Patent Success, Patent Holdup and the Structure of Property Rights

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Abstract

Innovation processes under patent protection generate holdup problems if complementary patents are owned by different firms (Hart, 1995). We show that shareholder ownership overlap across firms with patent complementarities helps mitigate such holdup problems and correlates significantly with higher patent investment and more patent success. The positive innovation effect is strongest for concentrated overlapping ownership and for the cases in which overlapping shareholders are dedicated investors, with long investment horizons and underdiversified portfolios.

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1 Introduction

Technological progress has been recognized as the main source of long-run economic growth (see, e.g., Solow, 1957; Hall, Jaffe, and Trajtenberg, 2005; Kogan, Papanikolaou, Seru, and Stoffman, 2017). However, the question of how corporate ownership structure and property rights in patents affect technological innovation remains relatively unexplored. This paper gives a new empirical perspective on the role of equity ownership structure in attenuating holdup problems induced by patent protection in the corporate innovation process.

Patent protection provides inventors with exclusive rights to the commercial use of their discoveries.[1] But such discoveries are often part of a larger technological process of sequentially patented innovations, and the full economic value of a new (downstream) patent might only be unlocked if the innovating firm can simultaneously secure access to many complementary (upstream) patents. Therefore, patent processes generate a holdup problem whenever such complementary patents are owned by different firms and ex-ante contracting is incomplete.

The need for ex-post bargaining often imposes two types of costs on an innovating firm, as emphasized by transaction cost theories (Coase, 1937; Williamson, 1975, 1985; Klein, Crawford, and Alchian, 1978). Ex-post costs include the time and effort spent in negotiating the ex-post division of surplus as well as the possibility of failing to reach an efficient agreement between contracting parties due to asymmetric information.[2] Ex-ante costs originate from underinvestment by the innovating firm because it fears that it will not recover its investment costs due to potential rent extraction by upstream firms owning complementary patents.

The property rights literature (Grossman and Hart, 1986; Hart and Moore, 1990; Hart, 1995) suggests that joint asset ownership attenuates holdup problems under conditions of ex-ante noncontractability and asset specificity. Which bundle of upstream patents is required in the commercialization phase of a new downstream patent is often unclear at the beginning of R&D investment in the new patent—prohibiting the possibility of ex-ante contracting. In some cases, the degree of upstream patent complementarity may be evaluated to some extent prior to patent investment, but ex-ante contracting is incomplete due to the difficulty of planning for all contingencies and,

[1] Blundell, Griffith, and Van Reenen (1999) document that at least 4,500 technologically important innovations were commercialized by British firms in the period 1945–1983.

[2] Haggling over the division of surplus and asymmetric information leads to ex-post inefficiencies for the innovating firm because some of the resources are not put to productive use, and the firm's patent cannot realize its full economic value without the complementary patents.

therefore the contract is subject to ex-post renegotiation. The second condition (asset specificity) is also fulfilled for many new downstream patents, for which upstream complementary patents can be regarded as a key complementary input and whose full economic value can be realized only in conjunction with these upstream complementary patents. [3]

Applying this insight to the patent process, we conjecture that joint share ownership by institutional investors of both upstream and downstream firms can similarly attenuate holdup and underinvestment problems and contribute to the patent success of the innovating firm.[4] Two separate channels can promote the internalization of such patent holdup: First, a *transfer internalization channel* implies that investors with joint ownership in the (downstream) innovating firm and the (upstream) firm holding a complementary patent could influence management of the downstream firm to internalize future patent rent transfers to the upstream firm (for the portion of the transfer payments received by the overlapping shareholders) and reduce underinvestment in the downstream patent. Hansen and Lott (1996) provide evidence that investors internalize externalities between firms in their investment portfolios. In a similar vein, He and Huang (2017) show that overlapping shareholders try to maximize their portfolio values by coordinating the product market strategies of same-industry firms they hold jointly.

Second, a *transfer reduction channel* suggests that if such patent rent transfer can only be obtained at an efficiency loss (for example, due to potential patent litigations that retard the commercial adoption of the patent), overlapping investors can contribute to a swift conflict resolution, thereby reducing the overall patent transfer payments and increasing ex-ante investment incentives by the downstream firm. For example, Albert J. Wilson, Vice President and Secretary of TIAA-CREF, noted in a public speech that his pension fund had applied pressure on both sides in the litigation cases of Pennzoil vs Texaco and Apple vs Microsoft toward resolving conflicts sooner than would have happened otherwise because of their overlapping fund ownership in both litigants (Hansen and Lott, 1996).

To subject this property-rights perspective of patent success to a systematic empirical examina-

[3]Klein *et al.* (1978) provide a classical example of asset-specificity represented by a piece of critical infrastructure such as a pipeline. Construction of a refinery connected to the pipeline represents an asset-specific investment. The value of the refinery depends on access to the pipeline. Under separate ownership, the refinery owner may be held up by the pipeline owner in the sense that the latter can raise the price of crude oil (as the refinery input) to a very high level. The holdup problem can only be overcome by joint ownership if ex-ante contracting (on pipeline access) is incomplete or difficult.

[4]In our empirical analysis, we identify upstream firms as those cited by a downstream innovating firm in its patent filings.

tion, we combine a large sample of U.S. patent data from the United States Patent and Trademark Office (USPTO) with institutional ownership data from Thomson Reuters for the period 1991–2007. In particular, we track stock ownership not only for the innovating firms, but also for firms owning complementary patents. The complementarities are identified directly from patent filings that explicitly list important upstream patents owned by other firms. By law, each newly filed patent must list prior art references (i.e., precursory or upstream patents) that are technologically related and material to the patentability of the new application. Although inventors have a duty of candor to disclose all material prior art, patent examiners in USPTO are officially responsible for constructing the list of references. According to Alcácer, Gittelman, and Sampat (2009), examiners insert at least one citation in 92% of patent applications, and examiner citations account for about 63% of all citations made by an average patent. Our analysis identifies potential patent holdup based on this list of prior art references and assumes that the list is exogenously determined by the technology to be patented. Indeed, the frequent addition of precursory patents by patent examiners suggests a limited scope in manipulating the reference list by the patent filing firms.

Prior research suggests that owners of upstream cited patents are reasonable proxies for the potential licensors of downstream citing patents (Ziedonis, 2004; Galasso and Schankerman, 2010; Noel and Schankerman, 2013). So-called patent-consultants occasionally disclosed that they screened the list of companies that cited their clients' patents to identify potential licensees (Ziedonis, 2004).[5] Interestingly, two U.S. inventors, Stephen K. Boyer and Alex Miller, were granted a patent (US6879990) in 2005 for the systematic use of patent citation references in identifying potential licensees.[6] Following this line of the literature and industry practice, our analysis uses patent citation links to upstream firms to proxy for asset complementarity and potential holdup problems faced by the downstream firm. Figure 1 provides supportive evidence for such a proxy: Firms with citation links are on average 23 times as likely to engage in patent-related lawsuits against each other than those without any citation links. The relative patent litigation risk related to citation links is even higher in R&D-intensive industry sectors such as pharmaceuticals

[5] Ziedonis (2004) discussed three cases in her paper (Mogee Associates, InteCap, and Delphion). Ambercite, another intellectual property consulting company advocated a similar approach in a recent internet posting (www.ambercite.com, 2014).

[6] They suggest creating a pool of associated patents that cite the target patents. Certain weighting scheme and ranking criteria are then applied to rank the owners of these associated patents to identify companies that most likely need a patent license from the target firms.

and telecommunications.[7] Notwithstanding the imperfect nature of the proxy, it allows us to identify asset complementarity for a large sample of firms—particularly among firms in the forefront of the innovation process.

Our main hypothesis is the *holdup attenuation hypothesis*, which argues that joint equity ownership between the downstream innovator and the upstream firms controlling complementary patents attenuates the holdup problem, increases investment in research and development (R&D), and contributes to the long-run patent success of the innovating firm. To test this hypothesis, we construct a new explanatory variable, *firm-level shareholder overlap* (SOL), which aggregates ownership share that investors own jointly in both the innovating firm and the firms controlling the complementary assets. Consider a patent p owned by a downstream firm $O(p)$ that cites a precursory patent p_u owned by an upstream firm $O(p_u)$. If two investors A and B, respectively, own 3% and 5% in the downstream firm $O(p)$, and 2% and 6% in the upstream firm $O(p_u)$, the pairwise shareholder overlap for the patent pair (p, p_u) amounts to 7% $[= min(3\%, 2\%) + min(5\%, 6\%)]$. The patent-level shareholder overlap (sol) of patent p follows by averaging pairwise shareholder overlap over all upstream patents cited by patent p, and the firm-level shareholder overlap (SOL) is obtained by averaging sol over all patents p filed by the same firm in a given year.

Following the literature, we only examine patents that are eventually granted by the USPTO. We measure patent success by the cumulative citation count $cites_{p,t}$ of each patent p that is filed in year t and subsequently granted. Overall firm-level patent success is denoted as $CITES_{s,t}$, which aggregates all future patent citations of the entire cohort of patents filed by firm s in year t. Our choice of proxy for patent success is widely used in the literature and is in line with the literature that shows a positive correlation of future citation count with the economic value of a patent (e.g., Harhoff, Narin, Scherer, and Vopel, 1999; Kogan *et al.*, 2017) and with firm value (e.g., Hall, Jaffe, and Trajtenberg, 2005).

Main Findings

We find strong evidence at both the firm and patent level that joint (overlapping) equity ownership in complementary patents fosters patent success through the attenuation of holdup. For

[7] The figure is based on the Audit Analytics Litigation database collected primarily from corporate disclosures to the Securities and Exchange Commission (SEC). Reported are 604 patent lawsuits over the period 2000-2007. Although these lawsuits may represent only a subset of all patent lawsuits, we are not aware of any reporting bias toward firm pairs with or without citation links. Previous literature, such as Schmidt (2012), has also employed this database to carry out litigation-related analysis.

example, an increase by one standard deviation in firm-level shareholder overlap $SOL_{s,t-1}$ with firms owning complementary patents enhances patent success as measured by a firm's (log) patent citations (*ln[1+CITES$_{s,t}$])* by 11.3% of its standard deviation. It also increases the extensive margin of patent production (i.e., number of patents successfully filed) by 18%. The results are qualitatively robust to the inclusion of various firm controls and industry or firm fixed effects, as well as to the alternative measurement of SOL with ownership data lagged by two to four years. The holdup attenuation effect also operates at the patent level within the firm: Of two patents filed by the same firm in the same year, the patent p with a higher patent-level shareholder overlap $sol(p, p^u)$ with its complementary upstream patents p^u is *ceteris paribus* more successful as measured by its (log) citations (*ln[1+cites$_{p,t}$]).*

In addition, we show a stronger effect of shareholder overlap on patent success when such overlap originates from *dedicated investors*, characterized by concentrated portfolio positions and a long-term investment horizon, and much less so when the overlap is from other investor types.[8] This finding suggests that long-term, dedicated overlapping shareholders have stronger incentives to resolve patent holdup conflicts. While recent research has highlighted the governance influence of long-term investors (Van Nieuwerburgh and Veldkamp, 2010; Asker, Farre-Mensa, and Ljungqvist, 2015; McCahery, Sautner, and Starks, 2016) our evidence differs in its focus on *inter-firm conflict* (rather than intra-firm conflict) in which dedicated overlapping shareholders play a special role.

We also find that the concentration of overlapping shareholder ownership matters for patent success. We argue that coordinated action might be easier to organize, and shareholders have stronger incentives to resolve a potential holdup if the downstream innovating firm and upstream firms are jointly owned by only a few relatively large shareholders. Large overlapping shareholders of innovating firms are more likely to simultaneously serve on the boards of both upstream and downstream firms. In particular, 11% of the downstream firms in our sample have on average one or more board members who also sit on the boards of some of their upstream firms.[9] Our

[8]We do not classify institutions based on the conventional approach because there is substantial heterogeneity even within the same class of institutions. For example, about 68% of hedge funds are among the top one-third of institutions with the highest portfolio turnover, but a significant proportion (about 16%) of them appears to pursue a long-term investment strategy, with low turnover. In our empirical analysis, we sort all institutions separately by their portfolio turnover and portfolio diversification every year. Dedicated investors are those among the top tercile of institutions with the highest portfolio concentration and lowest turnover. Overall, 21% of hedge funds, 30% of pension funds, 48% of bank trust and insurance companies, and 32% of investment companies are classified as dedicated investors.

[9]We obtain board data from the BoardEx database. The database has limited coverage prior to 2000, and it covers about 66% of CRSP stocks in 2000 and 74% in 2007 (Engelberg, Gao, and Parsons, 2013). We are able

result complements the finding by Chemmanur, Shen, and Xie (2017) that overlapping equity blockholders facilitates the formation of R&D-related strategic alliances between firms in the same industry and that such alliance contributes to patent success.

Previous research has argued that institutional ownership *per se* can provide better long-term managerial incentives conducive to the pursuit of R&D (Aghion, Van Reenen, and Zingales, 2013). Our more structural approach to institutional ownership based on the network of ownership links in a world of asset complementarity allows us to construct a simple falsification test of this hypothesis: we decompose institutional ownership into a component contributing to shareholder overlap (and therefore holdup reduction) and a second component of non-overlapping (or standalone) institutional ownership. If the investor type matters through the non-overlapping (or standalone) institutional ownership, we expect it to have a positive effect on R&D investment similar to overlapping institutional ownership. Yet, overlapping and non-overlapping institutional ownership have highly significant *opposite* signs in the R&D investment regression, for which we can provide a simple agency interpretation: Non-overlapping institutional investors face an shareholder conflict with the overlapping institutional investors, because the latter would like management of the downstream firm to internalize patent rents to the upstream firm and overinvest. Ordinary institutional owners without an investment interest in the upstream firm seek to prevent what they perceive as overinvestment in R&D. A larger share of non-overlapping institutional investors should therefore negatively correlate with R&D investment and indeed it does so.

To the best of our knowledge, the role of joint stock ownership structure in mitigating holdup problems in patent processes has not been subject to any systematic analysis. Ex-ante contracting about access to auxiliary patents is difficult before the feasibility and commercial potential of a new patent are established, typically only after large proportions of the patent investments have been sunk. Holdup expectations reduce ex-ante investment incentives (resulting in ex-ante inefficiency) unless overlapping shareholders internalize such rent extraction through simultaneous ownership in upstream and downstream firms. In addition, costly patent rent extraction (resulting in ex-post efficiency losses) might also be reduced through the power of overlapping shareholders vis-à-vis upstream firms.

to find board information for 1,755 downstream firms and 1,532 upstream firms in our sample during the period 2000–2006. For the 11% of the downstream firms that share one or more common board members with their upstream firms, their average shareholder overlap SOL is 12.25%, much higher than the average SOL (5.36%) for the rest of the firms.

Our paper continues as follows. In section 2.1, we present five different empirical strategies to address endogeneity problems. Section 2.2 surveys the related literature. In section 3, we discuss the data, variable construction, and summary statistics. Section 4 presents the empirical evidence, and section 5 concludes. We also provide an extensive Internet Appendix. Appendix A proposes a simple model of patent holdup to illustrate the mechanism through which shareholder overlap increases ex-ante patent investment. Appendix B documents the variable construction in more detail. Appendix C gives further regression results.

2 Methodology and Literature Review

2.1 Empirical Strategies

We pursue five different strategies to address the potential omitted variables and reverse causality issues in the empirical relation between shareholder overlap and patent success. First, we reproduce our firm-level regressions at the patent level while controlling for interacted firm and year fixed effects. These fixed effects control for all unobservable omitted variables at the level of the downstream firm. Effectively, we compare the success of any two patents filed by the same firm in the same year as a function of their patent-level shareholder overlap *sol* with the respective upstream firms. We find that this *within-firm* patent success is again positively correlated with patent-level variations in shareholder overlap at a high level of statistical significance. Any remaining omitted variable effect thus needs to operate on the patent-level success of the downstream firm and simultaneously correlate with the ownership structure of the patent-specific upstream firms (and therefore correlate with *sol*).

Second, to address endogeneity concern arising from the ownership structure of upstream firms, we instrument the patent-level shareholder overlap *sol* with the average market capitalization of patent-specific upstream firms. The average size of the upstream firms correlates positively with *sol* and thereby influences holdup intensity, but should otherwise be irrelevant for the patent success of the downstream patent. The exclusion restriction here is based on the assumption that larger firms do not have any structural advantage in the enforcement of patent rights. Using a two-stage least squares approach, we again confirm that the *within-firm* variation of patent success covaries strongly with patent-specific shareholder overlap even when the latter is instrumented by the average market capitalization of the upstream firms.

Third, we use a quasi-natural experiment of merger by institutional investors to identify exogenous variation in shareholder overlap, similar to He and Huang (2017). Such mergers can suddenly increase the patent-level shareholder overlap sol if the merging investors each own substantial investments in a downstream patent and a related upstream patent, respectively. We find that such a "merger treatment," generating a significant increase in sol, indeed increases the patent success of such downstream patents relative to a control group of patents that are filed by the same firm but do *not* experience the enhanced patent-level shareholder overlap in the same merger.

Fourth, to further probe omitted variables operating at the firm level, we design two placebo tests. We replace the actual shareholder overlap (SOL) with a placebo shareholder overlap. The latter is constructed by replacing each cited upstream firm with a "similar" firm not cited by the downstream firm for the given year. "Similarity" is defined either as belonging to the same industry and sharing the same firm characteristics ($SOL\_Placebo1$) or by closeness in terms of technological proximity ($SOL\_Placebo2$). In both cases, the placebo shareholder overlap has no statistically significant effect on holdup mitigation and patent success.

