Understanding the Mechanisms of Bridging Science and Technology Domains within Firms for Better Patent Performance

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Abstract: Scholars demonstrate that scientific ideas are not ready made inputs for technological innovation. They emphasize the importance of bridging scientists who are competent in both science and technology domains to translate the scientific competency of firms into better patent performance. I extend the current understanding of bridging the science-technology domains by showing that the degree to which bridging scientists enhance the patent performance depends on the extent to which their scientific findings are exploited in the patenting process. In the absence of conscious exploitation, mere presence of bridging scientists does not ensure translation of scientific competencies into better technological innovation.

Key Words: Bridging Scientists, Patent Performance, Complementary, Exploration and Exploitation

1. Introduction

The relationship between science and technology has been studied for a long time and still continues to be an important and relevant subject of enquiry by both practitioners and academia [1]. The aim of science is epistemic, more specifically to acquire knowledge, while the aim of technology is to construct things or process with socially useful function. Scholars have long believed that scientific input and R & D effort improve a firm’s technological innovation and performance [2],[3]. A study of 66 firms from seven major manufacturing industries estimates that about 11% of new products and 9% of new processes could not have been developed in the absence of scientific research from the academy [4]. Several explanations have been offered to illustrate the benefits of science for better technological innovation. Scholars have shown that scientific research enhances a firm’s absorptive capacity [5],[6] and serves as guideposts for the process of technological investigation [7], management of research activities [8], technological search [9] and firm entry into new technologies [10].

While these studies illustrate the benefits of scientific knowledge for technology innovation, the process of converting competencies of scientists into better technological performance is actually not simple or straightforward [11],[12]. Even at the policy level, several studies are investigating means through which universities and public research organizations can support regional economic development by contributing to the regional innovation process [13]. Studies also focus specifically on the mechanisms to facilitate technology transfer between academic and industry [14]. In spite of the difficulty in beneficiating from scientific competency, firms in high technology industries continue to spend heavily on scientific research through research programs organized internally and externally [15]. Firms also provide lucrative research funds and opportunities in order to attract star scientists into their organizations. With these huge investments emerges an important question: How do firms make use of the competencies of scientists and translate them into better patents?

The difficulty of converting the competencies of scientists into better technological performance has not been well investigated with a few exceptions such as [11]. Their study demonstrates that innovation builds on knowledge made in science, but science that is good for innovation is propelled by a logic different from that employed by the scientific community in determining valuable science. Using the patenting and publishing data in the biotechnology industry, they generated evidence to show that the logic of scientific discovery does not adhere to the same logic that governs the development of new technologies. Their findings suggest that by engaging the so-called bridging scientists, who work in both publishing and patenting domains, firms are in a better position to exploit the competencies of their scientists. Thus, their study suggests the importance of the individual-level mechanism of having incentives to encourage scientists to both publish and patent, thereby enabling the firm to convert the competencies of scientists into better technology patents.

While Gittelman and Kogut [11] suggest the importance of bridging scientists, it is not feasible to expect all scientists in a firm to be capable of performing both scientific research and also convert them into patents. According to the learning style inventory model proposed by Kolb, Osland and Rubin [16], different individuals are inclined to different styles of learning and knowledge generation. The two learning styles pertaining to knowledge generation in science and technology domains are 1) conceptualization and 2) experimentation. Conceptualization means designing an abstract concept? a theory
which is used to explain an occurrence; this is similar to producing scientific publications after research and theory testing. The process of trying out theories in practice is called experimentation, and this is equivalent to applying scientific knowledge in practice to the patenting process. Every person is inclined to either one learning style or, at maximum, two learning styles [16],[17]. Hence, it is not reasonable to expect every scientist who conducts scientific research within an organization to also focus on patenting activities in order to utilize the scientific knowledge that is generated. Further, relying solely on bridging scientists to bridge science and technology domains exerts pressure on individual scientists to span every possible technological boundary to which the scientific knowledge could be applied. While the learning style inventory model questions the viability of expecting all scientists to be involved in scientific research and technological innovation, March’s [18] explorative/exploitative learning framework provides a remedial solution. Exploration implies firm behavior characterized by search and discovery, while exploitation implies firm behaviors characterized by implementation and refinement [18]. In the context of science-technology relationship, scientists’ attempt to investigate new phenomena so as to provide a basic understanding of why phenomena occur is termed as exploration. Such exploration of basic science that is not of immediate commercial value gets published in open scientific arena. In contrast, inventors’ attempt to test and apply the scientific knowledge in their patenting activities is termed as exploitation. A recent study that builds on March’s [18] framework has emphasized the importance of delineating the different domains of experiential learning and advancing the notion of maintaining exploration/exploitation balance within and across the domains [19]. Extending the lessons from this branch of study and using publications and patents as proxies for activities related to science and technology domains, I advance the argument that apart from relying on bridging scientists, firms have to encourage inventors involved in patenting process to exploit the knowledge produced by their scientists. Organizations should have the necessary mechanisms such as lateral communication across functional domains, coordination across inter-disciplinary groups, incentives that encourage exploitation and reuse of internal knowledge etc. in place to ensure that the scientific publications produced by their scientists are independently exploited in the patent process by their inventors. Such a firm level mechanism enables firm to take advantage of the individual, group and organizational learning cycles and span the science-technology boundaries rather than relying solely on the bridging scientists[20]. The importance of such firm-level mechanism in benefiting from scientists has also been established in the past. A study by Furukawa and Goto [21] has shown that heavily-publishing scientists are not known to directly contribute to the patenting process. However, these scientists are known to help the firm indirectly by increasing the patenting activities of other inventors who collaborate with them. This emphasizes that firm-level knowledge sharing and integration are potential mechanisms for translating scientists’ competencies into better technological performance.

To further underscore the importance of firm-level mechanism over individual-level mechanism in bridging science-technology domains, I study the interaction effect between the two mechanisms. Specifically, I use the absorptive capacity literature to propose that, in the presence of firm-level exploitation mechanism, the contribution of bridging scientists to patent performance increases. Thus, the major tenet of this paper is to show how March’s exploration/exploitation framework complements the lessons drawn by Gittelman and Kogut [11] from the sociology and economics of science literature in explaining the mechanisms through which science-technology domains can be bridged within a firm.

