Technological Progress and Ownership Structure

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Abstract

Innovation processes under patent protection generate hold-up problems if complementary patents are owned by different firms. We show that in line with Hart and Moore (1990), shareholder ownership overlap across firms with patent complementarities helps mitigate such hold-up problems and correlates significantly with higher intensive and extensive margins of patent production. The positive innovation effect of shareholder overlap with owners of complementary patents is evident even across different patents filed by the same firm in the same year. Furthermore, the shareholder type matters: Shareholder overlap originating from more "activist-oriented" investors contributes more to a firm's future patent success.

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1 Introduction

While technological progress is recognized as the main source of long-run economic growth, its relation with corporate ownership structure and property rights in patents is less understood. This paper provides a new empirical perspective on the role an evolving equity ownership structure pays in attenuating hold-up problems induced by patent protection in the corporate innovation process.

Patents protection provides exclusive rights with respect to a specific product or process, but the full economic value of a patent may only be unlocked if the innovating firm can simultaneously secure access to other complementary patents. Thus, patent processes generate hold-up problems whenever such complementary patents are owned by rival firms and ex ante contracting is incomplete.[1] Building on the property rights theory of Hart and Moore (1990), we argue that joint equity ownership in the innovating firm and firms controlling complementary patents can attenuate the hold-up problem and contribute to the patent success of the innovating firm. We develop a simple model of optimal patent investment to show how such joint equity ownership can increase the intensive and extensive margins of the patent production.

To subject this property right perspective of patent success to an empirical examination, 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 1991–2010. In particular, we track stock ownership not only for the innovating firms, but also for firms owning the complementary patents. The complementarities are identified directly from the patent filings that explicitly list important precursory patents owned by other firms. Each patent filing might list prior art or precursory (downstream) patents that are technologically related and material to the patentability of the application.[2] These downstream patents might have to be licensed to the (upstream) innovator for him to realize the full value of his new patent (Ziedonis, 2004).[3] Our analysis replies on the citation conventions for precursory patents as a reasonable proxy for patent hold-up situation and assumes that the citation generating process is to a certain extent exogenous to the filing firm. Indeed, the frequent regulatory intervention by patent examiners in

[1] In particular, a technology driven innovation process delivers 'upstream' patents that typically build on and require the use of preceding 'downstream' patents. Modern patenting systems grant a patent owner the right to exclude others from incorporating the patented technology into their products. Therefore, to commercialize a new technology, a company faces potential hold-up from owners of the complementary patents.

[2] The U.S. patent law requires an invention to be useful, novel, and non-obvious to be patented.

[3] Ziedonis (2004) suggests that owners of cited patents are reasonable proxies for potential licensors of the citing patent. From this perspective, firms owning the cited patents can pose a hold-up threat to the upstream innovator.

the list of prior art references suggests a limited scope for strategic considerations in the citation of precursory patents by the filing firm (Alcácera, Gittelmanb, and Sampatc, 2009).[4]

Our main hypothesis states that joint equity ownership between the upstream innovator and the downstream firms controlling complementary patents attenuates hold-up problems and contributes to long-run patent success of the innovating firm. Following the existing literature, we measure patent success by the cumulative citation count of each patent that was filed and granted; this measure can be viewed as the intensive margin of patent production.[5] The extensive margin of patent production is measured by the number of successful patents (i.e., patent applications that are eventually approved by USPTO) a firm files in a given year. Our baseline analysis relates firm-level patent success *ln(1+CITES)*, calculated as the (log of) total number of future citations for all patents a firm filed in a given year, to *shareholder overlap* (SOL), which measures the average aggregate (percentage) shares held by the group of shareholders that invest in both the patent filing firm and the firms owning downstream complementary patents. Consistent with the *hold-up attenuation hypothesis* of joint equity ownership, we find that SOL emerges as the statistically and economically most significant determinant of patent success and it is positively related to both the intensive and extensive margin of patent production. This result holds regardless of whether SOL is measured based on equity ownership overlap in the patent application year, or 1–3 years prior to the patent application.

We further hypothesize that shareholder overlap can be a more powerful mechanism for hold-up resolution if the respective shareholders are so-called "activist" shareholders. In particular, institutional investors with more concentrated portfolio holdings (i.e., a high Herfindahl-Hirschmann index) should contribute more to the resolution of rent extraction problems than investors with more diversified portfolio holdings. Consistent with this intuition, we find a much stronger effect of shareholder overlap on patent success when such shareholder overlap originates from more concentrated (or "activist") shareholders.

Besides the firm-level evidence, we also find similar results at the patent level. Patent-level

[4] Patent examiners in USPTO are officially responsible for constructing the list of prior art references. However, inventors also have a "duty of candor" to disclose all material prior art and failure to do so can result in an "inequitable conduct" and the court may render the patent unenforceable. Using data from USPTO for all patents granted over the period 2001–2003, Alcácera, Gittelmanb, and Sampatc (2009) document that examiners insert at least one citation in 92% of patent applications. Overall, examiner citations account for 63% of all citations made by an average patent.

[5] See for example Aghion, Van Reenen and Zingales (2013) for a similar definition of firm level patent success.

regressions with interacted firm and year fixed effects represent a even more powerful test for the relation between *shareholder overlap* and future patent success. In this regression setup, we can directly compare the success of any two patents (in term of its future citations) filed by the same firm in the same year. The two patents are subject to different degrees of hold-up due to different degrees of shareholder overlap with the firms owning the respective complementary patents. Such a regression specification controls for all unobservable firm-level effects that might lead to a spurious correlation between shareholder overlap and patent success. We show that even within the same firm-year, patent success is correlated with the varying degree of hold-up across a firm's cohort of patents.

A potential cost of the hold-up problem in innovation is the reduction in R&D investment. We hypothesize that the hold-up attenuation role of joint shareholder ownership in firms owning complementary patents should generally mitigate this effect. We empirically examine this hypothesis and indeed find that R&D expenditure features a statistically and economically strong positive correlation with shareholder overlap. Furthermore, the hold-up attenuation effect on R&D expenditure strongly increases over time. The result is consistent with the interpretation that patent hold-up has increased its economic importance as a deterrent to R&D investment, supporting the claim that the current U.S. patent system is subject to increasing rent extraction as argued by the advocates of patent reform.[6]

Our analysis also considers a number of alternative hypotheses. Having shareholders who invest mostly in other innovative firms might increase shareholder overlap and simultaneously constitute an advantage for a firm engaged in patent competition. We control for this factor by constructing a firm-level proxy of *shareholder innovation focus* SIF. In addition, we control for a firm's institutional ownership share IO. Aghion, *et al.* (2013) highlights institutional investors' monitoring role and their willingness to support risky R&D investments that may pay off only in the long run. A number of other variables are also controlled for, which include the previous R&D investment $ln(1 + R\&D\ Stock)$, a measure of relative capital intensity $ln(1 + Capital/Labor)$, a firm size measure $ln(1 + Sales)$, and year and industry (or firm) fixed effects. Yet, the relation between the hold-up attenuation factor—*shareholder overlap*—and future patent success remains both statistically and economically significant.

[6] Both the Innovation Act (H.R.3309) and the Patent Transparency and Improvement Act (S. 1720) propose patent reform in pursuit of more narrowly and clearly defined patent rights against the background of dramatic increase in patent litigation (Schlicher, 2011, chapter 8).

To the best of our knowledge, the role of stock market ownership structure in mitigating hold-up problems in patent processes has not been subject to any systematic analysis. Ex ante contracting about access to auxiliary patents might be difficult before the feasibility and commercial potential of a new patent are established. Therefore, ex post bargaining should reduce the investment incentive. Our evidence suggests that rent extraction can be mitigated by joint equity ownership (especially by activist investors) in firms holding complementary patents.

Existing studies on patent hold-up problems (e.g., Shapiro, 2001; Ziedonis, 2004; and Hall and Ziedonis, 2007) find that licensing agreements are commonly used in practice—yet these might typically concern the ex-post rent allocation. Licensing agreement may involve substantial royalty fees and their negotiation may not represent a frictionless process. Alternatively, a firm may invent around the patented technology to avoid being held up, but this is not always possible given the cumulative and sequential nature of technological development. There is also evidence that firms seek outright ownership integration via mergers to resolve patent disputes, but such merger cases are often challenged by court and eventually fall through for anti-competitive reasons (Creighton and Sher, 2009). Our study suggests that in liquid equity markets, partial ownership integration via ownership overlap may be achieved at lower costs or may already exist if large institutional shareholders happen to hold shares in both concerned firms.

Notwithstanding its prominence in economic theory, the property rights view of the boundaries of the firm has seen very few empirical applications because a variety of obstacles. First, non-contractible hold-up problems might often be difficult to identify in a complicated business environment. Explicit citation of precursory patents in the patent documents provides a unique identification opportunity. Second, any underinvestment at the project level also tends to be difficult to measure because a firm can shift investments to other projects for which hold-up problems are less severe—analysis at the project level therefore requires a level of disaggregation typically not available for investment data. Third, investments may also involve intangibles resources (such as managerial attention) that pose additional measurement problems. For these reasons, we infer the (latent) underinvestment indirectly from diminished project (or patent) success. Future patent citations provide a sufficiently precise proxy for patent success at the firm (and patent) level to allow for a comprehensive study of hold-up in the patent process.

Patent reform has become a hotly debated policy issue. President Obama in his 2014 State of the Union Address singled out the patent system as a priority for economic reform. The

Administration has pushed USPTO to examine patent requests more rigorously and defined their patentable component more narrowly ex ante in order to reduce the reliance on the courts to make those determinations ex post. Galetovic, Haber, and Levine (2014), however, argue that there is no evidence that more patent litigation is associated with patent holders stymieing the commercialization of complex technologies or hindering innovation. The evidence in our paper suggests that shareholder overlap has become an increasingly important palliative to hold-up problems with respect to patent investment—an indication that the underlying patent hold-up problem itself may have become more significant after 2000.[7]

Other empirical work on the determinants of patent success focuses on the role of institutional shareholders. Aghion, Van Reenen and Zingales (2013) argue that a larger share of institutional shareholders is conducive to patent investment as these shareholders tend to pursue a long-run objective. Our more extensive data, however, shows that the statistical and economic significance of the institutional ownership variable vanishes once we control for the role of *shareholder overlap* as the relevant determinant of patent success. Bena, Ferreira and Matos (2014) relate patent success to foreign ownership, but it is unclear whether foreign ownership just proxies for more *shareholder overlap* in complementary patents as identified in this study. Brav, Jiang, and Tian (2014) show that hedge fund activism leads to more efficient use of innovative resources and human capital. Our study complements their finding and identifies activist shareholders as an important mechanism to alleviate hold-up problems in corporate innovation processes. Recent empirical work has also highlighted the complementarity between equity market development and the degree of patent innovation both in the cross-section of countries (Hsu, Tian, Xu, 2014) and for some particular event (Ostinelli, 2014). Insofar as equity market development allows for a better internalization of hold-up problems (though enhanced and adjustable *shareholder overlap*), our study can give these findings a deeper microeconomic interpretation rooted in the theory of the firm.