Fifth, we address the issue of reverse causality by examining the evolution of shareholder overlap around patent filing events. The corresponding evolution of the two placebo measures of shareholder overlap provides a natural benchmark for the null hypothesis of no reverse causality. If investors anticipate a positive effect of shareholder overlap on potential future patent success and strategically acquire overlapping ownership shares prior to the public disclosure of patent filings to benefit from such patent rents, then future patent success (at time $t + 1$) can cause shareholder overlap (at time t), resulting in a reverse causality problem in our regression setup. Our event study evidence for the evolution of shareholder overlap around the patent filing year show that the true shareholder overlap evolves similarly to the two placebo measures of shareholder overlap—with no discernible effect of future patent filings on the true SOL. This finding may not be surprising because patent developments are generally kept secret and trading on insider information is sanctioned by law.

2.2 Related Literature

Notwithstanding its prominence in economic theory, the property rights view of the boundaries of the firm has seen few empirical applications. A variety of empirical problems explains the scarcity of evidence. First, non-contractible holdup problems are often difficult to identify in a complicated business environment. Second, underinvestment at the project level requires a level of disaggregation typically not available for investment data. Any firm-level analysis is clouded by the fact that a firm can shift investments to projects for which holdup problems are less severe. Third, investments may involve intangible resources (such as managerial attention), which pose additional measurement problems. In this study, the potential holdup problem in patent success is identified directly through the explicit citation of precursory patents in patent filings. Furthermore, we infer (latent) project underinvestment indirectly from the diminished success of a patent. Future patent citations provide a sufficiently precise proxy for the success or the economic value of a patent (e.g., Harhoff *et al.*, 1999; Kogan *et al.*, 2017), allowing for a comprehensive study of how shareholder overlap or common equity ownership extends firm boundaries and attenuates holdup in patent processes.

Can firms avoid patent conflicts? Given the cumulative and sequential nature of technological development, it is not always possible to invent around a patented technology. In practice, licensing agreements are often used (e.g., Shapiro, 2001; Ziedonis, 2004; Hall and Ziedonis, 2001)—yet these typically concern only the ex-post rent allocation, and their negotiation might not be a frictionless process, resulting in efficiency losses. There is also evidence that firms seek outright ownership integration via mergers to resolve major patent disputes. But firm mergers involve high transaction costs and might be challenged in court for anti-competitive reasons (Creighton and Sher, 2009). Our evidence suggests that in liquid equity markets, partial ownership integration via shareholder overlap might be achieved at lower costs.

Recent empirical work on the determinants of patent success focuses on the role of institutional shareholders. Aghion, Van Reenen, and Zingales (2013) argue that institutional shareholders are conducive to patent investment and innovation success as these shareholders provide reassurance to managers who are concerned about the risk involved in innovation projects. Bena, Ferreira, Matos, and Pires (2017) and Harford, Kecskés, and Mansi (2017) argue that long-term institutional shareholders have stronger incentives to monitor managers and therefore contribute to innovation success. By contrast, our paper examines the role of institutional investors in a world of patent complementarities from a property rights perspective. Here, institutional investors can have conflicting shareholder interest with respect to patent investments depending on their ownership overlap with complementary patents.

Our work is also related to a nascent literature on the coordination role of common shareholders in corporate policies. Azar, Schmalz, and Tecu (2017) show that cross-holdings of institutional shareholders soften product market competition. He and Huang (2017) show that firms sharing common equity blockholders are more likely to engage in joint ventures, strategic alliances, and acquisitions with each other, resulting in higher profitability and market share growth. Chemmanur, Shen, and Xie (2017) focus specifically on R&D-related strategic alliances among same-industry firms backed by common equity blockholders. They show that such alliances have a positive effect on corporate innovation in that the benefits (such as knowledge spillover and human capital redeployment) outweigh the costs (such as moral hazard) of alliances. We note that in our empirical analysis, we control for two countervailing R&D spillover effects (i.e., technology spillover and product market rivalry effects) and show that our result is robust (as reported in section 4.8).

Recent empirical work has also highlighted the complementarity between equity market development and the degree of patent innovation (Hsu, Tian, and Xu, 2014). Insofar as equity market development allows for a better internalization of holdup problems (through enhanced and adjustable *shareholder overlap*), this paper offers a deeper microeconomic interpretation rooted in the theory of the firm for the documented findings.

3 Data

3.1 Patent Information

We collect patent and citation information from the data set provided by Kogan *et al.* (2017). The data set contains annual patent and citation information for patents granted over the period 1926–2010.[10] Patent applications that have not been approved are not included in the data set. Following the existing literature (e.g., Griliches, Pakes, and Hall, 1986), we use the total number of a patent p's future citations ($cites_{p,t}$) from the patent filing year t to 2010 as our proxy for patent success. Generally, a patent is not known to the public during its application stage until USPTO publishes it, typically 18 months after the filing date. For earlier patents (filed before November 29, 2000), patent applications are not published until after they are granted. According to Hall, Jaffe, and Trajtenberg (2001), it takes on average 18 months for a patent's application to be approved and about 95% of successful patent applications are granted within three years of

[10] The data set is available at https://iu.app.box.com/patents. We thank Professor Noah Stoffman for making the data set available to us.

application. So the lag between patent filing and the first citation can range from zero to three years in most cases.

We examine the firm-level patent citations by summing up the patent-level citations by patent filing year instead of grant year because the former is closer to the date of invention. We aggregate the count statistic $cites_{p,t}$ to the total number of future patent citations generated by the cohort of patents filed by firm s in year t, denoted by $CITES_{s,t}$. Self-citations are excluded. Patent and citation counts are set to zero whenever there is no patent or citation information provided in the data. We also examine the extensive margin of patent production $N_{s,t}$, defined as the number of patent filings by firm s in year t. The corresponding intensive margin is measured by the average citations per patent $\overline{cites}_{s,t}$ (which equals the ratio of $CITES_{s,t}$ to $N_{s,t}$). Because most of these patent-related measures feature highly right-skewed distributions, we generally apply a log transformation $ln(1+X)$ to obtain more normally distributed variables for regression analyses.

We follow standard procedures to adjust for patent and citation truncation biases. First, because the patent data set only includes those patents that are eventually granted, we use only patent applications up to 2007 in our empirical analysis to allow for a three-year window of future citations up to 2010. Second, we control for time fixed effects in all our regressions to account for the fact that earlier cohorts of patents have more time to be cited than later cohorts. Third, we adjust for patent citation count based on the shape of the citation-lag distribution suggested by Hall, Jaffe, and Trajtenberg (2001, 2005).[11] Fourth, as a robustness check, we count only the citations received during the calendar year of the patent grant and three subsequent years (Lerner, Sørensen, Strömberg, 2011). Note that because expired patents should not create any holdup problems, we ignore upstream cited patents that have expired by the time the shareholder overlap measure is constructed.[12]

[11] For example, for a chemical patent filed in 2000, we observe only 10 years of citations. According to Table 5 of Hall *et al.* (2011), for a typical chemical patent about 52.9% of the estimated total citations occur during the first 10 years. Therefore, we would divide the observed total by 0.529 to yield the truncation-adjusted total citations.

[12] According to USPTO, the 20-year protection period for utility patents starts from the grant date and ends 20 years after the patent application was first filed. The only exception applies to those patents that are filed before June 8, 1995; these patents have a protection period that is the greater of either the 20-year term discussed earlier or 17 years from grant date. (See http://www.uspto.gov/web/offices/pac/mpep/mpep-2700.pdf.)

3.2 Ownership Data

We obtain the ownership data from the Thomson Reuters 13F database. The SEC requires all institutional organizations, companies, universities, and so on that exercise discretionary management of investment portfolios over \$100 million in equity assets to report those holdings on a quarterly basis. All common stock positions greater than 10,000 shares or \$200,000 must be reported. Aghion, Van Reenen, and Zingales (2013) show reporting inconsistencies in ownership data prior to 1991, so we only use ownership data from 1991 onwards.

We then combine the patent and citation data with institutional ownership data for publicly listed firms in the United States. Our final sample includes all U.S. publicly listed firms that have more than one patent application over the sample period 1992–2007. We require each firm to have at least two valid observations because we control for firm fixed effects in our main regression specifications. Our final sample includes $2,964$ firms. We exclude all firm-year observations with missing values for the explanatory variables or control variables. The control variables, including the (log) stock market capitalization $ln(MktCap_{s,t-1})$, cumulative R&D investment $ln(1 + R\&D\ Stock_{s,t-1})$, capital intensity $ln(K/L_{s,t-1})$, and sales $ln(Sales_{s,t-1})$, are drawn from the Compustat database. The sample features $19,020$ firm-years of patent production involving a total of $581,240$ patents. On average, a firm produces 31 patents per year.

3.3 Variable Construction

A key explanatory variable in our analysis is *shareholder overlap*, which we define as follows: Let $O(p)$ designate the downstream innovating firm owning patent p and $O(p_u)$ represent the upstream firm owning patent p_u. The *pairwise (institutional) shareholder overlap* between the downstream patent p and an upstream patent p_u (listed in the patent filing) is defined as

$$PSOL(p, p_u) = \sum_i \min[w_{i,O(p)}, w_{i,O(p_u)}], \tag{1}$$

where $w_{i,O(p)}$ and $w_{i,O(p_u)}$ are the ownership share (relative to the total institutional ownership of the respective firm) of institutional investor i in firms $O(p)$ and $O(p_u)$, respectively. We lag the ownership measure by one year relative to the application year of patent p. The *patent-level shareholder overlap* (sol) follows as the (importance) weighted average of $PSOL(p, p_u)$ over the

N_p upstream patents of patent p, given by

$$sol_p = \sum_{u=1}^{N_p} w(p_u) PSOL(p, p_u). \tag{2}$$

The *firm-level shareholder overlap* (SOL) is obtained as the (importance) weighted average sol_p over all N_s patents filed by firm s in a given year, given by

$$SOL_s = \sum_{p=1}^{N_s} w(p) sol_p = \sum_{p=1}^{N_s} \sum_{u=1}^{N_p} w(p) w(p_u) PSOL(p, p_u). \tag{3}$$

A measurement issue concerns the choice of weights reflecting the relative importance of any patents p and p_u. In the context of our model (presented in Appendix A), a higher weight assigned to a more important upstream patent reflects the fact that its owner is likely to have a stronger bargaining power in terms of future rent extraction. A higher weight for a more important downstream patent reflects the fact that any percentage holdup loss from such a patent amounts to more value loss for the firm.

In our main empirical tests, we measure the relative importance by the relative (log) citation count as follows:

$$w(p) = \frac{ln[1 + cites_s(p)]}{\sum_{p=1}^{N_s} ln[1 + cites_s(p)]} \quad \text{and} \quad w(p_u) = \frac{ln[1 + cites(p_u)]}{\sum_{u=1}^{N_p} ln[1 + cites(p_u)]}. \tag{4}$$

In section 4.8, we report additional results using equal weights. The results are qualitatively similar.

A limitation of our analysis is that due to data constraint we can measure ownership only for publicly listed firms, but not for private firms. Data on the portfolio holdings of private investors are generally not publicly available either. As a result, we may underestimate the extent of shareholder overlap, especially when the proportion of privately owned upstream patents is large. This imprecise measure of shareholder overlap creates an attenuation bias in the OLS estimate of SOL. To mitigate this effect, we track the average share of privately owned upstream patents for each downstream firm s and include it as a control variable, denoted by $Private\ Patent\ Share_s$. Because this variable captures potential "underestimation" of the true SOL, we expect it to have a positive sign.

3.4 Summary Statistics

Institutional ownership in U.S. listed stocks has grown rapidly, from an average of 25% in 1991 to 49% in 2006. The corresponding share is considerably larger for patent filing firms and rises from 41% in 1991 to 71% in 2006. Patent filing firms tend to be larger, and institutional investors typically prefer large firms. Graphs A and B in Figure 2 depict the distributions of institutional ownership and firm-level shareholder overlap, respectively, for the period from 1991 to 2006. Parallel to the rise in institutional ownership, the average firm-level shareholder overlap increases from 5.6% in 1991 to 7.4% in 2006. In our analysis, time fixed effects are included in all regressions to ensure that the documented shareholder overlap effect does not capture any parallel time trend in patent success. Cross-sectionally, shareholder overlap is positively related to institutional ownership in the downstream firm and even more strongly with its market capitalization, as shown in Figure 2, Graphs C and D. Shareholder overlap also varies substantially across firms with similar levels of institutional ownership and market capitalization. Such large heterogeneity in a firm's indirect control over complementary upstream patents via overlapping shareholders could plausibly condition patent holdup and determine a firm's long-run patent success.

Table 1 reports the summary statistics of key variables used in our analysis. Patent-level shareholder overlap (sol) shows an average value of 14.4% with a standard deviations of 14.2%, much larger than the corresponding statistics of 6.2% and 6.3% for firm-level shareholder overlap (SOL). The higher mean and standard deviation for the former are explained by the fact that firms with many patent filings are usually larger and feature a higher level of shareholder overlap. Detailed definitions of all variables are provided in Appendix B.

4 Evidence of Patent Success

Patent is about the extension of ownership rights to new ideas, products, and processes. The element of novelty implies that the scope for ex-ante contracting prior to patent investment is limited. The property rights view of a firm is therefore a natural starting point for thinking about patent investment and development. We develop a simple model of holdup attenuation through shareholder overlap, from the property rights perspective (Appendix A). In this section, we examine several testable hypotheses implied by the model.

4.1 Baseline Specification

Our main hypothesis (*the holdup attenuation hypothesis*) argues that joint equity ownership between the downstream innovator and the upstream firms controlling complementary patents attenuates the holdup problem and contributes to the long-run patent success of the innovating firm.[13] The baseline regression linking patent success to shareholder overlap is

$$ln[1 + CITES_{s,t}] = \beta_0 + \beta_1 SOL_{s,t-1} + \beta_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \tag{5}$$

where a coefficient $\beta_1 \geq 0$ implies that more shareholder overlap with firms holding upstream patents should boost the downstream innovating firm's patent success because holdup problems are attenuated.[14] In the above specification, β_0 represents the overall constant for all observations, β_2 denotes the vector of coefficients for control variables, ϵ_s and μ_t denote, respectively, firm and year fixed effects, and $\eta_{s,t}$ is the error term.

We estimate Eq. (5) over the period 1992–2007. The citation count $CITES_{s,t}$ for patents filed by firm s in year t includes all future citations up to year 2010. *Shareholder overlap* ($SOL_{s,t-1}$) measures the ownership overlap at the end of year $t-1$ between the innovating firm and all other firms controlling complementary patents. For the choice of control variables, we follow Aghion, Van Reenen, and Zingales (2013) and include the cumulative R&D investment $ln(1+R\&D\ Stock_{s,t-1})$, a measure of relative capital intensity $ln(K/L_{s,t-1})$, and firm sales $ln(Sales_{s,t-1})$. We also control for firm size proxied by market capitalization value $ln(MktCap_{s,t-1})$ and the (weighted) share of private firms in the cited upstream firms, $Private\ Patent\ Share_{s,t-1}$.

In Table 2, Columns 1–2 present the results for all firms and Columns 3–4 firms in the top three R&D-intensive sectors (pharmaceuticals, computer hardware, and telecommunications equipment).[15] Robust standard errors clustered at the firm level are reported in parentheses. All

[13] We measure patent success in log terms as $ln[1+CITES]$ instead of $ln[CITES]$ because some firms register patents that have never been cited throughout the sample period. As discussed in section 4.8, using $ln[CITES]$ as the dependent variable yields qualitatively similar results.

[14] The Internet Appendix A derives a simple model of patent holdup and shareholder overlap. It suggests $\beta_1 = \frac{1}{b}\overline{L}$, where b is the convexity parameter of the patent cost function and $\overline{L}$ denotes the maximum profit share extracted by the upstream firm under zero shareholder overlap.

[15] Following Bloom, Schankerman, and Van Reenan (2013), we refer to pharmaceuticals, computer hardware, and telecommunications equipment as top the three R&D intensive sectors. Specifically, we identify each of these sectors with a corresponding industry in Fama-French 49-industry classification. The pharmaceutical sector corresponds to Fama-French industry #13 (drug: pharmaceutical product), the computer hardware sector to #35 (hardware: computer), and the telecommunications equipment sector to #37 (chips: electronic equipment).

specifications control for year fixed effects and industry fixed effects based on four-digit SIC codes. Columns 2 and 4 additionally control for the pre-sample mean of dependent variable, as proposed by Blundell, Griffith and Van Reenen (1999). The ordinary fixed effect estimator is consistent only if the independent variables are strongly exogenous with respect to the error term $\eta_{s,t}$. Theoretically, such strong exogeneity can be further relaxed (to sequential exogeneity or predetermined regressors) if a first difference (FD) estimator is used together with lagged regressors as instruments. But as in our case, limited within-firm variation for the regressors prevents instrumentation by lagged variables. Blundell, Griffith and Van Reenen (1999) therefore propose to replace the ordinary firm fixed effect estimator with the pre-sample mean of the dependent variable and show consistency under increasing time length of the pre-sample even if the regressors are only weakly exogenous. We following this procedure (also adopted by other researchers, e.g. Aghion, Van Reenen, and Zingales, 2013, and Blanco and Wehrheim, 2017) and construct a 25-year pre-sample mean of $CITES_{s,t}$.[16]

The baseline regression in Column 1 shows that *shareholder overlap SOL* represents a statistically and economically significant explanatory variable. The point estimate of 3.692 implies that an increase in shareholder overlap by one standard deviation (or 0.063) increases patent success in terms of a firm's log patent citation ($ln[1+CITES]$) by 11.3% of its standard deviation of 2.065, suggesting that shareholder overlap has an economically large attenuation effect on patent success. The control variables generally have the expected signs: Firm size correlates positively with the overall number of citations a firm receives, suggesting that large firms may generally be in a better position to assure the long-run success of their patents or may simply launch more successful patents. A higher stock of cumulative R&D spending and a higher capital intensity ratio also correlate positively with future patent success. As expected, *Private Patent Share* has the same sign as SOL because it proxies for the possible underestimation of shareholder overlap due to the unobserved overlap originating from private investors. The inclusion of the pre-sample mean as a proxy for firm fixed effects in Column 2 adds a statistically highly significant regressor; yet this pre-sample estimator avoids the saturation of the cross-sectional sample variation with firm fixed effects. Economically, we obtain a very similar coefficient β_1 as under OLS estimation, which suggests that our independent variable SOL is reasonably exogenous.

