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Nonlinear capital market payoffs to science-led innovation

Houdou Basse Mama*

ESCP Europe, Berlin, Germany

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ABSTRACT

This study explores the extent to which cross-sectional differences in firms' propensity to absorb and utilize scientific knowledge matter for their stock market and operating performance. Unlike previous empirical studies and given the coexistence of both benefits and potential costs to science-guided search, I conceptualize innovation as a recombinant search to hypothesize a non-monotonic relationship. Using patent data from the European Patent Office (EPO) relative to 3281 international firms over the 1999–2015 period, empirical tests yield evidence in support of the predictions. However, the effect varies with firm-level absorptive capacity, across industries and countries. As suggested by a limited attention model, I find a stronger payoff predictive power of science for firms with lower investor attention and higher valuation uncertainty. Besides, the association between science and future operating performance increases with time, indicating that firms' scientific capabilities are a potent driver of long-term profitability. The conclusions are robust to controlling for the endogenous nature of firms' use of scientific knowledge. By providing a useful basis upon which to judge the economic merit of firms' innovation endeavors, this study contributes to reducing capital market imperfections that curtail access to external finance and ultimately spurring private-sector investment in R&D. It also provides evidence of diminishing marginal payoffs to science-led search. Finally, the evidence is likely to be relevant to policymakers, who might wish to influence the innovation ecosystem in a way to sustain long-term prosperity.

1. Introduction

Companies increasingly recognize the value of external knowledge flows (Rigby and Zook, 2002) and are shifting away from the insular innovation culture. In a recent study, Arora et al. (2016) find that of the 16% of U.S. manufacturing firms with major innovations between 2007 and 2009, 49% of the innovations originated from identified outside sources. At the same time, large firms in the U.S. and Europe are withdrawing from open science, although scientific knowledge continues to be a useful input in firms' innovation programs (Arora et al., 2018; see also Narin et al., 1997). This transformation entails a redirection from more exploratory scientific research toward more product development and commercialization. However, such balancing act can irreversibly erode firms' internal scientific capabilities that are required for successfully internalizing scientific knowledge (Cohen and Levinthal, 1989).

The literature conceptualizes innovation as a combinatorial search over technology landscapes (e.g., Schumpeter, 1939; Nelson, 1986; Henderson and Clark, 1990; Fleming, 2001; Fleming and Sorenson, 2004) to identify mechanisms by which the internalization of scientific knowledge may affect firm-level inventive and financial performance. Acting "like a map" (Fleming and Sorenson, 2004, p. 926), science provides "offline" assessments of alternatives (Gibbons and Johnston, 1974) by reducing the solution space in the recombinant search and guiding inventors more directly toward more fruitful pastures (Fleming and Sorenson, 2004). Besides, science-led inventors possibly can avoid getting trapped in local optima and continue to search in a given direction despite negative feedback. Therefore, science-guided search will translate into superior search, which, in turn, promises greater financial payoffs.

Yet, the internalization of scientific knowledge does not occur without a cost.[1] With a few exceptions (Arora et al., 2016; Simeth and Cincera, 2016), previous empirical studies have surprisingly disregarded the costs inherent in science-led search. The existence of nonzero costs to science-guided search induces cross-sectional variations in the use of scientific knowledge and the efficiency with which it is used (Acs et al., 1994; Laursen and Salter, 2004; D'Este and Patel, 2007). While the empirical evidence is mostly supportive of a positive

* Correspondence to: Department of Finance, Chair of International Financial Markets, Heubnerweg 8-10, 14059 Berlin, Germany.
E-mail address: hbassemama@escpeurope.eu.

[1] As discussed in Section 2, such costs might fall within at least five cost types: direct costs due to absorptive capacity-building activities, negative externalities of unintended knowledge spillovers, costly strategies to retain star company scientists due to open science-induced visibility, relegation of technological innovation as a by-product of curiosity-oriented research, and inefficiencies due to company scientists "chasing cognitive rainbows" (Gavetti and Levinthal, 2000).

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effect on firm-level outcomes (Deng et al., 1999; Chen et al., 2016; Simeth and Cincera, 2016; Arora et al., 2018), there also exists evidence that scientific knowledge does not impact patent value (Konstantinidi et al., 2016) or is negatively related to patent quality (Gittelman and Kogut, 2003; Sapsalis et al., 2006). Therefore, the predominant practice of imposing linearity in exploring such a link might be inappropriate.

This study explores the extent to which cross-sectional differences in firms' propensity to absorb and utilize scientific knowledge matter for their stock market and operating performance. Given the coexistence of both benefits and potential costs to science-guided search, I hypothesize a non-monotonic relationship. Evidence of a significant relationship between science-guided search and future stock market performance would imply a relationship between science-guided search and future earnings and prior pricing inefficiency. Indeed, despite its availability to the public and its relative objective nature, patent information is highly technical (Gu, 2005), which may undermine investors' ability to correctly interpret its valuation implications. Salter and Martin (2001) maintain that the degree to which a firm draws on science (partly) mirrors the complexity of the technical problem it faces (see also Gibbons and Johnston, 1974; Cassiman et al., 2008). Limited investor attention and skepticism about complexity cause investors to neglect information about science-led innovation due to low salience and low processing fluency (Cohen et al., 2013; Hirshleifer et al., 2017; Brown et al., 2017). In turn, investor neglect increases return predictability (Hirshleifer et al., 2013).

