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Rich on paper? Chinese firms' academic publications, patents, and market value

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ABSTRACT

By combining various databases of academic publications and patents of China's publicly listed firms, we explore the effects of academic publications on firm valuation. We find that Chinese firms' academic publications are positively associated with their market valuation. More importantly, such a positive relation is more pronounced when these firms have stronger patent records, highlighting a synergy between basic research and applied technologies. Mechanism tests indicate that firms' academic publications promote their market values through enhancing their human capital and sending credible signals to the market. We also find that publications in English-language journals are more value-relevant than in Chinese-language journals.

1. Introduction

The motivation for corporations to publish their basic research in academic journals has been an intriguing topic due to the costly investment in fundamental science and the difficulty in appropriating the resulting knowledge. While prior studies have examined such motivation and associated consequences (Tijssen, 2004; Simeth and Cincera, 2016; Arora et al., 2018), these studies focus on publicly-listed firms in the U.S. or other developed countries.

This study examines the effects of corporations' basic research on their market values using Chinese data on firms' academic publications, patents, and corporate and managerial characteristics. Such an investigation is called for because, despite the increasing influence of their operations, Chinese firms have been characterized as technologically weak but have revealed strong ambition in catching up in globalized innovation competition (White et al., 2005; Chen et al., 2016; Appelbaum et al., 2016; Huang et al., 2017).

Despite this ambition, China's investments in some areas of fundamental technology have lagged. Consider the field of artificial intelligence (AI), which is the subject of Chinese national initiatives, and one in which Chinese scientific publications are increasingly well cited (O'Meara, 2019). Even in this field, China has lagged in developing core software and hardware tools, which has competitiveness implications. Instead, US companies have continued to dominate in these arenas, in open-source platforms such as TensorFlow in the former area, and semiconductor chips by Nvidia in the latter (O'Meara, 2019).

Our hypotheses and empirical tests are meant to inform such investments (in contrast with much of the literature, which has discussed government industrial policy). We first hypothesize that Chinese firms' academic publication records positively influence their market valuation because their upgrading in the value chain requires a transition from adopters to developers of new technologies (Liu and White, 2001). That transition often relies on human capital attraction and retention (Chen et al., 2016), and more generally, resources and attention from (potential) investors and customers (Hicks, 1995).

Our second hypothesis is that there are market value synergies between Chinese firms' academic publications and patents.[1] While appropriation is challenging on corporate scientific publications, when considered in conjunction with firm patenting, several factors may result in a positive firm market value effect: (1) scientists' capability in basic research may be related to their technology application ability (Gittelman and Kogut, 2003); (2) firms with stronger publication experience may have better-quality human capital to commercialize their technologies (Mansfield, 1991, 1998; Narin et al., 1997); and (3) patented

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[1] While prior studies have collectively suggested that both academic publications and patents are value-enhancing, whether and how these two elements complement each other has been under-explored. Thus far, the potential synergy between academic publications and patents has been briefly discussed in Cassiman et al. (2008) and Huang (2017), but related empirical evidence is lacking.

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technologies based on basic science are more difficult for others to imitate and thus may be a basis for competitive advantage (Huang and Murray, 2009).

Our final hypothesis is that Chinese firms' research appearing in journals in English are more valuable than that appearing in journals in Chinese from the shareholders' perspective because (1) publishing research in journals in English creates greater exposure and visibility to the international science community, which enhances the firm's credibility; (2) scientists and engineers who are able to publish in English-language journals are closer to the research frontier; and (3) publications in English better reflect internal communication across research centers located in different countries and areas.

To test our hypotheses, we start with a dataset covering manufacturing firms listed on the Shanghai and Shenzhen Stock Exchanges during 2006 to 2015 from the CSMAR database, which provides financial and accounting information of all Chinese listed firms. We then collect these sample firms' academic publications using the Scopus Database and China National Knowledge Infrastructure (CNKI, "中国知网") for corporate papers published in English and Chinese, respectively. We also collect sample firms' patent records from Chinese Innovation Research Database (CIRD) in Chinese Research Data Services Platform (CNRDS). This yields a sample of 1390 unique firms that have at least one granted patent. Among these firms, 1077 have at least one academic publication. In addition, an average firm produces 19.3 patents and 7.7 published papers (0.6 published papers in English and 7.1 published papers in Chinese) per year. In robustness checks, we also count the number of academic papers weighted by journal impact factors.

We measure Chinese firms' market values using Tobin's q,[2] and find that it is positively and significantly associated with the number of academic publications and patent counts. Our estimates suggest that when a firm's academic publications count increases from zero to 7.7 (the sample mean), its market value increases by 5.8% (equivalent to 473 million RMB). We empirically examine two main mechanisms, human capital and signaling, through which academic publications enhance firms' market values. We find that the number of academic publications is positively associated with the number of patent inventors, which is consistent with improved human capital (Gittelman and Kogut, 2003; Ho et al., 2019). As well, firms with more academic publications receive more attention from stock analysts, confirming the signaling effect of academic publications (Audretsch and Stephan, 1996; Azoulay, 2002; Hicks, 1995).

In addition, Chinese firms' market values are positively and significantly associated with the interaction between the number of academic publications and the number of patents. When both values increase from zero to their sample averages, their interaction increases a sample firm's market value by 122 million RMB. Furthermore, when we separate academic publications into publications in English and publications in Chinese, we find that English-language publications and their interaction with patents are more value-relevant.

This paper is related to prior research in the following ways. First, this study, based on Chinese firms' data, offers novel evidence on the value implications of basic research and academic publications from the perspective of emerging markets. Different from prior studies on basic research in China that tend to focus on the roles of governments, universities, and research institutes (Liu and White, 2001; Chen and Kenney, 2007; White et al., 2005), we show that Chinese firms may also play a gradually important role in basic research and such potential is recognized by stock markets. Second, we propose and empirically show the synergy of academic publications and patents on market valuation. This is new to the literature to our knowledge, and echoes prior studies based on individual inventor data (Gittelman and Kogut, 2003).

The remainder of the paper is organized as follows: Section 2 reviews prior literature on corporate academic publications and develop hypotheses. Section 3 describes data sources and collection, variable definitions, and research design. Section 4 presents the empirical results, and Section 5 discusses mechanism analyses. We present our identification tests and robustness checks in Section 6 and discuss the heterogeneous effects of corporate publications in Section 7. We conclude the paper with offering implications for corporate managers, shareholders, and policy makers in Section 8. All variable definitions are provided in the Appendix.

2. Literature and hypotheses development

2.1. Corporate academic publications: background

While published academic research is the foundation of modern society's technological progress (Mansfield, 1991, 1998), it is often costly in terms of both human and financial resources. As discussed in the economics literature (Levin et al., 1987), appropriability has been the core issue in the investment decision of companies in the private sector. Firms with scientists and engineers publishing their research in academic publications cannot appropriate all the benefits associated with those publications. In addition to the appropriability issue, agency issues may also exist: aiming to publish at academic journals may cause scientists to dilute their efforts in patenting and commercializing, and instead engage in activities with more private benefits (Thursby and Thursby, 2002; Lacetera, 2009). Despite these concerns, we still observe a large number of academic publications authored by scientists affiliated with companies in high-tech industries such as chemistry, electronics, and biology (Gittelman and Kogut, 2003; Lim, 2004; Simeth and Raffo, 2013).[3]

Prior studies have proposed several possible explanations for why firms publish academic papers. First, encouraging corporate scientists to publish academic papers promotes the advancement of the company's internal research and development, as well as commercialization capabilities (Cockburn et al., 1999; Gittelman and Kogut, 2003).[4] Second, academic publications can increase firms' visibility and reputation in the science community, strengthen firms' position in networks and professional associations, promote firms' collaboration with universities, and enhance firms' credibility with the public. These avenues for reputation-building could be particularly important for Chinese firms to incubate and attract talents (Wang and Shapira, 2012; Brehm and Lundin, 2012; Appelbaum et al., 2016). Third, firms may treat academic publications and dissemination of knowledge as strategic disclosures aimed at promoting the diffusion of particular technologies to effectively exploit their unique assets or to catalyze formal or informal industry standards (Teece, 1986; Harhoff et al., 2003; Huang, 2017).

As previously noted, Chinese firms have been aggressive in catching up in world-class technology competition (Fang et al., 2020). Prior studies have documented a positive influence of basic science on industrial technology in the U.S., especially in high-tech industries (Nelson, 1986; Narin et al., 1997; Sorenson and Fleming, 2004). Jaffe (1989) and Acs et al. (1992, 1994) find that university research budgets

[2] It is common in the literature to use Tobin's q to measure the effect of technological innovation on firm-level market values: see Griliches (1981), Lanjouw and Schankerman (2004), Hall et al. (2005), Bloom et al. (2013), Simeth and Cincera (2016).

[3] In fact, those scientists had made significant contributions to early development of some academic disciplines such as biology, chemistry, life sciences, and physics (Hicks, 1995; Cockburn and Henderson, 1998).

[4] Such policies facilitate firms' talent recruitment because some scientists prioritize reputation and research opportunities over monetary compensation (Stern, 2004; Sauermann and Cohen, 2010). In addition, scientists' incentive to publish in academic journals motivates them to attend conferences and remain embedded in external scientific networks (Cockburn and Henderson, 1998; Cockburn et al., 1999), which help firms absorb new technologies and stay on the research frontier (Gambardella, 1992).

positively influence local firms' patent outputs in drug and medical technology, electronics, optics, and nuclear technology. Cohen et al. (2002) survey also supports the positive influence of public research (conducted in either academia or government labs) on industrial R&D. For example, Audretsch and Stephan (1996) show that university scientists bring valuable knowledge to local biotechnology firms through employment or consultation relationships. However, while U.S. firms have access to basic science created by the public sector (including government labs and universities), Chinese high-tech firms may not have such benefits. In fact, research and business sectors have been disconnected in China for decades (Liu and White, 2001; Cao et al., 2013). Also, as pointed out in a statement of China's State Council in 2012: "… there is a lack of close cooperation between corporates and universities, and fundamental issues on the combination of technologies and economies remain unsolved." Thus, Chinese firms, especially those in high-tech industries, are more dependent on their own investment in human capital or access to foreign technologies.

2.2. Chinese firms' academic publications and market value

Simeth and Cincera (2016) and Arora et al. (2018) report a positive relation between U.S. public firms' academic publication count and their market valuation, which supports the value relevance of corporate academic research. Firms' academic publication records also reflect their scientific foundation and absorptive capacity, and are thus informative to stock markets. Academic publications are highly regarded by the scientist community, governments and the general public including potential customers (Hicks, 1995). Firms with strong academic publications are more likely to have more or closer collaborations with universities and thus have more innovation opportunities (Simeth and Cincera, 2016). For example, Cockburn and Henderson (1998) find that biotechnology firms with more scientists coauthoring with university researchers perform better in drug development. In addition, firms with strong academic publications have better credibility among potential customers and supply chain partners. All these lead to more favorable market valuation of their stocks.

We argue that the positive relation between academic publications and market values also appears and could be even more pronounced in China, especially in the recent past, due to the emergence of Chinese high-tech companies and the globalization of Chinese firms' operations. In the past, Chinese firms have been characterized as weak in basic research and heavily reliant on universities or global collaboration for knowledge sourcing (Wang and Shapira, 2012; Chen et al., 2016; Appelbaum et al., 2016). As Chinese firms gradually shift from technology adopters to developers, investing in more basic research may become more important (Liu and White, 2001; Motohashi and Yun, 2007). Thus, Chinese firms' academic publication records could reflect their efforts and investments in basic research that are conducive to future technological development and product invention, which is particularly informative for shareholders. Strong publication records thus serve as a credible signaling device to customers and potential collaborators, and such signals are particularly important for Chinese firms which are latecomers but intend to catch up in high-tech markets.

