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Innovation or imitation? The role of intellectual property rights protections[☆]

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ABSTRACT

We study how uncompensated research and development (R&D) spillovers – the leakage of proprietary information through imitation or theft – affect firms' investment decisions. Using variation in property rights protections across different regions within China we find that (1) uncompensated spillovers are greater in regions with weaker property rights, (2) such spillovers are associated with lower R&D expenditures, and (3) the latter is exacerbated in low property rights regimes. In addition to identifying a specific channel through which legal protections affect incentives for innovation and R&D, our results support arguments in the literature that the enforcement of property rights affects firm investment and growth.

1. Introduction

R&D investment is an intangible asset whose value is highly sensitive to the threat of expropriation. That is, absent strong property rights protections, firms will be unable to capitalize on their investment.

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Furthermore, as noted by Ayyagari et al. (2008a), many predictions stemming from the (Jensen and Meckling, 1976) nexus-of-contracts view of the firm rely on the extent to which the property rights assigned in contracts are protected in practice. As such, a natural research question is the association between law, finance, and firm-level investment. There is, however, limited evidence of this at the micro-level (Claessens and Laeven 2003; Desai et al., 2003).

We contribute to the literature by providing evidence of a specific channel through which legal protections affect incentives for innovation and R&D investment—the leakage of proprietary information through imitation or theft. We find evidence that R&D investments have positive spillover effects in that one firm's R&D benefits neighboring firms. However, when intellectual property rights protections are weak, a firm's ability to capture the gains from investment (by collecting fees from the neighboring firms) is limited, and this reduces the incentive to invest in innovation.

Using a sample of more than 300,000 Chinese industrial firms, and relying on the fact that local property rights protections vary across different regions within China, we find that R&D spillovers are larger in regions with weaker property rights protections and smaller in regions with stronger property rights protections. Such spillovers, in turn, are negatively associated with firms' research and development expenditures. The evidence also suggests that strong intellectual property rights protections discourage expropriation, thus mitigating the negative effects of spillovers on R&D investment, and encouraging innovation. These findings persist after controlling for other institutional factors including firms' access to external finance, local economic conditions, after considering the endogeneity of R&D spillovers using an instrumental variables approach, and after controlling for firm location selection effects using a two-stage Heckman regression.

We contribute to the literature examining aspects of legal protections, financial market development, and economic growth (for example, La Porta et al., 1997, 1998, 2000, and Carlin and Mayer, 2003). Research and development (R&D) is an important activity which, as noted by Brown et al. (2009), is a critical input to innovation and growth. At the same time, as highlighted by Lerner and Schoar (2005), little attention has focused on understanding the exact avenues through which legal systems affect financial development.[3] Our results also complement those of recent and contemporaneous papers. For example, Ayyagari et al. (2008b) report cross-country evidence that firms' innovative activities are closely related to institutional factors including competition and access to finance. In the context of China, Cull and Xu (2005) find that firms reinvest more of their profits when property rights protection and contract enforcement is stronger. Similarly, Long (2010) looks at business dispute resolutions in courts across China and reports that active court systems are associated with more: investment, adoption of technology, innovation, and complex transactions. Of importance, our findings suggest that strong property rights protections in certain regions of China are important in inducing investment in R&D, and spurring the entrepreneurial activity that is critical to China's long-term economic growth.

The remainder of this study is organized as follows. Section 2 provides further background and develops the hypotheses. Data and summary statistics are presented in Section 3. Section 4 shows methodology and empirical results. Section 5 concludes.

2. Background

Ayyagari et al. (2008a) hypothesize that there will be less investment and more opportunistic behavior if property rights are weak. Consistent with this view, Demirguc-Kunt and Maksimovic (1999) find higher levels of investment in fixed assets for firms in less-developed countries where property rights are stronger. At the industry-level, Claessens and Laeven (2003) report evidence of better property rights being associated with higher growth through improved asset allocation. Claessens and Laeven (2003) highlight the limited amount of work addressing such issues at the firm-level. Of the work that does focus on the firm, Besley (1995) reports a significant link between property rights

[3] Lerner and Schoar (2005) highlight that legal systems with weak contract enforcement impose constraints on the types on contracts that can be written, thus potentially distorting the contracting process for investors and adversely affecting entrepreneurial incentives.

and investment in Ghana. Similarly, Johnson et al. (2002) document that firms' reinvestment rates are positively affected by the security of property rights. More recent work focusing on China includes Cull and Xu (2005), Ang et al. (2009) and Lin et al. (2010). These papers show a link between property rights protections and investments in fixed assets or R&D in specific samples. Focusing on a broad sample of firms in various industries throughout China, we contribute to the literature by providing evidence of a specific channel through which legal protections may affect firm investment–R&D spillovers.

R&D spillovers are defined by Jaffe (1996) as "...the idea that some of the economic benefits of R&D activities accrue to economic agents other than the party that undertakes the research." Of note, in markets with strong property rights protections, knowledge transfers (or spillovers) resulting from R&D activities typically occur through contractual means, in particular, patents (Shapiro, 1985). The safeguarding of such contracts by the courts facilitates knowledge spillovers and thus the incentive to invest in R&D (Katz et al., 1990). Indeed, Frischmann and Lemley (2007), amongst others, argue that spillovers encourage greater innovation and "...are a ubiquitous boon for society".[4] However, if there is leakage of proprietary information through imitation or theft, and the courts are unwilling or unable to restrain such actions, then gains from a firm's investment in R&D might be lost to competitors. Even in countries with sound legal protections it is not costless to seek recourse through the courts, and firms are at risk of not being able to fully appropriate the benefits of firm-specific R&D. Using the courts to protect R&D investment is more costly when legal protection of property rights is weaker. This in turn will reduce the benefits of firm-specific R&D, thus curtailing individual firm's R&D activities (Suzumura, 1992).

While compensable transfer is the main channel of R&D spillovers in developed countries with strong intellectual property rights, Helpman (1993) argues that weak property rights exacerbate the negative effects associated with R&D spillovers, particularly in developing countries that "...have not signed international treaties concerning protection of intellectual property rights and others that have laxly enforced domestic laws and regulations designed for this purpose." (p. 1247). Imitation and information leakage are prevalent in developing countries, particularly when property rights protections are weak. Thus, also of importance is that the influence of R&D spillovers on R&D investment in developing countries may differ from that in developed countries, and the prior literature has largely focused on the latter.

More generally, our work has implications for the law-finance-growth literature that provides evidence of links between financial development, legal-systems, and economic growth at the country level. In addition to papers such as La Porta et al. (1997, 1998, 2000), Carlin and Mayer (2003), and Ayyagari et al. (2008a,b, 2010), related work includes King and Levine (1993), Beck et al. (2000), Beck and Levine (2002), and Rajan and Zingales (1998) amongst others. These papers generally conclude that legal protections and the state of financial market development are associated with economic growth.

Of note, many of these papers focus on developed, rather than emerging, markets and few are able to explain the anomalous finding for China highlighted by Allen et al. (2005). It is, therefore, important to understand such issues in the context of developing markets. China stands out in this regard as it is often criticized for its poor intellectual property rights protections. The Special 301 Report, conducted annually by the Office of the United States Trade Representatives, entails a detailed examination of the adequacy and effectiveness of intellectual property rights protections in about 90 countries. China is on its priority watch list. Moreover, anecdotal evidence suggests that imitation is an important form of uncompensated R&D spillovers in China. For example, General Motors sued Chinese Chery Automobile Co. over its Chery QQ which, was reported as being "...a blatant copy of the Daewoo Matiz." While the suit was ultimately settled out of court, the associated intellectual property rights issues apparently remain unresolved.[5] In contrast, Wynca Chemical Group sued Jinfanda Bio-Chemical

[4] Other work examining long-term economic growth focuses on the ex-post positive externalities of R&D spillovers, e.g., Romer (1986), Benhabid and Jovanovic (1991), Grossman and Helpman (1991), and Mansfield et al. (1977).

[5] "GM Daewoo Auto & Technology Co., the Korean subsidiary of GM, says the QQ is a knockoff of its own Matiz minicar, sold in China as the Chevrolet Spark since 2003. "The cars are more than similar," says Rob Leggat, vice-president for corporate affairs at GM Daewoo." On Dec. 16, GM Daewoo filed suit in a Shanghai court alleging that Chery Automobile Co. stole its trade secrets

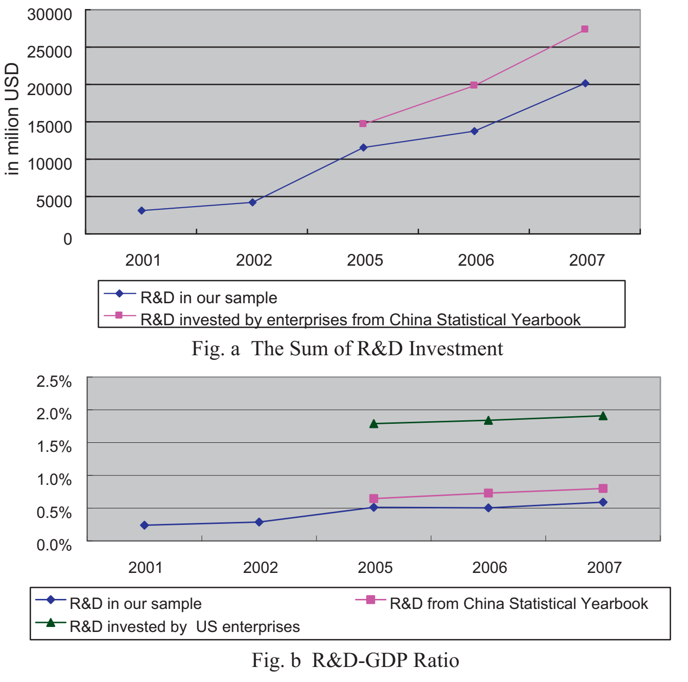

Fig. 1. (a) The sum of R&D investment. (b) R&D-GDP ratio. The R&D data in our sample are drawn from the annual census of Chinese industrial enterprises conducted by the National Bureau of Statistics of China. The China data are drawn from the China Statistic Yearbook edited by the National Bureau of Statistics of China. The US R&D data are drawn from Science and Engineering Statistics, National Science Foundation, Division of Science. The US GDP data are drawn from U.S. Department of Commerce, Bureau of Economic Analysis.

for patent infringement and was awarded a settlement of Renmin Bi (RMB) 20 million.[6] Interestingly, Chery is based in Anhui, the province with the lowest intellectual property rights (IPR) protection score in our sample, while Wynca and Jinfanda are based in Zhejiang, which has one of the highest IPR ratings. These cases are useful in illustrating both the types of spillover that can occur, and the nature of intellectual property rights protections present in some provinces. Note that the Rules for the Implementation of the Patent Law of China (Rule No.81) mandate that when a firm is indicted for patent infringement, the dispute should be handled by the administrative authority for patent affairs of the region in which the infringement has taken place or in which the firm is located. Thus, firms have little discretion as to where they can pursue a potential suit.

At the aggregate level, our priors are that the effects of R&D spillovers on R&D investment will depend critically on the property rights protections in different regions within China. Specifically we anticipate that when property rights are weak, most spillovers are uncompensated and the negative effects of spillovers will dominate the positive effects, thus reducing the incentives for individual firms to undertake R&D activities. Given that the R&D of industrial firms in China increased from 0.65% of GDP in 2005 to 0.80% by 2007, amounting to some $US 27 billion (Fig. 1), understanding what adds to and detracts from such activities is critical both at the firm and the economy level.

to make the QQ. (Business Week February 7, 2005, "Did Spark Spark a Copycat?"). At the same time, GM appealed to the State intellectual Property Office (SIPO) of China that the patent of Chery QQ should be invalid. SIPO stated that there was not enough evidence for infringement by Chery.