[16] Pre-sample means indeed show a high correlation with the firm fixed effects as one might expect. We also report the firm fixed effect regressions in Appendix C. The coefficient estimates for SOL remain statistically significant at the 1% level, but their size drops.

Columns 3–4 repeat these regressions for the top three R&D-intensive sectors. As expected, we find a statistically and economically stronger SOL effect in these sectors than in others. The point estimate for SOL in Columns 3–4 increases both by more than 25% compared with those in Columns 1–2. Not surprisingly, shareholder overlap matters most for patent success in those industries that are most patent-intensive.

4.2 Intensive versus Extensive Margins

Shareholder overlap may affect intensive and extensive margins differently. The intensive margin of patent success is captured by the average number of citations per patent $\overline{cites}$. Again, we use the logarithmic transformation $ln[1 + \overline{cites}]$ to obtain a suitable dependent variable for the regression

$$ln[1 + \overline{cites}_{s,t}] = \theta_0 + \theta_1 SOL_{s,t-1} + \theta_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \tag{6}$$

where $\theta_1 > 0$ implies that patent holdup reduces the average success of a firm's patents. A positive value of θ_1 points to ex-post patent value destruction under patent conflict rather than mere rent redistribution to upstream firms. By contrast, frictionless ex-post bargaining should primarily affect the extensive margin of patent production, but not the intensive margin of patents that come into existence.

Table 3, Columns 1–2 summarize the effect of shareholder overlap on the intensive margin. The regression in Column 1 yields a point estimate of 0.584, which implies that an increase in shareholder overlap by one standard deviation (or 0.063) corresponds to an increase in the average citation count per patent by a modest 3.2% of its standard deviation. In Column 2, we include again the pre-sample mean of the dependent variable as a control for permanent individual firm effects. Inclusion of the pre-sample mean in Column 2 generates a point estimate for SOL of 0.527, which is only slightly smaller than the estimate obtained in Column 1.

The empirical specification for the extensive margin uses the log number of patents as the dependent variable

$$ln[1 + N_{s,t}] = \psi_0 + \psi_1 SOL_{s,t-1} + \psi_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \iota_{s,t}, \tag{7}$$

where the coefficient ψ_1 captures the effect of holdup mitigation through shareholder overlap on the number of successful patent filings. The point estimate of 2.923 for ψ_1, reported in Column

3 of Table 3, suggests a strong economic significance for the shareholder overlap measure; a one-standard-deviation increase in SOL is associated with 18.4% increase in the number of patents. The coefficient retains statistical significance and economic significance in Column 4 where the pre-sample mean of the dependent variable is included.

Overall, the results suggest that shareholder overlap is associated with both more citations for each granted patent (i.e., the intensive margin of patent success) and more granted patents in total (i.e., the extensive margin of patent production). The relation between holdup mitigation and patent production appears economically much stronger for the extensive margin. Under shareholder overlap, firms tend to file more patents—presumably because of lower patent rent transfers and/or their internalization by overlapping shareholders.

4.3 Two Dimensions of SOL Heterogeneity

Which type of overlapping shareholder has the strongest incentives to resolve a potential patent holdup and the greatest ability to influence corporate managers in their R&D decisions? First, we conjecture that long-term institutional investors with concentrated portfolio positions are more likely to devote time and effort to resolving patent-related conflicts. Second, concentration of overlapping ownership among relatively few institutional investors limits free-riding and facilitates the coordination of investor influence.

To test the first hypothesis, we categorize institutional investors into (i) dedicated investors, (ii) intermediate investors, and (iii) transient investors based on a combination of portfolio concentration (proxied by the Herfindahl-Hirschman Index, HHI) and portfolio turnover (proxied by the churn ratio defined in Gaspar, Massa, and Matos, 2005).[17] At the end of each year, we sort all institutional investors by the HHI (in descending order) and churn ratio (in ascending order) and then calculate the combined rank as the average of the HHI rank and churn ratio rank in percentile. We label investors in the top tercile of the combined rank (high concentration and low turnover) dedicated investors, and investors in the bottom tercile (low concentration and high turnover) transient investors. The remaining the investors, in the middle tercile, are labeled intermediate investors. The labeling of investor types along the two sorting criteria is shown in Figure

[17] We provide detailed definitions of these variables in the Internet Appendix B.

3 and permits the decomposition of shareholder overlap according to the three investor types:

$$SOL_{s,t-1} = SOL\_Dedicated_{s,t-1} + SOL\_Intermediate_{s,t-1} + SOL\_Transient_{s,t-1}. \quad (8)$$

The regression result, reported in Column 2 of Table 4, confirms our hypothesis. The coefficient for $SOL\_Dedicated$ is 19.926, more than five times the estimate for SOL in the baseline regression of Table 2 (reproduced in Column 1 of Table 4). Shareholder overlap originating from the other two groups of investors shows a much weaker effect on patent success. This confirms the first hypothesis that investor type matters for the holdup attenuation effect.

The second hypothesis concerns the concentration of shareholder overlap rather than its type. If joint equity ownership is constituted by a few relatively large shareholders, coordinated investor action is easier to organize and incentives to do so strongest. We consider a downstream patent p filed by firm s in year t and a related upstream patent p_u owned by firm u. Let $i \in I_{(p,p_u),t-1}$ denote an overlapping investor, who at the end of year $t-1$ owns equity shares (relative to total institutional ownership) $w_{i,s}$ and $w_{i,u}$ in firms s and u, respectively. For a patent pair (p, p_u), we can define a Herfindahl-Hirschman Index ($hhi_{(p,p_u),t-1}$) based on the overlapping ownership shares $\varpi_i = \min[w_{i,s}, w_{i,u}]$ of all overlapping shareholders $i \in I_{(p,p_u),t-1}$. We can further aggregate this concentration measure $hhi_{(p,p_u),t-1}$ over all upstream patents p_u related to patent p and, subsequently, over all downstream patents p filed by firm s in year t to obtain a weighted Herfindahl-Hirschman Index ($WHHI$) of ownership concentration of overlapping shareholders, defined as

$$WHHI_{s,t-1} = \sum_{p=1}^{N_s} \sum_{u=1}^{N_p} w(p)w(p_u)hhi_{(p,p_u),t-1} \quad , \quad (9)$$

where $w(p)$ and $w(p_u)$ denote (as defined in Eq. (4)) the relative importance weights for patents p and p_u, respectively, and ownership shares are measured at the end of year $t-1$. $WHHI$ describes the concentration of overlapping ownership stakes at the firm level and thus captures the coordination problem among overlapping investors.

Table 4, Column 3 includes $WHHI$ as a separate control variable. The estimated coefficient is positive and statistically highly significant—suggesting that concentration of joint ownership shares by overlapping shareholders positively correlates with patent success beyond the shareholder overlap SOL itself. The coefficient estimate of 2.206 for $WHHI$ implies that an increase in the ownership concentration of shareholder overlap by one standard deviation (or 0.071) generates the same effect on patent success as raising SOL by 57.9% relative to its mean (= [0.071 × 2.206] / [4.361 × 0.062]). We infer that the coordination problem among dispersed overlapping institutional investors represents an important impediment to the exercise of effective shareholder power.

4.4 Patent-Level Regressions

In this section, we present patent-level regressions that use separate firm and year fixed effects and also interacted firm-year fixed effects. The latter specification identifies the holdup attenuation effect on patent success by relying entirely on the comparison of different patents filed by the same firm in the same year. In a second step, we propose the average size of the upstream firms as an instrument for patent-level shareholder overlap. The two-stage least squares (2SLS) procedure promises consistent estimates under the exclusion restriction that larger firms do not have any structural advantage in the enforcement of patent rights and that patent holdup attenuation operates only through patent-level shareholder overlap. Finally, we argue that the merger of institutional shareholders provides an exogenous change to shareholder overlap and therefore a quasi-natural experiment to investigate the role this shareholder overlap change plays in patent success.

Different patent filings by the same firm may cite different upstream patents, resulting in patent-specific holdup and shareholder overlap even within the same firm-year. The patent-specific holdup attenuation is captured by patent-level shareholder overlap $sol_{p,t-1}$ in the regression specification

$$ln[1 + cites_{p,t}] = \lambda_0 + \lambda_1 sol_{p,t-1} + \lambda_2 Controls_{p,t-1} + \delta_{s,t} + \pi_{f,t} + \tau_{p,t}, \qquad (10)$$

where $cites_{p,t}$ denotes the future citation count of patent p filed in year t. Similar to the firm-level regressions, the shareholder overlap variable lags the dependent variable by one year. The variable $\delta_{s,t}$ denotes the interacted firm and year fixed effects, $\pi_{f,t}$ represents the interacted technology field and year fixed effects, and $\tau_{p,t}$ is the residual term.[18]

Any omitted variable problem should be less severe for the patent-level regressions because the interacted year-firm fixed effects control for all unobservable (time-variant) influences at the level of the downstream firm. This sharper identification comes at a price: by conditioning on existing

[18] Hall, Jaffe, and Trajtenberg (2001) categorize technology classes into 36 technology fields.

patents, we exclude any effects of shareholder overlap on the extensive margin and focus exclusively on the intensive margin of patent success. Any remaining omitted variable effect in Eq. (10) needs to influence patent-level success of the downstream firm (i.e., $ln[1 + cites_{p,t}]$) and simultaneously correlate with the ownership structure of the patent-specific upstream firms (and hence correlate with $sol_{p,t-1}$). To address such a remaining endogeneity concern with respect to the ownership of the upstream firms, we conduct a 2SLS regression by instrumenting sol with the average market capitalization of the patent-specific upstream firms. The average size of these patent-specific upstream firms correlates positively with shareholder overlap ($sol_{p,t-1}$) but is unlikely to matter for the patent success of the downstream firm (i.e., has no correlation with the residual term $\eta_{p,t}$) if the enforcement of patent rights itself is not contingent on the size of upstream firms.

Because we control for the firm-year fixed effects in the patent-level regressions, we discard all firm-years that feature only one patent application. Such cases account for about 25% of the overall sample. The patent-level data thus feature a strong selection of firms with many patents—51% of all patent filings are from the 1% most patent-intensive firms (as measured by the total number of patent filings over the sample period) and the other 49% are from the remaining 99% of the firms. It is also noted that the patent-level citation success $cites_{p,t}$ can capture only the intensive margin, but not the extensive margin, of patent success.

Columns 1–2 in Table 5 find positive and statistically significant point estimates for patent-level shareholder overlap. Columns 3–4 report the first- and second-stage results of the 2SLS regression, respectively. The exclusion restriction in the first-stage for the instrument has a t-statistic of 99.6, which indicates a strong instrument. The second-stage point estimate for sol in Column 4 is at 0.283 almost identical to the OLS estimate in Column 2, given by 0.272. Overall, these results confirm the hypothesis that even within a firm the success of any specific patent depends on the holdup attenuation provided by overlapping shareholders.

Finally, we exploit a quasi-natural experiment of mergers between institutional shareholders, which can exogenously reshape shareholder overlap. This identification strategy follows He and Huang (2017) and takes advantage of the fact that institutional shareholders (e.g. bank holding companies, security brokers, asset management firms, etc.) often merge for reasons unrelated to the selection of their respective portfolio firms. Moreover, He and Huang (2017) argue that acquiring funds often continue to hold the target funds' portfolio (especially for block holding) after merger completion due to concerns about liquidity and the transaction costs of rebalancing. If the institutional shareholder of a downstream patent-owning firm merges with a second institutional shareholder owning firms with upstream patents related to the downstream patent, we expect the shareholder overlap *sol* for such a downstream patent to increase post-merger. The validity of this experiment relies on the assumption that the merger decision of two financial institutions is independent of holdup (and other) concerns about their portfolio firms. He and Huang (2017) defend this assumption by stressing that fund mergers are often driven by financial deregulation and/or concerns about distribution channels rather than issues pertaining to fund portfolios.

From SDC database we retrieve all merger deals between two financial firms or funds (SIC Code 6000–6999) announced during the period 1992–2006 and manually match each merger deal with the filings of institutional ownership in the Thomson Reuters 13F database. Following He and Huang (2017), we require that the target fund terminates 13F filings within one year of the merger date. For each merger deal, we consider a seven-year event window centered around the year of fund merger. We refer to "treated patents" as those downstream patents p fulfilling the following three conditions: First, at least one patent pair (p, p_u) with an upstream patent p_u experiences an increase in its shareholder overlap *sol* under the fund merger. Second, one merging fund holds least a 2.5% of total institutional ownership in the downstream firm. Third, the other merging fund owns at least 2.5% of institutional ownership in any one of the upstream firms.[19] Treated patents are identified based on the ownership information in the quarter immediately preceding the merger announcement date. The choice of a high ownership cut-off at 2.5% predicts a large increase in shareholder overlap for treated patents and this increase is likely to be persistent. Thus, we avoid the use of ownership information after the merger announcement, which might give rise to endogeneity concerns. As "control patents" we use all patents filed in the same year by the same downstream firm and assigned to the same patent class, but not affected by the fund merger because no upstream firm is owned by the other fund in the same quarter. In total, we identify 47 merger deals featuring $17,707$ treated patents and $70,383$ control patents.

We first establish that the merger events between two institutional investors (or funds) indeed feature an increase in the shareholder overlap for treated patents and (in a second stage) examine its effect on patent success. Defining dummy variables *Treat* for "treated patents" and *Post-Merger*

[19] We find broadly similar results if this threshold is increased to 5% of institutional ownership.

for observations after the fund merger, we estimate the two regressions

$$\begin{aligned} sol_p &= \gamma_0 + \gamma_1 \mathit{Treat} + \gamma_2 \mathit{Post\text{-}Merger} + \gamma_3 \mathit{Treat} \times \mathit{Post\text{-}Merger} + \xi_{e,s,f} + \varsigma_p \quad (11) \\ ln[1 + cites_p] &= \gamma_4 + \gamma_5 \mathit{Treat} + \gamma_6 \mathit{Post\text{-}Merger} + \gamma_7 \mathit{Treat} \times \mathit{Post\text{-}Merger} + \omega_{e,s.f} + \nu_p. \quad (12) \end{aligned}$$

The terms $\xi_{e,s,f}$ and $\omega_{e,s,f}$ represent fixed effects for each data cell characterized by a fund merger event e, a downstream firm s, and a patent class f. Each observation is a patent filed either before or after the merger event and comes as a treated or non-treated (control group) patent. Inclusion of the interacted fixed effects means that we compare only treated and control patents assigned to the same patent class, owned by the same firm, and subject to same merger event.

In Table 5, Column 5, the positive and statistically significant coefficient for the interaction term *Treat* ×*Post-Merger* confirms that treated patents increase their shareholder overlap (*sol*) in the three years following a fund merger. By contrast, this is not the case for control patents as indicated by the statistically insignificant coefficient for the dummy *Post-Merger.* Column 6 reports the parallel specification of Eq. (12) for fund merger effect on patent success. The positive and statistically significant estimate for the interaction term *Treat*×*Post-Merger* suggests that treated patents with their exogenous increase in shareholder overlap are more successful in terms of their citation count, which increases by roughly 13.5% relative to patents in the control group. This is evidence for a causal effect of shareholder overlap *sol* on patent success.

4.5 Two Placebo Tests

In this section, we conduct two different placebo tests to examine whether any unobservable factors could facilitate the formation of joint equity ownership between downstream and upstream firms and, simultaneously, enhance the patent success of downstream firms. For example, institutional investors may jointly hold equity shares in both upstream and downstream firms that operate in related product markets (e.g. supplier and customer) or technologically related sectors to take advantage of the stock price appreciation driven by the technological progress of firms in the relevant product or technology sectors. To show our findings are not driven by the aforementioned endogeneity, we replace the true shareholder overlap (SOL) with one of two placebo shareholder overlap measures, $SOL\_Placebo1$ and $SOL\_Placebo2$, the former retaining product market similarities and the latter technological similarities. For both placebo measures, we replace each upstream firm (cited by a patent belonging to the cohort of patents filed by a downstream firm in a given year) with a similar firm that is not cited by any patent in the same patent cohort. $SOL\_Placebo1$ chooses a placebo firm based on the criteria that it must have the same four-digit SIC codes as the true upstream firm and the shortest Euclidean distance to the true upstream firm in terms of (log) firm asset size and (log) number of patents filed in the past three years. $SOL\_Placebo2$ matches a placebo firm to the true upstream firm based on technological proximity (i.e., the closeness in the distribution of their patents across various technology fields) as defined by Bloom, Schankerman, and Van Reenen (2013).

Columns 4–5 of Table 4 show that the placebo measures $SOL\_Placebo1$ and $SOL\_Placebo2$ do not feature any statistically significant correlation with patent success. If the positive holdup attenuation effects of shareholder overlap documented in the previous sections are driven by unobservable factors that operate at the level of product market or technology sector, such omitted variables should similarly lead to a positive relation between placebo shareholder overlap and patent success. Yet, no such evidence is obtained for the two placebo measures of shareholder overlap, which is inconsistent with the omitted variable hypothesis.

