007. Column 4 includes only target firms with at least one patent or scientific publication. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. * significant at 5%; ** significant at 1%.

TABLE 6. RESEARCH BY TARGET FIRMS IN THREE-YEAR WINDOW AROUND ACQUISITION YEAR

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	Flow of scientific publications						Flow of patents		
	Count			Weighed by citations			Count		
Acquisition year:	All	1985-1996	1997-2004	1985-2004	1985-1996	1997-2004	All	1985-1996	1997-2004
Post-acquisition dummy	-0.079**	0.013	-0.198**	-0.298	0.902**	-1.839**	1.171**	2.036**	0.184
	(0.023)	(0.025)	(0.041)	(0.200)	(0.248)	(0.326)	(0.467)	(0.629)	(0.698)
p-value for difference in estimates:		*p-value* <0.01			*p-value* <0.01			*p-value* <0.01	
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean dependent variable	0.57	0.57	0.58	6.1	5.6	6.7	8.6	6.6	10.3
R^2	0.865	0.901	0.819	0.614	0.640	0.590	0.953	0.911	0.97
Observations	19,475	10,615	8,860	19,475	10,615	8,860	22,369	11,040	11,329

Notes: This table reports the results of OLS regressions that examine the effect of being acquired on publishing and patenting activity. Post-acquisition dummy receives the value of one for observations where the year is later than the acquisition value and zero otherwise. We include observations in a three-year window from the acquisition year. Robust standard errors are in brackets. * significant at 5%; ** significant at 1%.

TABLE 7. USE OF SCIENCE IN INNOVATION: CITATIONS BY PATENTS TO SCIENTIFIC PUBLICATIONS

Dependent variable: *Number of patent citations to science*							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	All	Publishing firms	Non-publishing firms	Pharma and Biotech	Chemicals	Electronics	Telecom and IT
Time trend	0.001	0.021	-0.017	0.045	0.016	0.046**	-0.001
	(0.015)	(0.017)	(0.020)	(0.055)	(0.040)	(0.014)	(0.014)
Cites made	0.089**	0.089**	0.089**	0.122**	0.100**	0.079**	0.133**
	(0.011)	(0.015)	(0.013)	(0.044)	(0.029)	(0.012)	(0.017)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.582	0.497	0.596	0.621	0.637	0.485	0.526
Observations	11,304	4,411	6,893	2,138	3,275	5,023	4,041

Notes: This table examines time trends in citations to scientific articles by patents for our Compustat sample of R&D-performing firms. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. * significant at 5%; ** significant at 1%.

TABLE 8. USE OF SCIENCE IN INNOVATION: AVERAGE AGE OF SCIENCE CITED IN PATENTS

Dependent variable: *Average publication year of cited science*								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Within-industries	Within-industries	Within-firms	Within-firms	Pharma and Biotech	Chemicals	Electronics	Telecom and IT
Time trend	0.974**	0.977**	1.001**	1.007**	0.983**	1.065**	0.978**	1.019**
	(0.012)	(0.015)	(0.018)	(0.024)	(0.036)	(0.030)	(0.031)	(0.033)
ln(*Patent stock*)$_{t-1}$	-0.122*	0.123*	0.012	0.011	0.278	0.016	0.216	0.201
ln(*Publication stock*)$_{t-1}$	0.224**	0.254**	0.317*	0.353*	0.249	0.286	0.219	0.265
	(0.036)	(0.071)	(0.158)	(0.191)	(0.208)	(0.195)	(0.198)	(0.191)
Time trend × ln(*Publication stock*)$_{t-1}$		-0.002		-0.002	0.002	-0.013**	0.001	-0.004
		(0.004)		(0.005)	(0.006)	(0.005)	(0.005)	(0.005)
	(0.063)	(0.063)	(0.107)	(0.107)	(0.209)	(0.155)	(0.132)	(0.146)
ln(*Sales*)$_{t-1}$	-0.058	-0.058	-0.668**	-0.672**	-0.548**	-0.533**	-0.439*	-0.655**
	(0.055)	(0.055)	(0.131)	(0.132)	(0.172)	(0.163)	(0.213)	(0.210)
Industry fixed effects	Yes	Yes	-	-	-	-	-	-
Firm fixed effects	No	No	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.580	0.580	0.691	0.691	0.786	0.735	0.714	0.736
Observations	6,251	6,251	6,251	6,251	1,789	2,529	3,418	3,041

Notes: This table examines the relationship between average publication year of cited articles and a firm's publication stock. The estimation sample consists of firms with patents that cite scientific articles. Standard errors (in brackets) are robust to arbitrary heteroskedasticity. * significant at 5%; ** significant at 1%.

TABLE 9. INVESTMENT IN SCIENCE BY EUROPEAN FIRMS

	(1)	(2)	(3)	(4)	(5)
Dependent variable:	*Flow of scientific publications*				
	All	Non-missing sales	Public *vs.* private	Sample years >10	First pub< 1980
Time trend	-0.046**	-0.111**	-0.045**	-0.066**	-0.212**
	(0.011)	(0.030)	(0.011)	(0.015)	(0.050)
ln(*Sales*)		0.322**			
		(0.137)			
Time trend × *Dummy for public*			-0.012		
			(0.024)		
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
R^2	0.724	0.676	0.724	0.722	0.719
Observations	38,018	15,135	38,018	11,451	2,999

Notes: This table examines time trends in scientific publications by European firms. We match our publication dataset to all Amadeus (private and public) firms. Financial data is available only from 1997, not for all firms. R&D is never reported. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms.