This paper is organized as follows. The next section provides an overview of prior studies pertaining to science-technology relationship and discusses the need for bridging the science and technology domains within the firm. In the subsequent sections I develop hypotheses pertaining to the two mechanisms through which the science-technology domains can be bridged, present the research method and results. The last section discusses the implications of the findings and the limitations of the study.

2. Literature Review

The notion that scientific research stimulates technological performance and economic growth has long been established [2],[4],[22],[23]. Both scientific research and scientists are known to have a significant positive effect on firms’ performances [24],[25].

Although research has reiterated the benefits of science and scientists for technology innovation, there is difficulty associated with the process of converting competencies of scientists into tangible benefits that a corporate firm demands. The reason is driven by the open norm of the scientific community and the general conflict involved in the adaptation of professionals, such as scientists, to organizational goals. Scientific endeavors were cloaked in secrecy until sixteenth century, but today scientific investigation receives a substantial amount of attention for its norm of openness. The institutionalization of science has encouraged the validation and diffusion of scientific ideas as open to public scrutiny [11],[26],[27]. The nature of the scientific community reinforces norms of rapid disclosure and wider dissemination of new discoveries to account for rapid validation of findings, reducing excess duplication of efforts, and enlarging the domain of complementarities. Consequently, the success of scientists and their professional reputation is tied to priority based publication in prestigious journals.

While firms have a lower incentive to let potentially valuable information spillover to the public domain, in order to attract and retain very good scientists, firms realign the incentive structure and allow scientists to publish their research findings [24],[28]. In addition to giving scientists autonomy and letting them operate in a community that values communism, firms must also become more adept at utilizing their scientific skills for better technological performance. The difficulty in achieving the above has been highlighted by Merton [29] wherein he mentions that professional scientists differ from ‘technicians’ (or technical inventors) who believe that their primary obligation is to make their technical skills available to the organization. Kornhauser [30] has termed this phenomenon as ‘professions limit organizations’, whereby professionals are constrained to act according to the requirements set by their profession rather than their corporate firms.

Thus, utilizing the competencies of scientists and translating them into better technological performance is not simple or straightforward. However, the question of how firms bridge sci-
ence and technology domains has not attained enough attention in the literature. Such an understanding is essential because, in the absence of mechanisms to translate the competencies of scientists into better technological performance, firms might not be able to directly benefit from their scientific investments. In the following section, I develop hypotheses pertaining to two important mechanisms in bridging the science and technology domains within firms. Since exploration of basic science does not immediately result in commercially viable technology, organizations typically encourage their scientists to publish such basic findings for the sake of reputation and defensive reasons. On the contrary, since patenting process is costly and time consuming, organizations typically patent only those technological findings, which they perceive to be commercially valuable. Hence, in the following section I equate organizations publications and patents as activities pertaining to science and technology domains respectively.

3. Theory and hypothesis development

3.1 Bridging Science-Technology Domains: Individual Level

The work of Arrow [31] exhibits science to be associated with features of public good and hence the need for academia and non-profit research to be involved in the production and dissemination of basic research findings. In subsequent research on the science and technology relationship, scholars started recognizing the importance of in-house scientific research for firms to even absorb scientific knowledge from the public domain [32],[33]. The development of pharmaceutical and biotechnology industries has also singled out the scientific competency of firms and the presence of star scientists as critical factors for successful and productive firms [24],[25],[34]. Newer biotechnology companies led by CEOs holding a PhD are also known to produce high impact patents than older companies led by non-PhDs [35].

Although scientists represent a vital resource for firms in high-tech industries, managing scientists who conduct fundamental research in industrial organizations creates friction. The friction is due to the conflicting nature of organizational demands and the identity of scientists being embedded in a collegiate reputation-based reward system of open science. Scientists are more inclined to utilize their competency in producing scientific publications so as to gain a reputation in the community of scientists. The institutionalization of science encourages scientists to validate and diffuse ideas as open to public scrutiny [27], which is promoted by the priority based publication systems. In contrast to the openness of science domain, the competitive advantage of science-based organizations depends on how the scientific findings are kept secret till those findings are converted into patentable innovation. Thus, the logic of scientific discovery does not adhere to the same logic that governs the development of new technologies and these conflicting logics pose potential problems for science based innovations.

Though scientific research programs can be tailored to be useful inputs for furthering scientific investigation as well as technological innovation, one major challenge for firms with industrial R& D function is to define the roles of scientists, identify and evaluate the competencies of individual scientists, and provide appropriate incentive schemes to align their interests accordingly. The ability of the firm to find a way to manage the two contradictory logics of science and innovation will be crucial for innovation performance [36]. However, ineffective human resource policy may also result in some scientists being trapped between the two evolutionary logics. The challenges faced by managers of boundary spanning activities that sometimes combine the opposing logics like independence of a researchers and the integration objectives of for-profit firms has been outlined in literature [37].

As implied in the study by Gittelman and Kogut [11], when scientists are properly motivated, they can be involved in generating both scientific findings such as publications as well as developing technologies, which is equated to patents in this study. This will enable them to establish links between the science and technology domains, thereby creating valuable innovations. An incentive structure that balances incentives based on science with rewards that are market oriented will induce scientists to play a dual role as both scientists and inventors, encouraging them to contribute to both knowledge domains, while inhabiting a single epistemic community. Their primary role as scientists in the community will facilitate firms to benefit from their networks and social interactions [38], generating a perpetual flow of external knowledge into the firm [21],[32]. Meanwhile, by making the scientists indulge in patenting process, a firm can utilize their tacit knowledge specific to internal scientific research to create technologies that no other firms can duplicate [39]. Thus, their secondary role as inventors aids in utilizing their scientific competencies in the patenting process, the consequence of which is found to have positive influence on the patent performance of the firm [11]. For example, if a scientist’s key research focuses on algae, his role is not just to publish papers regarding various properties of algae, but also in focusing on algae based research for food and fuel that provokes him to find solution for the bio-based chemicals and materials that are key to companies operating in the industry. Thus, the dual role of scientists enables them to be gatekeepers of knowledge to bring in new, related and complementary knowledge that is beneficial for technological innovation [11],[32],[40]. The role of bridging scientists for biotechnology industry has become so prominent that if a scientist thinks he has a good idea, he or she is encouraged to not only check the database of publications, but also patents since lots of ideas are in the latter database*1.