[6] China Chemical Report, September 6, 2009, "Zhejiang Wynca obtains patent judgment against Zhejiang Jinganda."

3. Data and summary statistics

3.1. Sample selection

The data are drawn from the annual census of Chinese industrial enterprises conducted by the National Bureau of Statistics of China (NBSC). The census covers all state-owned industrial enterprises and non-state-owned industrial enterprises with sales above RMB 5 million (around USD 600,000, based on the official exchange rate at the end of 2005), and these firms are required to report financial data to NBSC. An advantage of this database is its broad coverage of firms, including private firms which, as noted by Allen et al. (2005), are a major force behind economic development in China. Financial data in the NBSC census may have different qualities compared with those contained in public disclosures. One reason to expect a difference is that the data reported in the NBSC census are not audited. However, this does not necessarily mean that the financial data are not fairly presented. The data are generally not publicly available, and are kept confidential for a certain period. Therefore, managers have no incentive to manage NBSC disclosures for tax purposes. Moreover, given the confidentiality, managers of publicly listed companies have no pressure to manage these numbers to meet investor expectations. At the same time, managers are unlikely to be concerned about information leakage when reporting information on R&D to the NBSC and thus again have no incentive to manipulate those numbers. We should also note that this database has been widely used in economic studies on China issues, e.g., Jefferson et al. (2000), Hu et al. (2005).

We are able to obtain data on R&D expenditures only for years 2001, 2002, and 2005.[7] During this period, firms were required to expense R&D investment according to the *Accounting Standards for Business Enterprises—Intangible Assets*. The census requires that firms report the total amount of basic research costs, applied research costs, and development costs in the item "R&D expenditures." We use these reported values as the measure of firms' R&D investment. The census covers thirty one geographic regions, including twenty two provinces, five autonomous regions and four centrally administered municipalities (not including Taiwan, Hong Kong, or Macau).[8] We exclude firms in Tibet and Qinghai due to the limited number of observations in these two regions. Firms in the weapons and ammunition manufacturing industry are dropped from the sample due to the uniqueness of the industry and the special protections it is afforded. We also eliminate observations from the General Mining industry as firms in this classification report no R&D investment.

Given that a central focus of the paper is on R&D spillovers within regions and within industries, firms that switched regions or industries are excluded, as are those lacking sufficient data to estimate R&D spillovers.[9] This results in a base sample of 411,005 observations for estimating R&D spillovers comprising firms in thirty eight industries from twenty nine regions for years 2001, 2002, and 2005.

A slightly smaller sample with all required available covariates is used in the analyses of the relationship between R&D investment and R&D spillovers. Specifically, firms without ownership-structure information are dropped from the sample, as are those without the additional financial data we require for these specifications. Finally, as we measure R&D spillovers for industries within a region, industries within a region with less than twenty observations are also excluded. This results in a sample of 399,304 observations to examine the relationship between R&D investment and R&D spillovers.

The yearly distribution of R&D expenditures is reported in Table 1 , Panel A. In aggregate, approximately 11% of the firms report nonzero R&D expenditures. This is lower than, for example, the 25% reported by Lin, Lin, and Song (2010) using a World Bank survey. Of note, however, the Lin et al. study focuses on firms from 18 large Chinese cities, while the database we use covers industrial firms from all over China.[10]

[7] Although other financial data in year 2003 and 2004 are available in the census database, R&D expenditures are not available.

[8] There are also 54 national-level special economic zones in 48 cities in China, we control for these special zones in our analyses.

[9] Fewer than 30 firms in our sample changed regions.

[10] Discussions with NBS staff suggest that the large number of zero values R&D is not surprising, that (1) reporting this data is compulsory, (2) there is no obvious incentive not to report it, (3) most firms do not have R&D activity, and (4) that many firms acquire technologies instead of investing in R&D. Further confidence that the zero R&D expenditures reported in our sample

Table 1
Sample description.

Panel A: Yearly distribution of R&D expenditures
This panel presents the yearly distribution of observations, and observations with nonzero R&D in the tests examining the relationship between R&D investment and R&D spillovers. "Percentage" indicates the number of observations with nonzero R&D as a percentage of total number of observations in the year.

Year	*N*	Number of observations with nonzero R&D	Percentage
2001	94683	11867	12.53%
2002	116374	15434	13.26%
Pooled (2002&2005)	304621	32750	10.75%
2005	188247	17316	9.20%
Total	399304	27026	11.17%

Panel B: Proportion of non-zero R&D expenditures by firm size
This panel presents the size distribution of observations. "Small" indicates the smallest quartile observations and "Large" indicates the largest quartile observations. "Percentage" indicates the number of observations with nonzero R&D as a percentage of total number of observations in the quartile.

Size	*N*	Average total assets	Average R&D	Percentage
Small	99826	3746237	0.0436%	4.43%
Q2	99819	10086203	0.0735%	6.74%
Q3	99833	24575025	0.1127%	10.15%
Large	99826	312797192	0.2296%	23.37%

Panel C: Industry distribution
This panel reports the average R&D/Sales by industry, along with the percentage of observations in each industry with nonzero R&D.

Code	Industry name	*N*	Average R&D	Percentage Nonzero R&D
27	Medicals and Pharmaceuticals	8557	0.7189%	39.73%
41	Telecommunications	4431	0.6044%	23.74%
36	Specialty Machinery	14918	0.3347%	21.50%
40	Electronic & Electrical Equipment	15995	0.3197%	20.86%
37	Commercial Vehicles & Trucks	18124	0.2174%	20.57%
42	Meters and Instruments	3246	0.1645%	10.69%
35	Industrial Machinery	27797	0.1627%	15.12%
26	Chemical materials	30597	0.1526%	16.30%
29	Rubber products	4016	0.1226%	13.57%
15	Beverage	6982	0.0874%	13.45%
14	Food producer	9309	0.0752%	12.89%
31	Nonmetallic products	36332	0.0712%	8.85%
43	Other equipment manufacturers	2501	0.0681%	7.68%
25	Petrochemical	2370	0.0658%	10.68%
33	Nonferrous metal smelting	6924	0.0655%	10.90%
24	Education and sport products	5020	0.0632%	9.46%
34	Metal products	20870	0.0610%	7.73%
28	Chemical fiber producer	1621	0.0579%	12.28%
16	Tobacco	105	0.0551%	31.43%
30	Plastic products	17843	0.0535%	7.38%
23	Publishing	8901	0.0500%	5.12%
09	Nonferrous metal mining	2467	0.0497%	7.94%
10	Nonmetallic mining	3438	0.0474%	5.88%
19	Leather and fur clothing and goods	9322	0.0460%	7.51%
21	Furnishings	3967	0.0424%	7.51%
07	Oil & Gas producer	53	0.0359%	9.43%
44	Electricity, gas and hot water supplier	11619	0.0349%	6.21%
17	Textile	34349	0.0347%	6.40%
13	Food processor	23880	0.0346%	6.98%
12	Wood & Bamboo	390	0.0341%	2.31%
22	Paper producer and products	12772	0.0304%	5.86%
32	Black metal smelting	8608	0.0293%	6.83%
18	Clothing & Accessories	19212	0.0276%	4.74%
06	Coal mining	7579	0.0254%	4.83%

Table 1 (*Continued*).

Code	Industry name	*N*	Average R&D	Percentage Nonzero R&D
20	Wooden products	7041	0.0230%	5.35%
46	Piped water supplier	6185	0.0216%	1.99%
45	Coal gas supplier	295	0.0134%	3.39%
08	Black metal mining	1668	0.0102%	2.52%

The results in Panel B suggest that R&D expenditures (and reporting thereof) is related to firm size. Thus, we also report the industry distribution of the sample, along with average R&D expenditures deflated by total sales, in Panel C of Table 1. The Medical and Pharmaceuticals industry has the largest average R&D expenditures at 0.72% while the Black Metal Mining industry has the lowest average R&D expenditures at only 0.01%. The percentage of observations reporting nonzero R&D expenditures also varies greatly among industries, from 40% in Medicals and Pharmaceuticals to 2% in Piped Water Suppliers.

3.2. *Intellectual property rights protection*

As discussed previously, property rights protections vary substantially across China. For instance, the Special 301 Report, prepared by the Office of the United States Trade Representative, notes that intellectual property rights enforcement is inconsistent across regions, while the National Economic Research Institute (NERI) Index of Marketization (IM) of China's provinces (Fan and Wang, 2006) highlights variation in the institutional environment across the country.

We use several measures to capture China's local intellectual property rights protections. The first is the density of intellectual property law firms, measured as the number of intellectual property law firms in the region divided by regional population in millions.[11] The density of intellectual property law firms reflects the demand for IP rights enforcement.

The second measure is the intellectual property rights index (IPR index), a sub-index of the NERI Index of Marketization (IM) of China's provinces. The index measures the degree of legal protection for innovation and intellectual property rights based on a simple average of (1) the number of patents applied for divided by the number of science and technology personnel and (2) the number of patents approved divided by the number of science and technology personnel (Fan and Wang, 2006). A higher index is indicative of stronger intellectual property rights protections. One concern is that this index may also capture variation in economic development and education in different regions. That is, high tech companies are more likely to locate in regions with good economic development and education, and high tech companies also apply for more patents. To relieve concerns that a potentially spurious correlation affects our findings, we control for local economic development (as measured by local GDP per capita) and local education (as measured by the number of universities).

A third measure of intellectual property rights protection is the number of lawyers divided by the size of the population (Fan and Wang, 2006). A larger value suggests that there is a higher demand for lawyers, stronger legal enforcement, and therefore stronger property rights protections. This variable should not be affected directly by the distribution of high-tech industries. The indices are benchmarked relative to 1999, and are reported in Appendix A.

IPR1 ranges from 0 to 8.15 in year 2002, and from 0 to 8.91 in year 2005. *IPR2* ranges from 0.09 to 12.18 in year 2002, and from 0.48 to 25.13 in year 2005 while *IPR3* ranges from 0.19 to 11.28 in year 2002, and from 0.31 to 10.31 in year 2005, as presented in Appendix A, suggesting that the enforcement of property rights varies dramatically across the different regions. The Pearson (Spearman) correlations between the three measures of regional intellectual property rights are high, as presented in Table 2.

are not indicative of missing data is given by the fact that our sample, covering all state owned industrial firms and median to large non-state owned firms, represents almost 75% of total firm R&D investment according to the China Statistics Yearbook (Fig. 1).

[11] We also scale the number of intellectual property law firms by the number of firms in a region and by GDP per capita. The results are similar.

Table 2
Correlations between measures of regional property rights protections.

Variable	*IPR1*	*IPR2*	*IPR3*
IPR1	1.000	0.311**	0.795***
IPR2	0.786***	1.000	0.599***
IPR3	0.648***	0.559***	1.000

This table shows the correlations between measures on regional property rights protections. The upper (lower) triangular shows the Pearson (Spearman) correlation coefficients. *IPR1* is the density of intellectual property law firms, measured as the number of intellectual property law firms in the region divided by regional population. *IPR2* is the degree of legal protection for innovation and intellectual property rights based on an average of (1) the number of patents applied for divided by the number of personnel of science and technology and (2) the number of patents approved divided by the number of personnel of science and technology; *IPR3* is the number of lawyers divided by the size of the population.

* Significant at 0.1 level.