4.6 R&D Expenditure and Non-Overlapping Institutional Ownership

In this section, we examine whether shareholder overlap reduces R&D underinvestment, using the following linear panel regression

$$R\&D\ Exp_{s,t}/Assets_{s,t} = \kappa_0 + \kappa_1 SOL_{s,t-1} + \kappa_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \rho_{s,t}. \qquad (13)$$

Table 6, Column 1 reports the regression results. The effect of shareholder overlap is statistically and economically significant in the specification. The point estimate of 0.24 in Column 1 suggests that an increase in shareholder overlap by one standard deviation (or 0.063) increases the dependent variable by 9.9% of its standard deviation. The holdup attenuation effect of shareholder overlap on R&D investment is therefore economically important.

Previous research has argued that institutional ownership can *ceteris paribus* provide better long-term managerial incentives conducive to the pursuit of R&D (Aghion, Van Reenen, and Zingales, 2013). However, the statistically insignificant coefficient for institutional ownership (IO) in Column 2 does not support this argument. By contrast, the point estimate for shareholder overlap (SOL) in Column 3 retains its economic and statistical significance even after controlling for institutional ownership, which suggests that the property rights perspective developed in this paper is empirically more relevant.

We can further elaborate on this issue by decomposing institutional ownership $IO_{s,t}$ itself into ownership by overlapping institutional shareholders ($IO^{SOL}_{s,t}$) that contribute to shareholder overlap (i.e., all shareholders i with $\min[w_{i,O(p)}, w_{i,O(p_u)}] > 0$ for at least one pair (p, p^u)] and a residual non-overlapping component by institutional shareholders ($IO^{NOL}_{s,t}$). Formally, we have

$$IO_{s,t} = IO^{SOL}_{s,t} + IO^{NOL}_{s,t}.$$

By construction, $IO^{SOL}_{s,t}$ strongly correlates with our shareholder overlap measure $SOL_{s.t}$ with a correlation of 0.53.[20] If institutional ownership *per se* exerts a positive influence on R&D investment, we expect the same positive coefficient for both $IO^{SOL}_{s,t-1}$ and $IO^{NOL}_{s.t-1}$. The property rights view predicts an agency conflict between overlapping shareholders advocating more investment (due to transfer internalization) and non-overlapping institutional owners objecting to overinvestment under holdup; hence a larger share of overlapping (non-overlapping) institutional shareholders should be positively (negatively) correlated with R&D investment.

Column 4 of Table 6 modifies the specification in Eq. (13) to include both overlapping institutional ownership $IO^{SOL}_{s,t-1}$ and non-overlapping institutional ownership $IO^{NOL}_{s.t-1}$, and reveals opposite signs for the respective coefficients at high levels of statistical significance. It is not institutional ownership *per se* that matters for the level of R&D investment; instead, different types of institutional owners with different property rights exercise opposing influences on the R&D investment process. Our decomposition shows again that the property rights perspective is empirically pertinent.

4.7 Reverse Causality

We have adopted various econometric strategies to deal with potential endogeneity issues. Patent-level regressions have been used to deal with omitted firm-level variables, instrumental variables further limit endogeneity concerns to a specific exclusion restriction, and the quasi-natural experiment of fund mergers further strengthens the causal interpretation of our evidence. The two

[20]The SOL measure is generally smaller than IO^{SOL} because it only accounts for the minimum of ownership shares of the downstream and upstream firm as defined in Eqs. (1) and (3).

placebo tests presented in section 4.5 also alleviate concerns that omitted variables drive the evidence. Next, we discuss reverse causality as an alternative explanation for the correlation evidence. If investors anticipate a positive effect of shareholder overlap on potential future patent success and strategically acquire overlapping ownership shares prior to the public disclosure of patent filings to benefit from such patent rents, then future patent success (at time $t+1$) can cause shareholder overlap (at time t), resulting in a reverse causality problem in our regression setup.

The quasi-natural experiment of fund mergers represents one way to address the reverse causality concern. But a more direct approach insists on an event study, which quantifies reverse causality by documenting the evolution of shareholder overlap (relative to the two placebo measures) around patent filings. For each yearly cohort of patents filed between 1991 and 2007, we measure the evolution of the average firm-level shareholder overlap relative to the year of the patent filing. For a cohort of downstream patents filed in year t, let $SOL(t,k)$ represent the average shareholder overlap measured based on ownership data at the end of year $t+k$, where $k=-5,-4,...,0,1$. For example, $SOL(t,-3)$ denotes average shareholder overlap between downstream and upstream firms measured based on ownership at the end of year $t-3$ for all patents filed in year t. The average ownership overlap (measured at lag k) across all patent filing years is denoted by $\overline{SOL}(k)$ and is plotted in Figure 4.[21] As a benchmark, we also plot the evolution of the two placebo shareholder overlap measures, $\overline{SOL\_Placebo}1(k)$ and $\overline{SOL\_Placebo}2(k)$, defined analogous to $\overline{SOL}(k)$. The vertical line segment marks two standard deviations around the mean value for each measure. The figure shows that in the neighborhood of the patent filing year ($k=0$), the average shareholder overlap $\overline{SOL}(k)$ evolves similarly to the two placebo benchmarks, which are by construction devoid of future patent rents and thus not subject to any reverse causality concern.

Overall, we find no evidence that the shareholder overlap $\overline{SOL}(k)$ reacts endogenously in anticipation of patent rents from future patent filing. During the five-year run-up to the patent filing year, $\overline{SOL}(k)$ actually does not change much, with an aggregate change of only -0.00024, which is less than 0.5% of a standard deviation of SOL. This finding may not be surprising for at least two reasons: First, patent developments are generally kept secret so public information should be extremely scarce. Second, legal restrictions on insider trading limit the scope for stock

[21] We note that the full set of $SOL(t,k)$ cannot be calculated for all years. For example, for patents filed in 1992, we can only calculate $SOL(t,k)$ for $k>=-1$. Similarly, for patents filed in 2007, $SOL(t,k)$ can only be calculated for $k<=0$.

trading on private information.

4.8 Robustness Issues

Next, we report a series of robustness checks. First, we include *institutional ownership* ($IO_{s,t-1}$) as an additional explanatory variable of patent success in Column 2 of Table 7. Aghion, Van Reenen, and Zingales (2013) argue that R&D investments have a long-term horizon, and a high share of institutional investors allows management to focus on the long-term return on investment. The variable *shareholder overlap* ($SOL_{s,t-1}$) retains its high positive level of statistical significance.

Second, Bloom, Schankerman, and Van Reenen (2013) show two countervailing $R\&D$ spillover effects on a firm's innovation success: A positive effect due to technology spillover (from other firms that operate in similar technology fields) and a negative effect due to product market rivalry (from other firms that operate in similar product markets). Column 3 shows that even after accounting for these two factors, measured by $ln(SpillTech)$ and $ln(SpillSIC)$, the shareholder overlap effect remains quantitatively unchanged. Columns 4–5 include all the aforementioned explanatory variables simultaneously. Column 4 is estimated by OLS with $ln[1{+}CITES_{s,t}]$ as the dependent variable (as before). Column 5 uses $CITES_{s,t}$ as the dependent variable and is estimated by a negative binomial model. The shareholder overlap effect remains strong in both models.

Our baseline measure of $CITES$ follows Hall, Jaffe, and Trajtenberg (2001) in adjusting the citation count based on the shape of the citation-lag distribution. An alternative approach to treating the truncation issue associated with patent citation is to consider patent citations received within a specified period. Particularly, we count only the citations received during the calendar year of the patent grant and the three subsequent years and denote this citation count as $CITES^{3y}$. The modified shareholder overlap variable using corresponding importance weight is denoted by SOL^{3y}. The regression result reported in Column 6 is again robust to this alternative measure of citation count. We also repeat the benchmark regression of Column 1, but use $ln(CITES)$ for strictly positive observations as an alternative dependent variable. The economic significance of SOL, reported in Column 7, remains high in this smaller sample.

As patent citation count is often perceived as a value signal (Harhoff, Narin, Scherer, and Vopel, 1999; Hall, Jaffe, and Trajtenberg, 2005), overlapping institutional shareholders may promote cross-citations among firms in which they also have a joint equity stake. To eliminate such spurious effects from our regression, we exclude all citations that come from the upstream firms cited in the patent filings of the downstream firm. Column 8 repeats the baseline regression but uses this modified patent citation $ln(1 + CITES^F)$ as the dependent variable. The estimate of 3.252 for SOL is quantitatively similar to that of 3.45 reported in the baseline regression—suggesting that any potential bias arising from such citation manipulation is small.

Finally, we conduct a variety of robustness tests concerning the measurement of shareholder overlap. First, our baseline measure of shareholder overlap ($SOL_{s,t-1}$) is based on ownership stake at the end of year $t-1$. Column 9 of Table 7 replaces $SOL_{s,t-1}$ with $SOL_{s,t-2}$, which is measured based on ownership stake at the end of year $t-2$. The coefficient estimate for $SOL_{s,t-2}$ is statistically significant. Using equity stakes measured at years $t-3$ and $t-4$ still produces statistically significant point estimates for SOL, albeit at a smaller magnitude. Lastly, we create an equal-weight measure that simply aggregates all combinations of downstream and upstream patents under equal weights defined as SOL_equal. Notwithstanding the modification, we still find a qualitatively similar result, reported in Columns 10, for the holdup attenuation effect of shareholder overlap.

5 Conclusion

This paper provides a property rights perspective on the success of corporate innovation processes. The commercial success of patents often depends on access to complementary patents not under the direct corporate control of the innovating firm. Contracting frictions both ex-ante and ex-post provide benefits to joint ownership of complementary patents. We argue that the increasing and often overlapping equity ownership of institutional investors plays an important role in mitigating patent conflict and internalizing patent holdup. As a consequence, a firm's patent process is more successful if the firm has institutional owners that simultaneously own substantial stakes in other firms with complementary patents. Overlapping institutional ownership represents a tacit extension of the boundary of the innovating firm.

We identify complementary patents based on patent documents that directly list related precursory patents, which may have rival patent claims to new products. To measure the role of institutional owners, we define *shareholder overlap* (SOL) as the (importance-weighted) aggregate minimum ownership share that investors own jointly in both the innovating firm and the firms controlling complementary assets; an innovating firm with a large SOL value can be interpreted as having an "extended firm boundary." Our key finding is that *shareholder overlap* of institutional investors represents an important determinant for patent success both at the firm and patent level, where we measure patent success (in line with the literature) by future patent citations. An extended firm boundary also has a strong economic effect on the extensive margin of patent production, i.e. the number of successfully filed patents a firm develops.

We highlight that shareholder overlap is distinct from institutional ownership and itself a source of agency conflicts between different shareholders. In particular, we can decompose institutional ownership into (i) a component contributing to shareholder overlap with a strong positive impact on a firm's R&D investment and patent success and (ii) a component of non-overlapping (or standalone) institutional ownership with opposing interests. Non-overlapping institutional investors resist the internalization of patent holdup by overlapping shareholders and exercise a negative constraining influence on the level of R&D investment. Our focus on patent holdup thus provides a deeper and richer understanding for the role of institutional investors in the corporate innovation process.

The extension of intellectual property rights and the growing economic value of "infrastructure assets" like information, trading and distribution platforms in the digital economy make the property rights perspective arguably more relevant. It also shifts the focus from intra-firm or governance issues to inter-firm conflicts and their resolution. The corporate finance literature has examined institutional equity ownership mostly in relation to corporate governance. But as institutional ownership is often overlapping ownership across firms, it also represents a key factor for shaping inter-firm conflict, cooperation or collusion, as highlighted in more recent literature (Azar, Schmalz, and Tecu, 2017; Chemmanur, Shen and Xie, 2017). This calls for a broader industrial organization perspective on the role of institutional ownership, which we believe provides great opportunities for future research.

References

[1] Aghion, P., Van Reenen, J., Zingales, L., 2013. Innovation and institutional ownership. American Economic Review 103, 277–304.

[2] Alcácer, J., Gittelman, M., Sampat, B., 2009. Applicant and examiner citations in U.S. patents: an overview and analysis. Research Policy 38, 415–427.

[3] Asker, J., Farre-Mensa, J., Ljungqvist, A., 2015. Corporate investment and stock market listing: a puzzle? Review of Financial Studies 28, 342–390.

[4] Azar, J., Schmalz, M., Tecu, I., 2017. Anti-competitive effects of common ownership. Unpublished working paper. Ross School of Business Paper.

[5] Bena, J., Ferreira, M., Matos, P., Pires, P., 2017. Are foreign investors locusts? the long-term effects of foreign institutional ownership. Journal of Financial Economics (forthcoming).

[6] Blanco, I., Wehrheim, D., 2017. The bright side of financial derivatives: options trading and firm innovation. Journal of Financial Economics 125, 99-119.

[7] Bloom, N., Schankerman, M., Van Reenen, J., 2013. Identifying technology spillovers and product market rivalry. Econometrica 81, 1347–1393.

[8] Blundell, R., Griffith, R., Van Reenen, J., 1999, Market share, market value and innovation in a panel of British manufacturing firms. Review of Economic Studies 66, 529–54.

[9] Chemmanur T., Shen, Y., Xie, J., 2017. Innovation beyond firm boundaries: common blockholders, strategic alliances, and corporate innovation. Unpublished working paper. Boston College.

[10] Coase, R., 1937. The nature of the firm. Economica 4, 386–405.

[11] Creighton, S., Sher, S., 2009. Resolving patent disputes through merger: a comparison of three potential approaches. Antitrust Law Journal 75, 657–690.

[12] Engelberg, J., Gao, P., Parsons, C., 2013. The price of a CEO's rolodex. Review of Financial Studies 26, 79–114.

[13] Galasso, A., Schankerman, M., 2010. Patent thickets, courts and the market for innovation. RAND Journal of Economics 41, 472–503.

[14] Gaspar, J., Massa, M., Matos, P., 2005. Shareholder investment horizons and the market for corporate control. Journal of Financial Economics 76, 135–165.

[15] Griliches, Z., Pakes, A., Hall, B., 1986. The value of patents as indicators of inventive activity. NBER Working Paper No. 2083.

[16] Grossman, S., Hart, O., 1986. The costs and benefits of ownership: a theory of vertical and lateral integration. Journal of Political Economy 94, 691–719.

[17] Hall, B., Jaffe, A., Trajtenberg, M., 2001. The NBER patent citation data file: lessons, insights and methodological tools. NBER Working Paper No. 8498.

[18] Hall, B., Jaffe, A., Trajtenberg, M., 2005. Market value and patent citations. RAND Journal of Economics 36, 16–38.

[19] Hall, B., Ziedonis, R., 2001. The patent paradox revisited: An empirical study of patenting in the U.S. semiconductor industry, 1979-1995. Rand Journal of Economics 32, 101–128.

[20] Hansen, R., Lott, J., 1996. Externalities and corporate objectives in a world with diversified shareholder/consumers. Journal of Financial and Quantitative Analysis 31, 43–68.

[21] Harford, J., Kecskés, A., Mansi, S., 2017. Do long-term investors improve corporate decision making? Unpublished working paper. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2505261.

[22] Harhoff, D., Narin, F., Scherer, F., Vopel, K., 1999. Citation frequency and the value of patented inventions. Review of Economics and Statistics 8, 511–515.

[23] Hart, O., Moore, J. 1990. Property rights and the nature of the firm. Journal of Political Economy 98, 1119–1158.

[24] Hart, O., 1995. Firms, contracts, and financial structure. Clarendon Press, Oxford.

[25] He, J., Huang, J., 2017. Product market competition in a world of cross ownership: evidence from institutional blockholdings. Review of Financial Studies (forthcoming).

[26] Hsu, P., Tian, X., Xu, Y., 2014. Financial development and innovation: cross-country evidence. Journal of Financial Economics 112, 116–135.

[27] Klein, B., Crawford, R., Alchian, A., 1978. Vertical integration, appropriable rents, and the competitive contracting process. Journal of Law and Economics 21, 297–326.

[28] Kogan, L., Papanikolaou, D., Seru, A., Stoffman, N., 2017. Technological innovation, resource allocation and growth. Quarterly Journal of Economics (forthcoming).

[29] Lerner, J., Sørensen, M., Strömberg, P., 2011. Private equity and long-run investment: the case of innovation. Journal of Finance 66, 445–477.

[30] McCahery, J., Sautner, Z., Starks, L., 2016. Behind the scenes: the corporate governance preferences of institutional investors. Journal of Finance 71, 2905-2932.

[31] Noel, M., Schankerman, M., 2013. Strategic patenting and software innovation. Journal of Industrial Economics 61, 481–520.

[32] Schmidt, J., 2012. Perceived auditor independence and audit litigation: the role of nonaudit services fees. Accounting Review 87, 1033–1065.

[33] Shapiro, C., 2001. Navigating the patent thicket: cross-licenses, patent pools, and standard-setting. In: Jaffe, A., Lerner, J., Stern, S. (Ed.), Innovation Policy and the Economy. MIT Press, Cambridge, MA, pp. 119-150.

[34] Solow, R., 1957. Technical change and the aggregate production function. Review of Economics and Statistics 39, 312–320.

[35] Van Nieuwerburgh, S., Veldkamp, L., 2010. Information acquisition and portfolio underdiversification. Review of Economic Studies 77, 779-805.

[36] Williamson, O., 1975. Markets and Hierarchies: Analysis and Antitrust Implications. Free Press, New York.

[37] Williamson, O., 1985. The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting. Free Press, New York.

[38] Ziedonis, R., 2004. Don't fence me in: fragmented markets for technology and the patent acquisition strategies of firms. Management Science 50, 804–820.