The next section develops a simple model of patent hold-up in the spirit of Hart and Moore (1990); it motivates our variable measurement and provides parsimonious regression specifications. Section 3 discusses the empirical design and data. Empirical results are presented in Section 4. Section 5 examines alternative hypotheses and robustness checks. Section 6 concludes.

[7] A change in the patent environment is sometimes attributed to the growing role of non-practicing endities (NPEs) refered to as "patent trolls", which specialize in the enforcement of patent rights without having a commercial activity of their own.

2 A Model of Patent Investment

2.1 A Simple Benchmark (with No Hold-up Effect)

A risk neutral firm s can invest into a continuum of patent projects. Each project is represented by the index number p on the interval $[0, \infty)$, where a higher index number corresponds to higher patent development costs. For simplicity, we assume a continuous increasing convex cost function $C(p)$ with $C'(p) > 0$ and $C''(p) > 0$. The present value of the revenue of each patent project, $R_s(p)$, is proportional to the success of the patent proxied by number of future cites counts $cites_s(p)$; hence

$$R_s(p) = \alpha \times cites_s(p), \tag{1}$$

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 profit Π_s follows as

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

where the interval $[0, \overline{p}]$ denotes the range of patent projects the firm pursues. Profit 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

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

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

Proposition 1: Patent Production without Patent Hold-Up

A value maximizing firm optimally invest in the production of patents $[0, \overline{p}]$. For a patent-level expected citation count $E[cites_s(p)] = \mu_s$ proportional to firm patent revenue, a convex cost function $C(p) = cp^b$ implies for

(i) the extensive margin of patent production

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

(ii) the firm-level (log) citation counts

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

(iii) the (log) R&D expenditure

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

The firm level (log) citation count in Eq.(5) consist of the external margin in Eq. (4) plus the (log) intensive margin $lnE[cites_s(p)] = ln(\mu_s)$. Empirically, we can approximate the intensive margin by the average citation count $\overline{cites}_s$ of a firm's patents.

2.2 The Patent Hold-up Effect

Next, we enrich the model setting to account for hold-up problems with respect to the patent revenue $R_s(p)$. Suppose that commercialization of each patent p requires consent from the owners of downstream patent p_d with $d = 1, 2, ...N_p$.[8] These downstream patents allow their owners to extract part of the revenue (through, e.g., license fees) so that the firm's expected revenue decreases. We denote the share of revenue lost to each downstream by $L_s(p, p_d)$, and the aggregate revenue loss by

$$L_s(p) = \sum_{d=1}^{N_p} L_s(p, p_d). \tag{7}$$

The share $L_s(p) \in [0, 1]$ and its components $L_s(p, p_d)$ depend on the "toughness" of the bargaining of the owner of the downstream patent p_d. In the ideal case in which the institutional owners of firm s coincide with those of the firm owning p_d, no such rent extraction should take place so that $L_s(p) = L_s(p, p_d) = 0$. By contrast, the maximal rent extraction is likely to occur if there is no overlap in institutional ownership between the two firms. For simplicity, we assume that the ex-ante expectation for revenue loss is identical for all patents p produced by the same firm; hence $E[L_s(p)] = \overline{L}_s$.

[8] Ziedonis (2004) makes a similar argument and suggests that owners of cited patents are reasonable proxies for potential licensors of the citing patent. Note that p_d does not include any expired patents because they do not pose any threat to the commercialization of the citing patent.

Besides the revenue loss, the hold-up situation might also reduce the total (revenue) prospect of each individual patent itself. We assume that the expected number of citations diminishes according to

$$E\left[cites_s(p)\right] = \mu_s[1 - \overline{L}_s]^{\gamma}, \tag{8}$$

where γ denotes the elasticity of the expected patent success (measured by future citation count) to the retained revenue share, $1 - L_s(p)$, with $\gamma \geq 0$. For the special case $\gamma = 0$, patent hold-up does not compromise the overall long-term patent success, but amounts to a simple redistribution of future rents. Using a first-order Taylor expansion around The expected revenue from patent p follows as

$$E[R_s(p)] = \alpha[1 - \overline{L}_s] \; E\left[cites_s(p)\right] = \alpha\mu_s[1 - \overline{L}_s]^{1+\gamma}. \tag{9}$$

The optimal investment policy in the hold-up case requires maximization of the expected profit function

$$\max_{\overline{p}_L} \Pi_s = \int_0^{\overline{p}_L} \left[\alpha\mu_s[1 - \overline{L}_s]^{1+\gamma} - C(p)\right] dp, \tag{10}$$

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

$$\overline{p}_L = \left(\frac{\alpha\mu_s}{c}[1 - \overline{L}_s]^{1+\gamma}\right)^{\frac{1}{b}}. \tag{11}$$

Proposition 2: Patent Production with Patent Hold-Up

A value maximizing firm optimally invests in the production of patents $[0, \overline{p}]$. For a patent-level (ex-ante) expected citation count $E[cites_s(p)] = \mu_s[1 - \overline{L}_s]^{\gamma}$ proportional to patent revenue, and an (ex-ante) expected revenue loss $\overline{L}_s = E[L_s(p)]$ for each patent due to patent hold-up, we find for

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

$$ln[\overline{p}_L] = \frac{1}{b} ln\frac{\alpha}{c} + \frac{1}{b} ln(\mu_s) + \frac{1+\gamma}{b} ln[1 - \overline{L}_s] \tag{12}$$

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

$$ln[CITES_s] = \frac{1}{b} ln \frac{\alpha}{c} + \frac{b+1}{b} ln(\mu_s) + \frac{1+\gamma+b\gamma}{b} ln[1-\overline{L}_s], \tag{13}$$

(iv) the (log) R&D expenditure

$$ln[R\&D\ Exp] = ln \frac{c}{1+b} + \frac{b+1}{b} ln \frac{\alpha\mu_s}{c} + (1+\gamma)\frac{b+1}{b} ln[1-\overline{L}_s]. \tag{14}$$

The first term and second term in Eq. (13) are the same as in Eq. (5). The third expression in Eq. (13) and Eq. (14) captures how the hold-up problem reduces the overall patent success and R&D expenditure, respectively. All three equations feature the same (log) loss term $ln[1-\overline{L}_s] < 0$. We also note that the hold-up problem affects not only the *extensive margin* ($\overline{p}_L$), but also the *intensive margin* $E[cites_s(p)]$ of patent production if $\gamma > 0$.

2.3 Patent Hold-Up and Shareholder Overlap

The model estimation has to define empirical proxies for the patent-specific hold-up loss $L_s(p)$ and its unconditional expected value $E[L_s(p)] = \overline{L}_s$. Our basic assumption is that shareholder overlap reduces hold-up. Let $O(p)$ be an ownership function that assigns a patent p to a (single) firm owner at time t. The *pairwise (institutional) shareholder overlap* between the upstream patent p and downstream patent p_d (named in the patent filings) can be defined as

$$PSOL(p, p_d) = \sum_i \min[w_{i,O(p)}, w_{i,O(p_d)}], \tag{15}$$

where $w_{i,O(p)}$ and $w_{i,O(p_d)}$ are the ownership share (relative to total institutional firm ownership) of institutional investor i in, respectively, firms $O(p)$ and $O(p_d)$ at time t. Without loss of clarity, we omit the time index t from the variable expressions in this subsection. As a reduced form for the revenue loss $L_s(p, p_d)$ due to hold-up problems associated with the downstream patent p_d, we assumed

$$L_s(p, p_d) = \delta w(p_d) [1 - PSOL(p, p_d)], \tag{16}$$

where weight function $w(p_d)$ measures the importance of downstream patent p_d relative to all other downstream cited patents of the citing patent p. The parameter $\delta \in [0, 1]$ denotes the degree to which separate asset ownership translates into patent revenue sharing; a larger value for δ implies more substantial rent redistribution due to ownership separation. The total redistributed rents to the N_p downstream patent holders aggregate to a redistributive loss for patent p, given by

$$\begin{aligned} L_s(p) &= \sum_{d=1}^{N_p} \delta w(p_d) \left[1 - PSOL(p, p_d)\right] \\ &= \delta \left[1 - \sum_{d=1}^{N_p} w(p_d) PSOL(p, p_d)\right]. \end{aligned} \tag{17}$$

We can define *patent-level shareholder overlap* as

$$sol_p = \sum_{d=1}^{N_p} w(p_d) PSOL(p, p_d). \tag{18}$$

For the N_s patents filed by firm s at year t, we can approximate the average hold-up loss as

$$\begin{aligned} \overline{L}_s &= \sum_{p=1}^{N_s} w(p) L_s(p) = \delta \sum_{p=1}^{N_s} \sum_{d=1}^{N_p} w(p) w(p_d) \left[1 - PSOL(p, p_d)\right] \\ &= \delta \left[1 - \sum_{p=1}^{N_s} \sum_{d=1}^{N_p} w(p) w(p_d) PSOL(p, p_d)\right], \end{aligned}$$

where the weight $w(p)$ denotes the relative importance of patent p. The *firm-level shareholder overlap* can be defined as

$$SOL_s = \sum_{p=1}^{N_s} \sum_{d=1}^{N_p} w(p) w(p_d) PSOL(p, p_d), \tag{19}$$

which captures shareholder commonality between firm s and all other firms owning the downstream patents important to firm s. The hold-up loss terms in Proposition 2 can be approximated by

$$ln(1 - \overline{L}_s) \simeq -\overline{L}_s = \delta[SOL_s - 1]. \tag{20}$$

and substitution makes the model directly testable. The expression δSOL_s capture the hold-up attenuation through firm-level shareholder overlap relative to a total (non-attenuated) hold-up effect embodied by δ.