** Significant at the 0.01 level.

*** Significant at the 0.001 level.

To more fully address whether our empirical results are sensitive to different intellectual property rights measures, we also employ two additional proxies: (1) the transaction volume of technology transfers in a province divided by the provincial GDP as per (Ang et al., 2009), and (2) the market intermediaries and legal enforcement index, one of the five sub-indices of the NERI Index of Marketization (IM) of China's provinces (Fan and Wang, 2006). The latter sub index, also used by Wang et al. (2008), evaluates the general legal environment for each province or provincial level region and is measured using: the number of lawyers as a percentage of the population, the number of CPAs as a percentage of the population, the number of economic dispute cases accepted by the courts scaled by GDP, the number of economic dispute cases resolved by the courts as a proportion of cases accepted, intellectual property rights protection *IPR2* as described above, and the number of customer complaints solved as a percentage of the customer complaints accepted by the Administration for Industry and Commerce.

The above five measures of property rights protection are measured contemporaneously with variables such as R&D investment and spillovers, which may cause concern about spurious correlation. To alleviate this concern, we use two additional variables to measure local property rights protection following Fan, Wong and Zhang (forthcoming): (1) whether the region's sea or inland river ports were forcibly opened to foreigners as treaty ports after the first Opium War in 1842 during the Qing Dynasty (1644–1912 AD), and (2) whether the region leased territories to foreigners during the Qing Dynasty. We focus on British leased territories because the common law influence is the stronger in those areas and thus legal enforcement is stronger than in other territories.[12] These two variables capture the influence of foreign institutional development in a region. R&D investment and spillovers cannot have any impact on these two measures since the treaty ports and leased territories were opened to foreigners by exogenous forces over 100 years ago. However, the establishment of ports and territories that were influenced or governed by foreigners, like colonization, have likely had a long-term impact on the development of local legal institutions (Acemoglu et al., 2001). The results based on the alternative indices are qualitatively similar to those based on *IPR1*. Therefore we do not separately report these results but they are available upon request.

3.3. Descriptive statistics

Our subsequent analyses focus on 2002 and 2005 given the larger numbers of observations during those years. This results in 312,362 observations for R&D spillover estimation and 304,621 in the tests of relationship between R&D investment and R&D spillovers.[13] Table 3 reports descriptive statistics for the key variables used in subsequent analyses. Variable definitions are in Appendix B, while we report Pearson and Spearman correlations between variables in Appendix C. All financial variables and the spillover measures are winsorized at the top and the bottom 0.5% level.

[12] We also use all leased territories instead of just those leased by the British and the results are qualitatively similar.

[13] Our results are robust to using the full sample.

Table 3
Descriptive statistics.

Variable	N	Mean	Median	Std.	Min	Max
$LogSales_{ijt}$	312362	9.925	9.834	1.436	−0.179	18.649
$LogRD_{it}$	312362	0.550	0.000	1.722	0.000	14.648
$LogRDpool_{jt}$	312362	13.396	13.402	1.506	0.000	16.266
$LogFixedAssets_{it-1}$	312362	8.390	8.296	1.783	−0.173	18.356
$LogEmployment_{it-1}$	312362	4.809	4.745	1.141	0.000	11.903
RD_{it} (%)	304621	0.118	0.000	0.767	0.000	16.284
Spillover_IR	304621	0.483	0.359	0.463	−0.289	3.856
$CoreROS_{it}$	304621	0.010	0.022	0.192	−2.038	0.403
$Leverage_{it}$	304621	0.592	0.596	0.305	0.000	1.969
$Interest_{it}$	304621	0.015	0.003	0.038	−0.010	0.402
$Salesgrowth_{it}$	304621	0.391	0.134	1.174	−0.908	9.862
$LogTA_{it}$	304621	9.757	9.584	1.427	6.265	14.559
$LogAge_{it}$	304621	1.950	1.946	0.959	0.000	4.127
$Subsidies_{it}$	304621	0.003	0.000	0.013	0.000	0.119
$Collective_{it}$	304621	0.159	0.000	0.365	0.000	1.000
$Private_{it}$	304621	0.446	0.000	0.497	0.000	1.000
HK_{it}	304621	0.104	0.000	0.305	0.000	1.000
$Foreign_{it}$	304621	0.094	0.000	0.292	0.000	1.000
$Zone_{it}$	304621	0.624	1.000	0.484	0.000	1.000
GDP_{it}	304621	10.319	9.154	6.067	0.377	22.367
$University_{it}$	304621	52.863	61.000	15.215	8.000	73.000

This table presents descriptive statistics for key variables. $LogSales_{ijt}$ is the natural logarithm of sales of firm *i* in industry *j* in year *t*. $LogRD_{it}$ is the natural logarithm of R&D expenditures of firm *i* in year *t*. We add 1 to R&D expenditures to ensure a positive value of R&D investment for those with zero R&D. $LogRDpool_{jt}$ is the natural logarithm of the equal-weighted sum of R&D expenditures of firms in the same two-digit industry code *j* in year *t*, excluding the R&D expenditures of firm *i* for that year. $LogFixedAssets_{it-1}$ is the natural logarithm of fixed assets for firm *i* in year $t-1$. $LogEmployment_{it-1}$ is the natural logarithm of number of employees for firm *i* in year $t-1$. *R&D* is the ratio R&D expenditures to sales *n*; *Spillover_IR*, is the level of R&D spillovers for each two-digit industry code in each region; $CoreROS_{it}$, is profit from operation divided by sales; $Leverage_{it}$, is total liabilities divided by total assets at the beginning of year t; $Interest_{it}$, is net interest deflated by sales; $Salesgrowth_{it}$, is $(Sales_t - Sales_{t-1})/Sales_{t-1}$; $LogTA_{it}$, the natural logarithm of total assets; $LogAge_{it}$, the natural logarithm of the firm age at the year end since incorporation; $Subsidies_{it}$, amount of government subsidies divided by total assets; $Collective_{it}$, is an indicator variable equal to 1 if the controlling owner is a collective entity, and 0 otherwise; $Private_{it}$, is an indicator variable equal to 1 if the controlling owner is a private entity, and 0 otherwise; HK_{it} is an indicator variable equal to 1 if an entity from Hong Kong, Macau, or Taiwan is a blockholder, and 0 otherwise; $Foreign_{it}$, is an indicator variable equal to 1 if a foreign entity is a blockholder, and 0 otherwise; $Zone_i$, is an indicator variable equal to 1 if the firm operates in a city with national level special economic zoning, and 0 otherwise; GDP_{it}, is local GDP of each province in the corresponding year; $University_{it}$, is the number of universities in the province in the corresponding year. Scaled financial variables and *Spillover_IR*, other than *R&D* are winsorized at the top and the bottom 0.5%. *R&D* is winsorized at the top 0.05%.

R&D expenditures deflated by sales average 0.12%, but range from zero to 16.28%. The Pearson and Spearman correlations indicate that R&D expenditures are negatively correlated with leverage, and collective, private, and Hong Kong/Macau/Taiwan ownership; while they are positively correlated with the level of bank loans. Few firms in China issue bonds, rather they borrow from banks (Allen et al., 2005; Ayyagari et al., 2010) hence interest expense is largely indicative of bank loans. We use this variable as a proxy for access to external finance.[14] Similarly, R&D expenditures are positively correlated with size (measured by log of Total Assets), firm age, government subsidies, and foreign ownership.

With regard to ownership structure, we have information pertaining to paid-in capital from the state, a collective entity, a private entity, a foreign entity, or an entity from Hong Kong, Macau, or Taiwan. We calculate the percentage of paid-in capital and regard the largest owner as the controlling owner of a firm. *Collective* is an indicator variable equal to 1 if the control owner is a collective entity, and 0 otherwise. Collective owned firms refer to economic units where the assets are owned

[14] This is our best-available proxy given that data on external finance at the firm level are not available.

collectively. Of relevance, the government is less involved in the operations of collective owned firms relative to large state owned firms. *Private* is an indicator variable equal to 1 if the control owner is a private entity, and 0 otherwise. *HK* is an indicator variable equal to 1 if an entity from Hong Kong, Macau and Taiwan is the controlling owner, and 0 otherwise. *Foreign* is an indicator variable equal to 1 if a foreign entity is the controlling owner, and 0 otherwise.

4. Methodology and empirical results

In this section we present our multivariate analyses. In Section 4.1 we focus on measuring R&D spillovers, while Section 4.2 focuses on the link between R&D spillovers and property rights protections. In Section 4.3 we turn to an analysis of how R&D investment is related to spillovers.

4.1. Measurement of R&D spillovers

The empirical evidence to date suggests that R&D spillovers tend to be limited to firms operating in related industries and in close geographical proximity. Indeed, Marshall (1920) suggests the benefits of knowledge spillovers among firms within an industry as an explanation for the geographic concentration of industries. Moreover, Keller (2002) reports that the benefits from spillovers decline with distance and concludes that that technology spreads locally, rather than globally. Similarly, Jaffe et al. (1993) provide evidence of geographically located knowledge spillovers by studying patent citations. As a result, we focus on R&D spillovers conditioned on location and industry.

In doing so we employ the widely-used log-linear transformation of a Cobb-Douglas production function to measure R&D spillovers (see for example, Griliches, 1992; Coe and Helpman, 1995; Aitken and Harrison, 1999; Javorcik, 2004). Specifically, we use the following general form:

$$Y = AR^{\alpha}S^{\beta}K^{\gamma}L^{\lambda}$$

where Y is the output, A is a constant, R is firm-level R&D expenditures, S is measure of the available R&D spillover pool (R&D of competitors), K is physical capital investment, and L is labor input. To implement this empirically, we use the following specification for firms within each region:

$$LogSales_{ijt} = \alpha_0 + \alpha_1 LogRD_{it} + \alpha_2 LogRDpool_{jt} + \alpha_3 LogFixedAssets_{it-1} + \alpha_4 LogEmployment_{it-1} + \varepsilon \quad (1)$$

For all RMB denominated variables we deflate values by the industrial product factory price index for firm (i) for industry (j) for the corresponding year (t).[15] $LogSales_{ijt}$ is the natural logarithm of sales of firm i in industry j for the year in question. $LogRD_{it}$ is the natural logarithm of R&D expenditures of firm i. We add 1 to R&D expenditures to ensure a positive value of R&D investment for those with zero R&D, although our results are qualitatively similar if we measure R&D spillovers using only nonzero R&D expenditures.

Note that we use total sales instead of a more focused measure of R&D output, such as new product sales, because we hope to capture sales from not just innovation, but also imitation. A firm may be reluctant to report any imitation-based output as “new product” sales because any “new product” has to be verified by the government. That is, using only new product sales figures would underestimate the true level of spillovers. As is common in the literature, we refer to the aggregation of R&D for all firms in the same industry (excluding of the firm of interest) as the R&D “Spillover Pool.” This proxies for the amount of R&D knowledge that firms can potentially draw on. Thus, $LogRDpool_{jt}$ is the natural logarithm of the equal-weighted sum of R&D expenditures of firms in the same two-digit industry code j, excluding the R&D expenditures of firm i.

[15] The price index is available from the website of the National Bureau of Statistics of China (www.stats.gov.cn/).