Moreover, Gambardella (1992) suggests that firms' in-house scientific research raises their ability to absorb "public" science. Since Chen et al. (2016) point out Chinese firms' lack of absorptive capacity in digesting and internalizing innovation generated from universities, the capability of conducting basic science research is a particularly needed capability for Chinese firms. These discussions lead to our first hypothesis:

Hypothesis 1: Chinese firms' academic publications positively influence their market values.

2.3. The complementarity of Chinese firms' academic publications and patents in market valuation

While prior studies have collectively suggested that both academic publications and patents are value-enhancing, whether there is a synergy in these two elements in terms of market valuation is an open question.[5] In one strand of literature, using inventor-level data, Gittelman and Kogut (2003) show that scientists who are capable in both patenting and publishing tend to produce more influential patents in biotechnology industries. Mansfield (1991, 1998) and Narin et al. (1997) also show an increasingly important role of academic research in commercialized inventions. Moreover, Sorenson and Fleming (2004) show that the number of forward citations of corporate patents, as a common measure of patent influence, is positively associated with their backward citations to basic research. These studies highlight the potential synergy from academic publications and patents. Thus, being capable in both patenting and publishing is value-enhancing for shareholders.

Another strand of literature suggests the patenting-publishing synergistic effect may result from the broader application of basic research. As pointed out in Trajtenberg et al. (1997), patents that are based more on basic research tend to have broader applications. Similarly, Cassiman et al. (2008) find that patents that are based on academic publications tend to be cited by subsequent patents in a wider range of technology areas. Such diversity in the applications of patents built on basic research is more valuable to shareholders because those patents may generate more differentiated products and create more profits (Hirshleifer et al., 2018). In addition, the competitive advantages of such patented technologies may be more sustainable due to the possibly higher entry barrier in accessing basic science knowledge.

Moreover, patenting and academic publication experience suggests an organizational ambidexterity which may aid knowledge creation and commercialization (Huang and Murray, 2009),[6] which is a positive signal to stock markets.[7] Since the ability to understand and commercialize basic science is a rare asset for Chinese firms (Motohashi and Yun, 2007), we expect the synergy from academic research and patents to be particularly important for them. In addition, Brehm and Lundin (2012) confirm a complementary relationship between capabilities of acquiring external knowledge and exploitation capacity of transforming such knowledge among Chinese firms. Moreover, using a sample consisting of 400 innovative companies for the 2008–2011 period, Kafourosa et al. (2015) find that firms engaging in more university collaborations generate more new product sales. These studies collectively point to the potential synergy between academic publications and patents in China, and so we predict:

Hypothesis 2: Chinese firms' academic publications and patents are synergistic in market valuation.

2.4. Mechanisms: human capital and signaling

Our literature review suggests that Chinese firms' market valuation

[5] Scientists are, however, subject to time constraints and may face a trade-off between investing in publications and patents/commercialization activity more generally (Kinney et al., 2004; Arora et al., 2018).

[6] The value implication of ambidexterity is similar to the exploitation-exploration concept of Levinthal and March (1993) in that a firm not only needs exploitation of its existing opportunities to maintain its short-run profitability but also needs exploration of new knowledge sources to discover future directions to avoid radical changes in industry and market structures. He and Wong (2004) present the value implication of ambidexterity by showing that the interaction of exploration and exploitation is positively related to sales growth.

[7] Appelbaum et al. (2016) find that Chinese nanotechnology firms tend to focus on short-term improvements of existing products rather than fundamental scientific research, which dampens their long-term development.

increases with their academic publications because academic publications (and the associated synergies with patents) lead to better human capital and more credible signals of firm quality. Human capital is known to be an important factor of a firm's value due to its critical role in a firm's intangible assets including customer relationship, business secrets, know-how, and process innovation (Chemmanur et al., 2019; Gennaioli et al., 2013). Firms with strong academic publication records are likely to possess basic research-oriented human capital, which may also be valuable assets for generating future patents (Gittelman and Kogut, 2003; Ho et al., 2020). In addition, a survey of R&D managers by Cohen et al. (2002) suggests that firms learn from universities through published papers and reports, public conferences and meetings, informal information exchange, and consulting, which further confirms the effect of academic research on human capital.

In fact, human capital has been found to be an important contributing factor to Chinese firms' product invention and productivity (Fleisher et al., 2010). We argue that human capital is particularly important for Chinese firms due to relatively weak institutional environments and infrastructure in China (Huang et al., 2017): Chinese firms in general lack scientific knowledge spillovers/transfers from local universities (Liu and White, 2001; Cao et al., 2013). When a Chinese firm has good academic publications, its research staff are likely to be talented and its policies and cultures are likely research-oriented. Moreover, Chinese firms' academic publication records will earn credibility in the scientific community, which leads to more collaboration opportunities with prestigious labs and researchers from universities and also attracts capable job candidates. This process creates a positive cycle and further enhances human capital, likely resulting in better future patents and invention performance. In addition, the synergy between academic publications and patents also influences the development and accumulation of human capital. Gittelman and Kogut (2003) show that scientists who are capable in both publishing at academic journals and patenting can produce more influential patents, and Walsh et al. (2016) find that U.S. patents resulting from collaboration with universities are associated with higher technical significance. These studies confirm the synergy stemming from being able to handle basic science and applied technologies at the same time.

We argue that the synergy between academic publications and patents is particularly important for Chinese firms' human capital: Motohashi and Yun (2007) and Hong (2008) find a significantly increasing trend in the collaboration between universities and corporations in China, and Kafourosa et al. (2015) find that collaborating with universities increases Chinese firms' new product sales. These studies point to the importance of the combination of basic science and applied technologies for Chinese firms' human capital. We thus form the following hypothesis:

Hypothesis 3a: Chinese firms' academic publications and associated synergies with patents enhance firms' human capital.

Academic publications also work as valid signals of quality to stakeholders including potential customers, supply chain partners, and research collaborators (Hicks, 1995; Audretsch and Stephan, 1996; Azoulay, 2002). Due to the relatively weaker legal environment in China (Huang, 2010, 2017; Huang et al., 2017), these stakeholders rely more on credible signals to make their decisions. Innovative firms thus have an even stronger incentive to publish research papers (especially at premier academic journals) as a means of promoting themselves to their stakeholders. Moreover, due to language barriers and less transparent information environments, Chinese firms' innovation performance may be discounted by potential foreign investors and collaborators.[8] Such a discount will be less a concern for Chinese firms with strong academic publications.

The synergy between academic publications and patents serves as an important signal to stakeholders for the following reasons. First, as discussed, Chinese firms' performance in patents may not appropriately reflect their innovation capabilities (Jia et al., 2019). In addition, Liu and Jiang (2001), Wu (2010), and Chen et al. (2016) collectively point out Chinese firms' lack of absorptive capacity in digesting and internalizing innovation generated from universities. Furthermore, Motohashi and Yun (2007) find an increasing trend in Chinese manufacturing firms' outsourcing R&D to universities. Thus, the capability in handling both basic science research and applied technology development is a particularly scarce yet important competitive advantage for Chinese firms: the patent output of Chinese firms with strong publication records will be regarded as more supported by scientific research and are thus less discounted by the market.

Second, firms may sometimes expend resources in scientific research without commercial output (Simeth and Cincera, 2016). This scenario likely occurs to some Chinese firms that were spin-offs of universities or were research labs of state-owned enterprises due to economic reform since the 1980s (Xue, 1997; Hong, 2008; Liu et al., 2011): CEOs and executives of these firms may be faculty members or scientists who are less interested or capable in commercialization. However, if a Chinese firm performs well in both basic science and commercialization, it will receive great attention from stakeholders including stock investors as its investment in scientific research can be effectively and efficiently converted into profits. Moreover, these firms may be viewed as more independent in technology development and therefore may be expected to fare better in the marketplace. These discussions lead to the following hypothesis:

Hypothesis 3b: Chinese firms' academic publications and associated synergies with patents are strong positive signals to the market.

2.5. Chinese firms' language of publications

We further hypothesize that Chinese firms' research appearing in journals in English is more valuable than that appearing in journals in Chinese from the shareholders' perspective. First, it is well-known that academic publications are dominated by journals in English. Thus, publishing research in journals in English creates greater exposure and visibility to the science community, which enhances firms' credibility with potential foreign investors, customers, and supply chain partners.[9]

Second, more advanced research and knowledge appear in journals in English first. Scientists and engineers who are able to publish in journals in English are more likely to absorb the most recent technological development, which also leads to higher growth options. Moreover, scientists and engineers who can publish in journals in English are more able to communicate fluently in English with potential foreign collaborators, such as prestigious university labs or innovative firms, which is a common strategy for Chinese firms to advance their technologies (Liefner and Si, 2019). These abilities related to information access and cross-country collaboration can lead to competitive advantages for firms and are valuable intangible assets for shareholders.

Publications in English also reflect firms' efficiency in internal communication across research centers located in different countries and areas. It is common for high-tech firms to have overseas research collaborations and research laboratories in different countries. Prior studies have shown that multinational corporations (MNCs) can combine various knowledge sources across country locations to generate innovation that is difficult for competitors to copy (Martin and Salomon, 2003; Berry, 2014). Our discussions lead to our last hypothesis:

Hypothesis 4: Chinese firms' academic publications in English are more value-relevant than those in Chinese.

[8] See "Chinese firms are filing lots of patents. How many represent good ideas?" The Economist, October 14, 2010.

[9] For example, Fisman et al. (2018) use papers that have been cited by at last 100 times in journals in English in Web of Science to measure the academic achievement of Chinese scholars.

3. Data and research designs

3.1. Data sources

We start our data construction by collecting a list of all patenting firms that are in manufacturing industries and are listed on the Shanghai and Shenzhen Stock Exchanges for the period of 2006 to 2015 from the CSMAR database.[10] Our sample consists of 1632 unique firms (11,183 firm-year observations) in the period 2006–2015. We then collect these firms' academic publications ("papers"), patents, and financial and accounting information in the sample period. Following the literature (Tijssen, 2004; Simeth and Cincera, 2016; Arora et al., 2018), we use academic publications with coauthors' affiliation with Chinese public firms to construct the publication measures. We collect sample firms' academic publications using the Scopus Database and China National Knowledge Infrastructure (CNKI, "中国知网") for corporate papers published in English and Chinese, respectively.[11]

We then collect the sample firms' patent data from the Chinese Innovation Research Database (CIRD) in Chinese Research Data Services Platform (CNRDS).[12] We also collect sample firms' patents registered in the U.S., although the number of Chinese firms' U.S. patents is far smaller than that of their Chinese patents (which is consistent with Huang and Li (2019)). Lastly, we collect the financial and accounting data of our sample firms from the CSMAR Database.

In Fig. 1, we illustrate the trends of R&D investment intensity, patents, and academic publications of Chinese publicly listed manufacturing firms from 2006 to 2015. We find steady growth in the average number of academic publications, but this growth rate is not as high as that of R&D and patents. In addition, we find that firms with academic publications mainly concentrate in capital- and technology-intensive industries such as manufacturing of computers, communications and other electronic equipment (49.6% with at least one publication), pharmaceuticals (58.1% with at least one publication), chemical raw materials and chemical products manufacturing (59.2% with at least one publication), electrical machinery and equipment manufacturing (53.8% with at least one publication), and specialized equipment manufacturing industry (58.9% with at least one publication). We then present the average number of academic publications of firms in each industry in Fig. OA1 in the Online Appendix. Again, we find a fairly stable growth in academic publications.