A final measurement issue concerns the choice of weights reflecting the relative importance of patents p and downstream patents p_d. We argue that a suitable measure of relative importance is again the relative (log) citation count. Hence, we define

$$w(p) = \frac{ln[1 + cites_s(p)]}{\sum_{p=1}^{N_s} ln[1 + cites_s(p)]} \quad \text{and} \quad w(p_d) = \frac{ln[1 + cites(p_d)]}{\sum_{d=1}^{N_p} ln[1 + cites(p_d)]}. \tag{21}$$

2.4 Hypotheses

The model insights can be summarize into five testable hypothesis. The first two hypotheses concern patent success at the firm level:

H1: Firm Patent Success and Hold-Up Attenuation

The patent success of firm s in terms of future citation $CITES_{s,t}$ for its cohort of patents successfully submitted in year t should increase in the *firm-level shareholder overlap* $SOL_{s,t-1}$ between itself and the firms owning cited downstream patents posing potential hold-up problems.

H2: Extensive and Intensive Margins of Patent Production

The extensive margin of patent production (proxied by the number of patents $N_{s,t}$ successfully submitted in year t) correlates positively with the *firm-level shareholder overlap* $SOL_{s,t-1}$. The intensive margin $\overline{cites}_{s,t}$ as the average citation success of a firm's patents also correlated positively with $SOL_{s,t-1}$ if patent hold-up involves (inefficient) value destruction ($\gamma > 0$) and not only value redistribution.

A straightforward extension of the hold-up hypothesis distinguishes between active and passive shareholder, where we conjecture that the former should be more willing or capable of exercising their ownership power to resolve patent hold-up. Also a more concentrated ownership might be helpful to overcome the free-rider problem of costly lobbying in favor of patent dispute settlement:

H3: Shareholder Type and Concentration of Shareholder Overlap

Shareholder overlap (both at the firm and patent level) should be feature a stronger positive correlation with patent success if the overlapping shareholders are activist investors or if the overlapping equity stake is concentrated among few shareholders.

As the patent hold-up and its patent specific attenuation through shareholder overlap operates not only at the firm level, but also across different patents successfully submitted by the same firm in the same year, we can formulate the following within firm hypothesis:

H4: Patent Success within the Firm

Within a firm's cohort of successfully submitted patents, those with the largest *patent-level shareholder overlap* $sol_{p,t-1}$with respect to downstream cited patents feature the largest patent success in terms of future patent citations $cites_{p,t}$.

This latter hypothesis has the advantage that it can be tested using a rich set of interacted firm-year fixed effects—thus controlling for time varying unobservable firm heterogeneity.

Finally, Eq. (**??**) can be translated into the following hypothesis:

H5: Firm R&D Expenditure

A firm's (log) R&D expenditure increase (linearly) in *firm-level shareholder overlap.*

Firm data on R&D expenditure typically does not allow any cost attribution to individual patent projects; hence we can test for positive effect of shareholder overlap on R&D investment only at the firm level. At the same time this limitation justifies our focus on direct measures of patent success as given by the citation count.

3 Data

Our sample combines institutional ownership data with annual patent and citation data for all publicly-listed firms in the United States. Our ownership data is from the Thomson Reuters 13F database. SEC requires all institutional organizations, companies, universities, etc. 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) document reporting inconsistencies in the ownership data prior to 1991, so we start our ownership sample in 1991.

We collect patent and citation information from the latest version of the National Bureau of Economic Research (NBER) Patent Citation database, which includes annual data for patents granted during 1976–2006. We further supplement the NBER data set with the data set from Kogan, Papanikolaou, Seru, and Stoffman (2014). The combined data set provides annual patent and citation information for patents granted over 1976–2010.[9]

[9] The dataset includes information on patent assignee names, the number of patents, the number of citations received by each patent, a patent's application year and grant year, etc. We thank Prof. Noah Stoffman for making the dataset available to us.

Our measurement of innovation success follows the literature (Griliches, Pakes, and Hall, 1988). To distinguish influential innovations from incremental technological discoveries, we use the total number of future patent citations denoted by $cites$ from the year t of the patent filing up to 2010 as our proxy for patent success. At the firm level, we aggregate the count statistics $cites$ to the total number of future patent citations generated by all the successfully filed patent by firm s in year t and denoted it $CITES_{s,t}$. Self-citations are always excluded and patent and citation counts are set to zero whenever there is no patent or citation information provided. We also examine the extensive margin of patent production defined simply as the number of successful patent filings $N_{s,t}$ by firm s in year t. The corresponding intensive margin is measures by the average cites per patent $\overline{cites}_{s,t}$ and follows as the ratio of $CITES_{s,t}$ and $N_{s,t}$. As most of these measures of patent production and patent success feature highly right skewed distribution, we generally apply a log transformation $ln(1 + X)$ in order to obtain more normally distributed variables for regression analysis.

We carefully adjust for the two truncation problems commonly associated with patent data. First, the patent data set only includes those patents that are eventually granted. Because it takes on average two years for a patent's application to be approved, many patent applications filed in 2009 and 2010 are still not included in the data set. To mitigate this patent truncation bias, we use only patents granted up to 2007 in our empirical analysis.[10] Second, patents tend to receive citations over a long period of time, but in our data set we observe the citations only up to 2010. Following Hall, Jaffe, and Trajtenberg (2001, 2005), we correct for the truncation bias in citation counts by estimating the shape of the citation-lag distribution.

We gather all announced and completed US mergers and acquisitions recorded by Thomson Financial's SDC database with deals that are marked as a merger, an acquisition of majority interest, or an acquisition of assets. Since we wish to examine all deals where the control rights of target firm are transferred, a deal is retained only if the acquirer firm owns less than 50% of stakes in target firm prior to the announcement, seeks to own at least 50% shares of target firm and owns more than 90% of target firm after the transaction. We require 1) both acquirer and target firms' total assets are valued at more than \$1 million or the transaction value of the deal is no less than \$1 million (all in 1984 constant dollars) to exclude any small and economically insignificant deals;

[10] Hall, Jaffe, and Trajtenberg (2001) document that about 95% of successful patent applications are granted within 3 years of application.

2) both acquirer and target firms have at least one patent granted in the past five years before announcement since our key variable of interest *shareholder overlap* can only occur between two innovative firms; 3) both firms are covered by CRSP/Compustat database.

The key explanatory variable is the lagged *shareholder overlap* ($SOL_{s,t-1}$) at the firm level between the innovating firm and all firms controlling complementary patents. Calculation of the (weighted) *shareholder overlap* follows the definition in Eq. (19) with weights accounting for the relative importance of each upstream patent and each downstream patent. Since expired patents should not create any hold-up problems, we ignore cited patents that are filed 20 years before the application date of citing patents in constructing SOL.[11] The correspond shareholder overlap at the patent level is denoted by sol.

We also use a series of control variables, namely the previous R&D investment $ln(1 + R\&D\ Stock_{s,t-1})$, a measure of relative capital intensity $ln(1 + Capital/Labor_{s,t-1})$, and a firm size measure $ln(1 + Sales_{s,t-1})$. For simplicity, $ln(1 + Capital/Labor)$ is abbreviated as $ln(1 + K/L)$. To calculate these control variables, we obtain the accounting data from Compustat and the stock price and shares outstanding data from CRSP. We only consider U.S. publicly listed firm which have at least one patent granted over the sample period 1990-2010. Approximately 36% of all listed firms thus qualify as potential patent producers. Excluded are also all firm-year observations with missing values for the above mentioned control variables.

The summary statistics are reported in Table 1. The sample featuring $37,015$ firm-years of patent production involving a total of $713,319$ patents. On average a firm produces 19 patents and obtains an estimated number of 266 citations per year. The average (median) shareholder overlap at the firm level (SOL) is therefore low at 0.076 (0.000). The patent level statistics for shareholder overlap (sol) conditions on all successful patent filings and show an average (median) value of 0.250 (0.230). The institutional ownership generally exhibits an upward time trend time, from 29% in 1992 to 61% in 2007. Hence, the shareholder overlap statistics features a similar upward time trend.

[11] The normal protection term for utitlity patents in USPTO is 20 years from the first application date for applications before June 8, 1995. For those filed on and after the date, the 20-year protection term begins with the date of grant. Since our sample ends at 2007, patents filed on and after 1995 should still be under protection. (http://www.uspto.gov/inventors/patents.jsp#heading-5)

4 Evidence on Patent Success

4.1 Baseline Specification

Our baseline regression specification follows Eq. (**??**). As some firms in our sample feature patents without any citations, we replace the term $ln[CITES]$ with $ln[1{+}CITES]$ in the following linear regression specification:[12]

$$ln[1 + CITES_{s,t}] = \beta_0 + \beta_1 SOL_{s,t-1} + \beta_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \quad (22)$$

where the coefficient of interest is $\beta_1 = (\frac{1}{b} + \frac{\gamma}{b} + \gamma)\delta \geq 0$. More shareholder overlap with the cited downstream patents of a firm should boost its patent success as hold-up problems are attenuated.

We estimate Eq. (22) over the period 1992–2007. The citation count $CITES_{s,t}$ includes all future citations (up to year 2010) for patents filed by firm s in year t. We measure the *shareholder overlap* SOL in year $t-1$ to reduce the scope for reverse causality from patent applications (in year t) to shareholder ownership changes and therefore variations in SOL. The set of control variables includes the previous R&D investment $ln(1 + R\&D\ Stock)$, a measure of relative capital intensity $ln(1 + K/L)$, and a firm size measure $ln(1 + Sales)$.[13] These variables are all measured in year $t-1$. In addition, all regressions control for the pre-sample mean citation count of a firm's patents.