Table 1: Summary Statistics

Reported are the summary statistics of the regression variables. Firm-level dependent variables are (i) $CITES_{s,t}$, the number of future citations received by the cohort of patents filed by firm s in year t; (ii) $N_{s,t}$, the number of patents filed by firm s in year t; (iii) $\overline{cites}_{s,t}$, the average future citation count per patent for the cohort of patents filed by firm s in year t; (iv) $R\&D\ Exp_{s,t}/Asset_{s,t}$, the R&D expenditure relative to total assets, (v) $CITES^{F}_{s,t}$, a filtered citation measure, which removes all citations coming from those upstream firms that firm s has cited in its patent filings in year t, and (vi) $CITES^{3yr}_{s,t}$, the three-year future citation count. At the patent level we denote by $cites_{p,t}$ the total number of future citations received by patent p, filed in year t. $SOL_{s,t-1}$ and $sol_{p,t-1}$ refer to the shareholder overlap for firm s and patent p, respectively. We decompose $SOL_{s,t-1}$ into three components, representing the shareholder overlap originating from dedicated investors ($SOL\_Dedicated_{s,t-1}$), intermediate investors ($SOL\_Intermediate_{s,t-1}$), and transient investors ($SOL\_Transient_{s,t-1}$). $SOL\_Placebo1_{s,t-1}$ and $SOL\_Placebo2_{s,t-1}$ are the two placebo measures of shareholder overlap. We also consider two different shareholder overlap measures: $SOL^{3yr}_{s,t-1}$ (a cites-weighted measure based on three-year future citation) and $SOL\_Equal_{s,t-1}$ (an equal-weight measure). $MktCap^{u}_{p,t-1}$ denotes the average market capitalization value at the end of year $t-1$ of firms owning the upstream patent p^u to patent p. Institutional ownership of firm s at the end of year $t-1$ is denoted by $IO_{s,t-1}$ and is decomposed into ownership of overlapping shareholders IO^{SOL} and that of non-overlapping shareholders IO^{NOL}. $WHHI_{s,t-1}$ is the weighted Herfindahl-Hirschman Index of the ownership concentration of overlapping shareholders in firm s at the end of year $t-1$. $ln(SpillTECH_{s,t-1})$ and $ln(SpillSIC_{s,t-1})$ measures the extent of technology spillover and product market rivalry effect of $R\&D$, respectively, for firm s in year $t-1$. The control variables include the market capitalization ($MktCap_{s,t-1}$), cumulative R&D investment ($R\&D\ Stock_{s,t-1}$), capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$). Detailed definitions of the variables are given in Appendix B.

	Obs.	Mean	Median	STD	Skewness	Min.	P10	P90	Max.
Dependent Variables (measured in year t)									
$ln(1+CITES)$	19,020	3.948	3.912	2.065	0.116	0.000	1.317	6.619	11.640
$ln(1+N)$	19,020	1.964	1.609	1.340	1.351	0.693	0.693	3.912	8.395
$ln(1+\overline{cites})$	19,020	2.388	2.459	1.140	−0.181	0.000	0.886	3.772	6.643
$R\&D\ Exp/Assets$	19,020	0.082	0.029	0.153	5.777	0.000	0.000	0.210	3.704
$ln(1+cites)$	581,240	1.899	1.962	1.357	0.121	0.000	0.000	3.660	7.129
$ln(1+CITES^{F})$	19,020	3.904	3.869	2.048	0.121	0.000	1.287	6.549	11.565
$ln(1+CITES^{3yr})$	19,020	2.672	2.485	1.921	0.540	0.000	0.000	5.276	10.701
$ln(CITES)$	17,609	4.214	4.091	1.865	0.390	0.180	1.877	6.707	11.640
Independent Variables (measured in year $t-1$)									
SOL	19,020	0.062	0.044	0.063	1.487	0.000	0.000	0.150	0.541
$SOL\_Dedicated$	19,020	0.002	0.000	0.004	8.873	0.000	0.000	0.004	0.174
$SOL\_Intermediate$	19,020	0.027	0.019	0.027	1.610	0.000	0.000	0.064	0.248
$SOL\_Transient$	19,020	0.031	0.020	0.034	1.697	0.000	0.000	0.079	0.289
$SOL\_Placebo1$	19,020	0.050	0.038	0.048	1.513	0.000	0.000	0.114	0.483
$SOL\_Placebo2$	19,020	0.048	0.036	0.047	1.627	0.000	0.000	0.112	0.564
SOL^{3yr}	19,020	0.062	0.043	0.064	1.577	0.000	0.000	0.150	0.750
SOL_Equal	19,020	0.172	0.164	0.120	0.436	0.000	0.000	0.336	0.727
sol	581,240	0.144	0.111	0.142	1.169	0.000	0.000	0.342	0.850
$ln(MktCap^{u})$	581,240	8.023	7.574	4.359	0.430	0.042	2.555	14.361	20.216
$WHHI$	19,020	0.057	0.035	0.071	3.300	0.000	0.000	0.133	1.000
IO	19,020	0.479	0.497	0.266	−0.067	0.000	0.100	0.823	1.000
IO^{SOL}	19,020	0.379	0.367	0.278	0.182	0.000	0.000	0.760	1.000
IO^{NOL}	19,020	0.100	0.037	0.158	2.652	0.000	0.000	0.282	1.000
$ln(SpillTECH)$	19,020	10.607	10.743	1.064	−1.027	1.887	9.244	11.830	12.747
$ln(SpillSIC)$	18,945	8.659	9.061	2.275	−1.157	−8.085	5.650	11.229	12.599
Controls (measured in year $t-1$)									
$ln(MktCap)$	19,020	13.034	12.873	2.100	0.315	6.736	10.462	15.894	20.216
$ln(1+R\&D\ Stock)$	19,020	3.764	3.903	2.232	0.051	0.000	0.000	6.563	10.714
$ln(K/L)$	19,020	4.406	4.319	0.906	0.625	−1.410	3.372	5.533	10.296
$ln(Sales)$	19,020	5.428	5.464	2.564	−0.321	−6.215	2.239	8.685	12.722
$Private\ Patent\ Share$	19,020	0.735	0.769	0.200	−0.891	0.000	0.466	1.000	1.000

Table 2: Baseline Regressions

Reported are the firm-level OLS regressions of patent success ($ln(1+CITES_{s,t})$) on lagged *shareholder overlap* ($SOL_{s,t-1}$) for the sample period 1992-2007. $CITES_{s,t}$ denotes the number of future citations received by the cohort of patents successfully filed by firm s in year t. $SOL_{s,t-1}$ measures the average shareholder ownership overlap at the end of year $t-1$ between the innovating firm s and other firms owning complementary upstream patents. Columns 1–2 report the full sample results, whereas Columns 3–4 report the subsample results for the top three R&D-intensive sectors (pharmaceuticals, computer hardware, and telecommunications equipment). The control variables include the market capitalization ($MktCap_{s,t-1}$), cumulative R&D investment ($R\&D\ Stock_{s,t-1}$), capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$) for firm s in year $t-1$. All regressions control for year and industry (based on four-digit SIC codes) fixed effects. Firm fixed effects are substituted by pre-sample means of the dependent variable as proposed by Blundell, Griffith, and Van Reenen (1999). All regressions report robust standard errors clustered at the firm level in parentheses. Also reported are the total number of observations (*Obs.*) and adjusted R-squared (*Adj.* R^2). ** and * denote the 1% and 5% significance level, respectively.

Dependent Variable:	$ln(1+CITES)$			
	Full Sample		Top 3 R&D-Intensive Industries	
	(1)	(2)	(3)	(4)
SOL	3.692**	3.450**	4.685**	4.328**
	(0.495)	(0.484)	(0.826)	(0.805)
Controls:				
$ln(MktCap)$	0.317**	0.306**	0.381**	0.367**
	(0.018)	(0.018)	(0.032)	(0.031)
$ln(1+R\&D\ Stock)$	0.317**	0.251**	0.276**	0.213**
	(0.016)	(0.016)	(0.037)	(0.036)
$ln(K/L)$	0.029	−0.009	0.107*	0.040
	(0.032)	(0.031)	(0.059)	(0.056)
$ln(Sales)$	−0.024	−0.076**	−0.008	−0.055*
	(0.015)	(0.015)	(0.024)	(0.024)
Private Patent Share	0.422**	0.321**	0.624**	0.475*
	(0.120)	(0.117)	(0.195)	(0.189)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
BGV Firm FE Control	No	Yes	No	Yes
Obs.	19,020	19,020	5,898	5,898
Adj. R^2	0.526	0.542	0.564	0.577

Table 3: Intensive versus Extensive Margin

Reported are OLS regressions of the intensive margin ($ln(1+\overline{cites}_{s,t})$) and the extensive margin ($ln(1+N_{s,t})$) of patent production on the lagged *shareholder overlap* ($SOL_{s,t-1}$) for the sample period 1992-2007. $N_{s,t}$ denotes the number of patents filed by firm s in year t, and $\overline{cites}_{s,t}$ denotes the average future citation count per patent for the cohort of patents filed by firm s in year t. $SOL_{s,t-1}$ measures the average shareholder ownership overlap at the end of year $t-1$ between the innovating firm s and other firms owning complementary upstream patents. Columns 1–2 and 3–4 report the results for the intensive margin and extensive margin of patent production, respectively. The control variables include the market capitalization ($MktCap_{s,t-1}$), cumulative R&D investment ($R\&D\ Stock_{s,t-1}$), capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$). All regressions control for year and industry (based on four-digit SIC codes) fixed effects. Firm fixed effects are substituted by pre-sample means of the dependent variable as proposed by Blundell, Griffith, and Van Reenen (1999). All regressions report robust standard errors clustered at the firm level in parentheses. Also reported are the total number of observations (*Obs.*) and adjusted R-squared (*Adj.* R^2). ** and * denote the 1% and 5% significance level, respectively.

Dependent Variables:	$ln(1+\overline{cites})$		$ln(1+N)$	
	(1)	(2)	(3)	(4)
SOL	0.584*	0.527*	2.923**	2.936**
	(0.248)	(0.247)	(0.375)	(0.375)
Controls:				
ln(MktCap)	0.081**	0.081**	0.199**	0.184**
	(0.010)	(0.010)	(0.012)	(0.011)
$ln(1+R\&D\ Stock)$	0.023**	0.017*	0.262**	0.183**
	(0.007)	(0.008)	(0.013)	(0.011)
$ln(K/L)$	−0.039*	−0.049**	0.060**	0.051*
	(0.017)	(0.017)	(0.022)	(0.020)
ln(Sales)	−0.058**	−0.067**	0.036**	−0.007
	(0.009)	(0.009)	(0.009)	(0.009)
Private Patent Share	0.073	0.056	0.350**	0.282**
	(0.070)	(0.070)	(0.079)	(0.078)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
BGV Firm FE Control	No	Yes	No	Yes
Obs.	19,020	19,020	19,020	19,020
Adj. R^2	0.427	0.429	0.614	0.648

Table 4: Structure of Shareholder Overlap and Placebo Measures

Column 1 of the table reproduces the baseline regression in Table 2, Column 1. In Column 2, we decompose $SOL_{s,t-1}$ into three components, representing the shareholder overlap originating from dedicated investors ($SOL\_Dedicated_{s,t-1}$), intermediate investors ($SOL\_Intermediate_{s,t-1}$), and transient investors ($SOL\_Transient_{s,t-1}$). At the end of each year, we rank all institutional investors along two dimensions: Their portfolio concentration (in descending order) and portfolio turnover (in ascending order). We label dedicated, intermediate, and transient investors, respectively, as those in the top, middle, and bottom tercile of the combined rank of the two dimensions of shareholder activism. Column 3 expands the baseline regression by including the Weighted Herfindahl-Hirschman index of the ownership concentration of overlapping shareholders, $WHHI_{s,t-1}$. Columns 4-5 report the regression results of the two placebo tests, in which we replace $SOL_{s,t-1}$ in the baseline regression with a placebo shareholder overlap measure ($SOL\_Placebo1_{s,t-1}$ or $SOL\_Placebo2_{s,t-1}$). The control variables include the market capitalization ($MktCap_{s,t-1}$), cumulative R&D investment ($R\&D\ Stock_{s,t-1}$), capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$). The sample period is 1992-2007. We report p-values for the two null hypotheses of equal coefficients in the last two rows. The regressions control for four-digit industry, year fixed effects, and firm fixed effects are based on including pre-sample means of dependent variables proposed by Blundell, Griffith, and Van Reenen (1999). All regressions report robust standard errors clustered at the firm level in parentheses. Also reported are the total number of observations (*Obs.*) and adjusted R-squared (*Adj.* R^2). ** and * denote the 1% and 5% significance level, respectively.

Dependent Variable.:	$ln(1+CITES)$				
	(1)	(2)	(3)	(4)	(5)
SOL	3.450**		4.361**		
	(0.484)		(0.502)		
$SOL\_Dedicated$		19.926**			
		(5.090)			
$SOL\_Intermediate$		0.572			
		(0.975)			
$SOL\_Transient$		5.230**			
		(0.869)			
$WHHI$			2.206**		
			(0.264)		
$SOL\_Placebo1$				−0.082	
				(0.556)	
$SOL\_Placebo2$					0.518
					(0.524)
Controls:					
$ln(MktCap)$	0.306**	0.293**	0.324**	0.345**	0.341**
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
$ln(1+R\&D\ Stock)$	0.251**	0.250**	0.252**	0.258**	0.258**
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
$ln(K/L)$	−0.009	−0.008	−0.003	−0.004	−0.005
	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)
$ln(Sales)$	−0.076**	−0.075**	−0.072**	−0.070**	−0.070**
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
$Private\ Patent\ Share$	0.321**	0.280*	0.958**	−0.305*	−0.215
	(0.117)	(0.117)	(0.147)	(0.121)	(0.116)
Year FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
BGV Firm FE Control	Yes	Yes	Yes	Yes	Yes
Obs.	19,020	19,020	19,020	19,020	19,020
Adj. R^2	0.542	0.543	0.545	0.539	0.539
$H_0: SOL\_Dedicated = SOL\_Transient$		0.000			
$H_0: SOL\_Intermediate = SOL\_Transient$		0.000			

Table 5: Patent-Level Regressions

Reported are the patent-level OLS and 2SLS regressions of patent success ($ln(1 + cites_{p,t})$) on lagged *shareholder overlap* ($sol_{p,t-1}$) for the sample period 1992-2007. Because we control for firm-year fixed effects in the regressions, we discard all firm-years that feature only one patent application. $cites_{p,t}$ denotes the total number of future citations received by patent p, filed in year t. The variable $sol_{p,t-1}$ measures the average shareholder ownership overlap at the end of year $t-1$ between the firm owning patent p and other firms owning complementary upstream patents. Columns 1 and 2 report the patent-level OLS regression results, controlling for year, firm, and technology field fixed effects or the interacted year-firm and year-technology field fixed effects. Columns 3 and 4 report the first and second stage result of the 2SLS regression, respectively. The variable $ln(MktCap^u_{p,t-1})$ is the instrumental variable for $sol_{p,t-1}$. $MktCap^u_{p,t-1}$ denotes the average market capitalization value at the end of year $t-1$ of firms owning patent upstream patents p^u to the downstream patent p. Columns 5 and 6 are based on the fund merger event in which the patent-level shareholder overlap *sol* increases following the fund merger. The dummy *Post-Merger* marks the observations in the subsequent three years following the fund merger year t. The dummy *Treat* marks patents that increase their *sol* because of a fund merger. Control patents are those filed in the same year by the same firm, but do not feature such an increase in *sol* in the same merger event. Robust standard errors are clustered at the firm-year pair level for regressions presented in Column 1–4 and clustered at the event-firm pair level for regressions in Column 5–6. Also reported are the total number of observations (*Obs.*) and adjusted R-squared (*Adj.* R^2). ** and * denote the 1% and 5% significance level, respectively.

	Full Sample OLS		Full Sample 2SLS		Fund Merger Events OLS	
			1^{st} Stage	2^{nd} Stage		
Dependent Variable:	$ln(1 + cites)$	$ln(1 + cites)$	*sol*	$ln(1 + cites)$	*sol*	$ln(1 + cites)$
	(1)	(2)	(3)	(4)	(5)	(6)
sol	0.192**	0.272**		0.283**		
	(0.019)	(0.018)		(0.013)		
$ln(MktCap^u)$			0.024**			
			(0.000)			
Treat × *Post-Merger*					0.017**	0.135**
					(0.006)	(0.046)
Post-Merger					0.001	−0.566**
					(0.004)	(0.035)
Treat					0.071**	0.066**
					(0.008)	(0.025)
Year FE	Yes	No	No	No	No	No
Tech. FE	Yes	No	No	No	No	No
Firm FE	Yes	No	No	No	No	No
Year × Firm FE	No	Yes	Yes	Yes	No	No
Year × Tech. FE	No	Yes	Yes	Yes	No	No
Event × Firm × Tech. FE	-	-	-	-	Yes	Yes
Obs.	581,240	581,240	581,240	581,240	88,090	88,090
Adj. R^2	0.312	0.339	0.851		0.251	0.266

Table 6: R&D Expenditure and Shareholder Overlap

Reported are OLS regressions of the (log) R&D expenditure (relative to assets) for the sample period 1992-2007. $R\&D\ Exp_{s,t}/Assets_{s,t}$ denotes the R&D expenditure relative to total assets for firm s in year t. $SOL_{s,t-1}$ measures the average shareholder ownership overlap at the end of year $t-1$ between the innovating firm s and other firms owning complementary upstream patents. We denote institutional ownership (relative to total equity outstanding) by $IO_{s,t-1}$ and decompose it into the institutional owernship contributing to shareholder overlap $IO^{SOL}_{s,t-1}$, and the residual (standalone) institutional ownership $IO^{NOL}_{s,t-1}$ without joint equity ownership in firms owning complementary patents. The control variables include capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$) for firm s in year $t-1$. All regressions include year and industry (based on four-digit SIC codes) fixed effects. Robust standard errors clustered at the firm level are reported in parentheses. Also reported are the total number of observations (*Obs.*) and adjusted R-squared (*Adj.* R^2).