The importance of pushing scientists into marketable innovations has also been explained in a study on the Japanese and German biotechnology industries [41]. The study found that the biotech firms in these countries, unlike the American and British counterparts, had failed to capitalize on the competencies of their scientists for better technological performance because of the lack of science entrepreneurship in the broader industrial context. The inability of these countries to excel in the biotechnology field was said to be a consequence of which is found to have positive influence on the patent performance of the firm [11].

Following the above arguments and research findings, I posit that by defining the dual role of scientists in both publishing and patenting activities, firms can effectively bridge the science-technology domains. With the growing importance of individ-

*1 http://nbv.kncv.nl/nbc-14-biotechnology-delivering-value-bridging.10626.lynkx
uals as movers of knowledge between organizational boundaries [42], using scientists as the level of analysis facilitates firms to bridge the two domains. The above arguments suggest that:

Hypothesis 1:

The proportion of bridging scientists in a firm positively influences the firm’s patent performance.

3.2 Bridging Science-Technology Domains: Firm Level

Building on March’s [18] exploration/exploitation framework, a recent study that delineates distinct domains of exploration and exploitation provides some useful insights through which a firm can benefit from the competencies of its scientists [19].

Exploitation is defined as ‘refinement and extension of existing competencies’, and exploration as ‘embarking on new alternatives’. More specifically, exploration implies firm behavior characterized by search and discovery, while exploitation implies firm behaviors characterized by implementation and refinement [18]. Recent studies on exploration/exploitation have shown that the delineation of exploration and exploitation in different domains enable firms to simultaneously embark on both, thereby maintaining the balance [19],[43]. The capability of maintaining the exploration/exploitation balance by concurrently engaging in both types of knowledge searches is termed as ambidexterity.

Existing studies have used different proxies for exploration and exploitation. Some research looks at refinement of existing products as exploitation, whereas introduction of new product as exploration [44]. Some other scholars look at citations of patents and classify citations to new patents as exploitation and citation to patents that has been cited in the past as exploitation [45]. In the context of inter-organizational collaboration, the type of alliance (upstream/downstream) and familiarity of partners are used in measuring exploration and exploitation [19]. Thus, exploration and exploitation are context dependent and differs on the type and amount of learning rather than presence and absence of learning. In this research pertaining to bridging of science-technology domains, I classify a firm’s attempts to investigate new phenomena in generating theories on their basic understanding as exploration and I classify the firm’s attempts to test and apply the scientific knowledge in technology patenting activities as exploitation. Consequently, I measure generation of scientific publications as exploration and citations to scientific publications in patents as exploitation.

Though Gittelman and Kogut’s [11] suggestion that having bridging scientists enables the generation and application of scientific knowledge in technology, there are practical limitations associated with this approach. Exploration and exploitation require radically different mindsets and routines, and it is not reasonable to expect every scientist within firm to also be competent in patenting. Consequently, though engaging scientists in both publishing and patenting can lead to bridging of science and technology domains, a firm cannot solely rely on this individual incentive mechanism alone to exploit the knowledge possessed by its scientists.

The organization learning literature that emphasizes the need for carrying out exploration/exploitation in different domains and maintaining a balance both within and between them provides useful insights in overcoming the above-mentioned limitation [19]. Extending lessons from this branch of study, I distinguish the science and technology domains within an organization and advance the notion of letting scientists explore scientific areas and facilitating inventors in the technology domain to actively exploit the scientific knowledge generated by the science domain in the patenting process. The main role of scientists in the science domain will be to specialize in their expertise areas and generate important findings that are valuable to technology development. In addition to the scientific role, scientists who are competent in technology development should be permitted to play a dual role by engaging themselves in patenting activities.

However, firms should not wholly rely on their scientists playing the dual role in exploiting the scientific publications in patenting process. Instead, the capability of firms in bridging science and technology domains may depend on how well the firm has organizing principles to exploit the knowledge produced by the science domain in its technology domain. The organizing principles underlying firm level exploitation mechanism encompasses (a) the extent to which a firm has lateral communication across functional domains, (b) how work is coordinated within the organization and information disseminated across groups, (c) the collective experiences of members of firms that enable even tacit knowledge of scientists to be transformed into comprehensible code that can be exploited by technology inventors, (d) the introduction of an appropriate incentive structure to encourage employees to exploit the knowledge produced by colleagues, etc. The above mechanisms also form the basis of explaining firm heterogeneity in their capability to benefit from individual, groups and organizational learning abilities. Thus, while individual mechanism relies on individual bridging scientists as boundary spanners to span science-technology boundary, the firm level mechanisms outlined above leverage collectively on the individual, group and organizational members and their learning potential to convert the scientific competencies of the firm into better patents. The mechanisms also enable inventors from diverse application areas to span the science-technology boundary as a group and seek scientific findings that are of significance to their field. This alleviates the unrealistic pressure on individual bridging scientist to span boundaries of every technological application area in which his or her scientific findings could be exploited.

Statistics from a recent study on pharmaceutical industry by Furukawa and Goto [21] clearly underscore the importance of firm level exploitation mechanisms. Their study highlights how core scientists in five Japanese pharmaceutical firms ranked high in publication outcomes, but not in patent outcomes. In pondering over the contributions of core scientists, their study indicated that researchers who collaborated with core scientists had generated significantly higher number of patents than the researchers that did not collaborate with core scientists. According to them, intra organizational collaboration mechanisms stand out as an important means of benefiting from core scientists. Their study also highlights that core scientists are apt type of people to be fully absorbed in the quest of truth of a phenomenon. But, since core scientists rank poor in patent outcomes, it is important for firms to involve core scientists in the corporate community in order to benefit from them.