Table 2 presents the baseline regressions using the dependent variable $ln(1 + CITES)$ and $ln(CITES)$ in Columns (1)-(4) and (5)-(6), respectively. The latter two regressions discard all firm-year observations for which the $CITES$ count is zero. Column (1),(3) and (5) controls for year fixed effects, as well as industry fixed effects based on four-digit SIC codes, whereas Columns (2),(4) and (6) controls for year and firm fixed effects. The *shareholder overlap* SOL represents a statistically highly significant explanatory variable; the point estimate of 7.546 in Column (1) implies that an increase in shareholder overlap by one standard deviation (or 0.105) increases patent success in terms of overall firm citation statistics, $ln[1{+}CITES]$, by 31% of its standard deviation of 2.526, suggesting that shareholder overlap has an economically large attenuation effect on patent hold-up problems. Inclusion of firm fixed effects in Column (2) reduces the point

[12] We note that all results remain qualitatively similar if we restrict the sample to firms with a strictly positive number of citations and use ln[$CITES$] as the dependent variable.

[13] See for example Gompers and Metrick (2001) and Hall *et al.* (2005).

estimate of SOL by 70%. Because most variation in shareholder overlap is cross-sectional rather than intertemporal, the finding of a strong firm fixed effect may not be surprising.

Columns (3) and (4) interact the SOL with three time period dummies, marking separately years 1991–1996, 1997–2001, and 2002–2007. The decreasing period-specific point estimates in Column (4) for shareholder overlap suggests that the hold-up attenuation effect for patent success (as measured by ln[1+CITES]) decreased over time. This finding does not support the claim that patent hold-up has become more prevalent after 2000. Yet, the count statistics CITES might represent a problematic variable for intertemporal inference on the hold-up problem since the measurement period for the citation count linearly decreases along the time line. The time fixed effects included in the regression can adjust (under the log transformation) for a linear factor growth in the variable CITES, but cannot account for changes in higher moments of its distribution over time or increased measurement error with respect to true patent success.

Columns (5) and (6) focusing only on the firm-years with strictly positive citation counts and use $ln[CITES]$ as the dependent variable with very similar results. Here, an increase in firm level shareholder overlap by one standard deviation (= 0.105) increases the number of firm patent citations by approximately 37%. Again, the effect is much weaker if we include firm fixed effects so that identification shareholder overlap effect is restricted to its time variation for any given firm.

In all reported regressions, the *shareholder overlap* SOL is measured one year prior to the patent submissions year t. Investment decisions about R&D might have been take earlier so that so that a larger time lag than one year is called for. We therefore undertake a robustness check that larger time lags of two to four years do not substantially alter the results due to the high serial correlation of the SOL variable.

In the regressions without firm fixed effects (Columns (1)(3) and (5)), the control variables have the expected signs. A higher stock of accumulated past R&D spending correlates positively with future patent success. Firm size measured by $ln(1+Sales)$ also correlates positively with the overall number of citations a firm receives, suggesting that large firm may generally be in a better position to assure the long-run success of patents or may simply launch more successful patents.

Overall, we find a statistically and economically strong positive correlation between a firm's patent success and its *shareholder overlap* with firms controlling complementary patents named in its patent filings. The next subsection explores the intensive and extensive margin of patent production separately.

4.2 Intensive versus Extensive Margins

Shareholder overlap may affect the intensive and extensive margins differently. Moreover, separate specifications for them reveal different regression parameters. The specification for the intensive margin follows Eq. (**??**). Again, we replace the term $ln[\overline{cites}]$ with $ln[1 + \overline{cites}]$ to include firm-years without successful patent filings or consecutive patent citations. Specifically, we estimate the following equation:

$$ln[1 + \overline{cites}_{s,t}] = \theta_0 + \theta_1 SOL_{s,t-1} + \theta_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \tag{23}$$

where $\theta_1 = \gamma\delta > 0$ captures positive effect of less patent hold-up due to shareholder overlap on the average success (intensive margin) of all patents developed and granted. The parameter γ measures the efficiency loss due to patent hold-up as opposed to a distributional loss through rent dissipation. Rejection of $\theta_1 = 0$ in favor of $\theta_1 > 0$ suggests that the hold-up problem produces an adverse effect on the average success of granted patents beyond the rent redistribution between innovating upstream firm and the downstream firms.

Table 3, Columns (1)-(2) summarize the effect of shareholder overlap on the intensive margin. Column (1) excludes firm fixed effects so that both cross- and within-firm variation in shareholder overlap is reflected in the point estimate of 3.699. The economic significance of the shareholder overlap measure for the intensive margin $ln[1 + \overline{cites}]$ is only slightly smaller than for the overall citation count $ln[1+CITES]$. An increase in shareholder overlap by one standard deviation (or 0.105) contributes to the average citation count per patent by approximately 27% of its standard deviation. This suggests that shareholder overlap makes each granted patent more successful in terms of its average citation count. Inclusion of firm fixed effects in Column (2) restricts identification to intertemporal firm variation, but SOL still yields a statistically highly significant estimate.

Splitting the SOL effect into three five-year periods in Columns (3) and (4) shows that the hold-up attenuation effect on the intensive margin decreases over time. Those patents that were successfully submitted in 2002-2007 for approval benefited (in terms of their average future citation count) much less from shareholder overlap than the earlier cohorts submitted in 1991-1996.

The empirical specification for the extensive margin of patent production follows Eqs. (12) and (20) as

$$ln[1 + N_{s,t}] = \psi_0 + \psi_1 SOL_{s,t-1} + \psi_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \tag{24}$$

where the term N corresponds to the term $\overline{p}_L$ in our model in Section 2. Again, we replace $ln[N]$ with $ln[1+N]$ to include firm-years without any successful patent filings in the regression sample. The model implied constraint for the hold-up effect is $\psi_1 = (1+\gamma)\frac{1}{b}\delta > 0$.

The regression results for the extensive margin are presented in Table 3, Columns (5)–(8). The point estimate of 4.119 again suggests strong economic significance for the *shareholder overlap* measure; a one-standard-deviation increase in SOL is associated with a 29% increase in the number of patents relative to its standard deviation of 1.469. The coefficient remains statistically highly significant even after we include firm fixed effects in Column (6).

Unlike the variables *CITES* and $\overline{cites}_{s,t}$ that are measured with time varying measurement span, the extensive margin $ln[1 + N_{s,t}]$ does not suffer from the same measurement problem. The latter might therefore be better suited for intertemporal inference on the intensity of the hold-up problem and its attenuation through shareholder overlap. The intertemporal evidence for the extensive margin, reported in Column (7), shows an economically strong and statistically highly significant increase the attenuation effect of shareholder overlap. The point estimate for the period 2002-2007 increases by 26% relative to 1991-1996. Our evidence on the extensive margin, therefore, suggests either a greater effectiveness of shareholder power in alleviating the hold-up problem for the only marginally profitable patent project or an increase in the severity of the hold-up problem itself.

Overall, we conclude that shareholder overlap is strongly associated with both more citations for each granted patent (i.e., the intensive margin of patent success) and a firm's number of granted patents (i.e., the extensive margin of patent production). Moreover, the data suggests that patent hold-up became over time less severe for the intensive margin of patent production, but certainly more severe for its extensive margin. In the context of our model, this evidence is difficult to reconcile with an intertemporal increase in the hold-up parameter δ, which implies a positive effect on both the intensive and extensive margin of patent production. However, unlike in our model, different projects within the same firm might be subject to different degrees of hold-up risk. A general increase in hold-up risk may imply a positive attenuation effect (at the extensive margin) for marginally profitable patent project, and a selection effect for the smaller number of retained patent projects may explain why hold-up attenuation at the intensive margin becomes less crucial for patent success. The endogenous firm response to more hold-up risk could, therefore, consist in change in the patent portfolio towards a project selection with fewer patents with less hold-up risk.

4.3 Hold-up Resolution by Shareholder Type and Concentration of SOL

In this subsection, we disaggregate the shareholder overlap into its components sorted according to shareholder type. Ownership overlap by active shareholders should contribute more to the avoidance of cross-firm rent seeking than ownership overlap by passive shareholders. As a proxy for activism, we use the portfolio concentration of an investor measured by the Herfindahl-Hirschman index (HHI). Investors who concentrate their investments in relatively few stocks should be more prone to exercise shareholder power than fully diversified investors. Accordingly, shareholder overlap based on more concentrated investors should represent a more powerful influence for attenuating hold-up problems compared to that based mostly on investors who manage a highly diversified portfolio.

Specifically, for each firm-year we measure the weighted portfolio concentration of all overlapping investors $i \in I$ potentially involved in the hold-up attenuation as

$$WHHI_{s,t} = \sum_{p=1}^{N_s} w(p) \sum_{d=1}^{N_p} w(p_d) \sum_{i \in I} HHI_{i,t} \quad , \tag{25}$$

where $HHI_{i,t}$ denotes the Herfindahl-Hirschman index of the portfolio of each overlapping investor, who at time t owns equity in both firm s and the firm owning the downstream patent p_d. As in Eq. (19), the weights $w(p)$ and $w(p_d)$ represent the relative importance of patents p and p_d, respectively.

While conditioning on the same level of $SOL_{s,t}$, we sort firms into two groups depending on their weighted average portfolio concentration level of all overlapping investors measured by

$WHHI$. Formally, we define two dummy variables

$$D_{s,t}^{High} = \begin{cases} 1 & \text{if } \; WHHI_{s,t} > median\left[WHHI_{s,t} \mid SOL_{s,t}\right] \\ 0 & \text{otherwise} \end{cases}, \tag{26}$$

$$D_{s,t}^{Low} = \begin{cases} 1 & \text{if } \; WHHI_{s,t} \leq median\left[WHHI_{s,t} \mid SOL_{s,t}\right] \\ 0 & \text{otherwise} \end{cases}, \tag{27}$$

where we decompose $SOL_{s,t} = SOL_{s,t} \times D_{s,t}^{High} + SOL_{s,t} \times D_{s,t}^{Low}$. If more concentrated shareholders take on a more active role in attenuating patent hold-up, we expect to find a stronger positive regression coefficient for the interaction term $SOL \times D^{High}$ than for $SOL \times D^{Low}$.

Figure 1, Panel A graphs the (log) $WHHI$ against SOL. A median regression line (in black) separates firms into those above median (red dots) and those below median (blue dots) values of $WHHI$ conditional on a given level of SOL. Overlapping shareholders of firms above the median investor concentration correspond to more concentrated and presumably more activist-oriented investors, whereas those below the median should represent a more diversified and passive investor group presumably less inclined to resolve hold-up conflicts.