Dependent Variable:	*R&D Exp/Assets*			
	(1)	(2)	(3)	(4)
SOL	0.240^{**}		0.237^{**}	
	(0.043)		(0.042)	
IO		0.009	0.004	
		(0.008)	(0.007)	
IO^{SOL}				0.025^{**}
				(0.008)
IO^{NOL}				-0.047^{**}
				(0.009)
Controls:				
$ln(K/L)$	0.008^{**}	0.009^{**}	0.008^{**}	0.009^{**}
	(0.002)	(0.002)	(0.002)	(0.002)
$ln(Sales)$	-0.019^{**}	-0.017^{**}	-0.019^{**}	-0.018^{**}
	(0.002)	(0.002)	(0.002)	(0.002)
Private Patent Share	0.005	-0.039^{**}	0.005	-0.021^{**}
	(0.012)	(0.007)	(0.012)	(0.008)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	No
Obs.	19,020	19,020	19,020	19,020
Adj. R^2	0.278	0.275	0.278	0.279

Table 7: Robustness

Column 1 of the table reproduces the baseline regression in Table 2, Column 1. Additional explanatory variables, including *institutional ownership* ($IO_{s,t-1}$), *knowledge spillover* ($ln(SpillTech_{s,t-1})$), and *product market rivalry effect of R&D* ($ln(SpillSIC_{s,t-1})$) are added to Columns 2–4. The dependent variable in Columns 1–4 is $ln(1+CITES_{s,t})$. All specifications are estimated using OLS regressions except for Column 5, which estimates a negative binomial model with $CITES_{s,t}$ as the dependent variable. Column 6 measures patent success by three-year future citation counts, $CITES^{3yr}$, and defines a corresponding shareholder overlap SOL^{3yr} based on a modified patent success measure. Column 7 measures the patent success by $ln(CITES_{s,t})$. Column 8 uses a filtered citation measure, $ln(1+CITES^{F}_{s,t})$, as the dependent variable, which removes all citations coming from those upstream firms that firm s has cited in its patent filings in year t. Column 9 replaces $SOL_{s,t-1}$ in Column 1 with $SOL_{s,t-2}$, for which the ownership stake is measured at the end of year $t-2$. Column 10 replaces $SOL_{s,t-1}$ in Column 1 with an equal-weighted measure ($SOL\_Equal_{s,t-1}$). All regressions control for firm market capitalization ($MktCap_{s,t-1}$), cumulative R&D investment ($R\&D\ Stock_{s,t-1}$) at the beginning of the sample, capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$) for firm s in year $t-1$, as well as year, industry (based on four-digit SIC codes) and firm fixed effects controls (based on including pre-sample mean of dependent variables). The sample period is 1992-2007. Robust standard errors clustered at the firm level are reported in parentheses. Also reported are the total number of observations (*Obs.*) and adjusted R-squared (*Adj.* R^2). ** and * denote the 1% and 5% significance level, respectively.

Dependent Var.:	$ln(1+CITES)$				$CITES$
					Neg. Bino.
	(1)	(2)	(3)	(4)	(5)
SOL	3.450**	3.429**	3.476**	3.458**	2.806**
	(0.484)	(0.475)	(0.486)	(0.477)	(0.613)
IO		−0.567**		−0.564**	−0.704**
		(0.097)		(0.097)	(0.088)
$ln(SpillTECH)$			0.099**	0.095**	0.096**
			(0.032)	(0.032)	(0.032)
$ln(SpillSIC)$			−0.028	−0.028	−0.007
			(0.018)	(0.018)	(0.019)
Control variables	Yes	Yes	Yes	Yes	Yes
Year & Industry FE	Yes	Yes	Yes	Yes	Yes
BGV Firm FE Control	Yes	Yes	Yes	Yes	Yes
Obs.	19,020	19,020	18,945	18,945	18,945
Adj. R^2	0.542	0.545	0.543	0.545	

Dependent Var.:	$ln(1+CITES^{3yr})$	$ln(CITES)$	$ln(1+CITES^{F})$	$ln(1+CITES)$	
	(6)	(7)	(8)	(9)	(10)
SOL		3.224**	3.252**		
		(0.481)	(0.484)		
SOL^{3yr}	2.515**				
	(0.373)				
$SOL(t-2)$				2.385**	
				(0.432)	
SOL_Equal					2.518**
					(0.200)
Control variables	Yes	Yes	Yes	Yes	Yes
Year & Industry FE	Yes	Yes	Yes	Yes	Yes
BGV Firm FE Control	Yes	Yes	Yes	Yes	Yes
Obs.	19,020	17,609	19,020	18,109	19,020
Adj. R^2	0.605	0.525	0.538	0.539	0.547

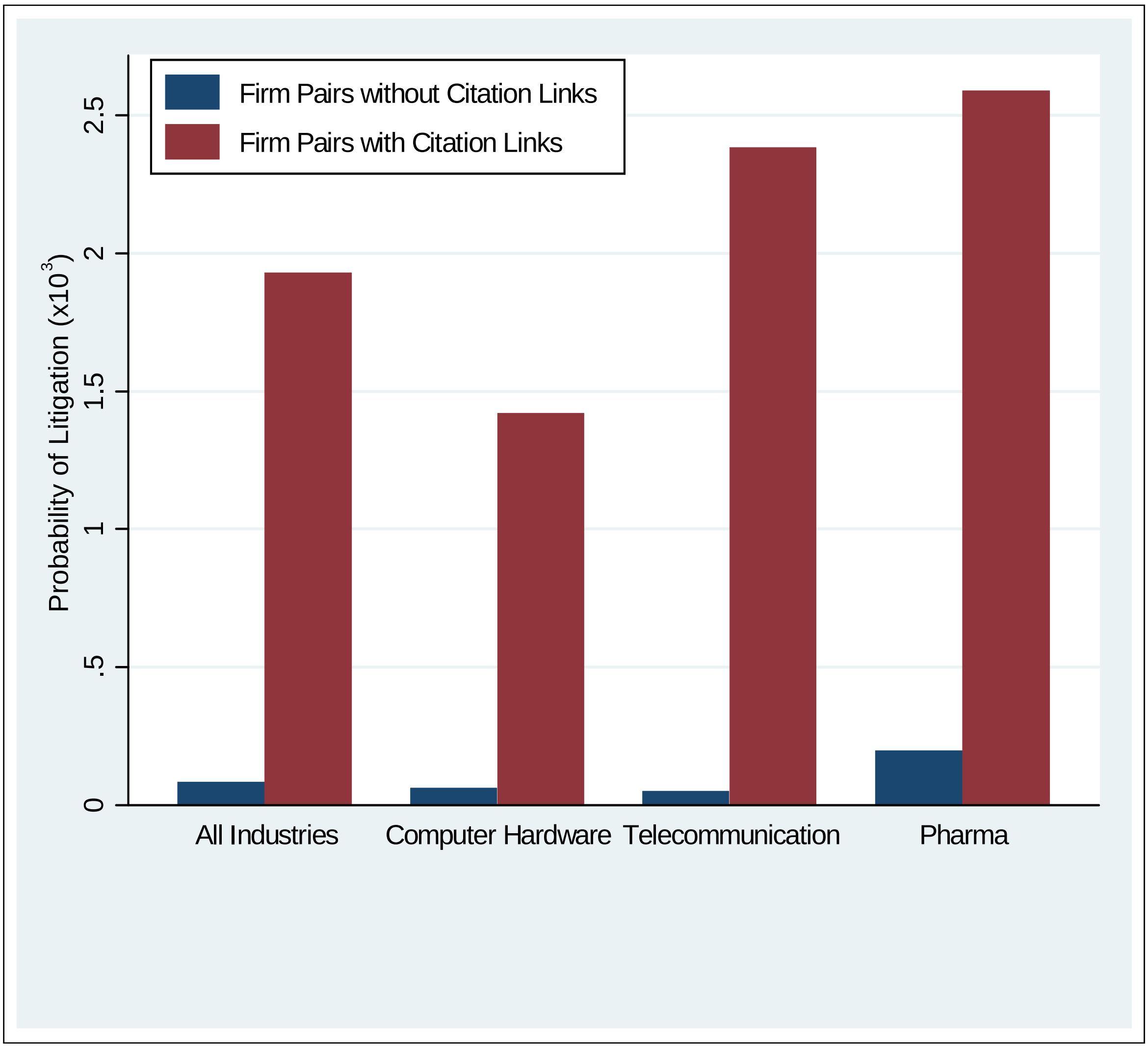

Figure 1: Probability of patent litigation for intra-industry firm pairs. This figure compares the likelihood of patent litigation for listed firm pairs with citation links to those without any citation link in the preceeding three years. For each year from 2000 to 2007, we form all intra-industry firm pairs (defined based on two-digit SIC codes) of all U.S. listed firms with at least one patent application in the preceeding three years and sort them into pairs with at least one patent citation link and pairs without any such link. The litigation likelihood is reported in the sample of all industries and each of three R&D intensive sectors, which are Computer Hardware, Telecommunications, and Pharma.

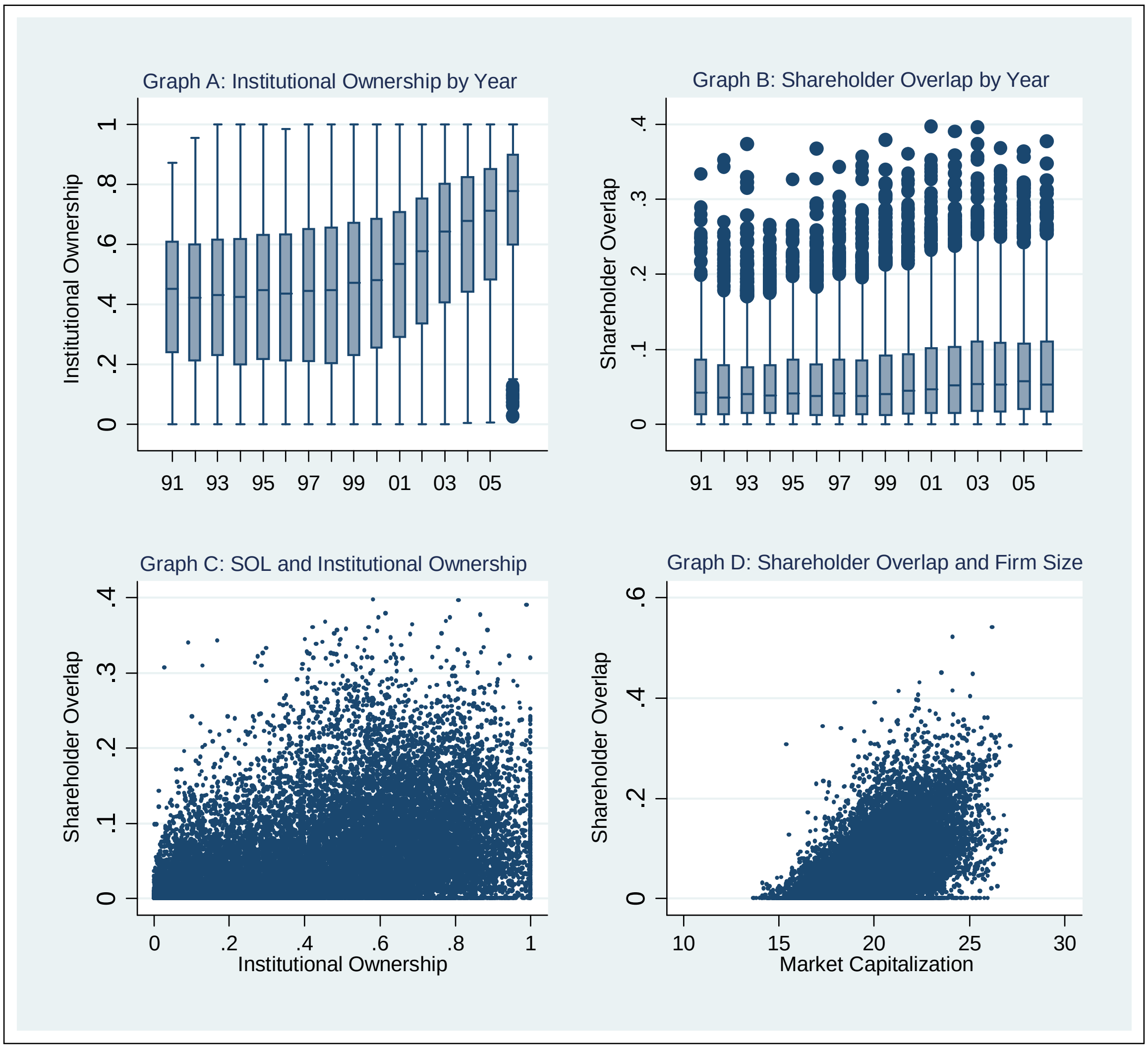

Figure 2: Institutional ownership and shareholder overlap. Graphs A and B are the box plots for the distribution of institutional ownership ($IO_{s,t}$) and shareholder overlap ($SOL_{s,t}$), respectively, by year from 1991 to 2006. The top, middle, and bottom values of each box represent the 75th, 50th, and 25th percentile of the distribution in the given year; the maximum and minimum of each vertical bar represent the upper and lower adjacent values, and the dots denote the observations outside the adjacent values. Graph C plots our sample along the dimension of shareholder overlap $SOL_{s,t}$ and institutional ownership $IO_{s,t}$, whereas Graph D plots along the dimension of shareholder overlap $SOL_{s,t}$ and firm size $MktCap_{s,t}$ for all firm-years.

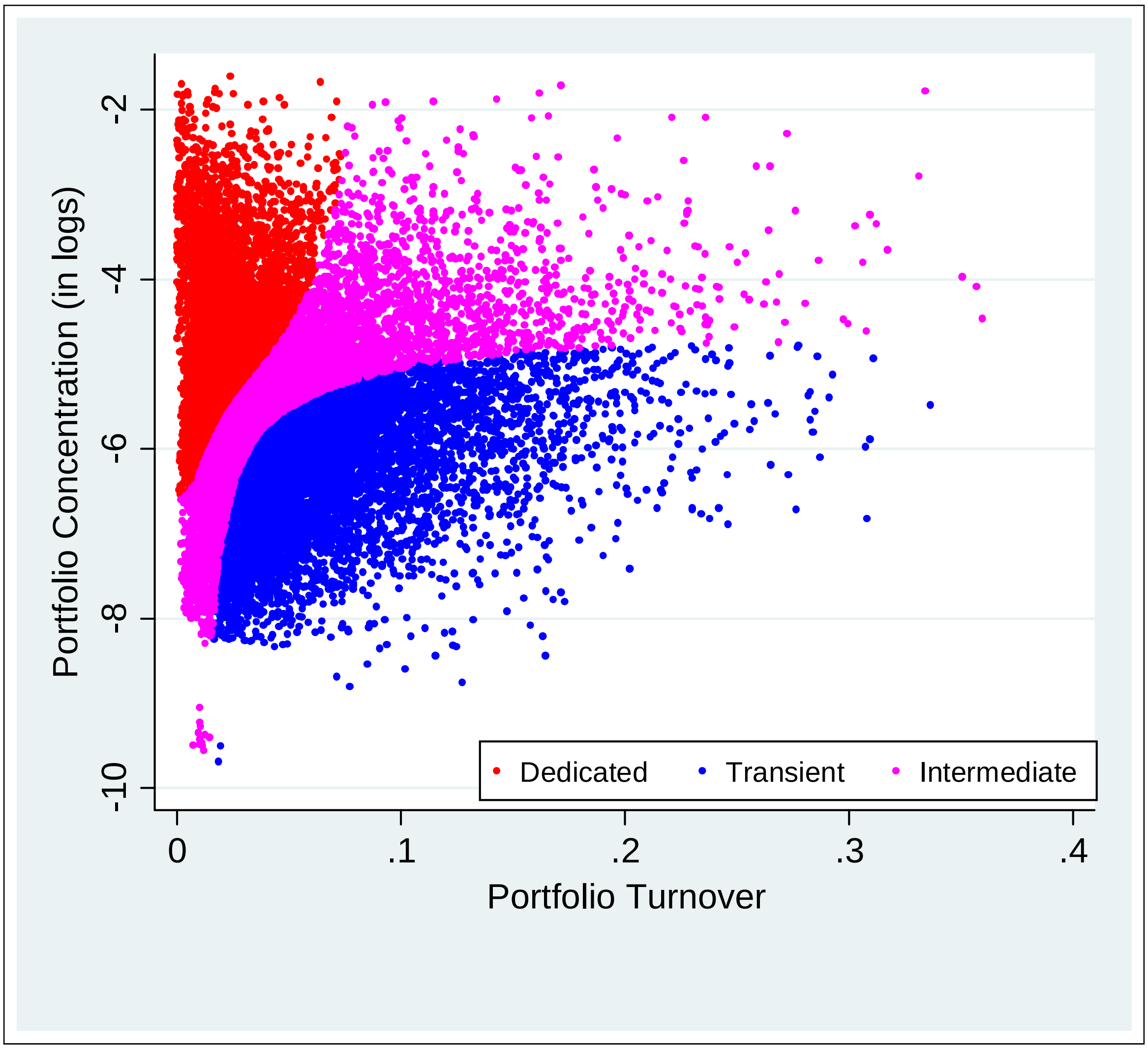

Figure 3: Shareholder overlap by investor types. Plotted are the (log) portfolio concentration and portfolio turnover of institutional investors (dedicated, intermediate, or transient investors) in our sample over the period 1991-2006. Specifically, at the end of each year, we rank all institutional investors along two dimensions: Their portfolio concentration (i.e., the Herfindahl-Hirschman Index of their equity portfolio holdings) in descending order and their portfolio turnover ratios in ascending order. We label the dedicated, intermediate, and transient investors as those in the top, middle, and bottom tercile of the combined rank, respectively.