The firm-level mechanism of exploiting scientific knowledge in the technology domain results in better technological perfor-
mance in the following ways. Firstly, firm-level exploitation mechanism provides inventors with quick and easy access to internally-generated scientific findings before being published, thereby enabling the inventors to introduce better patents earlier than other firms. Secondly, the firm level exploitation mechanisms help firms readily apply scientific knowledge to resolve many technical problems related to technological breakthrough development. Thirdly, firm-level exploitation mechanism increases a firm’s capability in realizing the benefits of its investment in internal basic research.

Following the above arguments, I posit that firms that are capable of exploiting internally-generated scientific knowledge in their patenting are in a better position to bridge the science and technology domains. The above arguments lead to the second hypothesis:

Hypothesis 2:

The degree to which a firm exploits its scientific publications in patenting positively influences the firm’s patent performance.

It is to be noted that Hypotheses 1 and 2 are not mutually exclusive. The first hypothesis explains the importance of nurturing bridging scientists, whose competence is invaluable to producing better patents. The second hypothesis puts emphasis on a broader firm-level exploitation mechanism. In other words, enabling inventors to access and apply the internally generated scientific knowledge as well as developing absorptive capacity for external sources of innovation would be the routines to establish inside a firm. Therefore, it is feasible for a firm to have both bridging scientists and the exploitation mechanism which utilizes the internally-generated scientific knowledge in the firm’s patenting activities. For example, consider a firm with two scientists (A & B) in the science domain. Scientist A may be competent in both the science and technology domains, and hence becomes a bridging scientist, whereas scientist B may be a pure scientist exclusively involved in generating scientific knowledge. In order to fully translate the competencies of both scientists into better innovation performance, the firm has to facilitate the process of exploiting both the scientists’ knowledge in the patenting process, rather than just relying on scientist A to do the job.

The following section develops the third hypothesis which underscores the importance of firm-level exploitation mechanism. I argue that in the presence of exploitation mechanism, the contribution of bridging scientists to technological performance increases.

3.3 Bridging Science-Technology Domains: Firm Level Moderating Individual Level

According to the absorptive capacity literature [5], a strong positive interaction exists between individual-level and firm-level mechanisms of capability building. It has been observed that the benefits derived from individual-level capabilities are significantly influenced by firm-level mechanisms such as knowledge transfer, integration, and exploitation across units. For example, more conducive organizational mechanisms are found to increase the effectiveness of intellectual human capital [46]. In particular, a study by Grosysberg, Nanda and Nohria [47] showed that when star financial analysts switched firms their short-term variations in performance were determined by organizational aspects of the new firm. Following this perspective, I hypothesize that the firm-level exploitation mechanism moderates the positive influence of bridging scientists on the patent performance. In other words, the degree of influence of bridging scientists on patent performance is higher for firms that are good at exploiting the scientific publications in its patenting activities. Two explanations support the moderating effect. The two explanations are based on the argument that the science-technology relationship is bi-directional. The first explanation corresponds to Brook’s [48] notion that scientific findings are important inputs to technological activities. The second explanation corresponds to the notion that technological activities can also be inputs to scientific exploration.

First, scientific knowledge exploitation in the patenting activity widens the scope of application of bridging scientists’ knowledge, thereby enhancing their contribution to patent performance. As emphasized by Brooks [48], scientific knowledge can help technology development in sundry ways. Science generates new knowledge that can function as inputs to develop patents across wide areas. For example, advancement in basic physics led to the discovery of the transistor, which was subsequently found to be useful in developing medical equipment such as hearing aids. Scientific knowledge can be used in designing engineering tool and techniques. In addition, science helps in evaluating technological areas.

Though the presence of bridging scientists can help in exploiting scientific knowledge, it is undue to expect bridging scientists to be involved in every application area to exploit the knowledge. Bridging scientists can help firms in translating abstract scientific theories into working ideas for patenting activities. Despite the surface level similarities, scientists and engineers are observed to exhibit different communication behavior [32]. Bridging scientists can act as a channel to translate the ideas of other core scientist within the firm into a language that can be easily interpreted by inventors. In the presence of such bridging scientists, when a firm encourages its inventors in the technology domain to exploit the knowledge, the translated ideas of bridging scientists can span a broader set of technology patenting. In doing so firms can also ensure that scientists’ are able to combine multiple fields of research, thereby complementing their specialists scientific knowledge to exploit their technological inventions in producing breakthrough products or service [49]. Thus, by widening the application of bridging scientists’ knowledge, firm-level exploitation mechanism can positively moderate the relationship between bridging scientists and the patent performance of firms.

Second, firm-level exploitation mechanisms enhance the value of bridging scientists by exposing them to novel scientific challenges during the exploitation process, thereby enabling them to come up with breakthrough scientific findings. The application of science knowledge to the technology innovation process is a rich source of novel scientific challenges. Exploration of these scientifically challenging questions would provoke the scientists to dig deeper into their scientific exploration process. Such deeper exploration arising out of challenges pertaining to exploration can enable the scientists to come up with scientific breakthrough that are in turn valuable to technological innovation. For example, the use of basic physics to understand some of the material processes and properties in semiconductor devices has led to the birth of a new scientific discipline called
Materials Sciences [48]. This discipline now has an extensive use in the technology innovation process, including innovations related to nutrition and dietetics. Firm-level mechanisms that encourage the exploitation of scientific knowledge in patenting would make inventors from diverse background experiment with the knowledge generated by scientists. Since bridging scientists are involved in science and technology domains, the firm-level exploitation mechanism would expose these scientists to challenges from new application areas. Novel questions arising from these diverse areas can be easily picked up by bridging scientists for further scientific exploration, thereby enhancing the value of bridging scientists for patent performance. The above arguments lead to the third hypothesis:

Hypothesis 3:

The relationship between bridging scientists and a firm’s patent performance is positively moderated by the degree to which the firm exploits its scientific publications in patenting.