Our literature review and news media searches suggest no dramatic and systematic policy change to firms' incentive to publish at academic journals during our study time period.[13] Our search also suggests that the number of corporate publications is not a key performance indicator for local government officers. Nevertheless, we do find sporadic municipal policies that encourage academic publications from both universities and corporations.[14] The literature has discussed Chinese governments' subsidy policies to encourage firms' R&D and patenting activities (Lei et al., 2012; Li, 2012; Guan and Yam, 2015; Boeing, 2016; Stuart and Wang, 2016); however, prior studies suggest that these subsidies are either inefficient or lead to rent-seeking behavior.[15] We also acknowledge that there was a patent system reform at the end 2008; nevertheless, our robustness check suggests that it does not affect our baseline results.[16]

To avoid the situation that average estimates presented in Figs. 1 and 2 may be driven by data skewness, we provide the 40th, 50th (median), 60th, 70th, and 80th percentiles across all sample firms in Fig. OA2 in the Online Appendix. The median (70th percentile) number of academic publications is 1 (4) across all years. These patterns suggest that the distribution of firms' academic publications is fairly skewed across firms. Meanwhile, the increasing R&D and patenting patterns remain across time.

In Fig. 2 Panel A, we present the average number of firms' new patents filed in China and the U.S. in each sample year. We observe a persistent increase in both series: an average firm files 7.31 Chinese patents and 0.14 U.S. patents in 2006, and these numbers increase to 22.02 and 1.78 in 2015, respectively. In Fig. 2 Panel B, we present the average number of firms' academic publications in Chinese and English in each sample year. We find that a steady increase in academic publications in Chinese, but some fluctuations in academic publications in English.

Table 1 lists the sample distribution: Panel A presents the

[10] We start our sample in 2006 because R&D expenditures reported are sparse before that year. We focus on manufacturing industries (industry codes C13 to C43 of China Securities Regulatory Commission). We then exclude firms that have *no* patent records in the period 2006-2015, firms in financial distress, and firms with missing values in variables used in our regression analysis. It is common in the literature to focus on patenting firms only (Aghion et al., 2013; Bloom et al., 2013). While there are 31 manufacturing industries in China, two of them do not have patent records and are thus excluded from our sample. Thus, we use the 29 manufacturing industries as defined by China Securities Regulatory Commission.

[11] The Scopus Database is the largest abstract and citation database of peer-reviewed literature in scientific journals. The CNKI is a key national information database construction project launched by Tsinghua University and Tsinghua Tong Fang Company in 1996, with the support from PRC Ministry of Education, PRC Ministry of Science, Propaganda Department of the Communist Party of China, and PRC General Administration of Press and Publication. CNKI has developed into a comprehensive knowledge resource system and includes Chinese journals, doctoral dissertations, masters' theses, conference proceedings, newspapers, government reports, statistical yearbooks, e-books, patents, standards, etc. To search a firm's paper records in English, we manually input each sample firm's name and select years and journals in the Scopus Database (detailed search procedure is provided in the Online Appendix Section 1). To search a firm's paper records in Chinese, we manually input each sample firm's name and select years and journals in the CNKI Database (detailed search procedure is provided in the Online Appendix Section 2). We exclude journals in humanities and social sciences.

[12] Our data provider CIRD has access to the original data of China National Intellectual Property Administration (CNIPA) and matches the patent information to our sample firms. We include all three types of patents in the Chinese patent system: invention patents, utility model patents, and design patents. However, we acknowledge that design patents may not be as important as the other two types of patents and that invention patents are the best-protected type of patents (Lei et al., 2012; Hu et al., 2017; Huang et al., 2017; Wang et al., 2020). We use the number of patents that are applied for and subsequently granted by a firm in a given year measuring a firm's technological innovation capacity. More details about Chinese firms' patent data can be found in Tong et al. (2018) and He et al. (2018).

[13] There were Chinese policies to encourage universities and research institutes to publish in academic journals, such as Projects 985 and 211. However, these projects mainly target universities, not firms. We refer interested readers to background research on Chinese government's innovation policies including Liu et al. (2011), Huang (2010), Cao et al. (2013), Sun and Cao (2014), and Guan and Yam (2015).

[14] For example, Shenzhen city used to provide RMB 1 million reward for each publication at top journals in the past. It is unclear whether this reward, however, provides strong enough incentives for firms to invest in processes resulting in top-tier academic publications.

[15] However, Lei et al. (2012) find that patent subsidies increase the number of patent applications because applicants broke up their inventions to generate more patent applications (to receive more subsidies). Guan and Yam (2015) show that financial incentives of the government, i.e. tax credits, special loans, and R&D grants, have a neutral or negative effect on patents. Boeing (2016) finds that R&D subsidies, on average, crowd out firms' own R&D investments. Stuart and Wang (2016) show that firms commit fraud to window-dress their financial performance to receive government grants.

[16] The third amendment was made in accordance with the decision on amending the patent law of the People's Republic of China issued at the sixth meeting of the Standing Committee of the Eleventh National People's Congress on December 27, 2008. In a robustness check, we split our sample into 2006-2008 and 2009-2015 sub-periods and find consistent results in each sub-period.

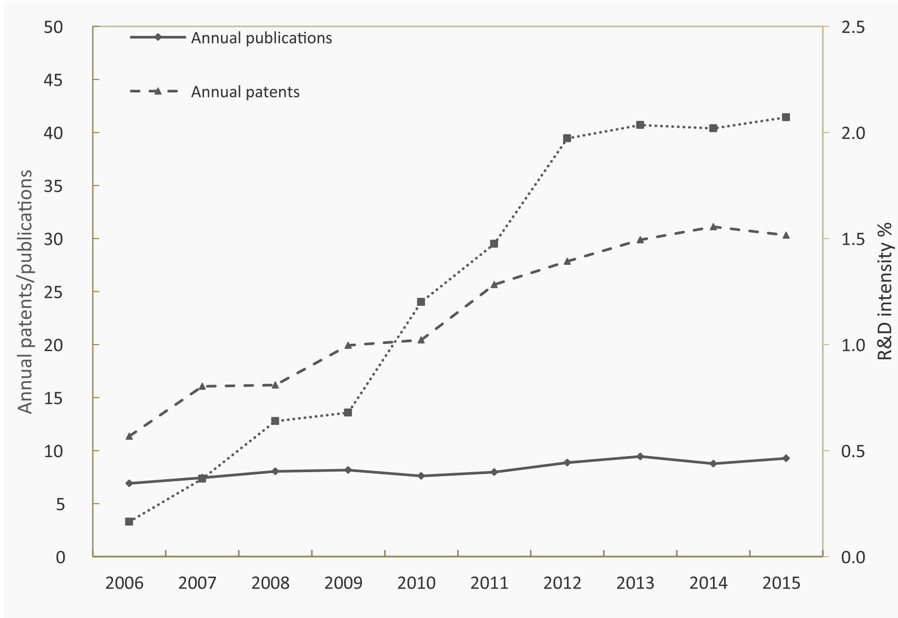


Fig 1. Academic publications, patents, and R&D intensity of Chinese publicly listed firms, 2006–2015. Note: The solid/green line denotes the average number of academic articles published by Chinese firms in each year; the dashed/red line denotes the average number of patents filed by Chinese firms in each year; and the dotted/blue line denotes the ratio of R&D expenditure to sales of Chinese firms in each year. All Chinese firms in our sample are those with at least one patent.

distribution of patent records by year (2006–2015), and Panel B presents the distribution of our firm-year observations by industry (spanning 29 industries). 353 unique firms in our sample have at least one academic publications in 2006, accounting for 53.2% of all firms (most of those are papers in Chinese). The number of firms that have academic publications increases to 892 in 2015, accounting for 57.6% of all firms. Consequently, nearly half of all firms in our sample published at least one journal article every year. Throughout our sample period, we have 1390 unique firms in our sample which have at least one granted patent. Among these firms, 1077 have at least one academic publication (the majority of which are in Chinese).

3.2. Main variables and summary statistics

To examine the effects of corporate papers and patents on a firm's market value, we estimate ordinary least squares regression models for firms' *Tobin's q*.[17] Our main explanatory variables of interest include *Papers, Papers in English, Papers in Chinese*, and their interaction with *Patents* based on filing year.[18] While our use of academic publications to measure a firm's science capability follows prior studies (Tijssen, 2004; Simeth and Cincera, 2016; Arora et al., 2018), our study features a refinement: we separate all papers into papers in Chinese-language journals and papers in English-language journals. In a robustness check, we also count the number of academic papers weighted by journal impact factors.

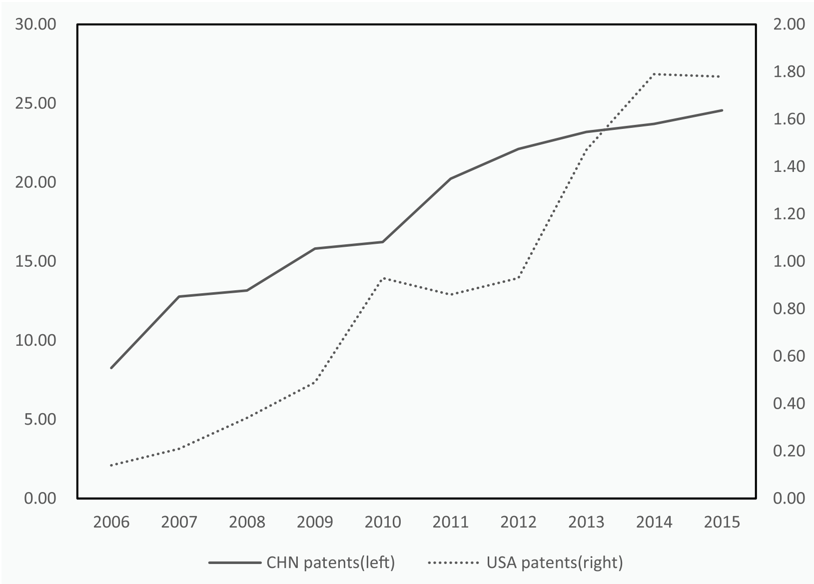
Table 2 presents the descriptive statistics of all variables used in our regressions. The mean and standard deviation of *Tobin's q* are 2.8 and 2.3, respectively. The mean and standard deviation of the market value among our sample firms are 8201 and 16,225 million RMB, respectively. The averages of *Papers, Papers in English*, and *Papers in Chinese* are 7.7, 0.6, and 7.1, respectively. Moreover, a sample firm has filed 19.3 patents per year.

To isolate the influence of academic publications and patents on a firm's Tobin's q, we also control for a series of firms' and shareholders' characteristics that are related to firms' market value. We control for Ln *(Assets)*, which is defined as the firm's total assets in logarithm and reflects its size (a necessary component for a Cobb-Douglas function) following Griliches (1981) and Hall (1993). In our robustness tests, we replace total assets with total market capitalization and find consistent results. We also consider an extensive set of control variables that have been shown to explain firms' innovation activities and market valuation in the literature. It includes Ln *(R&D)*, which denotes the firm's R&D expenditures plus one; *Leverage* is a firm's total debts over its total assets and reflects its financial conditions (Balsmeier et al., 2017); Ln *(PPE/#employees)* measures a firm's net property, plant, and equipment (PPE) scaled by the number of employees and reflects its capital intensity (Aghion et al., 2013); *Sales growth* denotes a firm's growth in revenue and reflects its momentum and growth prospects (Aghion et al., 2013); *Stock volatility* is the standard deviation of daily stock returns over the fiscal year of a firm and reflects its total riskiness (Hershleifer et al., 2018); Ln *(Board size)* is the number of board members in a firm and reflects the monitoring intensity (Balsmeier et al., 2017), *SOEs* is an indicator variable that equals one if a firm is state-owned and captures the differences of SOEs' and non-state-owned firms' goals (Jia et al., 2019), and *QFII* denotes the ratio of qualified foreign institutional investors in a firm and reflects its corporate governance and independence (Aghion et al., 2013).