This study makes three complementary research design choices. First, it adopts a portfolio analysis approach to investigate whether the stock market misprices innovation activities, depending on the absorption and use of scientific knowledge. Second, it uses Fama and MacBeth (1973) regressions to examine the direct effects of science-guided search on investors' firm-level growth expectations, as reflected by subsequent market-to-book ratios. Third, the Mishkin (1983) two-stage rational expectations framework is used to assess whether investors appropriately incorporate the implications of the internalization of scientific knowledge for future earnings into stock prices. These latter tests are complemented by Fama and MacBeth (1973) regressions in pinpointing the predictive power of science for future realized operating performance.

The sample covers 3281 international public firms from a wide spectrum of industries and countries, and spans the 1999–2015 period. These firms are required to hold at least one patent approved by the European Patent Office (EPO). I measure a firm's absorption and use of scientific knowledge by the closeness of its patents to science – that is, the degree to which a firm references non-patent literature in its own patent applications (e.g., Narin et al., 1997; Jaffe and de Rassenfosse, 2017). This measure is admittedly imperfect due to the complex social and institutional processes by which patents are made[2], but it is consistently used to indicate the "knowledge indebtedness of the invention to the cited research" (Breschi and Catalini, 2010, p. 17). Moreover, the fact that over 90% of non-patent references (NPRs) come from applicants rather than from patent examiners (Lemley and Sampat, 2012) makes a case for NPRs being a relevant "measure of science dependence" (Jaffe and de Rassenfosse, 2017, p. 1372). Arora et al. (2018, p. 23) contend that "[i]f corporate inventions are less likely to be science-based, there ought to be fewer citations to science by patents."

I find that the closeness of a firm's patents to science is non-monotonically related to subsequent stock returns, stock market valuations, and operating performance. However, the effect varies across industries, countries, and with firm-level absorptive capacity (AC). Interestingly, the association between science and future operating performance increases with time, consistent with the notion that firms' scientific capabilities are a potent driver of long-term profitability (Gu, 2005). Besides, maintaining closer ties with science when innovating is negatively (and linearly) associated with future stock market and operating performance beyond some threshold, reflecting potential diminishing marginal payoffs to science-led innovation. Furthermore, attesting to a limited investor attention model, the payoff predictive power of science-guided search is stronger for firms with lower investor attention and higher valuation uncertainty. The inferences are robust to controlling for the endogenous nature of citations to NPRs.

Clearly, the evidence has important implications. First, it implies that the value to a firm of science-led search is ambiguous due to non-linearity. This result is new to the literature. At a minimum, it indicates that non-linearity matters in studies that examine economic benefits of patent attributes, an issue which has hardly been addressed in previous studies. This study complements that by Chen et al. (2016), who find that science has a strong and positive causal effect on firms' total factor productivity (TFP) in Taiwan. It is also related to Simeth and Cincera (2016) who report a positive effect of a firm's active engagement in scientific disclosure on its contemporaneous market value. However, neither study empirically models non-linearity (see also Hirschey and Richardson, 2004). On the practical front, the closeness of a firm's patents to science appears as a powerful patent-based tool for investment and security analysis of innovative-intensive firms, a setting in which patent attributes are still scantily used (Deng et al., 1999). Given non-linearity, the results, however, warn against traditional constructions of long-short strategies from two extreme portfolios (low vs. high) in the distribution of a given conditioning variable.

My findings are likely to be relevant to policymakers who might wish to influence the innovation ecosystem in a way to sustain long-term prosperity. Given the positive moderating role of firm-level absorptive capacity (see also Oh, 2017), the inverse-U shaped relationship might partly reflect underestimated consequences of the delicate decline in corporate science (Arora et al., 2018) and the concomitant pervasive use of scientific knowledge. Finally, there is strong evidence that firms in innovative-intensive industries are more dependent on external equity finance (Brown et al., 2009). Given the value-relevance of firms' scientific capabilities, standard setters might find it judicious to induce firms to disclose that information, thereby reducing capital market imperfections that curtail access to external finance (Deeds et al., 1997; Brown et al., 2017).

2. Theoretical background and hypotheses

This study explores the financial payoff implications of heterogeneity across firms of the absorption and utilization of scientific knowledge. Scientific research is often considered a public good, and therefore likely feeds into the innovation processes of commercial firms (Nelson, 1986). Although the interaction between science and industrial innovation is multifaceted (Meyer-Krahmer and Schmoch, 1998), a salient example of knowledge spillover from academia to industry is the closeness of a firm's patents to science – that is, the degree to which a firm references non-patent literature in its own patent applications (Narin et al., 1997; Chen et al., 2016; Jaffe and de Rassenfosse, 2017). Roach and Cohen (2013) argue that non-patent references, not the generally used patent references, are a better measure of knowledge originating from public research.

The theoretical literature conceptualizes innovation as a combinatorial search over technology landscapes to identify mechanisms by which the absorption and use of scientific knowledge may affect firm-level inventive productivity and financial performance (Nelson, 1986).[3] Fleming and Sorenson (2004) identify three mechanisms. The first mechanism is termed "cheap offline experimentation": Science provides "offline" assessments of alternatives (Gibbons and Johnston, 1974;

[2] Engaged discussions of these issues are covered by, e.g., Gittelman (2008), Alcacer and Gittelman (2006), and Callaert et al. (2014).

[3] Recombination is viewed as the ultimate source of novelty (e.g., Schumpeter, 1939; Henderson and Clark, 1990; Fleming, 2001; Fleming and Sorenson, 2001).