Griliches (1979) and Raut (1995) measure the R&D pool over four years as they argue that the effects of R&D investment persist for at most this long. In contrast to these studies, our goal is to capture proprietary information contained in R&D spillovers (rather than the overall R&D spillovers). Survey evidence suggests that firms learn about rivals' R&D activities before new products are introduced, suggesting that R&D information spillovers typically involve the leakage of proprietary information (e.g., Cohen et al., 2002; Mansfield, 1985).[16] However, competitors also learn from public information contained in, for example, finished products, patent licensing, and other forms of technical transfer. In an attempt to discern the effects of proprietary information leakages, and thus exclude public information, we emphasize contemporaneous R&D expenditures in the spillover pool as a measure of aggregate R&D activity in an industry. Our rationale is that current R&D expenditures have not been incorporated into finished products or patents and are less likely to be discovered via public channels. At the same time, we recognize that there may be leakage from prior R&D expenditures. Our results are robust to the inclusion of a time-series dimension of R&D expenditures in the spillover pool.[17]

Although firms may learn from competitors, suppliers, customers and other technologically related firms, our focus is on R&D diffusion between competitors; hence we do not include R&D expenditures of firms in different industries when building the R&D spillover pool. Prior studies (e.g., Jaffe et al., 1993; Keller, 2002) find that benefits from spillovers decline with distance. That indicates that firms may have less ability to obtain R&D knowledge from competitors far away than from competitors in close regions. Our primary focus is on aggregate R&D investment within an industry across all regions, effectively placing equal weight on the R&D expenditures of all competitors. The rationale is that our focus is on how local IPR affects local firms' ability to learn from local competitors and competitors outside the region. According to the Rules for the Implementation of the Patent Law of China (Rule No. 81), when a firm is indicted for patent infringement, the dispute should be handled by the administrative authority for patent affairs of the region in which the infringement took place or in which the firm is located. That is, local property rights protections can affect R&D spillovers between firms within the region and from firms outside the region. This further supports the rationale for focusing on local intellectual property rights protections, and measuring spillovers at the (1) industry and (2) regional level (that is, industries within regions). However, we recognize that proximity may be important. To examine this issue, we conduct robustness tests where we apply reduced weight in the spillover pool calculation to R&D pools in regions that are far from the company and find that our main results persist.[18]

The coefficient α_2, thus provides a measure of how firm *i's* sales are related to the R&D pool. This is our estimate of "Spillovers." $LogFixedAssets_{it-1}$ is the natural logarithm of fixed assets for firm *i* in year $t-1$. $LogEmployment_{it-1}$ is the natural logarithm of number of employees for firm *i* in year $t-1$. *LogFixedassets* and *LogEmployment* proxy for the physical capital input and labor input, respectively. Consistent with prior research, e.g., Raut (1995), Coe and Helpman (1995), all available data (2001, 2002, and 2005) is used to estimate spillovers, and thus we assume that spillovers are constant for an industry/region.[19]

[16] Moreover, several theory papers model information related to R&D activities as being proprietary, e.g., Bhattacharya and Ritter (1983), and Yosha (1995).

[17] Following Raut (1995), we include lagged R&D expenditures for the previous two years in the R&D spillover pools. The discount factor that takes the depreciation of R&D capital into account is set at 0.85. We did not use lagged four years because of short sample period.

[18] We separate the R&D spillover pool into two components, one for the R&D expenditures of competitors in the firm's own region and adjoining regions and the other for R&D expenditures of competitors in regions farther away. We apply a discount factor (at 0, 0.2, 0.5 and 0.8) to the R&D pool in other regions to account for distance. Additionally, there are currently 54 national-level special economic zones and 53 national high-tech industrial development zones in China, and such zones tend to attract investment from foreign and high-tech firms. To address the concern that the spillover effect is mainly driven by firms clustering in special economic zones or high-tech industrial development zones, we conduct a similar test and apply a discount factor to the sum of R&D expenditures of firms located in cities that contain special economic zones or high-tech industrial development zones.

[19] When the R&D spillovers are measured with data for just 2002 and 2005, the results are qualitatively similar.

Table 4
R&D spillovers and legal protections: firm level.

Variable	2002			2005			Pooled		
	(1) *IPR1*	(2) *IPR2*	(3) *IPR3*	(1) *IPR1*	(2) *IPR2*	(3) *IPR3*	(1) *IPR1*	(2) *IPR2*	(3) *IPR3*
Intercept	3.253***	3.121***	2.752***	4.886***	4.818***	4.75***	4.296***	3.935***	3.811***
	(8.59)	(8.29)	(7.16)	(23.89)	(18.33)	(18.80)	(17.07)	(12.60)	(11.77)
IPR_{it}	0.044	0.141***	−0.164*	−0.067*	0.019	−0.100**	0.068	0.09***	0.107*
	(0.78)	(4.55)	(−2.62)	(−2.68)	(1.17)	(−2.95)	(0.93)	(4.79)	(2.08)
$LogRD_{it}$	0.097***	0.125***	0.105***	0.080***	0.084***	0.079***	0.088***	0.098***	0.086***
	(15.36)	(14.29)	(10.92)	(14.55)	(10.66)	(12.42)	(16.49)	(14.93)	(13.27)
$LogRD_{it}*IPR_{it}$	0.004	−0.005***	−0.002	0.004*	−0.0002	0.002*	0.004**	−0.001*	0.002*
	(1.26)	(−4.15)	(−0.89)	(2.15)	(−0.42)	(2.27)	(2.55)	(−1.87)	(1.92)
$LogRDpool_{jt}$	0.088***	0.109***	0.101***	0.061***	0.072***	0.060***	0.079***	0.114***	0.105***
	(8.41)	(8.07)	(7.28)	(6.36)	(6.05)	(5.70)	(8.09)	(9.06)	(8.47)
$LogRDpool_{jt}*IPR_{it}$	−0.016**	−0.006**	−0.008*	−0.001	−0.001	−0.002	−0.012*	−0.006***	−0.014**
	(−3.02)	(−3.20)	(−2.18)	(−0.51)	(−0.97)	(−1.30)	(−1.85)	(−4.77)	(−3.44)
$LogFixedAssets_{it-1}$	0.252***	0.254***	0.259***	0.250***	0.25***	0.253***	0.252***	0.254***	0.254***
	(23.33)	(22.52)	(21.79)	(25.77)	(28.53)	(26.65)	(30.16)	(33.94)	(29.89)
$LogEmployee_{it-1}$	0.502***	0.501***	0.499***	0.420***	0.42***	0.422***	0.452***	0.449***	0.452***
	(18.73)	(19.67)	(18.61)	(28.21)	(30.39)	(28.28)	(23.58)	(25.00)	(23.59)
GDP_{it}	0.052***	0.01	0.125***	0.014**	0.007	0.027**	0.024**	0.011	0.034***
	(3.68)	(1.20)	(6.85)	(2.91)	(1.12)	(3.28)	(3.56)	(1.60)	(3.75)
Year indicators							Included	Included	Included
Observations	120607	120607	120607	191755	191755	191755	312362	312362	312362
R^2	0.449	0.452	0.463	0.436	0.433	0.439	0.443	0.441	0.443

This table presents the firm-level relationship between *R&D Spillovers* and legal protections. The dependent variable, $LogSales_{ijt}$ is the natural logarithm of sales of firm *i* in industry *j* for the year in question. *IPR1* is the density of intellectual property law firms, measured as the number of intellectual property law firms in the region divided by regional population. *IPR2* is the degree of legal protection for innovation and intellectual property rights based on an average of (1) the number of patents applied for divided by the number of personnel of science and technology and (2) the number of patents approved divided by the number of personnel of science and technology; *IPR3* is the number of lawyers divided by the size of the population. $LogRD_{it}$ is the natural logarithm of R&D expenditures of firm *i*; $LogRDpool_{jt}$ is the natural logarithm of the equal-weighted sum of R&D expenditures of firms in the same two-digit industry code *j*, excluding the R&D expenditures of firm *i*; $LogFixedAssets_{it-1}$ is the natural logarithm of fixed assets for firm *i* in year $t-1$; $LogEmployment_{it-1}$ is the natural logarithm of number of employees for firm *i* in year $t-1$; GDP_{it} is GDP per capita for each region in year *t*. Robust *t*-statistics with clustering by region are reported in parentheses.

* Significant at 0.1 level.
** Significant at 0.01 level.
*** Significant at 0.001 level.

4.2. R&D spillovers and intellectual property rights protections

To focus on R&D spillovers and property rights protections we estimate Eq. (1) at the firm-level, albeit with a slightly different specification:

$$LogSales_{ijt} = \alpha_0 + \alpha_1 IPR + \alpha_2 LogRD_{it} + \alpha_3 LogRD_{it} \times IPR + \alpha_4 LogRDpool_{jt} + \alpha_5 LogRDpool_{jt} \times IPR + \alpha_6 LogFixedassets_{it-1} + \alpha_7 LogEmployment_{it-1} + \alpha_8 GDP_{it} + \varepsilon \quad (2)$$

GDP per capita, *GDP*, in each region in the corresponding year is included to control for the differences in the local economic environment that may affect firms' sales. Our focus in Eq. (2) is on the interaction of property rights protections with the R&D pool. In regions with weak protections, R&D spillovers are expected to be more severe, i.e., sales will depend more on the pool of R&D. Therefore the coefficient on the interaction term, α_5, is expected to be negative.

In Table 4 we report the firm-level results of Eq. (2) (for each year, and for the pooled sample). The *t* statistics are adjusted for regional clustering.[20] The interactions of *LogRDpool* and all the *IPR measures* are negative in both the regression for 2002 and the pooled regression. Consistent with our priors, firm-level sales depend more on competitors' R&D in regions with weak property rights than in regions with strong property rights. The pooled regression in the rightmost column of Table 4 shows that the interaction of *LogRDpool* and *IPR1* (coefficient of −0.012) is around 15.2% of the coefficient of *LogRDpool* (coefficient of 0.079). This suggests that when property rights protections increase by 1 unit, the dependence of a firm's sales on competitors' R&D investment declines by 15.2%.[21] Further, the coefficients for firm R&D interacted with *IPR1* and *IPR3* are positive in both the regression for 2005 and the pooled regression, suggesting that when property rights protections increase, the dependence of a firm's sales on its own R&D investment increases.

Overall, based on the results in Table 4, if a firm could, ceteris paribus, move from Anhui with an *IPR1* = .14 to Tianjin with an *IPR1* = 1.19 in 2002, then the dependence of the firm's sales on other firms' R&D would decline by 15%. This is consistent with increased property rights protections reducing spillovers, increasing a firm's ability to capture the gains from its R&D investments, and therefore inducing more actual R&D investment by the firm.

The results also support the contention that R&D spillovers vary across different regions in China. That is, R&D spillovers are larger in regions with weak intellectual property rights protections than in regions with strong protections. Moreover, the negative correlation between R&D spillovers and intellectual property rights protection supports the argument that weak intellectual property rights protections stimulate uncompensated R&D spillovers. Of course, as we argued above, R&D activities can be affected by both compensated R&D spillovers and uncompensated R&D spillovers. Thus the relationship between R&D investment and R&D spillovers may also differ across regions with different levels of intellectual property rights protection. We examine this issue in the next section.

4.3. *R&D investment and spillovers: firm-level analysis within regions and industries*

Thus far we document that that R&D spillovers are negatively associated with regional intellectual property rights protections. In this section, we examine how R&D investment is affected by R&D spillovers in regions with different levels of intellectual property rights protections. We argue that most spillovers are uncompensated in regions with weak intellectual property rights protections and the negative effects of spillovers will dominate the positive effects, thus reducing the incentives for individual firms to undertake R&D activities. However, in regions with strong intellectual property rights protections, R&D spillovers are relatively small and may arise from uncompensated imitation or compensated technical transfers. We do not make a prediction on the association between R&D investment and spillovers in such regions.