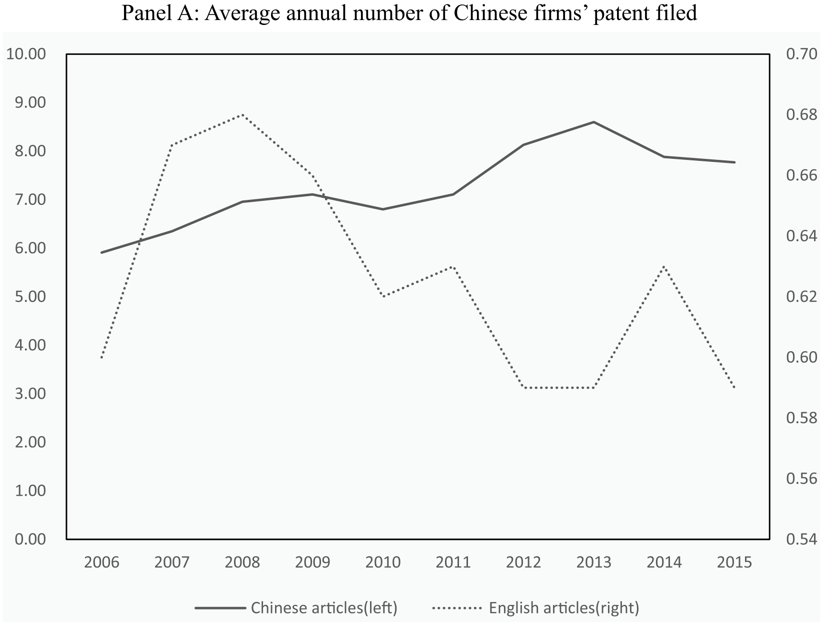
We winsorize all continuous variables at 1% at both tails to mitigate the influence of outliers. Table 2 also presents the summary statistics of control variables. An average firm in our sample has total assets of 6350

[17] It is common in the literature to use Tobin's q to measure how a firm's market value is influenced by its innovation activities, see Griliches (1981), Lanjouw and Schankerman (2004), Hall et al. (2005), Bloom et al. (2013), and Simeth and Cincera (2016). In our robustness checks, we replace Tobin's q with market value in logarithm (*Ln(Market value)*) for the dependent variable, following Lerner (1994), Blundell et al. (1999), Hsu et al. (2013), and obtain consistent results.

[18] *Papers* of firm *i* in year *t* is defined as the number of all academic publications we collect in Scopus and CNKI that have at least one coauthor listed as affiliated with firm *i* and published in year *t; Papers in English* of firm *i* in year *t* is defined as the number of all academic publications we collect in Scopus that have at least one coauthor listed as affiliated with firm *i* and published in year *t*; and *Papers in Chinese* of firm *i* in year *t* is defined as the number of all academic publications we collect in CNKI that have at least one coauthor listed as affiliated with firm *i* and published in year *t. Patents* denotes the number of all patents filed by (and are later granted to) firm *i* in China in year *t*.



Panel A: Average annual number of Chinese firms' patent filed



Panel B: Average annual number of Chinese firms' publications in Chinese and English

Fig 2. Patenting and publishing activities of Chinese listed firms, 2006–2015. Panel A: Average annual number of Chinese firms' patent filed (their patents in China in the solid/red line and their U.S. patents in the dotted/blue line), Panel B: Average annual number of Chinese firms' publications in Chinese (solid/red line) and English (dotted/blue line), Note: This figure presents average firm-year publications (in Chinese and English) and patents over time for publicly listed firms with at least one patent.

million RMB, spends 95 million RMB in R&D, is 8.69 years old, has a leverage ratio of 0.45, has sales growth of 15%, has stock volatility of 0.50, and has 8.82 board members. In addition, 11.1% of sample firms are foreign institutional investors. Lastly, 39.8% of sample firms are state-owned.

4. Papers, patents, and market values

Table 3 reports our estimation results from regressing firms' *Tobin's q* on their count of academic publications interacted with their patent count and a series of firms' characteristics. We estimate contemporaneous regressions because financial markets are expected to react immediately to new information about firms' innovation performance (Hall et al., 2005; Hsu et al., 2013).[19] We also control for industry and year fixed effects in our empirical models to account for industry

[19] Hsu et al. (2013) show that Chinese public firms' stock values are positively associated with their number of successful patent applications. Carpenter et al. (2021) show that stock prices in China have become as informative about firm future profits as they are in the U.S. since the reforms of the early 2000s. Chong et al. (2012) also find that China's stock market has become more efficient in our sample period (2006-2015). In our robustness checks, we also considered lead-lag regressions to accommodate possible time delay in stock markets' reactions.

Table 1
Distribution of the sample by year and industry.

Panel A: sample distribution by year			
Year	No. of firms	No. of publishing firms	Publishing firms (%)
2006	664	353	53.16
2007	719	380	52.85
2008	789	436	55.26
2009	848	467	55.07
2010	1102	582	52.81
2011	1291	681	52.75
2012	1403	760	54.17
2013	1391	802	57.66
2014	1435	838	58.40
2015	1541	887	57.56
Panel B: sample distribution by industry			
Industry	No. of firms	No. of publishing firms	Publishing firms (%)
Specialized equipment manufacturing industry	992	584	58.87
Instrumentation industry	132	64	48.48
Other manufacturing	106	8	7.55
Agricultural and sideline food processing industry	299	136	45.48
Chemical raw materials and chemical products manufacturing	1442	854	59.22
Chemical fiber manufacturing	244	124	50.82
Pharmaceutical industry	1470	854	58.10
The printing and recording media reproduction industry	65	29	44.62
Furniture manufacturing	43	20	46.51
Comprehensive utilization of abandoned resources	23	6	26.09
Culture, education, art, sports and entertainment products manufacturing	52	8	15.38
Nonferrous metal smelting and rolling industry	574	332	57.84
Wood processing and wood, bamboo, rattan, brown, grass products industry	96	33	34.38
Rubber and plastic products industry	334	169	50.60
Automobile industry	777	477	61.39
Electrical machinery and equipment manufacturing	1308	703	53.75
Leather, fur, feather and its products and footwear industry	43	15	34.88
Petroleum processing, coking and nuclear fuel processing industries	173	108	62.43
Textile industry	371	175	47.17
Textile clothing, clothing industry	179	41	22.91
Manufacturing of computers, communications and other electronic equipment	1917	950	49.56
General equipment manufacturing	733	441	60.16
Paper and paper products industry	266	165	62.03
Wine, beverage and refined tea manufacturing	440	299	67.95
Metal products industry	334	173	51.80
Manufacturing of railways, ships, aerospace and other transport equipment	373	112	30.03
Non-metallic mineral products industry	565	292	51.68
Food manufacturing	283	159	56.18
Ferrous metal smelting and rolling industry	361	275	76.18

Note: This table provides the number of firms, the number of publishing firms, and the percentage of publishing firms in the sample by year (Panel A) and by industry (Panel B).

heterogeneity and time trends in market valuation.[20] Our statistical inferences are based on standard errors that are clustered at the firm level, which correct the variation in estimation errors within each firm, such as serial autocorrelation.

Column (1) presents the results when we only include *Papers* and *Patents* in addition to control variables, and shows that *Tobin's q* is positively and significantly associated with both variables. The estimated coefficients on *Papers* and *Patents* in Column (1) are both significant at the 1% level, and the implied economic magnitude is as follows: when a firm's number of journal publications increases from zero to 7.7 (sample mean of *Papers*), a firm's market value increases by 5.8%; when a firm's patent count increases from zero to 19.3 (sample mean of *Patents*), a firm's market value increases by 2.3%. These increases in market value correspond to 473 and 190 million RMB, respectively, given that the mean market value of our sample firms is 8201 million RMB. This finding supports Hypothesis 1.

Column (2) presents the results when we further introduce the interaction term, *Papers* × *Patents*, into the model. We find that the coefficient on the interaction term is positive and significant at the 1% level, indicating the synergy of academic publications and patents in enhancing a firm's market value. In terms of economic magnitude, given that a firm's number of academic publications is 7.7 (sample mean of *Papers*) and its number of patents is 19.3 (sample mean of *Patents*), the estimated interaction effect reflects a growth of 1.5% in a firm's market value (i.e., an increase of 122 million RMB). This finding confirms the synergy of firms' scientific capability and industrial applications, and provides supportive evidence for Hypothesis 2.

Column (3) shows the estimation results when we include both *Papers in English* and *Papers in Chinese* and their interaction terms with *Patents* in the same regression. The coefficients on *Papers in English* and *Papers in Chinese* are 0.0044 and 0.0031, respectively, suggesting that global journal publications are more value-enhancing than local journal publications. The increase in market value by publishing one more global journal article is much more than that of publishing one more local journal article.

Moreover, coefficients on *Papers in English* × *Patents* and *Papers in Chinese* × *Patents* are 0.0021 and 0.0001, respectively, suggesting that global journal publications are associated with a greater synergy than local journal publications. Given the same number of patents, the increase in market value by publishing one more global journal article is much more than that associated with publishing one additional local journal article. These results support Hypothesis 4.

5. Mechanisms

In this section, we discuss two mechanisms through which corporate papers published in academic journals may affect firms' market values and/or enhance the effect of patents on firms' market values: first, firms with more academic publications may be those which encourage research staff to pursue more fundamental research, which enhances their ability to create more and better patents in the future - a human capital centered mechanism. Second, firms with more academic

[20] In a robustness check, we include *lagged Tobin's q* on the right-hand-side of the regression to account for persistence of *Tobin's q* and find consistent results (Griliches, 1981). We do not include firm fixed effects or lagged *Tobin's q* in our main regression for the reasons suggested by Hall et al. (2005): first, firm innovation and market value are persistent and may be highly correlated with individual effects, leading any effect of corporate papers and patents to be absorbed by firm fixed effects. Second, given our wide and short panel of 1,632 firms over 10 years (2006-2015), we are interested in the cross-sectional relation between market value and corporate papers and patents across firms. Third, given the large cross-section in our sample (over 1,000), each firm can reasonably be assumed to be a random draw from the same population (e.g., Petersen 2009).

Table 2
Descriptive statistics.