Even in the presence of bridging scientists, certain circumstances might prevent firms from translating the competencies of scientists into better patents. For instance, since scientific ideas serve as inputs for scientific research as well as technology development, it is vital that bridging scientists make use of the important scientific knowledge to generate valuable patents rather than merely investing their time and effort in furthering the scientific understanding. But, as the professional reputation of scientists is tied to their important discoveries in the scientific discipline, even bridging scientists might intend to use the knowledge for scientific advancement. Besides, as publishing scientists in firms receive lower wages than other scientists and inventors who are not allowed to publish, they have less incentive to exploit the important scientific findings for the benefit of the firm. Therefore, the professional orientation of bridging scientists can prevent a firm from translating their scientific competency into better technological innovation. Active collaboration between inventors and scientists can facilitate inventors to exploit important scientific findings in the patenting process. This can enable firms to overcome the incentive issues and to fully benefit from the competencies of bridging scientists. Further to the moderation effect of exploitation mechanism in enhancing the value of bridging scientists, the above argument emphasizes that, in the absence of firm-level exploitation mechanisms, the presence of bridging scientists alone may not help in bridging science and technology domains.

4. Research Methodology

4.1 Data

To test the hypotheses I collected data from the biotechnology industry. Biotechnology is recognized to be one of the most innovation-intensive industries [50]. The biotechnology industry was an ideal context in testing the framework because the industry is characterized by technological transformation and the widely-recognized importance of scientific research and intellectual human capital.

The data was drawn from Plunkett’s directory that comprises of 437 public-listed biotechnology firms. Biotechnology directories are one of the sources that prior studies have consulted in drawing their samples [51],[52].

I used the publication and patenting activities of these firms in testing the hypotheses. The patents issued to these firms between 1990-2000 were obtained from the NUS patent database[^3]. The database comprises of patents issued to firms by the United States Patent and Trademark Office (USPTO). Publication information of firms between 1980-2000 was obtained from Web of Science, ISI Science Citation Index (SCI). Global is used in collecting the financial data of these firms.

I used the three-digit patent classes and only included those patents that fall within the U.S. patent classes listed in Table 1, which belong to the biotechnology industry. The classes were chosen with reference from the USPTO Technology Profile Reports and from prior research [53]. Filtering those firms that did not have patent data in the specified classes between 1990-2000, the final sample size was 222 firms. Of the listed firms, 215 (437-222) firms were dropped from the directory because they had zero patents. To ensure that the results were still generalizable, I carried out a preliminary assessment of firm level variables. The average of firm R&D and firm size for 437 firms was not significantly different from the average of these variables in the final sample (as shown in Table 2). However, I found that the average age of the final sample firms was higher than that of average age for 437 firms. This is possibly because younger firms in the directory might not have patents issued between 1990-2000. Nevertheless, I do believe that the results of the study hold true even for younger firms, because the sample does indeed include younger firms such as Atherogenics and Arena.

4.2 Measures

4.2.1 Dependent Variable

Forward Citation: The dependent variable patent performance is measured using the forward citation of patents. A forward citation of patents is the cumulative number of citation accrued to an individual patent. Research demonstrates that the number of forward citations a patent receives correlates highly with the technological importance [54],[55]. On average, each patent in the sample received about 6 forward citations. Research demonstrates that the number of forward citations a patent receives correlates highly with the technological importance [54],[55]. On average, each patent in the sample received about 6 forward citations.

4.2.2 Independent Variables

Bridging scientists or Joint Patent-Publishers: This measure represents the percentage of patent inventors within a firm whose names are also listed on scientific papers published by the firm. In order to obtain this measure, I identified two overlapping sets of individuals for each firm. The first comprises of those scientists listed on at least one publication made by the focal firm, and the second list comprises of inventors involved in at least one patent issued to the focal firm. Based on these two lists, I calculated the percentage of individuals listed as inventors who are also listed as scientists for each firm. The measure is borrowed from Gittelman and Kogut [11].

Exploitation of science domain knowledge in technology domain or Relative use of a firm’s publications in patents: To determine the extent of use of internally-generated scientific knowledge in technology, I measured the proportion of the focal firm’s patents over all patents citing the focal firm’s scientific publications. To compute this measure, I first identified all the

[^2]: Plunkett’s Biotech and Genetics Industry Almanac 2005: the only comprehensive guide to biotechnology and genetic companies and trends/editor and publisher: Jack W. Plunkett.

[^3]: http://patents.nus.edu.sg/
publications produced by the focal firm and then all the patents citing those publications. For each publication, I checked the first assignee name of the citing patents to obtain a count of patents by focal firm and by other firms. Next, I computed the proportion of publication citations by focal firm over the total citations received by each publication. I then averaged this out for all the publications made by the focal firm. For each firm the value of this measure ranges from 0 to 1. The value 0 is assigned when focal firm’s citations are cited only by other firms and 1 when the publications are cited only by the focal firm Control Variables.

**Publication Volume**: This measure is the number of publications produced by the focal firm in the year of observation in which the firm filed a patent. I used the number of publications made by a firm as a proxy for its scientific capability. A number of scholars have used publication count to measure the scientific capability of firms [11],[53],[56]. A firm with strong scientific capability is able to identify new applications in the technology domain that might give rise to more valuable patents. Prior studies have also shown the significant relationship between publication count and patent performance. It is therefore imperative that I control for it.

**Non-patent Reference**: Non-patent reference is the count of the number of times a patent issued to a firm references non-patented literature. Every patent is required to list the prior art that it builds upon, and this includes both the patent and non-patent references. It has been observed by Fleming and Sorenson [9] that 69% of the non-patent references are from peer-reviewed scientific journals. Non-patent references cited by a patent are often used as an indicator of the science intensity of the invention that is found to be influencing the forward citation of patents [57]. Hence, I controlled for it. The average number of non-patent references cited by the patents under study is about 18.

**Firm’s Average Cites to Publications**: I use the citations received by the focal firm’s publications to represent the relative quality of the firm’s stock of scientific knowledge. Because a firm’s competency in generating high-quality scientific papers has been observed to impact its capability to produce high-impact innovation, I controlled for it. Number of Inventors: This measure is the number of inventors listed in a patent who are exclusively involved in patenting. Since the number of inventors listed in a patent represents the research effort and resources invested in coming up with the patent, I controlled for it.

**Other Control Variables (Technology class dummy variable, Number of claims, Patent age, Year fixed effects, R&D expenditure, Firm size, and Firm age)**: Forward citations may accrue to patents for other reasons such as technology field characteristics, patent characteristics and firm characteristics. Therefore, I included the patent-level and firm-level control variables to account for the heterogeneity among firms and for age and field effects. Patents belonging to a certain technology class may inherently be more cited than others. Similarly, patents with a higher number of years that elapsed since the patent was filed are capable of attaining higher citations. I also used year-fixed effects to capture the differences in citation probability across different years.