The regression results reported in Table 4 confirm this intuition. The decomposition of the overlap SOL into those firms with mostly concentrated portfolios for the overlapping investors (identified by $SOL \times D^{High}$) and those with mostly diversified portfolios (identified by $SOL \times D^{Low}$) shows that the former contributes to more patent success than the latter. A comparison of the hold-up attenuation effect between the concentrated and the diversified shareholders (conditional on the same level of shareholder overlap) reveals that the effect is 43% larger for the former than for the latter based on the estimates in Column (2) without firm fixed effects. The estimates in the specification with firm fixed effects, reported in Column (4), imply that the concentrated investors generate a 82% greater effect than the diversified investors on future patent success. These point estimates suggest that overlapping investors with concentrated portfolios exercise considerably more influence in favor of hold-up resolution, likely because it is in their interest to do so due to the joint ownership in firms with complementary patents.

An additional hypothesis concerns the concentration of the overlapping shareholdings in the hold-up situation. Independently of the type of shareholder and its overall portfolio concentration, the size distribution of the shareholder overlap might also matter. In particular, a highly concentrated shareholder overlap as measured by the Herfindahl-Hirschmann index of the overlapping equity shares SOL_HHI might make coordinated action easier and provide stronger shareholder incentives for hold-up resolution. We include SOL_HHI as a separate control variables in Table 4, Columns (5) and (6). The estimated coefficient is statistically highly significant and a positive value reveals that concentration of shareholder overlap correlates positively firm level patent success. More concentrated equity shares within the shareholder overlap appear to facilitate hold-up resolution.

4.4 Endogeneity Concerns and Patent-Level Regression

In the previous regressions, we show that our results are robust to a variety of observable firm characteristics. Yet, this may not fully address concern that unobservable firm level effects simultaneously influence a firm's patent citations and shareholder overlap.[14] To address this issue, in this subsection, we test the hold-up attenuation hypothesis at the patent level.

In our regression specification, we include not only firm and year fixed effects, but also their interaction $\epsilon_{s,t}$. Identification of the hold-up attenuation effect on patent success, therefore, relies entirely on the comparison of different patents filed by the same firm in the same year. Different patent filings by the same firm may name different downstream patents, resulting in patent-specific hold-up situations and shareholder overlap even within the same firm-year. The patent-specific hold-up attenuation is captured by the patent-level shareholder overlap sol, which can then be related to the (log) number of cites as follows:

$$ln[1 + cites_{p,t}] = \beta_0 + \beta_1 sol_{p,t-1} + \beta_2 Controls_{s,t-1} + \epsilon_{s,t} + \eta_{p,t}. \tag{28}$$

Table 5, Columns (1)-(2) report patent-level regressions. The dependent variable is $ln[1+cites_{p,t}]$, in which the subscript t denotes the application year of patent p. Similar to the firm-level regressions, all independent variables lag the dependent variable by one year.[15] Column (1) uses a combination of control variables and year and firm fixed effects, whereas Column (2) controls for the interaction of year and firm fixed effects, which makes observable firm-level controls redundant

[14] For example, media coverage may boost a firms citation count and simultaneously trigger stock purchases by investors with an investment bias towards technology stocks, thereby increasing the firm's shareholder overlap measure.

[15] For the lagged ownership overlap variable ($sol_{p,t-1}$), we follow the same estimation method as that for the contemporaneous sol except that the former is based on the institutional ownership at the end of year $t-1$.

and also controls for unobservable firm-year effects. This latter specification identifies the hold-up effect of different patents filed by the same firm in the same year. The result shows that such within-firm variation in the patent success is statistically significantly related to the patent-specific shareholder overlap sol.

Similar to subsection 4.3, we can condition on a given level of shareholder overlap at the patent level sol and then sort patents into those for which (importance weighted) overlapping investors are more activist (based on their overall portfolio concentration) and those likely to be more passive. Specifically, we first calculate the weighted portfolio concentration of the overlapping investors for each patent as

$$whhi_{p,t} = \sum_{d=1}^{N_p} w(p_d) \sum_{i \in I} HHI_{i,t} \quad . \tag{29}$$

and then define two dummy variables as

$$d_{p,t}^{High} = \begin{cases} 1 & \text{if} \quad whhi_{p,t} > median\left[whhi_{p,t} \mid sol_{p,t}\right] \\ 0 & \text{otherwise} \end{cases} , \tag{30}$$

$$d_{p,t}^{Low} = \begin{cases} 1 & \text{if} \quad whhi_{p,t} \leq median\left[whhi_{p,t} \mid sol_{p,t}\right] \\ 0 & \text{otherwise} \end{cases} . \tag{31}$$

Figure 1, Panel B provides a graphical illustration, in which observations $sol_{p,t} \times d_{p,t}^{High}$ and $sol_{p,t} \times d_{p,t}^{Low}$ are plotted in red and blue, respectively, against $sol_{p,t}$. The black line represents the conditional median approximated by a third-order polynomial in $sol_{p,t}$.

Table 5, Column (3) presents the regression results for the interaction of shareholder overlap with the two dummy variables. The point estimate for the more concentrated (and presumably more activist-oriented investors) increases to 0.305 and amounts to almost three times the corresponding shareholder overlap effect emanating from the more diversified investors. Overall, the economic significance of the within firm effect of variations in shareholder overlap is smaller, but far from negligible. An increase in $sol_{p,t}$ from the 10% to the 90% quantile (= 0.855) increase patent success by 11% of the standard deviation of the dependent variables $ln(1 + cites_{p,t})$.

So far, we have shown robust results at the patent-level even with the inclusion of the interacted firm-year effect. Yet, our analysis may still face selection problems operating at the patent level. In particular, the results may be tainted by reciprocal quotation and citation biases within firm ownership clusters. Firms may be more inclined to quote downstream patents of firms for which the existing shareholder overlap is large. Such a quotation bias may exist if the quotation of downstream patents is perceived as a value signal about these quoted patents, which would imply valuation benefits for the firm's own shareholders with joint ownership in the downstream cited firms. Moreover, the quoted downstream firms may in turn be more likely to cite the upstream innovator—amounting to a reciprocal advertisement channel rather than alleviation of a hold-up situation. In order to eliminate such spurious effects from our regression, we exclude from the patent-level citation count all citations that come from (i) firms quoted in patent p to obtain the first filtered citation measure $ln[1+\ cites^{F1}_{p,t}]$ or (ii) firms that the innovating firm has ever quoted previously during our sample period to obtain the second filtered citation measure $ln[1+\ cites^{F2}_{p,t}]$. Therefore, only citations from firms external to the quotation cluster are counted in these two measures of patent success.

Table 5, Columns (4)–(7), use the two filtered citation measures as the dependent variables. Overall, the point estimates for the shareholder overlap decrease but remain statistically significant. A split of the patent sample into those with more concentrated overlapping shareholders (with high $whhi$) and those with more diversified ones (with low $whhi$) yields a much larger point estimate for the former. Therefore, differences in shareholder activism also matter at the patent level within the same firm-year even when patent success is narrowly defined by citations coming from unrelated firms.

4.5 R&D Expenditure and Hold-Up

The evidence so far focus on patent success as an (output) measure for the hold-up attenuation of ownership overlap; yet the model also predicts a positive effect of shareholder overlap on R&D investment. To test this prediction, we undertake a linear regression

$$ln[1 + R\&D\ Exp] = \kappa_0 + \kappa_1 SOL_{s,t-1} + \kappa_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \tag{32}$$

where Eqs. (14) and (20) predict a positive a coefficient $\kappa_1 = (1 + \gamma)(1 + 1/b)\delta > 0$. We include the same control variables as in the previous regressions with the exception of $ln(1+R\&D\ Stock)$, which summarizes past R&D expenditure.

Table 6 reports the regression results. The effect of shareholder overlap is statistically and economically highly significant in specifications with and without firm fixed effects. An increase in shareholder overlap by one standard deviation (0.105) under firm fixed effects (Column (2)) increases (log) R&D expenditure by 0.099 or roughly 10%. The hold-up attenuation effect of shareholder overlap is therefore economically large.

The regressions in Columns (3) and (4) interact the SOL variable with time period fixed effects in, respectively, specifications without and with firm fixed effects. Unlike the citation count, which is measured over shorter period for more recent patent submission cohorts, the R&D expenditure variable is measured homogeneously over time. It may therefore be more suited for intertemporal inference on the severity of the hold-up problems. An increasing point estimate for the hold-up attenuation effect from 0.437 in 1991-1996 to 1.133 in 2002-2007 in Column (4) suggests that hold-up attenuation for the same level of shareholder overlap has indeed become much more potent. This could be explained either by more effective exercise of shareholder power on the part of the overlapping shareholder or by increased severity of the underlying hold-up problem itself. The finding of an increasing positive effect of shareholder overlap for R&D expenditure mirrors the result for the extensive margin of patent production documented in Table 3, Columns (7) and (8).

5 Robustness

This section discusses two alternative determinants of patent success and examines their empirical importance relative to shareholder overlap (SOL). In a widely noted contribution, Aghion et al. (2013) argue that R&D investments have a long time horizon and a high share of institutional investors allows management to focus on the long-run return to investment. Following their example, we measure the share of *institutional ownership* (IO) as the relevant proxy for investor patience. As institutional ownership also correlates with our shareholder overlap measure, it could potentially account for the firm level evidence presented in sections 4.1 to 4.3.

A second hypothesis concerns heterogeneous shareholder sophistication about innovation. Some shareholders might bring particular knowledge to the innovation process, allowing for better governance of the innovating firm. In particular, investors can specialize in acquiring shares in innovative firms with a disproportionate share of patents. Such a *shareholder innovation focus* is directly measurable based on ownership data in a simple three-step procedure. In the first step, we define for each listed firm the *firm innvation focus* (FIF) as the ratio of the future citation count of all patents filed by firm s' in year t to the industry total citation count during the same period. In a second step, we account for all institutional investors i in firm s and calculate their *investor innovation focus* (IIF) as the value-weighted average *firm innovation focus* for all stocks s' in their investment portfolio except for stock s itself. Formally,

$$IIF_{i,s,t} = \sum_{s' \setminus \{s\}} x_{i,s',t} \; FIF_{s',t} \quad , \tag{33}$$

where $x_{i,s',t}$ represents the value weight of firm s' in the portfolio of institutional investor i at the end of year t. For any individual institutional shareholder primarily investing in innovative firms, the IIF value should be high. In the third step, the *shareholder innovation focus* (SIF) for firm s is defined as the value-weighted average of each investor innovation focus,

$$SIF_{s,t} = \sum_{i} w_{i,s,t} IIF_{i,s,t} \quad , \tag{34}$$

where $w_{i,s,t}$ represents the equity shares of firm s held by institutional investor i relative to the aggregate holdings of all institutional investors at the end of year t. A firm mostly owned by investors with a high IIF should feature a high SIF value.[16] The shareholders' governance competence with respect to the innovating firm s, proxied by $SIF_{s,t}$, should have a positive effect on patent success of the firm.