Variables	N	Mean	Std	Median	Min	Max
Panel A: Dependent variables						
Tobin's q	11,183	2.8234	2.3068	2.1719	0.7647	32.3522
Market value (millions RMB)	11,183	8201.37	16,224.68	4082.00	101.23	507,603.48
Panel B: Independent variables						
Papers	11,183	7.7447	22.4856	1.0000	0.0000	203.0000
Papers in Chinese	11,183	7.4522	21.9925	1.0000	0.0000	223.0000
Papers in English	11,183	0.6181	7.9051	0.0000	0.0000	272.0000
Panel C: Control variables						
Patents	11,183	19.3461	81.8646	3.0000	0.0000	1488.0000
R&Dexp (millions RMB)	11,183	94.70	396.22	23.10	0.00	12,200.00
Assets (millions RMB)	11,183	6350.38	17,633.92	2226.73	17.96	511,630.69
Firm age (years)	11,183	8.6896	5.8538	8.0000	1.0000	26.0000
Leverage	11,183	0.4522	1.3071	0.4150	0.0071	96.9593
PPE/#employees (1000 RMB)	11,183	390.22	1088.19	239.99	2.20	46,569.82
Sales growth	11,183	0.1504	0.2961	0.1165	−0.4951	1.5289
Stock volatility	11,183	0.5006	0.1505	0.4655	0.2307	0.9315
Board size	11,183	8.8230	1.6963	9.0000	3.0000	19.0000
SOEs	11,183	0.3982	0.4895	0.0000	0.0000	1.0000
QFII	11,183	0.1114	0.4234	0.0000	0.0000	2.7400
Panel D: Other variables						
Hadlock and Pierce's (2010) financial constraints index	11,183	−3.4262	0.2536	−3.3950	−3.9812	−2.9342
G index	11,183	0.0239	1.0650	−0.1819	−3.2453	5.7604
TMT quality	11,183	0.1652	2.3929	−0.1513	−7.0393	15.7535
Board diversity	11,183	0.2325	2.5588	0.1349	−12.5113	13.0722
University firm	11,183	0.0111	0.1047	0.0000	0.0000	1.0000
CEO political connection	11,183	0.4068	0.4913	0.0000	0.0000	1.0000
CEO age	11,183	48.5161	6.5918	48.0000	25.0000	79.0000
CEO male	11,183	0.9472	0.2237	1.0000	0.0000	1.0000
CEO tenure	11,183	33.6684	32.6523	23.0000	0.0000	216.0000
Founder CEO	11,183	0.7021	0.4573	1.0000	0.0000	1.0000
Inventor CEO	11,183	0.3927	0.4884	0.0000	0.0000	1.0000
Academic CEO	11,183	0.0630	0.2430	0.0000	0.0000	1.0000
CEO GSI	11,183	−0.0343	0.8835	−0.2164	−1.2867	3.6446
CEO foreign experience	11,183	0.0438	0.2047	0.0000	0.0000	1.0000
Outside CEO	11,183	0.1879	0.3906	0.0000	0.0000	1.0000
Financial CEO	11,183	0.0464	0.2104	0.0000	0.0000	1.0000
Ln(locgdppp)	11,183	10.6759	0.5423	10.7650	8.6570	11.5895
LocUniversityNum	11,183	103.4908	34.5190	104.0000	6.0000	162.0000
LocLotterypp	11,183	244.2345	114.9416	244.0000	33.5026	684.2466
Inventor Num	11,183	28.4501	131.2193	4.0000	0.0000	3618.0000
Analyst coverage	11,183	13.7562	18.0362	7.0000	0.0000	83.0000
M&A	11,183	0.1049	0.3064	0.0000	0.0000	1.0000
Peer Effects	11,183	6.2952	16.6384	1.0000	0.0000	260.0472
Difficulty of Publication	11,183	1.0626	2.7703	0.0000	0.0000	53.5460

Note: This table reports descriptive statistics of the main variables defined in Appendix A. during the sample period 2001–2015. All continuous variables are winsorized at 1% at both tails. All variables are defined in the Appendix.

publications are regarded as having proven records in innovation, which increases the attention and credibility of their patents and technological competence – we label this a "signaling" mechanism.

5.1. The human capital mechanism

We argue that firms' academic publication records reflect their research staff's talent and technology as well as their policies and cultures in encouraging basic science and fundamental research. Thus, firms with stronger publication records are expected to create more and better patents in the future (Gittelman and Kogut, 2003; Ho et al., 2020). To examine this human capital mechanism, we regress our measure of human capital, number of inventors in logarithm, on firms' academic publications and other control variables used in Table 3. As shown in Column (1) in Table 4, *Papers* is positively and mostly significantly associated with the number of inventors, suggesting that firms with more academic publications have incubated and attracted more inventors. If a firm's paper count increases from zero to 7.7 (sample mean) per year, its associated number of inventors increases by 5.79.[21] In Columns (2) of Table 4, we find that the coefficient on *Papers* × *Patents* is significantly positive, confirming the synergy between basic science and applied technologies in human capital. In terms of economic magnitude, given that the sample average of paper count and patent count are 7.7 and 19.35 per year, respectively, their interaction increases the number of inventors by 0.89.[22] These results support Hypothesis 3a.

[21] Since Ln(1+ Inventors) = X and Ln(1+ Inventors + ΔInventors) = X + ΔX where ΔX = 0.0233×7.7 and ΔInventors = (1+ Inventors) × [exp(ΔX) – 1]. When we use the mean of Inventors (28.45), we get 5.79.

[22] Since Ln(1+ Inventors) = X and Ln(1+ Inventors + ΔInventors) = X + ΔX where ΔX = 0.0002×7.7 × 19.35 and ΔInventors = (1+ Inventors) × [exp(ΔX) – 1]. When we use the mean of Inventors (28.45), we get 0.89.

Table 3
Corporate publications, patents and market value.

	Tobin's q		
	(1)	(2)	(3)
Papers	0.0075***	0.0049***	
	(0.0014)	(0.0014)	
Patents	0.0012***	0.0006**	0.0005*
	(0.0003)	(0.0003)	(0.0003)
Papers × Patents		0.0001***	
		(0.0000)	
Papers in Chinese			0.0031**
			(0.0015)
Papers in Chinese × Patents			0.0001***
			(0.0000)
Papers in English			0.0044**
			(0.0020)
Papers in English × Patents			0.0021**
			(0.0006)
Ln (R&D)	-0.0272**	-0.0272**	-0.0273**
	(0.0137)	(0.0137)	(0.0137)
Ln (Assets)	-0.8289***	-0.8325***	-0.8355***
	(0.0593)	(0.0596)	(0.0597)
Leverage	0.4066***	0.4067***	0.4070***
	(0.0316)	(0.0314)	(0.0315)
Ln (PPE/#employees)	-0.1692***	-0.1690***	-0.1695***
	(0.0533)	(0.0532)	(0.0532)
Sales growth	0.5923***	0.5934***	0.5916***
	(0.0794)	(0.0794)	(0.0793)
Stock volatility	1.5971***	1.6021***	1.6002***
	(0.3869)	(0.3865)	(0.3868)
Ln (Board size)	-0.0166	-0.0208	-0.0013
	(0.1706)	(0.1700)	(0.1715)
SOEs	-0.2130***	-0.2110***	-0.1991***
	(0.0642)	(0.0640)	(0.0644)
QFII	0.1743***	0.1727***	0.1785***
	(0.0429)	(0.0427)	(0.0426)
Constant	8.0429***	8.0780***	8.0731***
	(0.6821)	(0.6826)	(0.6809)
Year fixed effects	YES	YES	YES
Industry fixed effects	YES	YES	YES
Observations	11183	11183	11183
Adjusted R^2	0.4159	0.4166	0.4171

Note: This table presents the results of the impact of corporate publications on market value. Also included in each regression, but unreported, are the control variables listed in Table 2. Standard errors in the brackets are corrected for clustering at the firm level. *, ** and ***indicate significance at the 0.10, 0.05 and 0.01 level (two-tailed), respectively. All variables are defined in the Appendix.

5.2. The signaling mechanism

Firms' academic publications also serve as signals of their scientific and technical capabilities to investors, analysts, and customers (Audretsch and Stephan, 1996; Azoulay, 2002; Hicks, 1995). Such signaling enhances all stakeholders' (including investors') confidence in the quality of a firm's patents and thus raises their value relevance, or draws more attention to the firm's patents and reduces the likelihood of undervaluation of these patents. To examine this mechanism, we use the number of stock analyst reports following a firm in a year (analyst coverage) as our proxy for market signaling because it reflects the attention from professionals who are more sophisticated and understand the value of firms' capability in basic science. We regress analyst coverage on firms' academic publications and other control variables used in Table 3. The results, reported in Columns (3) and (4) in Table 4, show that corporate academic publications are positively and mostly significantly associated with market attention. If a firm's paper count increases from zero to 7.7 (sample mean) per year, it is associated with 0.61 more analyst. The results are consistent with the proposition that corporate publications deliver strong signals to the market because firms with more journal publications receive more attention from analysts. On the other hand, we also find a significantly positive coefficient on *Papers × Patents* in Column (4), which suggests a synergistic effect of basic science and applied technologies on the signaling mechanism. In terms of economic magnitude, given that the sample averages of paper count and patent count are 7.7 and 19.35 per year, respectively, their interaction increases the number of analysts by 0.10. These results support Hypothesis 3b.

6. Identification and robustness checks

6.1. Identification for causality

We acknowledge that our estimation results may be potentially subject to various endogeneity issues. We try to address these issues by considering additional control variables, predictive regressions, difference-in-differences analysis, and instrumental variable regressions. We provide these results in the Online Appendix. In this section, we summarize our tests and results.

Omitted variables are a common endogeneity concern. When a firm has (unmeasured) favorable market prospects or technology opportunities, it may reveal both better innovation performance and higher market value appreciation. To rule out such a concern, we follow Griliches (1981) and include firms' *Tobin's q* in year t-1 as a control variable because all omitted variables should be reflected in stock prices faster before they enhance academic publications and papers. The results presented in Table OA1 in the Online Appendix suggest that even after we control for lagged *Tobin's q*, the positive effects of *Papers, Patents* and *Papers × Patents* on *Tobin's q* remain significant (albeit weaker in terms of coefficient magnitudes). In addition, the effect of *Papers in Chinese* becomes insignificant.

To further alleviate the concerns about potential omitted variables, we include several sets of control variables in Tables OA2 and OA3 in the Online Appendix, which include an extensive set of variables capturing board and top management teams (TMT) characteristics,[23] financial

[23] We include an indicator variable *University firm* that equals one if a firm is affiliated with a university and zero otherwise in Panel A; an indicator variable *Academic CEO* that equals one if a CEO has academic working experience and zero otherwise (White et al., 2014) in Panel B; an indicator variable *Inventor CEO* that equals one if the CEO has been listed as an inventor of a patent and zero otherwise in Panel C (Islam and Zein, 2020); *Board diversity*, an index that reflects the diversity of directors by gender, age, ethnicity, educational background, financial expertise, and breadth of board experience dimensions (Bernile et al., 2018) in Panel D; *TMT quality*, a variable reflecting top management team quality (Chemmanur et al., 2018) in Panel E; *CEO GSI*, the general skill index of CEO captures the generality of a CEO's human capital based on lifetime work experience in publicly traded firms prior to the current CEO position (Custódio et al., 2019) in Panel F; an indicator variable *Founder CEO* that equals one if the current CEO is the founder of the firm and zero otherwise (Adams et al., 2009; Fahlenbrach, 2009) in Panel G; an indicator variable *CEO political connection* that equals one if the current CEO has any political connection and zero otherwise (Faccio, 2006; Xu et al., 2015) in Panel H; *CSO firms*, a variable that reflects the work experience of TMT in technology-related positions, in Panel I; *CEO foreign experience* is an indicator variable that equals one if the current CEO has been studying or working abroad and zero otherwise (Yuan and Wen, 2018) in Panel J; *Outside CEO* is an indicator variable that equals one if the current CEO who comes from the outside of the firm and zero otherwise (Zhu and Shen, 2016) in Panel K; and *Financial CEO* is an indicator variable that equals one if the current CEO has past experience in either banking or investment firms, in a finance-related role, or in a auditing firm and zero otherwise (Custódio and Metzger, 2014) in Panel L; CEO age, gender, and tenure (*CEO age, CEO male*, and *CEO tenure*) in Panel M.

constraints,[24] corporate governance,[25] and local economic conditions (He et al., 2020).[26] We find that the coefficients of *Papers, Patents*, and *Papers* × *Patents* remain significantly positive in all panels of both tables. When we decompose *Papers* into *Papers in English* and *Papers in Chinese*, their interactions with *Patents* continue to have positive coefficients. Our consideration of an extensive list of control variables confirms that our main finding cannot be simply attributed to omitted variables.