TABLE 10. GLOBALIZATION AND INVESTMENT IN RESEARCH, 1998-2007

	(1)	(2)	(3)	(4)	(5)
Dependent variable:	ΔPubs		ΔPats	ΔR&D	ΔCapx
ΔChinese import penetration		-1.725**	2.635**	-0.431*	-1.989**
		(0.563)	(0.716)	(0.244)	(0.403)
Time trend	-0.011**	0.001	-0.063**	-0.010**	0.003
	(0.005)	(0.007)	(0.009)	(0.003)	(0.005)
Δ*R&D stock*	0.042*	0.038*	0.397**		
	(0.019)	(0.019)	(0.055)		
Δ*Sales*				0.474**	0.854**
				(0.031)	(0.053)
R^2	0.002	0.005	0.038	0.260	0.337
Observations	4,354	4,354	4,354	4,354	4,354

Notes: This table presents the estimation results for the effects of Chinese import penetration on investment by Compustat firms. Changes in Chinese import penetration are computed as the three-year change in import penetration. Changes in R&D stock and sales are similarly calculated as 3 year changes. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. *

TABLE 11. GLOBALIZATION AND MARKET VALUE

Dependent variable: ln(*Market value*)			
	(1)	(2)	(3)
		Chinese import	
		High (75th pct.)	Low (25th pct.)
ΔChinese import penetration × ln(*Publication stock*)$_{t-1}$	-0.803**		
	(0.330)		
ΔChinese import penetration × ln(*Patent stock*)$_{t-1}$	-0.018		
	(0.323)		
Time trend × ln(*Publication stock*)$_{t-1}$		-0.010**	0.001
		(0.003)	(0.001)
Time trend × ln(*Patent stock*)$_{t-1}$		0.010**	0.001
		(0.002)	(0.002)
ln(*Publication stock*)$_{t-1}$	0.084**	0.065	0.086**
	(0.015)	(0.042)	(0.022)
ln(*Patent stock*)$_{t-1}$	0.153**	0.031	0.068**
	(0.016)	(0.033)	(0.028)
ln(*Assets*)$_{t-1}$	0.436**	0.337**	0.288**
	(0.037)	(0.055)	(0.032)
ln(*R&D stock*)$_{t-1}$	0.096**	0.065**	0.154**
	(0.010)	(0.018)	(0.013)
ln(*Sales*)$_{t-1}$	0.339**	0.579**	0.387**
	(0.039)	(0.066)	(0.033)
Time trend		0.174	0.175*
		(0.118)	(0.099)
ΔChinese import penetration	-0.372**		
	(1.290)		
R^2	0.789	0.805	0.873
Observations	3,540	1,755	2,077

Notes: This table presents the estimation results for the effects of Chinese import penetration on the stock market value of publications. In column 1, the estimation period is 1998–2007. In columns 2 & 3, the estimation period is 1980–2007. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. * significant at 5%; ** significant at 1%.

TABLE 12. NARROWER FIRM SCOPE

	(1)	(2)	(3)	(4)	(5)
Dependent variable:	ΔPubs	ΔPats	ΔR&D	ln(*Market value*)	
Dependent variable:				ΔHHI SIC>0	ΔHHI SIC≤0
ΔHHI SIC	-0.323*	-0.113	-0.060		
	(0.145)	(0.097)	(0.048)		
Time trend	-0.022	-0.006			
	(0.016)	(0.004)			
Δ*R&D stock*	0.240	0.378**			
	(0.161)	(0.062)			
ln(*Sales*)$_{t-3}$	0.107**	0.036**	0.002		
	(0.040)	(0.015)	(0.007)		
Δ*Sales*			0.391**		
			(0.039)		
Time trend × ln(*Publication stock*)$_{t-1}$				-0.004**	-0.001
				(0.001)	(0.001)
Time trend × ln(*Patent stock*)$_{t-1}$				0.006**	0.004**
				(0.001)	(0.001)
ln(*Publication stock*)$_{t-1}$				0.109**	0.051**
				(0.020)	(0.020)
ln(*Patent stock*)$_{t-1}$				0.030	0.077**
				(0.023)	(0.018)
ln(*Assets*)$_{t-1}$				0.296**	0.278**
				(0.036)	(0.023)
ln(*R&D stock*)$_{t-1}$				0.043**	0.073**
				(0.009)	(0.007)
ln(*Sales*)$_{t-1}$				0.580**	0.517**
				(0.044)	(0.026)
R^2	0.039	0.113	0.282	0.887	0.827
Observations	7,573	7,573	7,558	2,609	6,653

Note: This table examines the relationship between narrower firm scope and investments in research and its implied value over time. Changes are at the three-year window preceding the focal year. For instance, column 1 uses the change in the flow of publications produced in the given year minus the flow of publications produced three years prior to that. Other changes are similarly defined. HHI is based on Compustat line-of-business data. Column 4 restricts the sample to firms that have narrowed their scope, whereas column 5 restricts the sample to firms that have increased their scope. All regressions include industry dummies. Standard errors (in brackets) are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firms. * significant at 5%; ** significant at 1%.