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Scientific linkages and firm productivity: Panel data evidence from Taiwanese electronics firms☆

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ABSTRACT

Using a panel of electronics firms listed on the Taiwan Stock Exchange, this paper explores the spillover of scientific research to the private sector by looking at the impact of the intensity a patent's backward citation of scientific publications relative to citation of other patents on the patent-owning firm's productivity. To identify the causal effect, we use measures of a firm's financial constraints as instrumental variables to account for the potential endogeneity of scientific citation intensity of a patent. The empirical results suggest that the citation of scientific publications by a patent has a strong and positive effect on the patent-owning firm's productivity.

1. Introduction

Knowledge is a public good, and it is likely that there are spillovers from academic science to commercial firms. Nelson (1986) survey research managers and find that university research is an important source of innovation in some industries. Jaffe (1989) and Adams (1990) show the importance of basic science for economic growth. Acs et al. (1992) find significant externalities from academic research on privative R&D and patenting (Cassiman et al., 2008). Mansfield (1991) and Cohen et al. (2002) also find that academic research is important for industrial innovation. Overall, findings by these studies show that knowledge spillovers from academia to industry have an impact on firms' abilities to innovate.

There are many examples of linkages between academic research and innovations by firms—university-industry collaboration (Zucker et al., 2002; Zucker and Darby, 2001), industry financing university research (OECD, 2004), university licensing (Thursby and Thursby, 2002), and citations to university patents (Trajtenberg et al., 1997), to name a few. An important example of spillovers from academic research to the private sector is the referencing of scientific papers by patents developed by firms (see Narin et al., 1997; and Hicks et al., 2001). For firms, academic research is a very important source of knowledge, a view also held by Jaffe et al. (2002). It leads firms into new areas of innovation and subsequently to new production processes and products. Additionally, academic science enables firms to circumvent needless experimentation. This, in turn, allows them to focus on only the most rewarding avenues of research. Branstetter and Ogura (2005) also indicate that basic science can open new research areas for applied researchers, as well as increase the level of applied research effort and its productivity. All these imply that the spillovers of knowledge from academic research lead to an increase in firms' research productivity (Evenson and Kislev, 1976; Gambardella, 1992).

There is a persistent rise in patents' citations of academic publications. For instance, Narin et al. (1997) report a threefold

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increase in the number of citations of academic literature in industrial patents in the United States during the mid-1990s. They also point out that 73% of the scientific articles cited by industry patents were authored at academic, governmental, and other public institutions.[1] Branstetter and Ogura (2005) show that there has been a rapid increase in citations of scientific articles in patents granted in the U.S. from the mid-1980s until the late 1990s. This increase is well above the increases in the U.S.'s R&D expenditure and the global output of scientific articles. Particularly, while the former increased by nearly 40% and the latter by 13%, scientific references of patent increased by more than 13-fold. This could mean that publicly funded science generated significant spillovers to industrial innovation during this period. Therefore, it would be interesting to see whether these knowledge spillovers from academia to the private sector bring about a contribution to firm productivity.

In addition to referencing academic works, each patent cites other previous patents (i.e., backward patent citations), which is another important knowledge source. Some researchers regard these patent citations as indicative of knowledge spillovers between innovative technologies of firms. For example, Nadiri (1993) indicates that the disclosure of new technologies in patents allows competitors to lower the cost of research by "working around" past patents. Reinganum (1989) and Cockburn and Henderson (1994) argue that firms may benefit from their competitors' research efforts, and knowledge spillovers encourage intellectual exchanges between research teams. Patent citations are basically the "paper trails" of these spillovers among firms (Fung, 2005). Fung (2005) regards backward patent citations as an indication of knowledge spillover, and finds that the intra- and inter-industry spillovers can improve firms' productivity growth. The findings of Deng (2008) suggest that knowledge spillovers received by firms through citation of previous patents bear substantial economic value. Furthermore, those that lag behind can receive benefits from knowledge spillover from leaders in the field, allowing the followers to catch up with the leaders. Peri (2004) believes that patent citations form links between inventions that reveal a learning process at the technological frontier. The above studies suggest that patent citations are a good measure for inter-firm knowledge spillovers.