Consistent with Besley (1995) and Johnson et al. (2002) we model R&D investment as a function of spillovers, firm characteristics, ownership structure, and other controls. In this analysis, the spillover measure is estimated as above, but for industries within regions. That is, Eq. (1) is estimated for each two-digit industry code for each region in order to estimate *Spillover_IR*—the value of the coefficient α_2, on *LogRDpool*.[22] A larger (smaller) α_2 indicates that the sales of firm *i* are affected more (less) by the R&D investment of competitors, indicating stronger (weaker) R&D spillovers. As reported in Table 3, spillovers for industries within a region, *Spillover_IR*, range from −0.289 to 3.856, with a mean of 0.483 (median 0.359). The economic interpretation (at the mean) is that when a firm's competitors within the same industry in the same region expend one additional RMB on R&D, the firm's

[20] When we control for industry and regional fixed effects, and adjust *t* for industry clustering the results are qualitatively similar.

[21] A 1-unit increase in IPR1 corresponds to the number of intellectual property law firms divided by the regional population increasing by 1.

[22] Our results are robust to the use of value weights using total assets, and to using firms in industries only where the spillover measure is positive.

sales increase by 0.483 RMB. Incorporating these measures into the analysis results in the following specification:

$$\begin{aligned} RD_{it} = {} & \alpha_0 + \alpha_1 Spillover\_IR_i + \alpha_2 CoreROS_{it} + \alpha_3 Leverage_{it} + \alpha_4 Interest_{it} + \alpha_5 Salesgrowth_{it} \\ & + \alpha_6 LogTA_{it} + \alpha_7 LogAge_{tt} + \alpha_8 Subsidies_{it} + \alpha_9 Collective_{it} + \alpha_{10} Private_{it} + \alpha_{11} HK_{it} \\ & + \alpha_{12} Foreign_{it} + \alpha_{13} Zone_i + \alpha_{14} GDP_{it} + \alpha_{15} University_{it} + Industry\_indicators + \varepsilon \end{aligned} \quad (3)$$

The dependent variable RD_{it} is firm-level R&D expenditure divided by sales. *Spillover_IR* is the estimated R&D spillover coefficient for each two-digit industry code in each region. $CoreROS_{it}$ and $Leverage_{it}$ are used to control for profitability and debt pressure. $Interest_{it}$ measures access to external finance. $Salesgrowth_{it}$ controls for firm growth. $LogTA_{it}$ is included to control for firm size while $LogAge_{it}$ is used to control for the stage in the firm's lifecycle. $Subsidies_{it}$, measured by subsidies deflated by sales, is included to capture the possibility that the R&D is supported by the government. The ownership variables, $Collective_{it}$, $Private_{it}$, HK_{it}, and $Foreign_{it}$, are as defined above.

Finally we include additional controls for the region in which the firm operates. There are currently 54 national-level special economic zones in 48 cities in China, and such zones tend to attract investment from foreign and high-tech firms. Thus, $Zone_t$ is an indicator variable equal to 1 if the firm is in a city with special economic zoning, and 0 otherwise. GDP_{it} is local GDP per capita of each province in the corresponding year. $University_{it}$ is the number of universities in the province in the corresponding year. *Industry_indicators* in the regression tables indicates the use of industry fixed effects. The complete definition of variables is presented in Appendix B.

The correlations between R&D and *Spillover_IR* are expected to vary across regions depending on the level of intellectual property rights protections. Thus, we partition the sample into two groups. The first, the "Strong IPR" group comprises firms in regions where the IPR index is above the median, the second comprises the remaining firms, the "Weak IPR" group.[23] If weak intellectual property rights exacerbate the negative effect of R&D spillovers on R&D expenditures, then we would observe a strong negative association between R&D expenditures and R&D spillovers in the Weak, but not so in the Strong IPR group.

Given that R&D expenditures cluster at zero, in the multivariate analyses we employ both Tobit and ordinary least squares (OLS) specifications. Table 5 Panel A contains the Tobit analyses, while Panel B reports the OLS results. We report results for 2002, 2005, and for a Pooled analysis. The first specification examines R&D expenditures and R&D spillovers for firms in regions with weak intellectual property rights protections, while the second repeats the analysis for firms in regions with strong protections. When participated by *IPR1*, *IPR2* and *IPR3*, the results remain the same. To conserve space, we only report results with *IPR1*.

Focusing on the pooled regressions, we find that the coefficient on *Spillover_IR* for Weak regions is −0.223, suggesting that an extra unit of R&D spillovers reduces R&D investment by 22.3%. This is consistent with our prior that R&D spillovers reduce firms' incentives to invest in R&D activities when intellectual property rights protections are weak. In contrast, the positive coefficient on *Spillover_IR* of 0.112 equates to a 11.2% increase in R&D expenditures with a unit increase in intellectual property rights protections in strong property rights regions. That is, the positive effects of R&D spillovers dominate in regions with strong IPR. These results are similar to the findings for each year of the analysis. In both 2002 and 2005, the coefficient on *Spillover_IR* is significantly negative for the Weak IPR group, but significantly positive in the Strong IPR group. Thus, the results suggest that, after controlling for firm characteristics, ownership structure, and regional characteristics, R&D expenditures are negatively associated with R&D spillovers for firms located in regions with weak property rights.

The results from the OLS regression model, presented in Panel B, are similar to those of the Tobit specification. Similar to Table 4, the *t*-statistics are adjusted for regional clustering. For each year, and for the pooled analysis, the first column reports results for firms in regions with weak intellectual

[23] Given that R&D spillovers are negatively associated with the IPR index, we estimate Eq. (3) separately for each group rather than interacting Spillovers with the IPR index.

Table 5
R&D spillovers and R&D investment: weak vs. strong property rights regions.

Panel A: Tobit specification

Variable	2002		2005		Pooled	
	Weak	Strong	Weak	Strong	Weak	Strong
Intercept	0.280 (0.65)	1.177*** (13.99)	0.299 (0.35)	0.276 (0.71)	0.469* (2.64)	1.020*** (19.71)
$Spillover\_IR_i$	−0.134* (4.46)	0.072* (5.65)	−0.288*** (11.66)	0.105*** (10.88)	−0.223*** (19.20)	0.112*** (25.85)
$CoreROS_{it}$	−0.576*** (27.76)	−0.533*** (57.16)	−0.432*** (11.22)	−0.181* (4.09)	−0.476*** (33.96)	−0.407*** (54.69)
$Leverage_{it}$	−0.336*** (16.31)	−0.472*** (70.54)	−0.368*** (16.68)	−0.560*** (102.2)	−0.339*** (31.17)	−0.495*** (156.7)
$Interest_{it}$	2.264*** (19.44)	0.617 (2.55)	3.593*** (26.33)	4.132*** (58.33)	2.659*** (43.16)	1.813*** (32.79)
$Salesgrowth_{it}$	−0.012 (0.31)	−0.037* (5.19)	−0.022 (2.14)	−0.074*** (44.66)	−0.029* (5.73)	−0.061*** (45.62)
$LogTA_{it}$	−0.059*** (16.57)	−0.089*** (76.89)	−0.055*** (12.92)	−0.063*** (39.94)	−0.060*** (32.89)	−0.079*** (123.6)
$LogAge_{it}$	−0.026 (1.26)	−0.065*** (16.10)	0.019 (0.70)	−0.010 (0.36)	−0.011 (0.48)	−0.043*** (13.86)
$Subsidies_{it}$	0.370 (0.04)	2.945* (5.98)	4.648** (7.28)	5.693*** (28.48)	3.257** (7.01)	4.778*** (35.39)
$Collective_{it}$	−0.115* (3.55)	−0.180*** (15.72)	−0.416*** (20.94)	−0.437*** (44.49)	−0.211*** (17.59)	−0.247*** (44.99)
$Private_{it}$	−0.030 (0.26)	−0.125** (9.03)	−0.304*** (29.14)	−0.173*** (20.33)	−0.184*** (20.87)	−0.137*** (23.53)
HK_{it}	−0.062 (2.15)	−0.227*** (19.20)	−0.308* (6.10)	−0.434*** (70.91)	−0.238** (8.19)	−0.317 (74.54)***
$Foreign_{it}$	−0.201* (4.11)	−0.177** (10.40)	−0.155* (2.81)	−0.349*** (55.70)	−0.154* (5.17)	−0.263*** (54.59)
$Zone_i$	0.153*** (12.27)	0.133*** (17.87)	0.004 (0.01)	0.297*** (92.59)	0.087** (7.41)	0.216*** (95.37)

GDP_{it}	0.020*	−0.003	0.023***	0.009***	0.018**	0.005***
	(2.89)	(2.13)	(11.44)	(42.45)	(10.40)	(24.59)
$University_{it}$	−0.003*	−0.003**	−0.004**	−0.004***	−0.003**	−0.004***
	(3.24)	(8.44)	(6.96)	(44.88)	(7.98)	(57.95)
Industry indicators	Included	Included	Included	Included	Included	Included
Year indicators					Included	Included
Observations	39697	76677	58329	129918	98026	206595

Panel B: OLS specification

Variable	2002			2005			Pooled		
	Weak	Strong	Dif	Weak	Strong	Dif	Weak	Strong	Dif
Intercept	−0.316***	−0.375***		−0.330***	−0.684***		−0.311***	−0.543***	
	(−5.64)	(−6.07)		(−5.32)	(−5.19)		(−6.27)	(−5.11)	
$Spillover\_IR_i$	−0.039**	0.023	0.063***	−0.101*	0.131	0.231***	−0.071**	0.073	0.145***
	(−3.05)	(1.59)	(5.12)	(−2.44)	(1.17)	(13.99)	(−3.42)	(1.14)	(13.96)
$CoreROS_{it}$	−0.047*	−0.081*		−0.037	−0.017		−0.038	−0.041	
	(−1.96)	(−2.07)		(−0.65)	(−0.30)		(−1.28)	(−1.10)	
$Leverage_{it}$	−0.068***	−0.096***		−0.049***	−0.134***		−0.059***	−0.119***	
	(−6.28)	(−5.18)		(−4.61)	(−4.21)		(−7.50)	(−4.73)	
$Interest_{it}$	0.311*	0.039		0.393	0.797**		0.326*	0.311*	
	(2.46)	(0.27)		(1.49)	(2.84)		(2.53)	(1.91)	
$Salesgrowth_{it}$	−0.003	−0.008**		−0.004**	−0.015**		−0.005**	−0.013***	
	(−0.92)	(−3.06)		(−4.03)	(−3.18)		(−3.31)	(−4.16)	
$LogTA_{it}$	0.039***	0.048***		0.040***	0.062***		0.040***	0.057***	
	(8.76)	(8.71)		(7.09)	(7.95)		(9.63)	(9.37)	
$LogAge_{it}$	−0.001	−0.011**		0.007	0.007		0.003	−0.002	
	(−0.09)	(−2.97)		(1.55)	(0.96)		(0.68)	(−0.36)	
$Subsidies_{it}$	0.549*	0.636		0.905*	1.894**		0.796**	1.385**	
	(2.03)	(1.62)		(2.64)	(3.66)		(3.09)	(3.19)	

Table 5 (*Continued*)