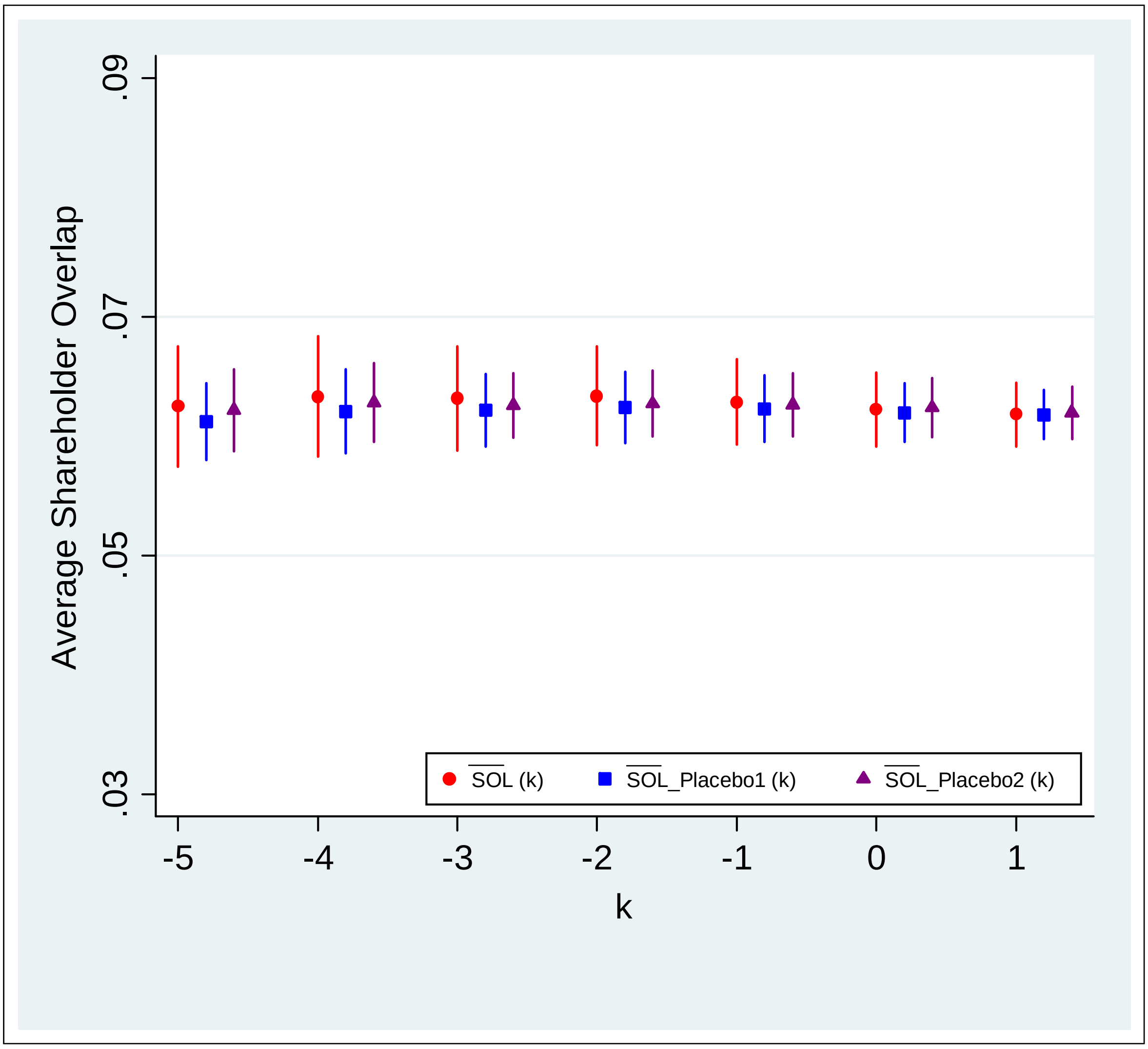

Figure 4: Evolution of Shareholder Overlap. The evolution of the average shareholder overlap $\overline{SOL}(k)$ between the innovating firm and other firms owning complementary upstream patents is plotted for the period from five years prior to the patent filing year to one year after the filing (i.e., $k = -5$ to 1), with the patent filing year denoted by $k = 0$. Each dot in the figure denotes the mean value of shareholder overlap for the given year k relative to the patent filing year, and the vertical segment above and below the dot denotes the standard deviation of the distribution of shareholder overlap for the given year. The evolution of the two placebo measures of shareholder overlap is also plotted. For ease of comparison, we adjust the value of $\overline{SOL\_Placebo1}(k)$ and $\overline{SOL\_Placebo2}(k)$ upward by 0.012 and 0.014, respectively, so that they would have the same mean value as $\overline{SOL}(k)$ for $k = 0$.

Internet Appendix

Not for Journal Publication

Patent Success, Patent Holdup and the Structure of Property Rights

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Appendix A. A Model of Patent Investment

A.1 A Simple Benchmark (with No Holdup Effect)

A risk-neutral firm s can invest in a continuum of patent projects. Each project is represented by the index number p on the interval $[0, \infty)$, with a higher index number corresponding to higher patent development costs. For simplicity, we assume a continuous increasing convex cost function $C(p)$ with $C'(p) > 0$ and $C''(p) > 0$ for the patent development costs. The present value from commercialization of the patent project, $V_s(p)$, is proportional to the success of the patent, proxied by the future citation count $cites_s(p)$. Hence,

$$V_s(p) = \alpha \times cites_s(p), \tag{A.1}$$

where $cites_s(p)$ is a random variable with the expected value $E[cites_s(p)] = \mu_s$, and $\alpha > 0$ is a constant. The total expected firm value Π_s follows as

$$\Pi_s = \max_{\overline{p}} \int_0^{\overline{p}} [\alpha\mu_s - C(p)]\, dp, \tag{A.2}$$

where the interval $[0, \overline{p}]$ denotes the range of patent projects the firm pursues. Value maximization implies the first-order condition $\alpha\mu_s = C(\overline{p})$. For a convex cost function $C(p) = cp^b$ ($b > 1$), we find that

$$\overline{p} = \left(\frac{\alpha\mu_s}{c}\right)^{\frac{1}{b}} \tag{A.3}$$

characterizes the optimal range of patent production. We summarize the model implications as follows:

Proposition 1: Patent Production without Patent Holdup

A value maximizing firm optimally invests in the production of patents on the line interval $[0, \overline{p}]$. Given a patent-level expected citation count $E[cites_s(p)] = \mu_s$ that is proportional to each patent's expected value and a convex cost function $C(p) = cp^b$, we find for

(i) the (log) extensive margin of patent production

$$ln[\overline{p}] = \frac{1}{b} ln\frac{\alpha}{c} + \frac{1}{b} ln(\mu_s) \tag{A.4}$$

(ii) the (expected) firm-level (log) citation count

$$ln[CITES_s] = ln \int_0^{\overline{p}} E[cites_s(p)]dp = \frac{1}{b} ln \frac{\alpha}{c} + \frac{b+1}{b} ln(\mu_s), \tag{A.5}$$

(iii) the (log) R&D expenditure

$$ln[R\&D\ Exp] = ln \int_0^{\overline{p}} cp^b dp = ln \frac{c}{1+b} + \frac{b+1}{b} ln \frac{\alpha \mu_s}{c}. \tag{A.6}$$

The firm-level (log) citation count in Eq. (A.5) is equal to the sum of the (log) extensive margin in Eq. (A.4) and the (log) intensive margin μ_s. Empirically, we can approximate the intensive margin by the average citation count $\overline{cites}_s$ of a firm's patents.

Next, we enrich the model and assume that commercialization of each new (downstream) patent p requires licensing of a complementary precursory (upstream) patent p^u, but efficient (ex-ante) contracting prior to investment is possible. We assume that such contracting gives a share $\overline{L}_s$ of the net profit of each patent to be transferred to the respective upstream firm owning patent p^u. The value of $\overline{L}_s$ $(0 < \overline{L}_s < 0)$ captures the relative strength of the negotiating position of the upstream firm relative to the downstream firm and (for simplicity) is assumed to be the same for all patents of firm s. The profit function of the (downstream) firm becomes

$$\Pi_s = \max_{\overline{p}} (1 - \overline{L}_s) \int_0^{\overline{p}} [\alpha \mu_s - C(p)]\, dp. \tag{A.7}$$

It is straightforward to see that the term $1 - \overline{L}_s$ does not enter the the first-order conditions for the investment choice of the downstream firm.

Proposition 2: Ex-Ante Contracting with Upstream Patent Owners

If commercialization of each patent requires access to a complementary upstream patent p^u, efficient contracting on the sharing of the net profit $\alpha \mu_s - C(p)$ in each patent yields the same patent investment outcome as in proposition 1.

A.2 Holdup in the Absence of Ex-Ante Contracting

Next we assume that the downstream firm cannot secure a licence for patent p^u before its investment in the patent development, which become sunk costs in ex-post negotiations. In particular, the upstream patent p^u itself may not exist prior to investment in the development of patent p or its complementary nature to patent p becomes evident only upon the filing of the latter. Again, the upstream firm will require transfer of the profit share $\overline{L}_s$ of any agreement (reflecting the strength of patent p^u), which now excludes the sunk patent development costs $C(p)$. This implies that in the absence of ex-ante contracting, but rational anticipation of ex-post negotiations, the profit function of the downstream firm changes to

$$\Pi_s = \max_{\overline{p}} \int_0^{\overline{p}} \left[(1 - \overline{L}_s)\alpha\mu_s - C(p)\right] dp. \tag{A.8}$$

The optimal patent range $[0, \overline{p}_h]$ has the upper limit

$$\overline{p}_h = \left(\frac{\alpha\mu_s}{c}[1 - \overline{L}_s]\right)^{\frac{1}{b}} \tag{A.9}$$

and we can summarize the patent investment policy as follows:

Proposition 3: Patent Production in the Patent Holdup Case

The downstream firm faces a holdup problem if each (downstream) patent p requires licensing access to an upstream patent p^u (asset specificity) and the upstream firm can negotiate a share $\overline{L}_s$ of the surplus of such an agreement, and ex-ante contracting prior to patent investment $C(p)$ is not possible. Under such holdup, we obtain for

(i) the (log) extensive margin of patent production

$$ln[\overline{p}_h] = \frac{1}{b} ln\frac{\alpha}{c} + \frac{1}{b} ln(\mu_s) + \frac{1}{b} ln[1 - \overline{L}_s] \tag{A.10}$$

(ii) the (expected) firm-level (log) citation count

$$ln[CITES_s] = \frac{1}{b} ln\frac{\alpha}{c} + \frac{b+1}{b} ln(\mu_s) + \frac{1}{b} ln[1 - \overline{L}_s], \tag{A.11}$$

(iii) the (log) R&D expenditure

$$ln[R\&D\ Exp] = ln\frac{c}{1+b} + \frac{b+1}{b} ln\frac{\alpha\mu_s}{c} + \frac{b+1}{b} ln[1 - \overline{L}_s]. \tag{A.12}$$

Eqs. (A.10)–(A.12) are exactly the same as Eqs. (A.4)–(A.6) except for the last term. The last term in Eqs. (A.10)–(A.12) features the same (log) loss term $ln[1 - \overline{L}_s] < 0$ and captures how the holdup problem reduces the extensive margin of patent production, overall patent success, and R&D expenditure, respectively.

A.3 Holdup Attenuation Through Shareholder Overlap

Next we argue that shareholder overlap between the downstream firm and the upstream firms modifies the value $\overline{L}_s$. Consider first the case in which both firms have the same owner. Such a common owner would fully internalize the holdup by either *not* requiring the transfer payment $\overline{L}_s$ (as it only transfers wealth from one fully owned company to another) or instruct the downstream firm to ignore the transfer when setting $\overline{p}$. This brings us back to the efficient patent investment in proposition 1. Incomplete *pairwise (institutional) shareholder overlap* between the downstream and the upstream firm defined in Eq. (1) represents the intermediate case between maximum holdup $\overline{L}_s$ and full internalization given by $\overline{L}_s = 0$. In this case the downstream firm is characterized by an agency conflict: Overlapping shareholders seek transfer internalization, whereas stand-alone (non-overlapping) shareholders see this as distortion of the patent investment process. For simplicity, we assume that more pairwise shareholder overlap increases internalization linearly, that is

$$L_s = \overline{L}_s[1 - PSOL(p, p^u)].$$

Using the approximation $ln(1-\overline{L}_s) \simeq -\overline{L}_s$ in Eqs. (A.10)–(A.12) implies regression specifications

$$ln[\overline{p}_h] = \psi_0 + \psi_1 PSOL_s \qquad \text{(A.13)}$$

$$ln[CITES_s] = \beta_0 + \beta_1 PSOL_s \qquad \text{(A.14)}$$

$$ln[R\&D\ Exp] = \kappa_0 + \kappa_1 PSOL_s, \qquad \text{(A.15)}$$

with restrictions $\psi_1 = \beta_1 = \frac{1}{b}\overline{L}_s > 0$, and $\kappa_1 = \frac{b+1}{b}\overline{L}_s > 0$. This implies that pairwise shareholder overlap positively influences the extensive margin $\overline{p}_h$ of patent production, increases firm-level patent success $CITES_s$ and boosts R&D expenditure. The intensive margin of patent production is constant at μ as holdup does not compromise efficient ex-post negotiation in this model. In the more general case in which a patent p face potential holdup from multiple upstream patents $u = 1, 2, ...N_p$ and holdup attenuation can differ across patents, we replace the (constant) pairwise shareholder overlap $PSOL_s$ with the firm-level shareholder overlap SOL_s defined in Eq. (3).

Appendix B. Variable Definitions

Variable	Description
$N_{s,t}$	Number of patents filed by firm s in year t. Only those patents that are ultimately granted are included in our sample. [Source: Kogan *et al.,* 2017]
$cites_{p,t}$	Total future citation count for patent p, which is filed in year t and subsequently granted by USPTO. All self-citations are excluded. Because we only observe citations up to the end of 2010, we correct for this truncation bias using the estimated citation-lag distribution suggested by Hall, Jaffe, and Trajtenberg (2001). [Source: Kogan *et al.,* 2017]
$CITES_{s,t}$	Total future citation count for the cohort of patents filed by firm s in year t. Only those patents that are subsequently granted by USPTO are included in our sample. [Source: Kogan *et al.,* 2017]
$\overline{cites}_{s,t}$	Average future citation count per patent for the cohort of patents filed by firm s in year t. [Source: Kogan *et al.,* 2017]
$CITES^F_{s,t}$	Total filtered future citation count for the cohort of patents filed by firm s in year t. It removes from $CITES_{s,t}$ those citations that come from the upstream firms cited in the patent filings of the downstream firm s in year t. [Source: Kogan *et al.,* 2017]
$CITES^{3yr}_{s,t}$	Three-year citations received by the cohort of patents filed by firm s in year t. For each patent, we count citations received in the calendar year of patent grant and three subsequent years. Only those patents that are subsequently granted by USPTO are included in our sample. [Source: Kogan *et al.,* 2017]
$R\&D\ Exp_{s,t}$	Total $R\&D$ expenditure (in million U.S. dollars) for firm s in year t. The Compustat Mnemonic is XRD. [Source: Compustat-CRSP merged database]

Variable	Description
$sol_{p,t}$	Shareholder overlap for patent p, filed in year t. It is the weighted average of pairwise shareholder overlap $PSOL(p, p_u)$ across all upstream patents (p_u, $u = 1, 2, .., N_p$) cited by patent p, where $PSOL(p, p_u)$ is measured according to Eq. (1). The weight for an upstream patent p_u is the ratio of its future citations to the aggregate future citations of all cited upstream patents. [Source: Kogan *et al.*,, 2017; Thomson Reuters 13F]
$SOL_{s,t}$	Shareholder overlap for firm s in year t. It is the weighted average of $sol_{p,t}$ across all patents p filed by firm s in year t. The weight for a patent p is the ratio of its future citations to the aggregate future citations of all patents filed by the firm in the year. [Source: Kogan *et al.,* 2017; Thomson Reuters 13F]
$SOL\_$ $Dedicated_{s,t}$	Shareholder overlap of dedicated investors for firm s in year t. It is exactly the same as $SOL_{s,t}$ except that only the overlapping shares of dedicated investors are counted. Dedicated shareholders are the one-third of investors with the most concentrated portfolio and least portfolio turnover. Specifically, at the end of each year, we rank all institutional investors by the Herfindahl-Hirschman Index (HHI) of their equity portfolio holdings (in descending order) and the turnover ratio (in ascending order). We label dedicated investors as those in the top tercile of the combined rank of the two ranks. The HHI is calculated as the sum of squares of each individual stock's weight in the investor's overall equity portfolio. The turnover ratio for investor i in year t is calculated based on Gaspar, Massa, and Matos (2005) as $\frac{\sum_{j\in\Omega}\lvert Q_{j,i,t}P_{j,t}-Q_{j,i,t-1}P_{j,t-1}-Q_{j,i,t-1}\Delta P_{j,t}\rvert}{\frac{1}{2}\sum_{j\in\Omega}(Q_{j,i,t}P_{j,t}+Q_{j,i,t-1}P_{j,t-1})}$ where $Q_{j,i,t}$ is the number of shares of stock j held by investor i at the end of year t, $P_{j,t}$ is the price of stock j at the end of year t, and Ω is the pool of all stocks held by the investor in the year. [Source: Kogan *et al.,* 2017; CRSP and Thomson Reuters 13F]