Reverse causality is another common endogeneity concern. We thus also estimate predictive models by regressing *Tobin's q* in $t+1$ on firms' academic publication and papers in year t (together with *Tobin's q* in year t being controlled on the right-hand side).[27] Such a lead-lag regression mitigates the reverse causality concern (as future *Tobin's q* is unlikely to explain current academic publications and papers, especially when current *Tobin's q* has been controlled). We find significant predictive ability of academic publications and their synergy with patents for *Tobin's q* in $t+1$ in Table OA4 in the Online Appendix.

We also utilize the Chinese government talent policy in 2012 as an exogenous policy shock to estimate a difference-in-differences regression. In 2012, the Chinese government introduced policies to encourage universities and research institutes to exchange talents with enterprises.[28] We argue that this policy shock enhances the effect of *Papers* × *Patents* on firm value because university professors are more than willing to collaborate with firms, which is expected to enhance the effect of firms' scientific finding/knowledge and associated synergy with patents on firm value. This relation can be further elaborated as follows: consider Firm A with an academic publication and Firm B without. Under the policy shock in 2012, Firm A will absorb more capabilities from universities than Firm B because the former has stronger scientific foundation and can communicate with university professors (Cohen and Levinthal, 1989). It is also worth mentioning that this policy shock is unrelated to firms' market value (except working through enhancing firms' scientific development). We find that this is indeed the case in the results reported in Table OA5 in the Online Appendix.

Finally, we further address potential endogeneity issues by proposing instrumental variables and implementing two-stage least squares regressions. In particular, we propose two instrumental variables that are related with *Papers* but unrelated to *Tobin's q: Peer Effects* and *Difficulty of Publication*.[29] In addition to those two instrumental variables, we also introduce two interaction terms of *Peer Effects* × *Patents* and *Difficulty of Publication* × *Patents* as another two instrumental variables because our baseline model also includes the interaction term between *Papers* and *Patents*.[30] We then use these four instrumental variables in a two-stage least square (2SLS) regression and present the results in Table OA6 in the Online Appendix. The first-stage regression results are presented in Column (1) and Column (2), in which we regress *Papers and Papers* × *Patents* on these four instrumental variables and all control variables in our baseline regression.[31] Column (3) reports the second-stage results of the 2SLS regressions, in which we regress *Tobin's q* on instrumented *Papers* and *Papers* × *Patents* (i.e., the predicted values of these two variables based on the first-stage regressions). Since these two main explanatory variables are now based on the first-stage regressions, their explanatory ability for market value will be free from the omitted variable issue. We find that instrumented *Papers* and *Papers* × *Patents* positively explain *Tobin's q*, supporting a causal interpretation of our main results.

6.2. Robustness checks

In this section, we briefly discuss robustness checks to address quality difference in patents, quality difference in publications, and alternative explanations. We provide the associated tables in the Online Appendix.

Profitability. To substantiate the value implication of academic publications and associated synergy with patents, we examine their effects on firms' future profitability. We define a firm's profitability as its earnings before interest, taxes, and depreciation and amortization (EBITDA) scaled by its total sales. We regress firms' profitability in years $t+1$, $t+2$, and $t+3$ on their *Papers, Patents, Papers* × *Patents*, and other control variables in year t. We find that Chinese firms' profitability increases with their academic publications, patents, and the interaction of them in Table OA7 of the Online Appendix. These results support the positive effect of Chinese firms' basic research and associated synergy with applied technologies on their future profitability, which corroborates our baseline result for the value implication of corporate publications.

Patent quality. Since U.S. patents could be more valuable than Chinese patents, we are interested in analyzing how such heterogeneity in patent quality affects our results. We thus decompose *Patents* into the number of patents that are not filed to the U.S. (*ChPatents*) and the number of patents that are also registered in the U.S. (*USPatents*). When we estimate the regression using these decomposed patent counts, we find that the coefficients on *USPatents* are larger than those on *ChPatents* in Table OA8 of the Online Appendix, confirming that U.S. patents are more valuable. More importantly, the coefficients on *Papers in English* ×

[24] Hadlock and Pierce (2010) financial constraints index is defined as $-0.737\times Ln\ (Assets) + 0.043\times Ln\ (Assets)^2 - 0.04\times$ *Firm age*. Higher scores of Hadlock and Pierce (2010) index indicate that firms are more financially constrained.

[25] Corporate governance is also another possible omitted variable as it has been shown to affect both firm value (Bebchuk and Weisbach, 2010; Nini et al., 2012) and corporate innovation (O'Connor and Rafferty, 2012; Sapra et al., 2014). To ensure our findings are not driven by corporate governance, we add to our baseline model the corporate governance index (*G index*) using the method of principal component analysis (PCA).

[26] We consider the following local variables including economic development (the natural log of local GDP per person, Ln*(locgdppp)*), the number of local universities (*LocUniversityNum*), and local gambling culture (the average sales of lotteries per person, *Loclotterypp*).

[27] This regression also accommodates the time lag in market reactions: investors may need some time to digest information about firms' innovation activities and result in a delay in the relation between academic publications/patents and market valuation.

[28] "Opinions of the Central Committee of the CPC and the State Council on Deepening the Reform to the Science and Technology System and Speeding up the Building of the National Innovation System" (中共中央国务院关于深化科技体制改革加快国家创新体系建设的意见), see: http://www.gov.cn/gongbao/content/2012/content_2238927.htm; http://english.www.gov.cn/archive/state_council_gazette/2015/06/08/content_281475123394051.htm.

[29] The first one, *Peer Effects,* is defined as the average number of academic publications that published in the same journals by all other firms that share the same province and same industry. The second one, *Difficulty of Publication*, is defined as the average impact factors of journals in which the firm has published in during fiscal year *t*. We argue that these two instrumental variables satisfy the relevance condition and exclusion restriction: on the one hand, firms with more peers publishing in journals are also more likely to publish (due to peer pressure or learning), and firms that publish in better quality journals are subject to greater difficulty. On the other hand, as these two instrumental variables are specific to academic publications, they are thus unrelated to a firm's market valuation unless through the instrumented explanatory variables *Papers* and *Papers* × *Patents*.

[30] The use of the interaction between an instrumental variable and another variable as an additional instrumental variable follows Angrist and Pischke (2008), Balli and Sørensen (2013), Popova (2014), Heimer (2016), and Bun and Harrison (2019).

[31] The Sargan test does not reject the null hypothesis and suggests that our instrumental variables are valid.

USPatents are much larger than those on *Papers* × *Patents* in Table 3. These results confirm our baseline results and highlight the heterogeneous effects of patent quality.

Journal quality. We further examine the heterogeneity in quality for papers published in journals based on journal impact factors. We replace *Papers in English* with *Papers in English (IF Adj)*, which is defined as the sum of impact factor-weighted number of papers published in journals in English. When we include *USPatents, Papers in English (IF Adj)*, and *Papers in English (IF Adj)* × *USPatents* in the regression model, the coefficients on *Papers in English (IF Adj)* and *Papers in English (IF Adj)* × *USPatents* are significantly positive in Table OA9 of the Online Appendix, suggesting that publishing in a more influential global journal is associated with higher market valuation. These results remain robust when we include Chinese patents and papers in Chinese adjusted for journal impact factors.

Collaboration with university researchers. Since universities are well-known to be the source of basic science, we anticipate that firms' publications coauthored with university researchers are closer to basic science and more fundamental. We thus collect the co-authorship information of corporate papers and split them into two groups: *NonUnivJoint Papers* denotes the number of papers published by firms alone and *UniversityJoint Papers* denotes the number of papers jointly published with universities. As shown in Table OA10 in the Online Appendix, while each variable shows significant explanatory power for firms' market values, *UniversityJoint Papers* dominates *NonUnivJoint Papers* in economic magnitude when they co-exist in regressions, confirming that our baseline results are indeed driven by the academic merit of corporate publications.

Alternative model specifications and variable definitions. We further consider the following alternative model specifications: (a) replacing the dependent variable, *Tobin's q*, by a firm's market value in logarithm, Ln *(Market value)*; (b) using one-year lagged *Patents, Papers in Chinese*, and *Papers in English* as the main explanatory variables; (c) excluding firm-years without academic publications from our sample; (d) using the sample period of 2009–2015 to explore the effects of papers and patents on firm value after the 2008 subprime crisis; (e) excluding firms engaging in mergers and acquisitions in the previous two years to avoid the influence of academic publications and patents of acquired targets; and (f) excluding firms with their headquarters in the four first-tier cities (Beijing, Shanghai, Guangzhou, Shenzhen) from our sample. As shown in Table OA11 in the Online Appendix, the effects of academic publications and associated synergy with patents on firm value remain significantly positive.

7. Heterogeneous effects

Our empirical analyses thus far present a robust and positive average effect of academic publications on firm value. However, we acknowledge that such an effect may be subject to heterogeneity in firms' incentives, industry conditions, and institutional environments; we therefore implement additional tests to examine the heterogeneous effects of academic publications.

Intellectual property protection and patent litigation. It has been documented in the literature that China exhibits substantial regional variation in intellectual property (IP) protection (Ang et al., 2014; Huang et al., 2017; Fang et al., 2017). Since IP protection affects the value of corporate patents, it enhances the effect of the synergy of academic publications and patents on firm value. To examine this proposition, we separate our sample into high and low IP protection groups based on Fan and Wang's (2018) province-level IP protection index. As shown in Panel A of Table 5, the coefficient on *Papers* in the high IP protection group is higher than that of the low IP protection group (0.61% vs. 0.27%). Moreover, the coefficient on *Papers* × *Patents* is only significant in the high IP protection group, suggesting that the synergy only concentrates in the high IP protection group. As supplementary evidence, we also examine whether local IP lawsuits influence the synergy of academic publications and patents. We collect city-level patent lawsuits per 10,000 residents[32] and separate our sample into the high and low patent lawsuits groups. Similarly, we find that the effect of academic publications only concentrates in the high patent lawsuits group, which is reported in Panel B of Table 5. Nevertheless, we find that the synergy of academic publications and patents on firm value remain consistent and significant in both subsamples.

SOEs vs. non-SOEs and political connection. As discussed in the literature, Chinese governments have policy targets and designed incentives for corporate patent output (Li, 2012; Jia et al., 2019). Thus, we are interested in knowing whether and how government policies influence the effect of academic publications and their synergy with patents on firm value. We thus split our sample into SOEs and non-SOEs or whether CEOs have political connections and estimate our baseline regression in each subsample. Our premise is that SOEs or firms with politically connected CEO are influenced by government policies to a greater extent. As shown in Panel C of Table 5, we first find that the effect of academic publications remains significant in both SOE and non-SOE groups; nevertheless, the coefficients on *Papers* in SOEs is smaller than that of non-SOEs (0.23% vs. 0.40%). In terms of the synergy between academic publications and patents, we find that the coefficients on *Papers* × *Patents* are 0.02% and 0.01% for non-SOEs and SOEs, respectively, with statistical significance. In the subsample based on CEOs' political connection, we find similar results in Panel D of Table 5. While these results suggest that government policies may indeed affect our results to some degree, our finding that the value effect of academic

Table 4
Mechanism tests: human capital and signaling.