Panel B: OLS specification

Variable	2002			2005			Pooled		
	Weak	Strong	Dif	Weak	Strong	Dif	Weak	Strong	Dif
$Collective_{it}$	−0.029**	−0.061**		−0.085***	−0.188**		−0.055***	−0.120**	
	(−3.42)	(−2.96)		(−8.19)	(−3.97)		(−7.41)	(−3.82)	
$Private_{it}$	−0.002	−0.031		−0.058***	−0.115		−0.035***	−0.075*	
	(−0.25)	(−1.58)		(−6.08)	(−2.85)*		(−7.31)	(−2.69)	
HK_{it}	−0.053**	−0.097***		−0.090***	−0.220***		−0.069***	−0.162***	
	(−2.98)	(−4.38)		(−4.77)	(−4.40)		(−4.98)	(−4.45)	
$Foreign_{it}$	−0.050*	−0.095**		−0.080***	−0.198**		−0.056**	−0.147**	
	(−2.11)	(−3.55)		(−5.68)	(−3.49)		(−3.58)	(−3.45)	
$Zone_i$	0.023**	0.017		0.008	0.046**		0.014	0.034**	
	(3.05)	(1.28)		(0.60)	(3.18)		(1.52)	(3.22)	
GDP_{it}	−0.002	−0.001		−0.004*	0.003		−0.003	0.002	
	(−0.61)	(−0.28)		(−1.91)	(0.81)		(−1.52)	(0.69)	
$University_{it}$	−0.0001	−0.0001		0.0001	−0.0003		0.0002	−0.0003	
	(−0.02)	(−0.29)		(0.02)	(−0.59)		(0.04)	(−0.53)	
Industry indicators	Included	Included		Included	Included		Included	Included	
Year indicators							Included	Included	
Observations	39697	76677		58329	129918		98026	206595	
R^2	0.045	0.047		0.057	0.065		0.049	0.055	

Regression results examining the association between R&D spillovers and R&D investment in regions with weak versus strong intellectual property rights protections. The dependent variable *RD* is the ratio R&D expenditures to sales; $Spillover\_IR_i$, is the level of R&D spillovers for each two-digit industry code in each region; $CoreROS_{it}$, is profit from operation divided by sales; $Leverage_{it}$, is total liabilities divided by total assets at the beginning of year t; $Interest_{it}$, is net interest deflated by sales; $Salesgrowth_{it}$, is $(Sales_t - Sales_{t-1})/Sales_{t-1}$; $LogTA_{it}$, the natural logarithm of total assets; $LogAge_{it}$, is the natural logarithm of the firm age (years since incorporation); $Subsidies_{it}$, is the amount of government subsidies divided by total assets; $Collective_{it}$, is an indicator variable equal to 1 if the controlling owner is a collective entity, and 0 otherwise; $Private_{it}$, is an indicator variable equal to 1 if the controlling owner is a private entity, and 0 otherwise; HK_{it} is an indicator variable equal to 1 if an entity from Hong Kong, Macau, or Taiwan is a blockholder, and 0 otherwise; $Foreign_{it}$, is an indicator variable equal to 1 if a foreign entity is a blockholder, and 0 otherwise; $Zone_i$, is an indicator variable equal to 1 if the firm operates in a city with national level special economic zoning, and 0 otherwise; GDP_{it} is local GDP per capita of each province in the corresponding year; $University_{it}$, is the number of universities in the province in the corresponding year. Scaled financial variables and *Spillover_IR*, other than *RD* are winsorized at the top and the bottom 0.5%. *RD* is winsorized at the top 0.05%.*Weak* indicates regions with *IPR1* less than median *IPR1* while *Strong* indicates *IPR1* larger than median *IPR1*. Panel A reports the results of a Tobit Specification, while Panel B reports the results of an ordinary least squares (OLS) specification. Chi square statistics are reported in parentheses in Panel A and robust *t*-statistics with clustering by region are reported in parentheses in Panel B.

* Significant at 0.1 level.

** Significant 0.01 level.

*** Significant at 0.001 level.

property rights protection, while the second column reports the results for Strong property rights regions. We also report the difference of the coefficients between the two groups. In 2002 and 2005, and the pooled regression, the coefficient of *Spillover_IR* in the weak group is significantly negative and significantly smaller the coefficient of *Spillover_IR* for the strong group. The results are again consistent with a negative association between R&D investment and spillovers that is stronger in regions with weak intellectual property rights relative to regions with strong property rights.

In aggregate, the results suggest that R&D investment is negatively associated with R&D spillovers in regions with weak intellectual property rights protections. That is, when property rights are weak, the negative effects of R&D spillovers outweigh the benefits, thus reducing firms' incentive to invest in R&D. Thus, it appears that weak intellectual property rights in many regions of China allow for uncompensated imitation, reducing the ability of firms to appropriate gains from innovation, and thus exacerbating the negative effect of R&D spillovers.

Evidence of a negative association is less obvious in regions with strong intellectual property rights protections. In such regions, there is evidence of a positive (or at least non-negative) association between R&D investment and spillovers, suggesting that property rights protections may facilitate innovation and growth in these regions. At the same time, the correlation between R&D and spillovers in the full sample is positive, suggesting that in regions with strong property rights compensated R&D facilitates innovation. That is, the positive effects of R&D spillovers dominate the negative effects. Of course, the endogeneity of Spillovers is of concern for our analysis, and we address this issue in the next section.

4.4. Self-selection in location

The analysis in Section 4.3 documents a negative association between R&D investment and R&D spillovers in regions with weak property rights. However, the concern remains that this result is attributable to omitted variables that simultaneously drive lower R&D investment and large R&D spillovers. For example, firms with more R&D investment are likely in greater need of intellectual property rights protections, and thus may choose to locate in areas with stronger property rights laws. Conversely, firms with smaller R&D investment depend less on intellectual property rights protections, therefore are more likely to be located in areas with weaker property rights laws.[24] That is, property rights are endogenous to firms' location choices. If so, the association between R&D investment and R&D spillovers illustrated above would be overstated.

Given our findings that uncompensated spillovers are higher in regions with low intellectual property protection, one might expect firms with more R&D investment to avoid these regions. However, government controlled companies are primarily owned by local government and promote employment and economic development in the local area (36% of the sample). Moreover, it is costly for privately owned companies to move location because the owner's personal business network is hard to move. The fact that we observe very few firms in the database moving between regions (9, 5, 9 observations in 2001, 2002 and 2005, respectively) further suggests that relocating is difficult. However, we recognize that firms may elect to start up in different regions, thus we use a two-stage Heckman regression to control for the potential effects of self-section in company location. In the first stage, we model the decision to choose a location with strong property rights protections, and in the second stage we include the Inverse Mills Ratio as an additional explanatory variable in Eq. (3).

All else equal one would expect that the decision to locate in a region with strong property rights is a function of: (1) Ownership type. Foreign (including Hong Kong, Macau and Taiwan) owners have more freedom to choose location than private owners and government owners, while private owners have more freedom than government owners. (2) Industry. R&D investment and the need for intellectual property rights are affected by industry characteristics. (3) Firm age. As China's markets have become more developed, newer firms arguably have greater flexibility to choose their location. We also control

[24] Firms located in areas with weak property rights may choose to enter industries in less need of intellectual property protection. We control for industry to eliminate this concern.

for differences in the local economy, whether or not the company location is a special economic zone, and for the overall level of education in the region.

We estimate the following probit model in the first stage:

$$IPR\_high_{it} = \alpha_0 + \alpha_1 Private_{it} + \alpha_2 HK_{it} + \alpha_3 Foreign_{it} + \alpha_4 LogAge_{it} + \alpha_5 Zone_i + \alpha_6 GDP_{it} + \alpha_7 University_{it} + Industry\_indicators + \varepsilon \quad (4)$$

where IPR_High_{it} is the indicator variable equal to 1 if the company locates in a region with strong property rights (above median) and 0 otherwise. $Private_{it}$, HK_{it}, and $Foreign_{it}$ are as defined above. $LogAge_{it}$, the natural logarithm of the firm age since incorporation. The following three variables are included to control for differences in local policies, economy, and education. $Zone_i$ is an indicator variable equal to 1 if the firm is in a city with special economic zoning, and 0 otherwise. GDP_{it} is local GDP per capita of each province in the corresponding year. $University_{it}$ is the number of universities in the province in the corresponding year.

The results of Heckman procedure are presented in Table 6. The left column reports the results of the probit regression in the first stage. We find that the coefficients of HK_i, and $Foreign_i$ are significantly positive after controlling for industry effects, showing that foreign companies are more likely to locate in regions with strong intellectual property rights. The coefficient on firm age is significantly negative suggesting that young companies are also more likely to locate in regions with strong property rights. This is also consistent with our expectation that investors now have more flexibility in choosing location. The results in the second stage regression are presented in the right columns. Lambda is the Inverse Mills Ratio from the first stage. The coefficient of Lambda in the strong group is insignificant and that in the weak group is only significant at 10%, suggesting that there is no serious selection bias. In regions with weak property rights, the coefficient of *Spillover_IR* is still significantly negative, consistent with the results in Table 5. The yearly results are qualitatively the same as the pooled results reported in Table 6.

4.5. Time variation in intellectual property rights: difference-in-difference analysis

To further address causality concerns in this section we examine how variation in intellectual property rights affects the association between R&D investment and spillovers. Comparing values in 2002 and 2005, while the index of intellectual property rights increases for most provinces, the rankings remain similar. Nine regions (31.0%) have the same rankings and fifteen regions (51.7%) change one or two position in ranking. Few regions experience large variation between 2002 and 2005, among which the most improved increases its standing 6 places from 124th to 18th, and the worst performer drops 4 places from 20th to 24th.

This variation in intellectual property rights provides a quasi-natural experiment to investigate how changes in intellectual property rights influence the association between R&D investment and spillovers. Thus, we estimate the following difference-in-difference regression:

$$RD_{it} = \alpha_0 + \alpha_1 Spillover\_IR_i + \alpha_2 IPR\_C_i + \alpha_3 Spillover\_IR_i \times IPR\_C_i + \alpha_4 CoreROS_{it} + \alpha_5 Leverage_{it} + \alpha_6 Interest_{it} + \alpha_7 Salsesgrowth_{it} + \alpha_8 LogTA_{it} + \alpha_9 LogAge_{it} + \alpha_{10} Subsidies_{it} + \alpha_{11} Collective_{it} + \alpha_{12} Private_{it} + \alpha_{13} HK_{it} + \alpha_{14} Foreign_{it} + \alpha_{15} Zone_i + \alpha_{16} GDP_{it} + \alpha_{17} University_{it} + Industry\_indicators + \varepsilon \quad (5)$$

where IPR_C_i is a dummy variable that equals one if firm *i* locates in the region with the largest variation from 2002 to 2005. Given that the best and the worst performers are all regions with weak property rights protections, we estimate Eq. (5) based on firms located in regions with weak property rights. That is, *IPR_C* equals zero if firm *i* is located in other regions with weak protections. The definition of other variables is the same as in Eq. (3).

The coefficient of interest in Eq. (5) is the interaction between *Spillover* and *IPR_C*. When a region experiences a large change in intellectual property rights protections, the firms in the remaining (also in the weak property rights group) act as a control group—one that does not experience a large shift

Table 6
Heckman two-stage least squares results for location choice.