Variable	Description
$SOL\_Intermediate_{s,t}$	Shareholder overlap of intermediate investors for firm s in year t. The overlapping shares are counted only for intermediate investors, who are the middle one-third of shareholders based on the combined rank of the HHI of their equity portfolio holdings (in descending order) and the turnover ratio (in ascending order). [Source: Kogan *et al.,* 2017; CRSP and Thomson Reuters 13F]
$SOL\_Transient_{s,t}$	Shareholder overlap of transient investors for firm s in year t. The overlapping shares are counted only for transient investors, who are the bottom one-third of shareholders based on the combined rank of the HHI of their equity portfolio holdings (in descending order) and the turnover ratio (in ascending order). [Source: Kogan *et al.,* 2017; CRSP and Thomson Reuters 13F]
$SOL\_Placebo1_{s,t}$	First placebo shareholder overlap measure for firm s in year t. It is constructed in the same way as $SOL_{s,t}$ except that we replace every cited upstream firm with a *similar* firm that is *not* cited by the downstream firm s in the given patent application year t. A placebo firm is chosen based on the criteria that it must have the same four-digit SIC code as the true upstream firm and that it has the shortest Euclidean distance from the upstream firm in terms of (log) firm asset size and (log) number of patents filed in the past three years. Specifically, the Euclidean distance between a true upstream firm u and a placebo firm x is $\sqrt{(\frac{\ln(Asset_x)}{\ln(Asset)\_mean} - \frac{\ln(Asset_u)}{\ln(Asset)\_mean})^2 + (\frac{\ln(1+M_x)}{\ln(1+M)\_mean} - \frac{\ln(1+M_u)}{\ln(1+M)\_mean})^2}$, where $Asset$ and M denote the total firm assets and the number of patents a firm files in the past three years (from $t-2$ to t), respectively. The suffix $\_mean$ refers to the industry average based on four-digit SIC codes. [Source: Kogan *et al.,* 2017; Thomson Reuters 13F and Compustat-CRSP merged database]

Variable	Description
$SOL\_Placebo2_{s,t}$	Second placebo shareholder overlap measure for firm s in year t. It is constructed in the same way as $SOL\_Placebo1_{s,t}$ except that the placebo firms are matched to the true upstream firms based on their technological proximity. Following Bloom, Schankerman, and Van Reenen (2013), we measure technological proximity between a true upstream firm u and a placebo firm x by $\frac{T_u T_x'}{\sqrt{T_u T_u'}\sqrt{T_x T_x'}}$, where $T_u = (T_{u,1}, ..., T_{u,K})$ and $T_x = (T_{x,1}, ..., T_{x,K})$. $T_{u,k}$ denotes the ratio of the number of patents filed by firm u in technological field $k \in [1, K]$ in the past three years to the total number of patents it filed during the same period. $T_{x,k}$ is defined analogously. The chosen placebo firm features the greatest value in the technological proximity measure among all firms not cited by the downstream firm in the given year. [Source: Kogan *et al.,* 2017; Thomson Reuters 13F]
$SOL^{3yr}_{s,t}$	Shareholder overlap weighted by three-year citations for firm s in year t. It is defined in the same way as $SOL_{s,t}$ except that we replace the log citation counts $ln[1 + cites(p)]$ in Eq. (4) with $ln[1 + cites^{3yr}(p)]$, where $cites^{3yr}(p)$ denotes the future citations received by patent p in the calendar year of patent grant and three subsequent years. [Source: Kogan *et al.,* 2017; Thomson Reuters 13F]
$SOL\_Equal_{s,t}$	Equally-weighed shareholder overlap for firm s in year t. It is the same as $SOL_{s,t}$ except that we use equal weights for each patent in the calculation of shareholder overlap. [Source: Kogan *et al.,* 2017; Thomson Reuters 13F]
$IO_{s,t}$	Aggregate institutional ownership of firm s in year t. It is the ratio of the number of shares held by institutional investors to the total number of shares outstanding for firm s at the end of year t. [Source: CRSP and Thomson Reuters 13F]
$IO^{SOL}_{s,t}$	Overlapping institutional ownership of firm s in year t. For each patent application year t, we identify all *overlapping shareholders* that hold joint equity stake in firm s and its upstream patent-owning firms and compute the ratio of the total number of shares held by overlapping institutional shareholders to the total number of shares outstanding for firm s at the end of year t. [Source: CRSP and Thomson Reuters 13F]

Variable	Description
$IO^{NOL}_{s,t}$	Non-overlapping institutional ownership of firm s in year t. It is calculated as the difference between aggregate institutional ownership $IO_{s,t}$ and overlapping institutional ownership $IO^{SOL}_{s,t}$. [Source: CRSP and Thomson Reuters 13F]
$MktCap_{s,t}$	Market capitalization value (in thousand U.S. dollars) of firm s at the end of year t. [Source: CRSP]
$MktCap^{u}_{p,t}$	Average market capitalization value (in thousand U.S. dollars) of firms owning patent p's upstream patents u at the end of year t. [Source: Kogan *et al.,* 2017; CRSP]
$R\&D\ Stock_{s,t}$	Cumulative R&D investment (in million U.S. dollars) of firm s at the end of year t. Following Hall, Jaffe, and Trajtenberg (2005), we measure $R\&D\ Stock_{s,t}$ as $R\&D\ Expenditure_{s,t} + (1-\delta) \times R\&DStock_{s,t-1}$, where δ represents the private depreciation rate of knowledge and is set to be 0.15. [Source: Compustat-CRSP merged database]
$K/L_{s,t}$	The ratio of capital (Compustat Mnemonic: $PPEGT$; in million U.S. dollars) to labor (Compustat Mnemonic: EMP; in thousands) for firm s in year t. [Source: Compustat-CRSP merged database]
$Sales_{s,t}$	Total amount of sales (Compustat Mnemonic: $SALE$; in million U.S. dollars) for firm s in year t. [Source: Compustat-CRSP merged database]
$Private\ Patent\ Share_{s,t}$	Average proportion of private upstream patents for firm s in year t. For each patent p filed by firm s in year t, we calculate the share of privately owned upstream patents. We then average this private patent share across all patents filed by firm s in year t, with the weight of each patent p given by w(p) in Eq. (4). [Source: Kogan *et al.,* 2017]

Variable	Description
$WHHI_{s,t}$	Weighted Herfindahl-Hirschman index of shareholder overlap concentration for firm s in year t. For each patent p filed by firm s in year t, we identify all the overlapping shareholders $i \in I_{p,pu}$ who have a joint equity stake in firm s and the firm owning the upstream patent p_u. We then calculate $hhi_{p,p_u,t}$ as the Herfindahl-Hirschman index based on the overlapping ownership share of each overlapping shareholder $i \in I_{p,pu}$, with the ownership measured at the end of year t. $WHHI_{s,t}$ is the weighted average of $hhi_{p,p_u,t}$ across all patents p owned by firm s and their respective upstream patents p_u, where the weight for each patent is given by Eq. (4). [Source: Kogan *et al.,* 2017; Thomson Reuters 13F]
$SpillTech_{s,t}$	Technology (or knowledge) spillover from other firms for firm s in year t. It is the technological proximity-weighted sum of *R&D Stock* of all firms in year t except firm s. Technological proximity between firms m and s is defined by $\frac{T_m T_s'}{\sqrt{T_m T_m'}\sqrt{T_s T_s'}}$, where $T_m = (T_{m,1}, ..., T_{m,K})$ and $T_s = (T_{s,1}, ..., T_{s,K})$. $T_{m,k}$ denotes the ratio of the number of patents filed by firm m in technological class $k \in [1, K]$ over the whole sample period to the total number of patents it filed during the same period. $T_{s,k}$ is defined analogously. [Source: Kogan *et al.,* 2017; Compustat-CRSP merged database]
$SpillSIC_{s,t}$	Product market rivalry effect of *R&D* for firm s in year t. It is the product market proximity-weighted sum of *R&D Stock* of all firms in year t except firm s. Product market proximity between firms m and s is defined by $\frac{X_m X_s'}{\sqrt{X_m X_m'}\sqrt{X_s X_s'}}$, where $X_m = (X_{m,1}, ..., X_{m,Q})$ and $X_s = (X_{s,1}, ..., X_{s,Q})$. $X_{m,q}$ denotes the share of firm m's sales in industry $q \in [1, Q]$ relative to its total sales during the year, averaged over the whole sample period. Industries are defined by four-digit SIC codes. $X_{s,q}$ is defined analogously. [Source: Kogan *et al.,* 2017; Compustat-CRSP merged database]

Appendix C. Robustness Tests

Table C1: Firm Level Citation Counts by Adjustment Method

Reported are average patent count (Column 3) and summary statistics of three citation-based measures for the patent success at the firm level. The basic patent success measure, labelled as "No Adjustment" in Columns 4-6, is given by the number of future citations received by all patents filed by a firm in a given year. Self-citations are excluded. We also report two adjusted citation-based measures which aim at fixing the truncation issues associated with patent citation count. The first adjusted measure in Columns 7-9 follows Hall et al. (2001) and represents the main firm-level patent success measure used in our baseline regressions. The second adjusted measure in Columns 10-12 restricts citations to a three-year period after the patent is granted and is labelled as "3-Year Future Citations".

Year	Obs.	Patents per firm	Firm level citation count (*CITES*)								
			No Adjustment			Hall et al. (2001)			3-Year Future Citations		
			Mean	Median	STD	Mean	Median	STD	Mean	Median	STD
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1992	911	26	474	62	2,072	585	79	2,479	133	17	633
1993	1,053	23	447	57	1,897	568	73	2,330	136	16	622
1994	1,186	23	459	57	2,233	597	75	2,794	157	19	828
1995	1,284	26	481	60	2,360	647	85	3,052	186	21	1,000
1996	1,264	26	474	56	2,398	655	80	3,195	211	23	1,146
1997	1,426	29	496	50	2,859	717	75	3,961	246	23	1,518
1998	1,385	29	428	43	2,555	647	71	3,708	235	22	1,485
1999	1,375	30	369	36	2,196	594	61	3,385	217	20	1,396
2000	1,323	34	320	30	1,695	551	55	2,807	195	18	1,093
2001	1,354	36	237	26	1,158	450	49	2,115	144	16	736
2002	1,316	38	181	19	814	376	41	1,623	108	11	504
2003	1,215	39	124	12	554	291	31	1,254	69	6	316
2004	1,109	39	81	7	346	220	21	902	39	3	164
2005	1,058	37	49	5	210	160	18	654	19	2	81
2006	963	31	27	3	107	114	13	427	7	1	29
2007	798	24	15	2	65	90	11	359	3	0	10
Total	19,020	31	304	27	1,819	474	49	2,581	141	11	930

Table C2: Shareholder Overlap by Weighting Method

Reported are summary statistics for the four measures of shareholder overlap based on different weights for patent importance. The shareholder overlap measure used in our baseline regression is given by the cites-weighted shareholder overlap (SOL), where the importance weight is based on the patent future citation count (Columns 3-4). The other three measures are (i) shareholder overlap weighted by three-year citations, where the patent importance weight is based on the number of citations received in the three-year period after patent grant date (Columns 5-6); (ii) the rank-weighted shareholder overlap, where the importance weight is based on the rank of the patent future citation count relative to those patents that are assigned to the same USPTO technology class and that are filed in the same year (Columns 7-8), and (iii) equally-weighted shareholder overlap, where all patents are regarded as equally important in constructing shareholder overlap measure (Columns 9-10).

Year	Obs.	Shareholder overlap (SOL) by weights ($\times 100$)							
		Cites weighted		3-Year cites		Rank weighted		Equally weighted	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1992	911	5.63	4.20	5.49	4.02	5.60	4.24	15.75	14.46
1993	1,053	5.19	3.57	5.08	3.49	5.19	3.69	14.47	13.29
1994	1,186	5.42	4.05	5.39	4.01	5.41	3.95	15.27	14.18
1995	1,284	5.52	3.93	5.49	3.82	5.50	3.90	15.01	13.66
1996	1,264	5.72	4.12	5.69	4.19	5.71	4.15	15.25	14.40
1997	1,426	5.52	3.85	5.46	3.72	5.55	3.90	15.07	13.79
1998	1,385	5.69	4.16	5.66	4.06	5.70	4.29	15.26	13.92
1999	1,375	5.76	3.84	5.71	3.89	5.78	3.87	15.65	14.11
2000	1,323	6.16	4.09	6.15	4.03	6.24	4.28	16.70	15.61
2001	1,354	6.42	4.52	6.36	4.24	6.49	4.67	17.90	17.53
2002	1,316	6.94	4.76	6.94	4.86	7.03	4.85	19.34	19.82
2003	1,215	6.89	5.20	6.84	5.07	7.00	5.26	19.32	19.77
2004	1,109	7.53	5.42	7.52	5.29	7.64	5.76	20.91	22.04
2005	1,058	7.30	5.30	7.48	5.39	7.41	5.63	19.97	20.66
2006	963	7.47	5.79	7.41	5.51	7.63	6.00	21.15	21.92
2007	798	7.41	5.37	7.37	5.42	7.49	5.56	22.02	23.13
Total	19,020	6.23	4.42	6.20	4.35	6.28	4.50	17.24	16.43

Table C3: Robustness to Firm Fixed Effects Estimator

We extend our baseline regressions in Table 2 by including additional two columns that include a set of firm dummies to control for firm fixed effects. Columns 1–3 report full sample results and Columns 4–6 show subsample for the three most R&D-intensive sectors (pharmaceuticals, computer hardware, and telecommunications equipment). The control variables include the market capitalization ($MktCap_{s,t-1}$), cumulative R&D investment ($R\&D\ Stock_{s,t-1}$), capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$) for firm s in year $t-1$. The year and industry fixed effects are a set of year dummies and four-digit SIC industry dummies. Firm fixed effects are based on including pre-sample means of the dependent variable following Blundell, Griffith, and Van Reenen (1999) in Columns 2 and 5 or including a set of firm dummies in Columns 3 and 6. All regressions report robust standard errors clustered at the firm level in parentheses. ** and * denote the 1% and 5% significance level, respectively.

Dependent Variable:	$ln(1+CITES)$					
	Full Sample			Top 3 R&D-Intensive Industries		
	(1)	(2)	(3)	(4)	(5)	(6)
SOL	3.692**	3.450**	1.586**	4.685**	4.328**	2.914**
	(0.495)	(0.484)	(0.440)	(0.826)	(0.805)	(0.799)
Controls:						
$ln(MktCap)$	0.317**	0.306**	0.145**	0.381**	0.367**	0.158**
	(0.018)	(0.018)	(0.021)	(0.032)	(0.031)	(0.035)
$ln(1+R\&D\ Stock)$	0.317**	0.251**	0.154**	0.276**	0.213**	0.258**
	(0.016)	(0.016)	(0.041)	(0.037)	(0.036)	(0.077)
$ln(K/L)$	0.029	−0.009	−0.067	0.107	0.040	−0.034
	(0.032)	(0.031)	(0.042)	(0.059)	(0.056)	(0.073)
$ln(Sales)$	−0.024	−0.076**	−0.010	−0.008	−0.055*	−0.012
	(0.015)	(0.015)	(0.023)	(0.024)	(0.024)	(0.032)
$Private\ Patent\ Share$	0.422**	0.321**	0.124	0.624**	0.475*	0.186
	(0.120)	(0.117)	(0.112)	(0.195)	(0.189)	(0.192)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	No	Yes	Yes	No
BGV Firm FE Control	No	Yes	No	No	Yes	No
Firm FE	No	No	Yes	No	No	Yes
Obs.	19,020	19,020	19,020	5,898	5,898	5,898
Adj. R^2	0.526	0.542	0.727	0.564	0.577	0.747

Table C4: Robustness to Different Time Lags for Shareholder Overlap

We repeat the baseline regression for different time lags of ownership measurement in the computation of SOL. The variables $SOL(t-k)$ is similar to $SOL_{s,t-1}$ in the baseline regression except that the former is based on institutional ownership at the end of year $t-k$ instead of $t-1$. The control variables include the market capitalization ($MktCap_{s,t-1}$), cumulative R&D investment ($R\&D\ Stock_{s,t-1}$), capital to labor ratio ($K/L_{s,t-1}$), sales ($Sales_{s,t-1}$), and the average proportion of privately owned upstream patents ($Private\ Patent\ Share_{s,t-1}$) for firm s in year $t-1$. Firm fixed effects are based on including pre-sample means of the dependent variable following Blundell, Griffith, and Van Reenen (1999). Industry fixed effects are based on four-digit SIC codes. All regressions report robust standard errors clustered at the firm level in parentheses. We denote by ** and * the statistical significance at the 1% and 5% level, respectively.

Dependent Variable:	$ln(1+CITES)$				
	(1)	(2)	(3)	(4)	(5)
SOL	3.450**				
	(0.484)				
$SOL(t-2)$		2.385**			
		(0.432)			
$SOL(t-3)$			1.581**		
			(0.428)		
$SOL(t-4)$				0.959*	
				(0.436)	
$SOL(t-5)$					0.720
					(0.459)
Control Variables	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
BGV Firm FE Control	Yes	Yes	Yes	Yes	Yes
Obs.	19,020	18,109	17,056	15,870	14,586
Adj. R^2	0.542	0.539	0.535	0.531	0.531