Table 7 presents the regression results for the two alternative hypotheses. Column (2) replaces *shareholder overlap* $SOL_{s,t-1}$ in the benchmark regression of Column (1) with *institutional ownership* $IO_{s,t-1}$ as the key explanatory variable. As argued by Aghion, Van Reenen and Zingales (2013), institutional ownership features a statistically significant correlation with the citation success of a firm. Yet, inclusion of both *shareholder overlap* and *institutional ownership* in Column (3) reveals that the former retains its full economic and statistical significance, whereas the coefficient for *institutional ownership* is reduced by more than half.

An increase by one standard deviation for the institutional ownership $IO_{s,t-1}$ (= 0.287) improves patent success by only 3% of the standard deviation of the dependent variable $ln[1+CITES_{s,t}]$—an economically minor effect. Column (5) uses an alternative measure of shareholder overlap $SOL^{CAP}_{s,t-1}$, which computes shareholder overlap relative to total outstanding shares as opposed to

[16] Note that the *shareholder innovation focus* is calculated only with respect to their investment bias toward innovative firms other than firm s itself. Otherwise, this variable would be positively correlated with the patent citations of firm s by construction even in the absence of investment clustering around innovative firms.

the aggregate institutional holdings. Formally, we have the relationship

$$SOL^{CAP}_{s,t-1} = SOL_{s,t-1} \times IO_{s,t-1}. \tag{35}$$

Under this second definition of *shareholder overlap*, *institutional ownership* retains no significance at all. Institutional ownership in stock seems to weakly correlate with patent success only because it is also correlated with shareholder overlap.

To verify that this result is robust, Table 7, Columns (6)–(8) report analogous regressions based on the same patent sample as in Aghion, Van Reenen, and Zingales (2013). We also mimic their specification by using $ln[CITES_{s,t}]$ as the dependent variable and use the same control variables as they use.[17] Column (6) reproduces their benchmark regression (reported in Table 1, Column (2) of their paper) and shows a statistically significant positive coefficient of 0.005 for institutional ownership (IO). However, Columns (7)–(8) show that this statistical significance is again not robust to inclusion of *shareholder overlap*, measured by either SOL or SOL^{CAP}. In conclusion, neither their sample nor the extended sample used in our study shows that institutional ownership correlates with a firm's patent success in an economically significant way.

In Table 7, Columns (4)–(5) report the results for the measure of *shareholder innovation focus*. The variable $SIF_{s,t-1}$ features statistically significant coefficient, but an increase by one standard deviation of SIF (= 1.480) implies an increase of $ln[1+CITES]$ by only 1.5% of it standard deviation. Overall, *shareholder overlap* emerges as the robust explanatory variable. In particular, it does not proxy for having shareholders who generally invest in other innovative firms but rather captures the specific shareholder nexus between the innovating firm and those firms that pose a hold-up threat.

6 Conclusion

This paper provides a property rights perspective on the success of patent processes. We argue that the success of patents often depends on access to complementary patents not under the direct control of the innovating firm. From a property rights perspective, the 'extended boundary' of the

[17] Aghion, Van Reenen, and Zingales (2013) use $ln[CITES_{s,t}]$ as the dependent variable in their benchmark regression in Table 1, Column (2). They include $IO_{s,t}$, $ln(R\&D\ Stock_{s,t})$, $ln(K/L_{s,t})$, and $ln(Sales_{s,t})$ as the regressors. We use the exact same set of variables in our regressions reported in Columns (6)–(8). Their dataset is available at: https://www.aeaweb.org/articles.php?doi=10.1257/aer.103.1.277

firm includes such patents if both the innovating firm and the firm owning complementary patents are linked by joint shareholder ownership. This should particularly be the case if such shareholder overlap comes from activist investors who exercise power over both firms and can thus mitigate the hold-up problem.

Our identification strategy is based on patent documents that directly cite related patents, which may have rival patent claims to new products. 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 the complementary assets; an innovating firm with a large SOL value can be interpreted as having an extended firm boundary. As underinvestment due to patent hold-up is difficult to measure, we focus instead on the measurement of patent success proxied by future citations as its empirical corollary.

The empirical evidence supports the view that shareholder overlap is a statistically and economically important determinant of patent success. This finding is robust to a variety of control variables and the inclusion of time, industry, and firm fixed effects. Using interacted firm and time fixed effects, we show that two patents from the same year cohort and the same firm perform differently depending on their respective (patent-level) shareholder overlap.

Finally, we disaggregate shareholder overlap into cases in which such overlap is accomplished by activist investors and cases in which such overlap results from diversified investors. Patent success is found to be considerably more pronounced across and within firms when shareholder overlap originates from activist owners—suggesting that the 'extended boundaries' of the innovating firm depend also on the type of institutional shareholder.

The intertemporal analysis of the patent hold-up problem and its attenuation through shareholder overlap suggests that the patent hold-up problem intensified after 2000 at the extensive margin but became less severe at the intensive margin of the average patent. This is consistent with an endogenous firm response to more patent hold-up risk whereby firms selects fewer patent projects that are on average less subject to hold-up.

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Table 1: Summary Statistics

Reported are the summary statistics for all regression variables in the sample period 1992–2007. Dependent firm level variables are (i) $CITES_{s,t}$ as number of future citations received by the cohort of patents successfully filed by firm s in year t, (ii) $N_{s,t}$ as the number of successfully filed patents, (iii) $\overline{cites}_{s,t}$ as the average future citations per patent for the cohort of patents filed by firm s in year t, and (iv) $R\&D\ Exp$ as R&D expenditure for firm s in year t. At the patent level, (v) $cites_{p,t}$ denotes the total number of future citations (exclusive of self-citations) received by patent p successfully filed in year t, whereas (vi) $cites^{F1}_{p,t}$ and (vii) $cites^{F2}_{p,t}$ also exclude of citations coming from all firms quoted in the patent application of patent p (for filter $F1$) and all firms that patent p's innovator has ever quoted previously (for filter $F2$), respectively. The explanatory variables $SOL_{s,t-1}$ and $sol_{p,t-1}$, refer to the *shareholder overlap* for firm s or a patent p, respectively. $IO_{s,t-1}$ is the aggregate *institutional ownership* of firm s as of the end of year $t-1$. $SOL^{CAP}_{s,t-1}$ is defined like $SOL_{s,t}$ except that institutional ownership shares are calculated relative to the total shares outstanding instead of the aggregate share holdings of all institutions. The *shareholder innovation focus* $SIF_{s,t-1}$ is defined as the investment bias of a firm's shareholders towards firms with a large share of patents. $SOL\_HHI_{s,t-1}$ represents the Herfindahl-Hirschmann index of concentration for the shareholder overlap for patents filed in year $t-1$. At the firm level, dummy $D^{High}_{s,t-1}$ ($D^{Low}_{s,t-1}$) is equal to one for firms for which the overlapping shareholders have (on average) portfolios with an above (below) the median portfolio concentration conditional on SOL. At the patent level, the dummy $d^{High}_{p,t-1}$ ($d^{Low}_{p,t-1}$) is equal to one for patents for which the overlapping shareholders have (on average) portfolios with an above (below) the median portfolio concentration conditional on sol. The control variables include the (log of) lagged cumulative R&D investment, $ln(1+R\&D\ Stock_{s,t-1})$; lagged capital to labor ratio, $ln(1+K/L_{s,t-1})$; and lagged sales, $ln(1+Sales_{s,t-1})$. The variable definitions are described in detail in the appendix.

	Obs.	Mean	Median	STD	Skewness	Min.	P10	P90	Max.
Dependent Variables (measured in year t)									
$ln(1+CITES)$	37,015	2.268	1.606	2.526	0.723	0.000	0.000	5.893	11.640
$ln(CITES)$	19,630	4.223	4.077	1.917	0.433	0.155	1.827	6.798	11.640
$ln(1+N)$	37,015	1.159	0.693	1.469	1.589	0.000	0.000	3.258	8.395
$ln(1+\overline{cites})$	37,015	1.345	1.065	1.446	0.549	0.000	0.000	3.362	6.643
$ln(1+R\&D\ Exp)$	37,015	2.063	1.809	1.938	0.838	0.000	0.000	4.705	9.408
$ln(1+cites)$	713,319	1.819	1.866	1.343	0.163	0.000	0.000	4.037	6.969
$ln(1+cites^{F1})$	713,319	1.757	1.806	1.324	0.197	0.000	0.000	3.488	6.961
$ln(1+cites^{F2})$	713,319	1.552	1.563	1.271	0.347	0.000	0.000	3.241	6.933
Independent Variables (measured in year $t-1$)									
SOL	37,015	0.076	0.000	0.105	1.340	0.000	0.000	0.239	0.708
$SOL \times D^{High}$	37,015	0.038	0.000	0.083	2.417	0.000	0.000	0.166	0.647
$SOL \times D^{Low}$	37,015	0.038	0.000	0.083	2.418	0.000	0.000	0.169	0.708
SOL^{CAP}	37,015	0.044	0.000	0.067	1.612	0.000	0.000	0.152	0.454
SIF	37,015	4.670	4.656	1.480	1.128	0.000	2.960	6.401	50.017
IO	37,015	0.443	0.435	0.287	0.150	0.000	0.060	0.837	1.000
SOL_HHI	37,015	0.084	0.000	0.143	2.783	0.000	0.000	0.252	1.000
sol	713,319	0.250	0.230	0.169	0.509	0.000	0.044	0.899	0.909
$sol \times d^{High}$	713,319	0.125	0.000	0.173	1.273	0.000	0.000	0.402	0.850
$sol \times d^{Low}$	713,319	0.125	0.000	0.173	1.273	0.000	0.000	0.401	0.909
Controls (measured in year $t-1$)									
$ln(1+R\&D\ Stock)$	37,015	2.982	3.065	2.366	0.391	0.000	0.000	6.041	10.714
$ln(1+K/L)$	37,015	4.377	4.256	1.061	0.718	0.000	3.227	5.696	11.102
$ln(1+Sales)$	37,015	5.343	5.264	2.466	0.058	0.000	2.187	8.657	12.722