	1st stage		2nd stage	
			Weak	Strong
Intercept	−2.179***	Intercept	−0.830**	−0.573***
	(6545)		(−3.62)	(−4.33)
$Private_{it}$	−0.001	$Spillover\_IR_i$	−0.072**	0.067
	(0.01)		(−3.47)	(1.06)
HK_{it}	0.391***	$CoreROS_{it}$	−0.037	−0.041
	(807)		(−1.24)	(−1.11)
$Foreign_{it}$	0.084***	$Leverage_{it}$	−0.060***	−0.118***
	(44.96)		(−7.67)	(−4.75)
$LogAge_{it}$	−0.025***	$Interest_{it}$	0.331*	0.310*
	(57.67)		(2.54)	(1.88)
		$Salesgrowth_{it}$	−0.005**	−0.034***
			(−3.42)	(−4.09)
		$LogTA_{it}$	0.040***	0.057***
			(9.72)	(9.37)
		$LogAge_{it}$	0.007*	−0.002
			(2.33)	(−0.35)
		$Subsidies_{it}$	0.781**	1.384**
			(3.00)	(3.21)
		$Collective_{it}$	−0.054***	−0.118**
			(−7.29)	(−3.77)
		$Private_{it}$	−0.036***	−0.072**
			(−7.43)	(−2.61)
		HK_{it}	−0.015	−0.156***
			(−0.37)	(−4.41)
		$Foreign_{it}$	−0.069***	−0.145**
			(−6.84)	(−3.48)
$Zone_i$	0.014*	$Zone_i$	0.016	0.033**
	(5.15)		(1.59)	(3.14)
GDP_{it}	0.194***	GDP_{it}	0.026*	0.003
	(68396)		(1.71)	(0.69)
$University_{it}$	0.010***	$University_{it}$	−0.002	−0.0002
	(3845)		(−1.57)	(−0.49)
		Lambda	0.223*	0.025
			(1.99)	(0.57)
Industry indicators	Included	Industry indicators	Included	Included
Year indicators	Included	Year indicators	Included	Included
Observations	304621	Observations	98026	206595
Pseudo R^2	0.405	R^2	0.058	0.055

This table presents the Heckman two-stage least square results controlling for location choice. The dependent variable in the first stage regression is IPR_High_{it}, the indicator variable equal to 1 if the company locates in a region with strong property rights (above median, measured by *IPR1*) and 0 otherwise. $Private_{it}$, is an indicator variable equal to 1 if the controlling owner is a private entity, and 0 otherwise; HK_{it} is an indicator variable equal to 1 if an entity from Hong Kong, Macau, or Taiwan is a blockholder, and 0 otherwise; $Foreign_{it}$, is an indicator variable equal to 1 if a foreign entity is a blockholder, and 0 otherwise; $LogAge_{it}$, the natural logarithm of the firm age at the year end since incorporation.
The dependent variable in the second-stage regression, *R&D*, is R&D expenditures deflated by sales. Independent variables include $Spillover\_IR_i$, which is instrumented level of R&D spillovers for each two-digit industry code in each region from the first-stage regression; $CoreROS_{it}$, is profit from operation divided by sales; $Leverage_{it}$, is total liabilities divided by total assets at the beginning of year t; $Interest_{it}$, is net interest deflated by sales; $Salesgrowth_{it}$, is $(Sales_t - Sales_{t-1})/Sales_{t-1}$; $LogTA_{it}$, the natural logarithm of total assets; $LogAge_{it}$, the natural logarithm of the firm age (years since incorporation); $Subsidies_{it}$, is the amount of government subsidies divided by total assets; $Collective_{it}$, is an indicator variable equal to 1 if the controlling owner is a collective entity, and 0 otherwise; $Private_i$, HK_i, and $Foreign_i$ are as defined above. $Zone_i$, is an indicator variable equal to 1 if the firm operates in a city with national level special economic zoning, and 0 otherwise; GDP_{it}, local GDP per capita of each province in the corresponding year; $University_{it}$, is the number of universities in the province in the corresponding year; Lambda is the Inverse Mills Ratio from the first stage in the Heckman two-stage regression model. Scaled financial variables and $Spillover\_IR_i$, other than *R&D* are winsorized at the top and the bottom 0.5%. *R&D* is winsorized at the top 0.05%. Chi square statistics are reported in parentheses in the first stage regression and robust *t*-statistics with clustering by region are reported in parentheses in the second stage regression.

* Significant at 0.1 level.
** Significant at 0.01 level.
*** Significant at 0.001 level.

in property rights protections. Relative to the control group, a large decline in intellectual property rights should enhance the negative impact of spillovers on R&D investment ($\alpha_3 < 0$), while a large improvement in intellectual property rights should weaken the negative impact ($\alpha_3 > 0$).

Similar to Eq. (3) we employ both Tobit and ordinary least squares (OLS) specifications. The results are reported in Table 7. The first two columns reports how worsening intellectual property rights protections affect the association between R&D investment and spillovers. The coefficients of the interaction between *Spillover* and *IPR_C* are negative in both the Tobit and OLS specifications, and significant at 0.001 in the OLS regression, suggesting that worsening intellectual property rights protections exacerbate the negative effect of spillovers on R&D investment. The right two columns report how improved intellectual property rights protections affects the association between R&D investment and spillovers. The coefficients of the interaction between *Spillover* and *IPR_C* are positive in both specifications, and significant at the 10% level in the OLS regression, showing that improved intellectual property rights protections attenuate the negative effect of spillovers on R&D investment.

Taken together, we find evidence consistent with large changes in intellectual property rights affecting the association between R&D investment and spillovers, thus mitigating concerns about causality.

4.6. Control variables

Focusing on the control variables, there are several interesting findings. The variable *Leverage*, measured by total liabilities divided by total assets at the beginning of year *t*, is negatively associated with R&D expenditures in all regressions (in Tables 5–7), suggesting that firms with more debt invest less in R&D. In almost all specifications R&D expenditures are positively associated with access to external finance, (using our proxy variable *Interest*), particularly for the Strong IPR group. This result is consistent with the prior literature suggesting that access to external finance is associated with greater innovation. Of note, however, is that our spillover results are present even when we include this proxy for access to external finance.

Subsidies, measuring governmental subsidies, is positively associated with R&D investment and more so for the Strong IPR group, consistent with government support inducing R&D investment. *Zone*, the indictor variable equal to 1 if the firm is in a city with national-level special economic zones, and 0 otherwise is also positively associated with R&D expenditures in almost all analyses.

The coefficients on the *Ownership* variable indicators are all negative. This implies that that collectively-owned firms, privately-owned firms, and foreign-owned firms have lower R&D investment relative to state firms, consistent with the Chinese government playing a major role in spurring R&D investment.

5. Conclusion

In viewing the firm as a nexus of contracts, the property rights of contracting parties and the security of those property rights clearly influence decision making, and thus firm-level outcomes. As such, ongoing work continues to examine interactions between legal protections, financial markets, and the incentives for innovation and investment. More recently, there has been increased emphasis on connections between law, finance and property rights at the firm-level.

We contribute to the literature by studying the association between R&D investment and property rights protections across different regions within China. We identify a specific channel through which property rights affect R&D investment, the leakage of proprietary information or R&D spillovers. Our results suggest that R&D spillovers are larger in regions with weak intellectual property rights relative to regions with strong intellectual property rights. Moreover, the negative association between R&D expenditures and spillovers is larger in regions with weak intellectual property rights protections, suggesting that weak property rights protections undermine incentives to invest in R&D activities. Conversely, our results indicate that strong intellectual property rights restrain R&D spillovers and provide incentives for firms to invest in R&D. Our analyses control for access to

Table 7
The impact of intellectual property rights on the association between R&D investment and spillovers: difference-in-difference estimations.

Variable	Down		Up	
	Tobit	OLS	Tobit	OLS
Intercept	0.299 (0.35)	−0.341*** (−5.42)	0.308 (0.37)	−0.333*** (−4.99)
$Spillover\_IR_i$	−0.294*** (11.52)	−0.097* (−2.39)	−0.288*** (11.04)	−0.117* (−2.47)
IPR_C_i	−0.045 (0.05)	0.114*** (6.17)	−0.140 (0.21)	−0.019 (−0.59)
$Spillover\_IR_i$*IPR_C_i	−0.135 (0.19)	−0.185*** (−10.58)	0.075 (0.07)	0.060* (2.05)
$CoreROS_{it}$	−0.432*** (11.09)	−0.037 (−0.67)	−0.428*** (10.99)	−0.039 (−0.68)
$Leverage_{it}$	−0.369*** (16.74)	−0.048*** (−4.54)	−0.367*** (16.48)	−0.049*** (−4.57)
$Interest_{it}$	3.586*** (26.22)	0.386 (1.46)	3.625*** (26.50)	0.392 (1.49)
$Salesgrowth_{it}$	−0.022 (2.14)	−0.004** (−4.01)	−0.022 (2.19)	−0.004** (−4.03)
$LogTA_{it}$	−0.055*** (13.00)	0.041*** (7.06)	−0.055*** (13.02)	0.040*** (7.13)
$LogAge_{it}$	0.019 (0.67)	0.007 (1.56)	0.019 (0.68)	0.008 (1.63)
$Subsidies_{it}$	4.638** (7.25)	0.936* (2.81)	4.712** (7.43)	0.909* (2.66)
$Collective_{it}$	−0.416*** (20.94)	−0.085*** (−8.22)	−0.416*** (20.91)	−0.085*** (−8.20)
$Private_{it}$	−0.305*** (29.28)	−0.057*** (−6.08)	−0.303*** (28.98)	−0.058*** (−6.07)
HK_{it}	−0.310* (6.16)	−0.090*** (−4.81)	−0.307* (6.04)	−0.089*** (−4.70)
$Foreign_{it}$	−0.158* (2.90)	−0.080*** (−5.73)	−0.155* (2.78)	−0.080*** (−5.56)
$Zone_i$	0.003 (0.01)	0.008 (0.62)	0.005 (0.01)	0.008 (0.63)
GDP_{it}	0.023*** (11.40)	−0.004* (−1.89)	0.025** (10.01)	−0.004 (−1.69)
$University_{it}$	−0.004* (6.38)	0.0001 (0.06)	−0.005* (5.99)	0.0003 (0.44)
Industry indicators	Included	Included	Included	Included
Observations	58329	58329	58329	58329
R^2		0.058		0.057

This table presents results of difference-in-difference regressions examining the impact of intellectual property rights on the association between R&D investment and spillovers. The dependent variable, *RD* is the ratio R&D expenditures to sales; $Spillover\_IR_i$, is the level of R&D spillovers for each two-digit industry code in each region; $CoreROS_{it}$, is profit from operation divided by sales; $Leverage_{it}$, is total liabilities divided by total assets at the beginning of year *t*; $Interest_{it}$, is net interest deflated by sales; $Salesgrowth_{it}$, is $(Sales_t - Sales_{t-1})/Sales_{t-1}$; $LogTA_{it}$, the natural logarithm of total assets; $LogAge_{it}$, is the natural logarithm of the firm age (years since incorporation); $Subsidies_{it}$, is the amount of government subsidies divided by total assets; $Collective_{it}$, is an indicator variable equal to 1 if the controlling owner is a collective entity, and 0 otherwise; $Private_{it}$, is an indicator variable equal to 1 if the controlling owner is a private entity, and 0 otherwise; HK_{it} is an indicator variable equal to 1 if an entity from Hong Kong, Macau, or Taiwan is a blockholder, and 0 otherwise; $Foreign_{it}$, is an indicator variable equal to 1 if a foreign entity is a blockholder, and 0 otherwise; $Zone_i$, is an indicator variable equal to 1 if the firm operates in a city with national level special economic zoning, and 0 otherwise; GDP_{it} is local GDP per capita of each province in the corresponding year; $University_{it}$, is the number of universities in the province in the corresponding year. Scaled financial variables and $Spillover\_IR_i$, other than *R&D* are winsorized at the top and the bottom 0.5%. *R&D* is winsorized at the top 0.05%. Down means the region with the largest drop in the ranking of intellectual property rights and Up means the region with the largest improvement in the ranking. IPR_C_i equals one if firm *i* is in the region marked as Down in the left two columns, and if firm i is in the region marked as Up in the right two columns. Chi square statistics are reported in parentheses in the Tobit regressions and robust *t*-statistics with clustering by region are reported in parentheses in the OLS regressions.