Firms may be highly innovative for different reasons. Larger firms have this capability due to economies of scale and scope, younger firms because they represent the knowledge of the younger vintage, and some firms devote more resources to R&D. Hence, I included firm-level control variables such as R&D expenditure, size of the firm as measured by the number of...
employees, and age of the firm as measured by the number of years since the firm was founded.

The summary data for the dependent and independent variables and the correlation between the variables at the patent level are reported in Table 2.

### 4.3 Analysis

Since the dependent variable is forward citation count, the count model was more appropriate for the study. The Poisson model is a frequently used count model. As patent citations exhibited over-dispersion, I used the negative binomial model that is best suited for estimating an over-dispersed parameter. The results of negative binomial regression are presented in Table 3. All specifications include fixed effects for both technology class and application year from 1985-2000. I used robust standard errors adjusted for clustering of firm to control for random firm effects.

#### 4.3.1 Results pertaining to Control Variables

Model 1 in Table 3 presents the results for all the control variables. The publication volume has a negative influence on the forward citation of patents ($p \leq 0.01$). On the contrary, the non-patent reference has a significant positive influence ($p \leq 0.01$) on the forward citation of patents. One possible explanation of the result is that when firms concentrate more on producing scientific publications, their attention towards developing important technologies might deteriorate and result in fewer forward citations for their patents. This explanation is also consistent with the result pertaining to the publication citation. The quality of firms’ publications, as reflected by the average cites to publications, has a negative relationship with the forward citation of patents ($p \leq 0.10$). This shows that when firms engage in the generation of cutting-edge scientific research, their technological performance suffers. As expected, the firm age and number of inventors have, respectively, a negative and positive impact.

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### Table 3: Negative Binomial Regression in Testing the Impact of Bridging Scientists, Exploitation of Science Domain Knowledge, and Control Variables on Forward Citation

| Variables                                      | Model 1          | Model 2          | Model 3          | Model 4          | Model 5          |
|------------------------------------------------|------------------|------------------|------------------|------------------|------------------|
| Constant                                       | -0.0465          | -0.0739          | -0.3861          | -0.4773*         | -0.4741*         |
|                                                | [0. 3830]        | [0.3479]         | [0.3831]         | [0.3559]         | [0.3522]         |
| **Independent Variables**                      |                  |                  |                  |                  |                  |
| Bridging scientists                            | 1.1610***        | [0.5504]         | 1.3101***        | 1.4573***        |                  |
|                                                | [0.5830]         | [0.5591]         | [0.5630]         | [0.5603]         |                  |
| Exploitation of science domain knowledge       | 0.3722*          | [0.2553]         | 0.4323**         | 0.5603*          |                  |
|                                                | [0.2568]         | [0.3002]         | [0.2568]         | [0.3002]         |                  |
| Bridging Scientists’ Exploitation of science   | -0.6558          |                  |                  |                  |                  |
| domain knowledge                               |                   |                  |                  |                  |                  |
|                                                | [1.0979]         |                  |                  |                  |                  |
| Firm-Level Control Variables                   |                  |                  |                  |                  |                  |
| Publication Volume                             | -0.0003***       | [0.0001]         | -0.0004***       | -0.0002***       | -0.0002***       |
|                                                | [0.0001]         | [0.0001]         | [0.0001]         | [0.0001]         | [0.0001]         |
| Publication citation                           | -0.0415**        | [0.0305]         | -0.0582*         | -0.0731**        | -0.0975**        |
|                                                | [0.0368]         | [0.0456]         | [0.0508]         | [0.0552]         | [0.0552]         |
| Firm age                                       | -0.2230***       | [0.0545]         | -0.2725***       | -0.2060***       | -0.2587***       |
|                                                | [0.0613]         | [0.0499]         | [0.0554]         | [0.0559]         | [0.0559]         |
| Firm size                                      | 0.0321           | [0.0346]         | 0.0081           | -0.0501*         | 0.0261           |
|                                                | [0.0324]         | [0.0340]         | [0.0303]         | [0.0292]         | [0.0292]         |
| R&D Expenditure                                | 0.0257           | [0.0298]         | 0.0288           | 0.0320           | 0.0369           |
|                                                | [0.0291]         | [0.0303]         | [0.0303]         | [0.0295]         | [0.0293]         |
| Technological Strength                         | -0.0024***       | [0.0006]         | -0.0022***       | -0.0002***       | -0.0021***       |
|                                                | [0.0006]         | [0.0006]         | [0.0006]         | [0.0006]         | [0.0005]         |
| No. of Inventors                               | 0.0878***        | [0.0258]         | 0.0593***        | 0.0933***        | 0.0617***        |
|                                                | [0.0184]         | [0.0279]         | [0.0189]         | [0.0187]         | [0.0187]         |
| Patent-Level Control Variables                 |                  |                  |                  |                  |                  |
| Patent age                                     | 0.1812***        | [0.0219]         | 0.1792***        | 0.1846***        | 0.1828***        |
|                                                | [0.0212]         | [0.0212]         | [0.0212]         | [0.0204]         | [0.0205]         |
| Non patent reference                           | 0.0033***        | [0.0012]         | 0.0036***        | 0.0031***        | 0.0035***        |
|                                                | [0.0011]         | [0.0011]         | [0.0011]         | [0.0011]         | [0.0011]         |
| Log Likelihood                                 | -20506.10        | -20483.69        | -20488.22        | -20459.97        | -20458.76        |
| No. of Observations                            | 7648             | 7648             | 7648             | 7648             | 7648             |

* $p \leq 0.1$, ** $p \leq 0.05$, *** $p \leq 0.01$. Standard error is provided in the parentheses.

Technology class dummy variables and year fixed effect were included but not reported.