	Ln (1+Inventor Num)		Analyst Coverage	
	(1)	(2)	(3)	(4)
Papers	0.0233***	0.0134***	0.0793***	0.0340***
	(0.0010)	(0.0014)	(0.0101)	(0.0123)
Patents		0.0021***		0.0194***
		(0.0004)		(0.0040)
Papers × Patents		0.0002***		0.0007***
		(0.0000)		(0.0003)
Ln (R&D)	0.0651***	0.0651***	0.5159***	0.5160***
	(0.0044)	(0.0043)	(0.0500)	(0.0489)
Ln (Assets)	0.2407***	0.1741***	6.3406***	5.9172***
	(0.0179)	(0.0167)	(0.1959)	(0.1964)
Leverage	0.0093	0.0072	-0.0179	-0.0331
	(0.0091)	(0.0093)	(0.1649)	(0.1666)
Ln (PPE/#employees)	-0.1185***	-0.0871***	-1.6258***	-1.4140***
	(0.0171)	(0.0166)	(0.1867)	(0.1888)
Sales growth	0.0068	0.0157	9.0203***	9.0719***
	(0.0466)	(0.0455)	(0.5438)	(0.5417)
Stock volatility	-0.1691	-0.1097	-3.1767**	-2.8136**
	(0.1399)	(0.1360)	(1.3642)	(1.3543)
Ln (Board size)	0.2972***	0.2610***	1.9750**	1.7623**
	(0.0757)	(0.0730)	(0.7672)	(0.7617)
SOEs	0.0425	0.0918***	-5.8205***	-5.5009***
	(0.0313)	(0.0314)	(0.3187)	(0.4239)
QFII	0.1613***	0.1080***	5.5835***	5.2334***
	(0.0330)	(0.0319)	(0.4305)	(0.4239)
Constant	-0.4475**	-0.1238	-38.1438***	-36.2299***
	(0.2205)	(0.2122)	(2.2560)	(2.2232)
Year fixed effects	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES
Observations	11183	11183	11183	11183
Adjusted R^2	0.3245	0.3555	0.3134	0.3234

Note: This table presents the results of the human capital and signaling effects of corporate publications. Also included in each regression are the control variables listed in Table 2. Standard errors in the brackets are corrected for clustering at the firm level. *, ** and ***indicate significance at the 0.10, 0.05 and 0.01 level (two-tailed), respectively. All variables are defined in the Appendix.

[32] Data source: https://wenshu.court.gov.cn/ (China Statistical Yearbook for Regional Economy).

publications and the synergy on firm value remain significantly positive among non-SOEs and CEOs without political connection suggests that our results may not entirely driven by government policies.

Research orientation. We consider the following four variables that capture Chinese firms' research orientation in different dimensions: the existence of independent/organizationally-separate research institute, the position of the Chief Science Officer (CSO), whether a firm is affiliated with a university, and whether the CEO is a patent inventor.

First, we search the websites of our sample firms to identify if each of them has any independent/organizationally-separate research institute ("研究院/研究所"). We then separate our sample into firms with independent research institutes and those without. As shown in Table OA12 in the Online Appendix, the effect of academic publications on firm value exists in both subsamples. In addition, the effect of *Papers* × *Patents* appears more robust in firms with independent research institutes. These results are fairly intuitive: when firms recognize the importance of their scientific background, they are more likely to set up research labs and such an investment pays off (as perceived by stock markets).

Second, we collect data for the existence of a Chief Science Officer (CSO) or related position in the management teams, and split our sample into firms with and those without a CSO. As shown in Table OA13 in the Online Appendix, we find the effect of academic publications and associated synergies with patents remain significant in both groups; nevertheless, the coefficients on *Papers* and *Papers* × *Patents* in firms with CSOs appear more robust and higher in magnitude than those without.

Third, we separate our sample firms into university firms (*University firm*) and other firms,[33] and examine the effects of academic publications and associated synergies with patents on firm value in each subsample. As shown in Table OA14 in the Online Appendix, the effect of academic publications and their synergies with patents also exist in non-university firms. Nevertheless, the effect of university firms' academic publications, especially those published in journals in English, appears to be stronger than that in other firms.

Lastly, we also collect the patenting records of Chinese firms' CEOs, and split our sample into CEOs who are patent inventors (*Inventor CEO*) and those who are not. As shown in Table OA15 in the Online Appendix, we find the effects of academic publications and associated synergies with patents remain significant in both groups. Nevertheless, the coefficients on *Papers* and *Papers* × *Patents* in firms with inventor CEOs appear more robust and higher in magnitude than those without.

These additional tests confirm that the effect of academic publications is conditional on firms' incentive to publish: when firms perceive higher value from academic publications and basic science, they are more willing to invest resources in related activities (which are also valued by stock investors).

Export dependence. As discussed in our hypothesis development, firms' academic publications serve as signals to potential customers (especially foreign ones). To verify this proposition, we split our sample into two group: high and low export firms.[34] As shown in Table OA16 in the Online Appendix, the effect of academic publications in English is significant in both groups; however, the coefficient estimate of *Papers in English* in the high export group is triple the size of the low export group (0.0147 vs. 0.0048). More importantly, the coefficient on *Papers in English* × *Patents* is only significant in the high export group. These results confirm the higher value of academic publications in English: on the one hand, these publications are valid signals to broader audience bases; on the other hand, the ability to absorb advanced knowledge and to publish in academic journals in English reflects corporate scientists' and engineers' abilities to communicate or even collaborate with foreign companies, labs, and universities.

Table 5
Cross-sectional differences in the effects of corporate publications and patents on market value

Panel A: Local IP protection	Low local IP protection (1)	High local IP protection (2)
Papers	0.0027**	0.0061***
	(0.0011)	(0.0012)
Patents	0.0018***	0.0003
	(0.0004)	(0.0002)
Papers × Patents	0.0000	0.0002***
	(0.0000)	(0.0000)
Control	YES	YES
Year fixed effects	YES	YES
Industry fixed effects	YES	YES
Observations	4573	6610
Adjusted R2	0.4390	0.4138
Panel B: Local IP lawsuits	Fewer IP lawsuits (1)	More IP lawsuits (2)
Papers	0.0016	0.0064***
	(0.0013)	(0.0011)
Patents	0.0016**	0.0005***
	(0.0007)	(0.0002)
Papers × Patents	0.0001***	0.0001***
	(0.0000)	(0.0000)
Control	YES	YES
Year fixed effects	YES	YES
Industry fixed effects	YES	YES
Observations	3220	7953
Adjusted R2	0.3604	0.4524
Panel C: State ownership	Non SOE (1)	SOE (2)
Papers	0.0040*	0.0023***
	(0.0024)	(0.0007)
Patents	0.0011**	0.0001
	(0.0004)	(0.0001)
Papers × Patents	0.0002***	0.0001**
	(0.0001)	(0.0000)
Control	YES	YES
Year fixed effects	YES	YES
Industry fixed effects	YES	YES
Observations	7186	3997
Adjusted R2	0.4207	0.4709
Panel D: Political connection	Not politically connected (1)	Politically connected (2)
Papers	0.0035	0.0029***
	(0.0024)	(0.0007)
Patents	0.0009***	0.0004**
	(0.0004)	(0.0002)
Papers × Patents	0.0002***	0.0000***
	(0.0000)	(0.0000)
Control	YES	YES
Year fixed effects	YES	YES
Industry fixed effects	YES	YES
Observations	6634	4549
Adjusted R^2	0.4117	0.4764

City-level patent subsidy. The literature has suggested an active role of Chinese governments in promoting corporate patents (Li, 2012; Jia et al., 2019; Fang et al., 2020). We thus collect data on city-level government subsidies for firms' patenting activities.[35] We then estimate our baseline regressions by introducing another variable *CityPatSub* (an

[33] It is well-known that a non-trivial portion of Chinese public firms are affiliated with universities. These "university firms" may have stronger incentive to publish.

[34] When a firm's sales in overseas markets scaled by its total sales exceeds the average ratio in the same industry and the same year, it is classified as high export one.

[35] The city-level subsidies policy documents were collected from www.pkulaw.cn, www.lawyee.net, and city government official websites.

indicator variable that equals one if the city has provided patent subsidy and zero otherwise) interacted with *Papers* and *Patents*. We find that the coefficients on *Papers* × *Patents* and *Papers* × *Patents* × *CityPatSub* are significantly positive in Table OA17 in the Online Appendix. These results suggest that while these subsidies enhance the synergy between academic publications and patents, their existence is not the only reason for academic publications and their synergy with patents in influencing firm value.

8. Concluding remarks

In this study, we explore the effect of a firm's academic publications on its market value using a sample of Chinese public firms over the period 2006 to 2015. In line with our hypotheses, our empirical analyses show that Chinese firms with more academic publications are associated with higher market valuation (measured by Tobin's q). More importantly, such an effect is more pronounced when these firms also file more patents, which highlights an important synergy between basic science and industry applications at the firm level. We have discussed various possible endogeneity concerns and addressed them by considering different regression specifications, controlling for a wide set of potential omitted variables, implementing a difference-in-differences analysis based on Chinese government talent policy in 2012, and estimating two-stage least square (2SLS) regressions.

When we separate these publications into those in English and in Chinese, we find that the value effect of the former is greater than the latter. This finding is intuitive because more advanced science is more likely published in English-language academic journals, and publications in these journals are more credible and serve as stronger signals to the market. We also propose and find empirical support for two underlying mechanisms: the human capital mechanism and the signaling mechanism. Chinese firms with more academic publications are associated with more inventors, supporting the human capital mechanism. In addition, Chinese firms' academic publications offer positive signals to stock analysts and investors, which strengthens outsiders' confidence in these firms' patents and associated technologies.

This study provides new insights to the literature on the value implications of corporate publications. We present novel evidence based on Chinese firms which are attempting to catch up technologically, and play an increasingly important role in the global economy. Our results of a significantly positive effect of the synergy between academic publications and patents on Chinese firm values highlight the importance of basic research for firms facing fierce global technology competition, even those from emerging countries. To our knowledge, the synergy of academic publications and patents in firm market value has not been previously empirically tested.

We conclude by discussing policy implications and a few possible future directions. Our results suggest that even in a quickly developing innovation economy such as China's, there is a corporate role (and incentive) for contributing to open science. Doing so may be synergistic with typical appropriation activities such as patenting due to attracting and retaining human capital, as well as signaling to the investment community. However, policy tools and incentives require careful analysis, monitoring, and periodic review. Prior studies have documented the resource misallocation triggered by government subsidies and the rent-seeking behaviors of Chinese firms (Lei et al., 2012; Guan and Yam, 2015; Stuart and Wang, 2016; Boeing, 2016). Since basic science research requires longer investment and is subject to greater information asymmetry compared to applied R&D and patenting, it may be even more challenging for governments to design and monitor related policies for corporate academic research. More generally, since academic research is typically associated with positive externalities and corporations are profit-driven, whether (and how) governments should allocate tax payers' money to corporations rather than universities is another important, debatable issue.

Based on our empirical evidence, there are a number of avenues which future researchers may investigate. For example, is it better to recruit and retain technical staff who can individually contribute and span the domains of open and commercial science, or should managers target a division of labor (such as collaboration with university scientists) to operationalize these contributions? As a firm manager, is it better to err on the side of "too much" open science or "too little"? How might the answers to these research questions depend on industry, stage of industry evolution, and more generally business environment? Much work in this domain lies ahead; our hope is that the work presented here will spur these and other future research efforts (Faccio et al., 2006).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.respol.2021.104319.