Table 2: Baseline Regressions

Reported are firm level OLS regressions of patent success (measured as the (log) future citation count, $ln(1+CITES_{s,t})$ or $ln(CITES_{s,t})$, for all patents filed by firm s in year t) on the lagged *shareholder overlap*, $SOL_{s,t-1}$, for the sample period $1992-2007$. The regression using $ln(CITES_{s,t})$ excludes all firm-years in which a firm does not file patents producing future citations. Shareholder overlap measures the average shareholder ownership overlap between the innovating firm and other firms owning the precursory complementary patents. The Period dummy identifies time periods of 1992-1996 ($D^{1992-1996}$), 1997-2001 ($D^{1997-2001}$), and 2002-2007 ($D^{2002-2007}$). The control variables include the (log of) lagged cumulative R&D investment, $ln(1+R\&D\ Stock_{s,t-1})$; lagged capital to labor ratio, $ln(1+K/L_{s,t-1})$; and lagged sales, $ln(1+Sales_{s,t-1})$. All regressions control for the pre-sample mean citation count for each firm. Industry fixed effects are based on four-digit SIC codes. The last row of the table reports the p-value for the null hypothesis that the estimated regression coefficients are the same for the interaction terms $SOL \times D^{1992-1996}$, $SOL \times D^{1997-2001}$ and $SOL \times D^{2002-2007}$. All regressions report robust t-statistics in brackets. We denote by *, **, and *** the statistical significance at the 10%, 5%, and 1% level, respectively. The variable definitions are described in more detail in the appendix.

Dependent Variable:	$ln(1+CITES)$				$ln(CITES)$	
	(1)	(2)	(3)	(4)	(5)	(6)
SOL	7.546***	2.337***			3.523***	1.246***
	[35.44]	[12.69]			[18.18]	[7.33]
$SOL \times D^{1992-1996}$			8.877***	4.422***		
			[28.96]	[14.92]		
$SOL \times D^{1997-2001}$			8.469***	3.581***		
			[30.97]	[15.72]		
$SOL \times D^{2002-2007}$			6.832***	1.606***		
			[29.18]	[7.71]		
Controls:						
$ln(1+R\&D\ Stock)$	0.307***	−0.042	0.303***	−0.071**	0.249***	0.113**
	[15.27]	[−1.27]	[15.02]	[−2.15]	[10.65]	[2.46]
$ln(1+K/L)$	0.089***	−0.027	0.069***	−0.101***	0.069**	−0.141***
	[3.69]	[−0.83]	[2.94]	[−3.20]	[2.40]	[−3.54]
$ln(1+Sales)$	0.068***	0.161***	0.054***	0.056**	0.083***	0.090***
	[4.87]	[6.55]	[3.87]	[2.46]	[5.32]	[2.83]
Period dummy	NO	NO	YES	YES	NO	NO
Year FE	YES	YES	NO	NO	YES	YES
Industry FE	YES	NO	YES	NO	YES	NO
Firm FE	NO	YES	NO	YES	NO	YES
Obs.	37,015	37,015	37,015	37,015	19,630	19,630
Adj. R^2	0.553	0.715	0.544	0.705	0.544	0.740
$p-value$			0.000	0.000		

Table 3: Intensive versus Extensive Margin

Reported are OLS regressions for (i) the intensive margin, $ln(1+\overline{cites}_{s,t})$, and (ii) 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. We denote by $N_{s,t}$ the number of successful patents filed by firm s in year t, and by $\overline{cites}_{s,t}$ the average future citations per patent for the cohort of patents successfully filed by firm s in year t. Shareholder overlap measures the average shareholder ownership overlap between the innovating firm and other firms owning the precursory complementary patents. Period dummy identifies time periods of 1992-1996 ($D^{1992-1996}$), 1997-2001 ($D^{1997-2001}$), and 2002-2007 ($D^{2002-2007}$). The control variables include the (log of) lagged cumulative R&D investment, $ln(1+R\&D\ Stock_{s,t-1})$; lagged capital to labor ratio, $ln(1+K/L_{s,t-1})$; and lagged sales, $ln(1+Sales_{s,t-1})$. All regressions control for the pre-sample mean citation count for each firm. Industry fixed effects is based on four-digit SIC codes. The last row of the table reports the p-value for the null hypothesis that the estimated regression coefficients are the same for the interaction terms $SOL\times D^{1992-1996}$, $SOL\times D^{1997-2001}$ and $SOL\times D^{2002-2007}$. All regressions report robust t-statistics in brackets. We denote by *, **, and *** statistical significance at the 10%, 5%, and 1% level, respectively. The variable definitions are described in more detail in the appendix.

Dep. Variable:	$ln(1+\overline{cites})$				$ln(1+N)$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SOL	3.699***	0.877***			4.119***	1.610***		
	[32.73]	[7.00]			[28.25]	[17.39]		
$SOL\times D^{1992-1996}$			5.431***	2.796***			3.568***	1.590***
			[28.08]	[13.87]			[19.43]	[10.41]
$SOL\times D^{1997-2001}$			4.293***	1.527***			4.194***	1.917***
			[28.02]	[10.09]			[23.99]	[16.87]
$SOL\times D^{2002-2007}$			2.805***	0.174			4.513***	1.834***
			[23.95]	[1.30]			[27.29]	[15.23]
Controls:								
$ln(1+R\&D\ Stock)$	0.078***	−0.131***	0.077***	−0.144***	0.233***	0.103***	0.230***	0.083***
	[8.72]	[−5.78]	[8.64]	[−6.54]	[14.79]	[5.16]	[14.64]	[4.29]
$ln(1+K/L)$	0.037***	−0.018	0.021	−0.075***	0.061***	−0.003	0.058***	−0.016
	[2.60]	[−0.75]	[1.56]	[−3.23]	[3.87]	[−0.23]	[3.72]	[−1.12]
$ln(1+Sales)$	−0.020***	0.080***	−0.030***	0.006	0.080***	0.088***	0.076***	0.061***
	[−2.63]	[4.56]	[−4.04]	[0.38]	[8.39]	[7.74]	[8.11]	[5.68]
Period dummy	NO	NO	YES	YES	NO	NO	YES	YES
Year FE	YES	YES	NO	NO	YES	YES	NO	NO
Industry FE	YES	NO	YES	NO	YES	NO	YES	NO
Firm FE	NO	YES	NO	YES	NO	YES	NO	YES
Obs	37,015	37,015	37,015	37,015	37,015	37,015	37,015	37,015
Adj. R^2	0.322	0.485	0.314	0.475	0.657	0.846	0.653	0.840
$p-value$			0.000	0.000			0.038	0.512

Table 4: Hold-Up Resolution by Investor Types and Concentration of Shareholder Overlap

The baseline regression in Table 2 are repeated for a split of *shareholder overlap* ($SOL_{s,t-1}$) into two components which represent mostly active or passive investor types, respectively. We define a firm-level dummy variable $D^{High}_{s,t-1}$ ($D^{Low}_{s,t-1}$) as equal to one and zero otherwise if the average portfolio concentration of all overlapping shareholders is above (below) the median value conditional on a given level of $SOL_{s,t-1}$. The interaction term $SOL_{s,t-1} \times D^{High}_{s,t-1}$ therefore represent cases of overlap from shareholder with mostly concentrated (or activist) ownership, whereas $SOL_{s,t-1} \times D^{Low}_{s,t-1}$ represents an overlapping shareholdership of more diversified (or passive) investors. The regressions in Columns (5) and (6) expend the baseline regressions by a direct measure of the Herfindahl-Hirschmann index of shareholder overlap, $SOL\_HHI_{s,t-1}$, instead of a variable decomposition. The control variables include the (log of) lagged cumulative R&D investment, $ln(1 + R\&D\ Stock_{s,t-1})$; lagged capital to labor ratio, $ln(1 + K/L_{s,t-1})$; and lagged sales, $ln(1 + Sales_{s,t-1})$. All regressions control for the pre-sample mean citation count for each firm. All regressions report robust t-statistics in brackets. The last row of the table reports p-values for the null hypothesis that the estimated regression coefficients are the same for $SOL \times D^{High}$ and $SOL \times D^{Low}$. We denote by *, **, and *** the statistical significance at the 10%, 5%, and 1% level, respectively. The variable definitions are described in more detail in the appendix.