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### Table 4: Analysis of Correlation Differences

| Variables                                      | Group 1:          | Group 2:          | Z Value | Significance |
|------------------------------------------------|------------------|------------------|---------|--------------|
| Bridging Scientists and Forward Citation       | High Exploitation | Low Exploitation  | 4.03    | The difference is significant ($p \leq 0.01$). Moderation Supported |
| relationship                                   | of science domain | knowledge (Z1)    |         |               |
|                                                | knowledge (Z2)    |                 |         |               |
|                                                | 0.0726           | -0.0195          |         |               |

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on the forward citation of patents ($p \leq 0.01, p \leq 0.01$). Firm size and R&D expenditure do not have a significant relationship with the forward citation of patents. A plausible explanation for R&D and firm size being insignificant is that increased R&D spending and economies of scale need not necessarily increase the quality of innovation, as measured by the forward citations. The technological strength of a firm, as measured by the number of patents generated by the firm, is negatively associated with forward citation of patents ($p \leq 0.01$). This shows that quality of patents is inversely proportional to the quantity generated. The significant ($p \leq 0.01$) positive effect of patent age shows that older patents receive more citations.

4.3.2 Results pertaining to the independent variables

Model 2 presents the results after including the first independent variable, bridging scientists. The coefficient of bridging scientists is positively significant ($p \leq 0.01$) suggesting that the presence of bridging scientists confirms the translation of scientific competency into valuable patents for firms. The Wald’s chi squared test of 4.45 ($p \leq 0.05$) confirms that bridging scientists variable creates a statistically significant improvement in the fit of the model. Thus, hypothesis 1 is accepted.

Model 3 includes the second independent variable, which is the extent to which organizations exploit their scientific publications in their technology domain. The positive significant coefficient ($p \leq 0.10$) supports hypothesis 2 that firms’ endeavors toward the exploitation of their scientific knowledge in technology innovation will increase the forward citation rates of their patents. The Wald’s chi squared test of 2.95 ($p \leq 0.10$) confirms that including the variable creates a statistically significant improvement in the fit of the model. Model 4 includes both the independent variables. The Wald’s chi squared test of 5.22 ($p \leq 0.10$) signifies improvement in the fit of the model as compared to the base model 1. The significant coefficients of both ‘bridging scientists’ and ‘exploitation of science domain knowledge’ confirm the acceptance of hypotheses 1 and 2. Model 5 introduces the interaction term of the two independent variables under study. Since hypothesis 3 pertains to degree moderation, an insignificant interaction term need not mean that the hypothesis is rejected. The following section elaborates on the methodology in testing the degree moderation.

4.3.3 Results pertaining to the moderation effect

The moderation effect is usually tested by observing the interaction term of regression analysis. However, such a test will only verify the moderating effect of the form of relationship, not the degree of relationship. The degree of relationship between a dependent variable Y and an independent variable X indicates the percentage of Y variance accounted for by X. The form of relationship denotes the amount of score difference in Y associated with a unit change in X. As argued by Arnold [58], the form of relationship between two variables is indicated by the coefficients of the regression equation, whereas the degree of relationship is measured by the magnitude of the correlation coefficient. Since the third hypothesis is regarding the moderation of degree, I observed the correlation coefficient to test the effect.

In testing the moderating effect of the degree of relationship between bridging scientists and technology performance, I performed a mean split on the variable ‘exploitation of science do-
main knowledge’, resulting in two groups. In other words, I broke the sample into two groups based on the extent to which the firms exploited their scientific knowledge in the technology domain. With the mean of scientific knowledge exploitation in technology being 0.29, I had the high exploitation group comprising of 47% of the sample firms. The low exploitation group had about 53% of the sample firms. The technique of splitting the sample is also consistent with Baron and Kenny’s [59] third case of moderation, wherein it is suggested that, at some value of ‘exploitation of science domain knowledge’, the ‘bridging scientists’ become more effective in increasing the technological performance of firms. Their study also suggests the approach of dichotomizing the moderating variable to evaluate a variable’s moderating effect. Thus, in testing the degree of moderation using the above technique, I observe the correlation between bridging scientists and forward citation for both the groups. According to Arnold [58], the following formulae are used in testing the difference in correlation between the two groups to confirm the significance of moderation effect:

Fisher

\[
Fisher\ Z = \frac{(Z_1 - Z_2)}{\sqrt{\frac{1}{n_1 - k - 2} + \frac{1}{n_2 - k - 2}}}
\]

where \(k\) is the number of independent variables and \(n\) is the size of the group. \(Z_1\) and \(Z_2\) are obtained by the Fisher Z transformation of the partial correlations between bridging scientists and forward citation obtained for the two subgroups, given by

\[
Z_i = 0.5 \times LN\left(\frac{1 + r_i}{1 - r_i}\right)
\]

where LN is the natural log and \(r_i\) is the partial correlation coefficient.

Table 4 reports the result of correlation analysis for testing the moderating effect of bridging scientists. The significance of the Z value shows that, in the presence of exploitation of scientists’ knowledge in the technology domain, bridging scientists account for much higher variance in the forward citation of patents. This confirms that exploitation of science domain knowledge moderates the degree of relationship between bridging scientists and technology innovation performance, thus supporting hypothesis 3.

Apart from testing the correlation differences, I also estimated the regression coefficients of bridging scientists for the two subgroups. This was done to understand the extent to which the relationship between bridging scientists and forward citation of patents is moderated by the exploitation mechanism. It is evident from Table 5 that the regression coefficient of bridging scientists in explaining the forward citation of patents for high exploitation group is significant at the 10% level of significance. On the contrary, the coefficient is insignificant for the low exploitation group. Taken together, the results show that, when the exploitation of science domain knowledge in technology domain is low, the mere presence of bridging scientists is not capable of generating valuable technological innovation. Thus, the results strongly confirm the moderating effect of ‘exploitation of science domain knowledge in technology domain’ in explaining the relationship between ‘bridging scientists’ and ‘forward citation of patents’.