There exist other views on the implications of a patent's citation of previous patents, arguing that citing more previous patents may imply that the citing patent is less original, especially when the patents cited are important ones (Jaffe et al., 2002). This is because existing patents represent previously discovered technological knowledge in the process of technology development, a patent citing too many previous patents may implies that it does not have very much novel contribution or it is low in creativity (see also Trajtenberg et al., 1997). Also, it is the legal duty for a firm to cite previous patents when it files a patent application for its inventions, such that the citation of previous patents may not reflect spillovers of knowledge.[2]

The above discussion suggests that while the backward citation of patents may or may not be interpreted as spillovers of knowledge among firms, the citation of scientific publications represents the flow of knowledge from academia to industry. However, there are not many studies on how the citation of scientific publications by a patent affects the patent-owning firm's productivity. Most of the existing studies explore how scientific linkages affect a firm's inventive productivity. For example, Aoki and Branstetter (2004) find a positive association between the intensity of patent citations related to academic science and subsequent research productivity at the firm level. Branstetter and Ogura (2005) support the idea that the main source of U.S. inventive activity has changed during the sample period, and comes with an increased emphasis on the use of the knowledge generated by university-based scientists. On the other hand, they find a positive relationship between a firm's inventive productivity and scientific linkages. Others who examine the relationship between scientific linkage and inventive productivity, such as Sorenson and Fleming (2004), Cassiman et al. (2008) and Nagaoka (2007), also find a positive relationship. These studies indicate that scientific linkage improves a firm's innovation productivity, implying that scientific linkage is likely to enhance a firm's productivity.

This paper uses patent data of electronics firms listed on the Taiwan Stock Exchange (TSE) which held at least one U.S. patent approved by the USPTO (United States Patent and Trademark Office) to evaluate the contribution of scientific linkages to total factor productivity (TFP) of the firm. Our data set includes a sample of 149 firms for the period 2004–2008. Taiwanese firms hold a very important position in the world market of semiconductors, computers and peripheral equipment, and electronic parts and components. Furthermore, the inventive activities of Taiwanese electronics firms are vigorous. According to the USPTO, the number of U.S. patents issued to firms in Taiwan ranked 4th in the world in 2008 (National Science Council, 2008).

Our firm-level scientific linkage is measured by the number of scientific publications cited by a firm's patents relative to the citations of other patents (i.e., intensity of citation of scientific publications). Before giving a precise definition of our measure of scientific linkage, we first explain the reference information of a patent. For a U.S.-approved patent, the references include citations of previous patents as well as non-patent references (NPRs, Narin et al., 1997). The former can be divided into U.S. patent citations and non-U.S. ones. The latter can be separated into several types, including scientific journal papers, conference proceedings, books, and many non-scientific citations such as industrial standards, technical disclosures, engineering manuals, and every other conceivable kind of published material (Narin et al., 1997).

In the literature, "scientific linkage" is measured in different ways. Nagaoka (2007) uses the CHI research scientific citation index. Branstetter and Ogura (2005) use the number of U.S. patent citations made to scientific articles generated by academic research in the state of California. Cassiman et al. (2008) use the scientific non-patent references (SNPR) cited by the focal patent and found in the Institute for Scientific Information (ISI) to measure the invention-specific scientific connection. By linking to ISI, they could single out the scientific articles in the NPRs. We utilize Cassiman et al.'s (2008) definition and Narin et al.'s (1997) classification to define scientific linkage, i.e., references of scientific publications found in the ISI (including journal articles, conference proceedings, books, and working papers).[3]

Our empirical analysis of the relationship between scientific publications and firms' productivity accounts for the possible endogeneity of scientific publications. Endogeneity of scientific citation has never been considered in previous studies. It is likely that there are unobserved factors affecting a firm's productivity, such as the firm's operating style and practices, R&D strategy, technical capa-

[1] Branstetter (2004) also suggests that there is an increasing trend in the science references cited by patents.

[2] Even though there exist different interpretations of backward citation of patents, there is no doubt that knowledge spillovers between firms are important. For example, by examining the relationship between a firm's productivity and other firms' patent applications (i.e., an indicator of their knowledge stock), Lee et al. (2015) find that knowledge spillovers from firms in the same business group are more significant than those from other firms. They also investigate the relative importance of inter- and intra-sector knowledge spillovers, and find that both are equally important.

[3] The university publications could include technical reports or working papers but not journal or conference papers generated by university-based scientists.

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