* Significant at 0.1 level.
** Significant at 0.01 level.
*** Significant at 0.001 level.

external finance, the state of the local economy, and persist after considering the endogeneity of R&D spillovers using an instrumental variables approach. Further, in the IV analyses we find that strength of the negative association between R&D expenditures and the level of spillovers is larger.

Our findings also contribute to the literature examining links between law, finance, and economic growth. Of note, the growth of the Chinese economy appears as a counter-example to the conventional wisdom that a country's economic development depends critically on its financial markets and legal structures. In addition to the potential for transactions to be safeguarded by informal mechanisms, such as reputation, custom, and social norm (Allen et al., 2005; Allen and Qian, 2009), it appears that local property rights protections also play an important role in China's development. From a public policy perspective, moves that provinces can take to enhance such protections will likely further enhance the country's economic development.

Appendix A. Intellectual property rights index for each region

IPR1 is the density of intellectual property law firms, measured as the number of intellectual property law firms in the region divided by regional population. *IPR2* is the degree of legal protection for innovation and intellectual property rights based on an average of (1) the number of patents applied for divided by the number of personnel of science and technology and (2) the number of patents approved divided by the number of personnel of science and technology; *IPR3* is the number of lawyers divided by the size of the population.

Region	*IPR1*		*IPR2*		*IPR3*	
	2002	2005	2002	2005	2002	2005
Anhui	0.14	0.18	0.66	1.41	1.24	0.76
Beijing	8.15	8.91	4.82	8.35	11.28	10.31
Chongqing	0.23	0.29	2.54	5.80	2.86	2.75
Fujian	0.29	0.31	4.34	5.44	2.03	1.69
Gansu	0.12	0.12	0.09	0.84	1.01	0.53
Guangdong	0.51	0.78	11.44	19.36	3.64	2.71
Guangxi	0.17	0.17	0.52	0.73	0.72	0.60
Guizhou	0.13	0.16	0.42	1.03	0.19	0.00
Hainan	0.25	0.24	0.88	0.64	1.86	1.36
Hebei	0.21	0.20	1.47	1.72	1.19	0.93
Heilongjiang	0.39	0.42	1.39	2.61	2.08	1.35
Henan	0.09	0.12	0.69	1.76	1.01	0.71
Hubei	0.23	0.26	1.76	3.23	1.25	0.95
Hunan	0.27	0.35	1.43	3.08	1.24	1.13
Jiangsu	0.41	0.49	4.39	9.69	2.31	1.76
Jiangxi	0.17	0.21	0.67	1.19	0.80	0.31
Jilin	0.48	0.48	1.36	2.12	1.76	1.12
Liaoning	0.93	0.95	3.34	5.72	2.69	2.45
Neimenggu	0.17	0.17	0.27	0.48	1.52	1.38
Ningxia	0.00	0.00	0.80	0.76	2.68	1.80
Shaanxi	0.33	0.43	0.87	1.47	1.75	1.13
Shandong	0.22	0.25	2.75	5.66	1.74	1.53
Shanghai	1.72	2.36	12.18	25.13	11.28	10.31
Shanxi	0.09	0.15	0.34	0.57	2.22	1.50
Sichuan	0.18	0.22	1.66	2.99	1.28	1.20
Tianjin	1.19	1.25	5.05	11.00	5.11	4.04
Xinjiang	0.26	0.25	0.27	0.79	2.08	2.20
Yunnan	0.14	0.22	0.58	1.07	1.13	1.12
Zhejiang	0.47	0.69	9.59	17.63	3.23	2.20

Appendix B. Description of variables

Variables	Definition
$LogSales_{ijt}$	The natural logarithm of sales deflated by industrial product factory price index of the industry.
$LogRD_{it}$	The natural logarithm of R&D expenditures deflated by industrial product factory price index of the industry.
$LogRDpool_{jt}$	The natural logarithm of the sum of R&D expenditures of firms in the same two-digit industry code excluding those of the individual firm per se deflated by industrial product factory price index of the industry.
$LogFixedassets_{it-1}$	The natural logarithm of fixed assets deflated by industrial product factory price index of the industry in the last year.
$LogEmployment_{it-1}$	The natural logarithm of number of employees in the last year.
RD_{it}	Percentage of R&D expenditures deflated by sales.
$Spillover\_IR_i$	Level of R&D spillovers for each two-digit industry code in each region.
$CoreROS_{it}$	Profit from operation divided by sales.
$Leverage_{it}$	Total liabilities divided by total assets at the beginning of year t.
$Interest_{it}$	Net interest deflated by sales.
$Salesgrowth_{it}$	$(Sales_t - Sales_{t-1})/Sales_{t-1}$
$LogTA_{it}$	The natural logarithm of total assets.
$LogAge_{it}$	The natural logarithm of the firm age at the year end since incorporation.
$Subsidies_{it}$	Subsidies divided by total assets.
$Collective_{it}$	Indicator variable equals 1 if the control owner is a collective entity, and 0 otherwise.
$Private_{it}$	Indicator variable equals 1 if the control owner is a private entity, and 0 otherwise.
HK_{it}	Indicator variable equals 1 if an entity from HK, Macau and Taiwan is a blockholder, and 0 otherwise.
$Foreign_{it}$	Indicator variable equals 1 if a foreign entity is a blockholder, and 0 otherwise.
$Zone_i$	Indicator variable equals 1 if the firm is in a city with national level special economic zones, and 0 otherwise.
GDP_{it}	Local GDP divided by local population of each province in the corresponding year.
$University_{it}$	The number of universities in the province in the corresponding year.
IPR1	The density of intellectual property law firms, measured as the number of intellectual property law firms in the region divided by regional population.
IPR2	The degree of legal protection for innovation and intellectual property rights is based on the number of patents applied for divided by the number of personnel of science and technology and the number of patents approved divided by the number of personnel of science and technology. Higher index suggests stronger protection in intellectual property rights.
IPR3	The number of lawyers divided by the size of the population. A larger value suggests that there is a higher demand for lawyers, stronger legal enforcement, and therefore stronger property rights protections.

Appendix C. Pearson and Spearman correlation matrix of variables

The upper (lower) triangular shows the Pearson (Spearman) correlation coefficients and p values.

	RD_{it}	$Spillover\_IR_i$	$CoreROS_{it}$	$Leverage_{it}$	$Interest_{it}$	$Salesgrowth_{it}$	$LogTA_{it}$	$LogAge_{it}$	$Subsidies_{it}$
RD_{it}	1.000	0.025	−0.020	−0.019	0.033	−0.015	0.106	0.022	0.024
		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Spillover\_IR_i$	0.033	1.000	−0.030	−0.001	0.031	0.052	−0.033	−0.009	0.010
	0.000		0.000	0.437	0.000	0.000	0.000	0.000	0.000
$CoreROS_{it}$	0.052	0.011	1.000	−0.261	−0.423	0.110	−0.017	−0.158	−0.042
	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000
$Leverage_{it}$	−0.015	0.001	−0.337	1.000	0.205	−0.047	0.052	0.119	0.002
	0.000	0.753	0.000		0.000	0.000	0.000	0.000	0.296
$Interest_{it}$	0.101	0.089	−0.070	0.177	1.000	−0.069	0.194	0.138	0.000
	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.895
$Salesgrowth_{it}$	0.011	0.042	0.229	−0.054	−0.034	1.000	0.034	−0.187	−0.016
	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000

	RD_{it}	$Spillover\_IR_i$	$CoreROS_{it}$	$Leverage_{it}$	$Interest_{it}$	$Salesgrowth_{it}$	$LogTA_{it}$	$LogAge_{it}$	$Subsidies_{it}$
$LogTA_{it}$	0.225	−0.016	−0.005	0.065	0.244	0.036	1.000	0.152	0.022
	0.000	0.000	0.008	0.000	0.000	0.000		0.000	0.000
$LogAge_{it}$	0.065	−0.002	−0.130	0.081	0.118	−0.188	0.141	1.000	0.026
	0.000	0.256	0.000	0.000	0.000	0.000	0.000		0.000
$Subsidies_{it}$	0.119	−0.039	−0.062	0.015	0.082	−0.016	0.190	0.042	1.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
$Collective_{it}$	−0.031	0.053	0.032	0.019	0.033	−0.045	−0.087	0.215	0.015
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Private_{it}$	−0.044	0.025	0.116	0.001	0.012	0.116	−0.231	−0.318	−0.061
	0.000	0.000	0.000	0.648	0.000	0.000	0.000	0.000	0.000
HK_{it}	−0.016	−0.162	−0.016	−0.071	−0.100	−0.029	0.116	−0.025	−0.015
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Foreign_{it}$	0.016	−0.057	0.048	−0.085	−0.080	0.008	0.150	−0.079	0.019
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zone	0.024	−0.067	−0.023	0.023	−0.099	−0.047	0.051	0.018	0.023
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GDP_t	−0.022	−0.416	0.093	−0.016	−0.176	0.026	−0.004	−0.155	−0.071
	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000
University	−0.032	0.021	0.092	0.014	−0.076	0.117	−0.026	−0.129	−0.080
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	$Collective_{it}$	$Private_{it}$	HK_{it}	$Foreign_{it}$	*Zone*	GDP_t	*University*
RD_{it}	−0.028	−0.019	−0.014	0.012	0.040	0.037	−0.015
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Spillover\_IR_i$	0.029	0.003	−0.110	−0.026	−0.053	−0.271	−0.094
	0.000	0.073	0.000	0.000	0.000	0.000	0.000
$CoreROS_{it}$	0.041	0.124	0.008	0.031	−0.012	0.069	0.101
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Leverage_{it}$	0.021	−0.028	−0.066	−0.078	0.019	−0.032	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Interest_{it}$	−0.007	−0.095	−0.048	−0.045	−0.039	−0.139	−0.123
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Salesgrowth_{it}$	−0.043	0.073	−0.021	0.001	−0.040	−0.023	0.083
	0.000	0.000	0.000	0.675	0.000	0.000	0.000
$LogTA_{it}$	−0.097	−0.230	0.102	0.150	0.048	0.007	−0.021
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$LogAge_{it}$	0.193	−0.312	−0.042	−0.085	0.016	−0.120	−0.139
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Subsidies_{it}$	0.075	−0.029	−0.043	−0.038	0.007	0.014	−0.048
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$Collective_{it}$	1.000	−0.390	−0.148	−0.140	−0.006	−0.104	0.082
		0.000	0.000	0.000	0.001	0.000	0.000
$Private_{it}$	−0.390	1.000	−0.306	−0.289	−0.064	0.068	0.163
	0.000		0.000	0.000	0.000	0.000	0.000
HK_{it}	−0.148	−0.306	1.000	−0.110	0.040	0.096	0.056
	0.000	0.000		0.000	0.000	0.000	0.000
$Foreign_{it}$	−0.140	−0.289	−0.110	1.000	0.105	0.162	0.036
	0.000	0.000	0.000		0.000	0.000	0.000

	$Collective_{it}$	$Private_{it}$	HK_{it}	$Foreign_{it}$	$Zone$	GDP_t	$University$
Zone	−0.006	−0.064	0.040	0.105	1.000	0.210	−0.016
	0.000	0.000	0.000	0.000		0.000	0.000
GDP_t	−0.130	0.125	0.110	0.152	0.167	1.000	0.180
	0.000	0.000	0.000	0.000	0.000		0.000
University	−0.081	0.156	0.058	0.027	−0.027	0.283	1.000
	0.000	0.000	0.001	0.000	0.006	0.000	

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