Appendix

Variable	Definition
Panel A: dependent variables	
Tobin's q	Firm *i*'s market-to-book ratio during the fiscal year *t* is calculated as market value divided by book value of assets. The market value of equity is calculated by the number of outstanding shares multiplied by the stock price at the end of the fiscal year. The market value of debt is calculated applying the book value of liabilities (Blundell et al., 1999; Hall and Oriani, 2006; Ceccagnoli, 2009). The firm's book value is represented by its assets at the end of the fiscal year. (China Stock Market & Accounting Research Database, CSMAR)
Market value (¥ millions)	Firm *i*'s market value equals the product of the total number of shares issued by a stock and the annual closing price. (China Stock Market & Accounting Research Database, CSMAR)

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Variable	Definition
Panel B: tested variables	
Papers	The number of firm *i*'s academic publications in Chinese and English journals during year *t*. (China National Knowledge Infrastructure, CNKI; Scopus database)
Papers in Chinese	The number of firm *i*'s academic publications in Chinese journals during year *t*. (China National Knowledge Infrastructure, CNKI)
Papers in English	The number of firm *i*'s academic publications in English journals during year *t*. (Scopus database)
Patents	Firm *i*'s total number of patents filed (and eventually granted) in year *t*. (Chinese Innovation Research Database, CIRD)
Chpatents	Firm *i*'s total number of patents filed and eventually granted only in China in year *t*. (Chinese Innovation Research Database, CIRD)
USpatents	Firm *i*'s total number of patents filed and eventually granted both in China and US in year *t*. (Chinese Innovation Research Database, CIRD)
Panel C: control variables	
R&D (¥ millions)	Firm *i*'s research and development (R&D) expenditure (¥ millions). (Chinese Innovation Research Database, CIRD)
Assets (¥ millions)	The total assets of firm *i* during year *t* (¥ millions). (China Stock Market & Accounting Research Database, CSMAR)
Firm age (years)	Firm *i*'s age equals the difference of fiscal year *t* minus the firm's IPO year. (China Stock Market & Accounting Research Database, CSMAR)
Leverage	Firm *i*'s book value of total debts divided by the book value of total assets during year *t*. (China Stock Market & Accounting Research Database, CSMAR)
PPE/#employees	Firm *i*'s net property, plant, and equipment (PPE) scaled by the number of employees during year *t* (in 1000 RMB). (China Stock Market & Accounting Research Database, CSMAR)
Stock volatility	Stock volatility is the standard deviation of daily stock returns over a given year. (China Stock Market & Accounting Research Database, CSMAR)
Board size	Number of Board members. (Chinese Research Data Services Platform, CNRDS)
QFII	Firm *i*'s QFII (Qualified Foreign Institutional Investor) holdings during the fiscal year *t*. (Institutional Ownership Research Database, IORD)
SOEs	Dummy variable equals to one if a firm is a state-owned enterprise, otherwise equals to zero. (China Stock Market & Accounting Research Database, CSMAR)
Sales growth	Sales growth is change in sales scaled by lagged sales. (Financial Indicator Database of Listed Companies, CNFI)
Panel D: other related variables	
Inventor Num	Firm *i's* number of inventors (holding at least one patent) in year *t*. (Chinese Innovation Research Database, CIRD)
Analyst Coverage	The number of reports that follow firm *i* in year t. (China Stock Market & Accounting Research Database, CSMAR)
University firm	Dummy variable equals to 1 if the firm belongs to the university, otherwise equals to 0. (Baidu search)
Academic CEO	Dummy variable equals to 1 if the firm's CEO has worked in the university and other scientific research institutions, otherwise equals to 0. (Chairman and CEO Research Database, CCEO; Baidu search)
Inventor CEO	Dummy variable equals to 1 if the firm's CEO holds patents, otherwise equals to 0. (National Intellectual Property Administration, PRC, CNIPA; Chairman and CEO Research Database, CCEO; Baidu search)
Board diversity	The Board diversity index is measured by a combination of six individual proxies of Board members refer to Bernile et al. (2018). The six director characteristics include: (1) the fraction of female directors (pct_female); (2) the mean number of other boards in the China's stock market firms on which current members serve (num_boards); (3) the standard deviation of directors' age (stdev_age); (4) the Herfindahl concentration indexes for director ethnicity (HHI_ethnicity); (5) the Herfindahl concentration indexes for institution where the directors received their Bachelor's degree (HHI_bachelor); (6) the Herfindahl concentration indexes director financial expertise (HHI_finexpert). We normalize each diversity component by its mean and standard deviation, so that their scale is comparable, and then equally weight each factor to construct the board diversity index: Board diversity = std(pct_female) + std (stdev_age) + std(num_boards) − std(HHI_ethnicity) − std(HHI_bachelor) − std(HHI_finexpert). (Chinese Research Data Services Platform, CNRDS; Baidu search)
TMT quality	The top management team quality index is measured by a principal component analysis using seven individual proxies of top management quality refer to Chemmanur et al. (2011). These seven individual proxies include: (1) the number of executive officers and vice presidents on a firm's management team; (2) the percentage of the management team with a MBA degree; (3) the percentage of management team members who are certified accountants; (4) the percentage of management team members who have served as executive officers and/or vice presidents at other firms prior to joining the firm; (5) the percentage of team members who have previously been partners in a law or accounting firm; (6) the ratio of CEO salary and bonus to the average salary and bonus of other team members; (7) the median tenure of the management team, defined as the median number of years that team members have served with a firm; (8) the tenure heterogeneity, defined as the coefficient of variation of the team members' tenures. (Chinese Research Data Services Platform, CNRDS; Baidu search)
CEO GSI	We calculate the general skill index of a firm's CEO (*CEO GSI*) referring to Custódio et al. (2013) and Custódio et al. (2017). The general skill index of CEO captures the generality of a CEO's human capital based on lifetime work experience in publicly traded firms prior to the current CEO position. A CEO who worked in different organizational areas, for multiple firms, in different industries, or in a conglomerate firm or who has served as CEO previously is classified as having more general skills. (Chairman and CEO Research Database, CCEO; Baidu search)
Founder CEO	Dummy variable equals to 1 if the firm's CEO is the firm's founder, otherwise equals to 0. (Chairman and CEO Research Database, CCEO; Baidu search)
CEO political connection	Dummy variable equals to 1 if the firm's CEO has political connections, otherwise equals to 0. (Chairman and CEO Research Database, CCEO)
CSO firms	A variable that reflects the work experience of TMT in technology-related positions. The positions we define as CSO include "首席科学家"; "首席科学专家"; "首席专家"; "首席科学官"; "研究部科学家"; "研究部首席科学家"; "研究部高级科学家"; "高级科学家"; "首席技术科学家"; "首席物理学家"; "首席研究员". (Chinese Research Data Services Platform, CNRDS; Baidu search)
CEO foreign experience	

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Variable	Definition
	CEO foreign experience is an indicator variable that equals one if the current CEO has been studying or working abroad and zero otherwise (Yuan and Wen 2018). (Chairman and CEO Research Database, CCEO; Baidu search)
Outside CEO	Dummy variable equals to 1 if a firm's current CEO comes from the outside of the firm, otherwise equals to 0 (Zhu and Shen 2016). (Chairman and CEO Research Database, CCEO; Baidu search)
Financial CEO	Dummy variable equals to 1 if a firm's current CEO has past experience in either banking or investment firms, in a finance-related role, or in an auditing firm and zero otherwise (Custódio and Metzger 2014). (Chairman and CEO Research Database, CCEO; Baidu search)
CEO age	The age of a firm's CEO at the end of the fiscal year. (Chairman and CEO Research Database, CCEO)
CEO male	Dummy variable equals to one if the CEO's gender is male, otherwise equals to zero. (Chairman and CEO Research Database, CCEO)
CEO tenure	CEO tenure, defined as the number of months a CEO is in office. (Chairman and CEO Research Database, CCEO)
Hadlock and Pierce's (2010) financial constraints index	Hadlock and Pierce's (2010) index is defined as $-0.737 \times \text{Ln (Assets)} + 0.043 \times \text{Ln (Assets)}^2 - 0.04 \times \text{Firm age}$. By construction, higher scores of Hadlock and Pierce's (2010) index indicate that firms are more financially constrained. (China Stock Market & Accounting Research Database, CSMAR)
G index	The corporate governance G-index is measured by a principal component analysis using eight individual proxies of corporate governance refer to Gompers et al. (2003). The proxies include: (1) whether the CEO is also chairman or vice chairman of the board; (2) the percentage of outside directors; (3) the stock share of the top five executives; (4) the share holdings of the largest shareholder; (5) the concentration ratio of the second to the tenth largest shareholders; (6) dummy variable about whether the firm has a parent company; (7) dummy variables about whether the firm listed in other markets; (8) dummy variable about whether the firm is controlled by the government. (Chinese Research Data Services Platform, CNRDS; Baidu search)
Ln(locgdppp)	Natural logarithm of local GDP per person of the province that a firm located. (Chinese Regional Economy Database, CRED)
LocUniversityNum	The number of local universities of the province that a firm located. (Chinese Regional Economy Database, CRED)
LocLotterypp	The local average lottery sales per person of the province that a firm located. (Website of Ministry of Civil Affairs of the People's Republic of China)
Year2012	An indicate variable which equals to 1 if the date later than 2012 (including year 2012), otherwise equals to 0 if the date earlier than 2012. In 2012, the CPC Central Committee and the State Council released "Opinions on deepening the reform of science and technology system and accelerating the construction of national innovation system". This document aims to speed up the construction of a public service system for talents, improve the mechanism for the flow of scientific and technological talents, and encourage two-way exchanges of innovative talents among scientific research institutions, colleges and enterprises.
Peer Effects	Peer Effects is defined as the average number of academic publications that published in the same journals by all other firms that share the same province and same industry.
Difficulty of Publication	Difficulty of Publication is defined as the average impact factors of journals in which the firm has published in during fiscal year t.
Profitability	EBITDA ratio is defined as the ratio of earnings before interest, taxes, and depreciation and amortization (EBITDA) divided by the firm's sales. (China Stock Market & Accounting Research Database, CSMAR)
Papers in English (IF Adj)	Papers in English (IF Adj) are defined as the sum of impact factor-weighted number of papers published in journals in English.
UniversityJoint Papers	The number of firm i's academic articles published during the fiscal year t with universities. We manually check each academic publication's author affiliation. If the article's author affiliation includes universities, we call this article a university joint paper. (China National Knowledge Infrastructure, CNKI; Scopus database)
M&A	Dummy variable equals to 1 if the firm *i* engages in mergers and acquisitions during year *t*. (Mergers and Acquisitions Database, CMAD)
Research Lab Subsidiary	Firms have independent research lab subsidiaries. We manually check each listed firm's subsidiaries according to their firm name and firm introduction text. If the subsidiary firm's name include "研究院/研究所(research institute)", or the firm's main business is research and development, we call this subsidiary firm a research lab subsidiary. (China Stock Market & Accounting Research Database, CSMAR; Wind Database; Baidu search engine)
High/low export	Firms with sales ratio from overseas markets in total sales exceed/below the average ratio in the same industry and the same year, otherwise equals to 0. (Wind Database)
CityPatSub	Dummy variable equals to 1 if the city that the firm located issued patent subsidy program, otherwise equals to 0. (The China's city level patent subsidy policy documents were manually collected from www.pkulaw.cn, www.lawyee.net, Wind database, and government official website)
High/low local IP Protection	Dummy variable equals to 1 if the Fan and Wang (2018) IP protection index of the province that the firm located exceeds/falls below the average index in the whole country and the same year, otherwise equals to 0. The IP protection index is defined as the average value of all the sub-indices (consumer protection; Number of granted patents divided by the number of scientific and technical staff; Number of patent applications divided by the number of scientific and technical staff). The calculation of the sub-index takes the base year as the benchmark, and adopts a relative scoring system of 0 to 10 points, with the province with the highest degree of IP protection in this sub-category being 10 points and the province with the lowest being 0 points. The scores of the remaining provinces are 0 to 10 points, calculated according to the relative difference between their index and the provinces with the highest and lowest scores in this sub-category. (Fan, G., Wang, X., 2018. Marketization index of China's provinces: NERI report 2018. Social Sciences Academic Press, Beijing, China.)
High/low local patent lawsuits	Firms in cities with the number of patent lawsuits per 10,000 residents exceeds/falls below the average number of local patent lawsuits per 10,000 residents, otherwise equals to 0. (https://wenshu.court.gov.cn/; China Statistical Yearbook for Regional Economy)

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