One might suspect that the story behind such a relationship is that the firm-level mechanism of exploitation is actually capturing the bridging scientists’ efforts in exploiting science knowledge in the technology domain. Nevertheless, this reason appears to be unlikely because, in the data, very few inventors (2.5% of the inventors) referenced their own publication materials. While Sorenson and Fleming [60] observed about 3% of the inventors in their sample to reference their own publications, in this study I found the percentage to be much smaller. Hence, it is highly unlikely that the result pertaining to firm-level bridging mechanism is confounded because of bridging scientists. In addition, it is important to note that, in the presence of firm-level exploitation mechanisms, the main effect of bridging scientists on forward citation rate of patents is positively significant (Table 3). If the firm-level mechanism is capturing the effect of exploitation of knowledge by bridging scientists, then the main effect of bridging scientists should become insignificant in Table 3.

Negative Binomial Regression in Testing the Impact of Bridging Scientists, Exploitation of Science Domain Knowledge, and Control Variables on Forward Citation

5. Discussion and Conclusion

While many studies explore the benefits of science to technology development, this study focuses on the means through which firms are able to make use of the competencies of scientists and translate them into better technological innovations. This study investigates two important mechanisms of bridging science-technology domains, one at the individual level and the other at the firm level, and has several important findings to enrich this branch of literature.

The first mechanism explored in the study is the extent to which a firm has bridging scientists, who are involved in both scientific research and technological innovation. In other words, these scientists publish as well as patent. The results are consistent with Gittelman and Kogut’s [11] assertion that bridging scientists improve the technological performance of firms. Further to bridging scientists, in the second mechanism I show that it is also important for firms to have an exploitation mechanism in place so as to ensure that the knowledge generated by their scientists is exploited by the inventors in technology domain. One of the main contributions of the study is to show that the degree to which bridging scientists enhance the technological performance is much higher in the presence of a firm-level exploitation mechanism. In the absence of calculated exploitation of scientific knowledge in the technology domain, bridging scientists do not play a significant role in explaining the technological performance. Therefore, the mere presence of bridging scientists in an organization does not ensure a smooth transfer of knowledge between science and technology domains.

Consequently, the research demonstrates that March’s exploration/exploitation framework complements the sociology and economics of science literature in understanding the mechanisms of transforming competencies of scientists into better technological innovation. Science and technology are two distinct domains within a firm. Apart from maintaining exploration/exploitation balance within each domain, it is also important that knowledge exploration of the science domain is complemented by the exploitation of such knowledge in the technology domain. This underlines Lavie and Rosenkopf’s [19] suggestion that firms ought to be ambidextrous in maintaining an exploration/exploitation balance, both within and across do-
main. Bridging science-technology domains is not a simple human capital story of having scientists who are involved in both patenting and publishing. Firms have to acknowledge the challenges in making the transition from science domain exploitation to technology domain exploitation, and attempt to have premeditated mechanisms to bridge the gap. Inventors involved in developing technologies should be encouraged to actively experiment and make use of the knowledge generated by the scientists. Similarly, scientists should be encouraged to coordinate with inventors in solving basic problems encountered in the technology development process. This underscores active communication, coordination and knowledge sharing within an organization to let individuals specialize in their expertise area, yet not to let them work solo.

There are a few other results worth explaining to understand the science-technology relationship. First, the non-patent reference also termed as the science intensity of patents was found to be a significant predictor of patents’ values. This result, together with the negative relationship of publication volume with patent performance, suggests that a firm’s ability to generate scientific knowledge does not result in the firm generating better technological innovation. On the contrary, a firm’s capability to apply scientific knowledge in technology development guarantees generation of valuable technological innovation. This report is consistent with the findings of Gittelman and Kogut [11]. I follow their contention in saying that it is only through the skilful application of science to the innovation process that firms can transform their scientific capability into valuable innovation. This has important implications for firms with low R&D budgets. These firms can encourage their inventors to effectively utilize scientific findings in their technology innovation process, so as to benefit from the scientific community’s knowledge spillover.

Second, the publication citation has a negative influence on the forward citation of patents. This shows that a firm’s capability to generate cutting-edge science is not helpful for its technological innovation. Rather, the extra attention paid in creating cutting-edge science diverts the firm’s attention from working on valuable technologies. As explained above, another plausible reason could be that the cutting-edge science represents an embryonic stage of research which the firms’ are unable to translate into patentable innovations. Thus, indulging in breakthrough science is detrimental to firms’ technological performance if they fail to exploit the breakthrough results in developing valuable patents.

This research is subject to a number of limitations. The first one is pertaining to patent data. Restricting the scope to patent data has several limitations because not all companies have the same propensity to patent and firms can limit their patents only to their most successful innovations. In spite of the above limitations, patent data has been widely used in testing the factors contributing to innovation [11],[60]. Secondly, a count of all non-patent references is considered when measuring a firm’s capability to apply science to technology development. A more appropriate measure would have been to consider only citations to scientific publications. However, this limitation is to some extent mitigated by the observation of Fleming and Sorenson [9] that the majority of the non-patent references are citations to scientific publications. This research interprets the citations of publications in patents as the usage of scientific knowledge in technology. However, practitioners such as Narin, Hamilton, and Olivastro [61] have acknowledged that such linear science-push perspective is simplistic and inaccurate. Also, though the paper discusses firm level mechanisms, the study does not capture them explicitly, but only the outcome of such mechanisms as represented by exploitation of publications in patents.

Third is a limitation pertaining to publications. Not all firms involved in scientific research have the inclination to disclose their findings by publishing. Even among publications, there are articles that can be classified as basic journals and applied journals [53]. Similarly, applying scientific knowledge in practice is so vast that some could be termed as exploration whereas others as exploitation. A fine-grained approach in categorizing publications and citations can strengthen the implications. There are also publications made by firms through collaboration with other firms and universities. This study includes all publications that are affiliated with the sample firms, irrespective of whether the publication is associated with more than one organization or not. However, not considering the information on collaboration is not a major limitation of the study because the publication is still a strong predictor of the knowledge captured by the firm and that the firm has acquired the tacit knowledge of individuals engaged in the research [25].

Fourth, this study exploring the relationship between science and technology in biotechnology industry can be generalized to only those industries where scientific findings are important inputs for technological innovation.

Despite the above limitations, the study has enhanced the understanding of bridging the science and technology domains. In summary, the research has made an important empirical contribution by showing that the degree to which bridging scientists enhance the technological performance of a firm depends on the extent to which the firm exploits its scientific findings in technology development.

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