Dependent Variables:	$ln(1 + CITES)$					
	(1)	(2)	(3)	(4)	(5)	(6)
SOL	7.546***		2.337***		6.955***	2.212***
	[35.44]		[12.69]		[32.34]	[11.58]
$SOL \times D^{High}$		4.930***		2.444***		
		[14.13]		[7.92]		
$SOL \times D^{Low}$		2.409***		1.053***		
		[8.93]		[4.65]		
SOL_HHI					1.659***	0.228**
					[15.81]	[2.42]
Controls:						
$ln(1 + R\&D\ Stock)$	0.307***	0.269***	−0.042	−0.041	0.307***	−0.039
	[15.27]	[14.87]	[−1.27]	[−1.28]	[15.80]	[−1.19]
$ln(1 + K/L)$	0.089***	0.071***	−0.027	−0.027	0.081***	−0.028
	[3.69]	[3.38]	[−0.83]	[−0.83]	[3.57]	[−0.84]
$ln(1 + Sales)$	0.068***	0.080***	0.161***	0.157***	0.090***	0.164***
	[4.87]	[6.33]	[6.55]	[6.56]	[6.65]	[6.70]
Year FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	NO	NO	YES	NO
Firm FE	NO	NO	YES	YES	NO	YES
Obs	37,015	37,015	37,015	37,015	37,015	37,015
Adj. R^2	0.553	0.580	0.715	0.717	0.561	0.716
$p - value$		0.000		0.000		

Table 5: Patent-Level Regressions

Reported are OLS regressions of patent success measured at the patent level on the lagged *shareholder overlap* for the sample period 1992 − 2007. Patent success is proxied by $ln(1 + cites_{p,t})$ as the (log) future citation count received by a patent p filed in year t excluding self-citations. The first filtered version of the citation count, $cites^{F1}_{p,t}$ excludes in addition citations coming from all firms quoted in the patent application of patent p. The second filtered citation measure, $cites^{F2}_{p,t}$, excludes in addition citations coming from all firms that patent p's innovator has ever quoted previously.The overall patent-level *shareholder overlap* ($sol_{p,t-1}$) is interacted with a patent-level dummy $d^{High}_{p,t-1}$ ($d^{Low}_{p,t-1}$), which is equal to one and zero otherwise if the portfolio concentration of the overlapping shareholders is above (below) median conditional on a given level of shareholder overlap $sol_{p,t-1}$. The control variables include the (log of) lagged cumulative R&D investment, $ln(1 + R\&D\ Stock_{s,t-1})$; lagged capital to labor ratio, $ln(1 + K/L_{s,t-1})$; and lagged sales, $ln(1 + Sales_{s,t-1})$. All regressions control for the pre-sample mean citation count for each firm. All regressions report robust t-statistics in brackets. The last row of the table reports the p-value for the null hypothesis that the estimated regression coefficients are the same for $sol \times d^{High}$ and $sol \times d^{Low}$. We denote by *, **, and *** the statistical significance at the 10%, 5%, and 1% level, respectively. The variable definitions are described in more detail in the appendix.

Dep. Variable:	$ln(1 + cites)$			$ln(1 + cites^{F1})$		$ln(1 + cites^{F2})$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
sol	0.114**	0.176***		0.095**		0.091**	
	[2.41]	[3.87]		[2.00]		[2.18]	
$sol \times d^{High}$			0.233***		0.187***		0.205***
			[3.68]		[3.03]		[3.86]
$sol \times d^{Low}$			0.067		0.060		0.047
			[1.37]		[1.34]		[1.22]
Controls:							
$ln(1 + R\&D\ Stock)$	−0.142***						
	[−2.69]						
$ln(1 + K/L)$	0.087						
	[0.94]						
$ln(1 + Sales)$	−0.058						
	[−1.47]						
Year FE	YES	NO	NO	NO	NO	NO	NO
Firm FE	YES	NO	NO	NO	NO	NO	NO
Year × Firm FE	NO	YES	YES	YES	YES	YES	YES
Obs	713,319	713,319	713,319	713,319	713,319	713,319	713,319
Adj. R^2	0.309	0.325	0.326	0.314	0.315	0.282	0.282
$p - value$			0.000		0.004		0.000

Table 6: R&D Expenditure and Firm Mergers

Reported are OLS regressions of R&D expenditure on the lagged *shareholder overlap* for the sample period $1992 - 2007$. R&D expenditure is measured for every firm-year (s, t) and $SOL_{s,t-1}$ represents firm-level shareholder overlap with all cited firms in the successful patent applications of firm s in year $t - 1$. Period dummy identifies time periods of 1992-1996 ($D^{1992-1996}$), 1997-2001 ($D^{1997-2001}$), and 2002-2007 ($D^{2002-2007}$). The control variables include lagged capital to labor ratio, $ln(1 + K/L_{s,t-1})$; and lagged sales, $ln(1 + Sales_{s,t-1})$. All regressions control for the pre-sample mean citation count for each firm. Industry fixed effects is based on four-digit SIC codes. The last row of the table reports the p-value for the null hypothesis that the estimated regression coefficients are the same for $SOL \times D^{1992-1996}$, $SOL \times D^{1997-2001}$ and $SOL \times D^{2002-2007}$. All regressions report robust t-statistics in brackets. We denote by *, **, and *** the statistical significance at the 10%, 5%, and 1% level, respectively. The variable definitions are described in more detail in the appendix

Dep. Variables:	$ln(1 + R\&D\ Exp)$			
	(1)	(2)	(3)	(4)
SOL	3.594***	0.944***		
	[18.11]	[10.47]		
$SOL \times D^{1992-1996}$			2.727***	0.437***
			[11.16]	[3.20]
$SOL \times D^{1997-2001}$			3.574***	0.829***
			[15.23]	[8.36]
$SOL \times D^{2002-2007}$			3.920***	1.133***
			[18.89]	[9.42]
Controls:				
$ln(1 + K/L)$	0.163***	−0.014	0.167***	0.010
	[6.42]	[−0.67]	[6.62]	[0.48]
$ln(1 + Sales)$	0.351***	0.256***	0.354***	0.283***
	[24.48]	[15.64]	[24.94]	[18.29]
Period dummy	NO	NO	YES	YES
Year FE	YES	YES	NO	NO
Industry FE	YES	NO	YES	NO
Firm FE	NO	YES	NO	YES
Obs	37,015	37,015	37,015	37,015
Adj. R^2	0.676	0.928	0.676	0.927
$p - value$			0.048	0.004

Table 7: Alternative Explanatory Variables

We compare three potential determinants of innovation success, namely (i) *shareholder overlap* ($SOL_{s,t-1}$) between an innovating firm and downstream firms with complementary patents as a proxy for a attenuation of a patent hold-up problem, (ii) *shareholder innovation focus* ($SIF_{s,t-1}$) as a proxy for a firm's shareholders focus on research intensive portfolio investments and (iii) *institutional ownership* ($IO_{s,t-1}$) as advocated by Aghion, Van Reenen and Zingales (2013) as a proxy for investor patience. $SOL^{CAP}_{s,t-1}$ is measured as $SOL_{s,t-1}$, but the ownership share is scaled by the total shares outstanding instead of aggregate institutional share holdings. Columns 1–5 use full sample period $1992-2007$, and Columns 6–8 use the sample of Aghion, Van Reenen and Zingales (2013), which spans the shorter period 1991 to 2002. The dependent variable $ln(1+CITES_{s,t})$ is the (log) number of total future citations received by the cohort of patents successfully filed by firm s in year t. The first five regressions use the same control variables as in the previous tables. The last three regressions use the same dependent variable, $ln(CITES_{s,t})$, and control variables as in Aghion, Van Reenen and Zingales (2013). Robust t-statistics are reported in brackets. We denote *, **, and *** statistical significance at the 10%, 5%, and 1% level, respectively. The variable definitions are described in more detail in the appendix.

Dep. Variables:	$ln(1+CITES)$					$ln(CITES)$		
	Full Sample					ARZ Sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SOL	7.546***		7.474***	7.427***			3.732***	
	[35.44]		[34.89]	[34.72]			[7.64]	
SOL^{CAP}					10.876***			6.402***
					[30.92]			[7.72]
IO		0.562***	0.263***	0.259***	−0.085	0.005***	0.003	−0.000
		[6.14]	[3.41]	[3.36]	[−1.04]	[2.94]	[1.39]	[−0.24]
SIF				0.025***	0.033***			
				[2.77]	[3.56]			
Controls:								
$ln(1+R\&D\ Stock)$	0.307***	0.420***	0.304***	0.302***	0.321***	0.337***	0.301***	0.304***
	[15.27]	[18.32]	[15.07]	[15.00]	[15.66]	[8.43]	[7.92]	[7.95]
$ln(1+K/L)$	0.089***	0.114***	0.087***	0.087***	0.101***	0.261***	0.236***	0.236***
	[3.69]	[4.09]	[3.64]	[3.62]	[4.13]	[3.09]	[2.82]	[2.82]
$ln(1+Sales)$	0.068***	0.106***	0.050***	0.046***	0.060***	0.310***	0.242***	0.239***
	[4.87]	[5.98]	[3.30]	[3.06]	[3.87]	[6.94]	[5.41]	[5.27]
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	NO	NO	NO	NO	NO	NO	NO	NO
Obs	37,015	37,015	37,015	37,015	37,015	4,025	3,823	3,823
Adj. R^2	0.553	0.562	0.666	0.666	0.665	0.611	0.629	0.628

Appendix

Variable	Description
$ln(1+CITES_{s,t})$	The natural logarithm of one plus $CITES_{s,t}$. $CITES_{s,t}$ is the number of future citations received by the cohort of patents filed by firm s in year t. We count the future citations till the end of 2010 and exclude all self-citations. Only those patents that are ultimately granted are included in our sample. Following Hall, Jaffe and Trajtenberg (2001), we correct for the truncation in citation count based on the estimated empirical distribution of citation-lag. [Source: NBER Patent database and Kogan et al. (2014)]
$ln(CITES_{s,t})$	The natural logarithm of $CITES_{s,t}$. It is defined exactly the same as $ln(1+CITES_{s,t})$ except we do not plus one in parentheses. [Source: NBER Patent database and Kogan et al. (2014)]
$ln(1+N_{s,t})$	The natural logarithm of one plus the number of patents filed by firm s in year t. Only patents that are ultimately granted are included in our sample. [Source: NBER Patent database and Kogan et al. (2014)]
$ln(1+\overline{cites}_{s,t})$	The natural logarithm of one plus $\overline{cites}_{s,t}$. $\overline{cites}_{s,t}$ denotes the average future citations per patent for the cohort of patents filed by firm s in year t, calculated as $CITES_{s,t}$ divided by $N_{s,t}$. [Source: NBER Patent database and Kogan et al. (2014)].
$ln(1+R\&D\ Exp_{s,t})$	The natural logarithm of one plus *R&D Expenditure* (Compustat Mnemonic: XRD), which is based on the latest fiscal year-end value prior to the end of calendar year t and is measured in million U.S. dollars. [Source: Compustat-CRSP merged database]
$ln(1+cites_{p,t})$	The natural logarithm of one plus $cites_{p,t}$. $cites_{p,t}$ denotes the number of future citations received by patent p, which is filed in year t. The future citations are counted till the end of 2010, and all self-citations are excluded. The truncation bias in citation count is adjusted based on the estimated empirical distribution of citation-lag. [Source: NBER Patent database and Kogan et al. (2014)]
$ln(1+cites^{F1}_{p,t})$	The natural logarithm of one plus $cites^{F1}_{p,t}$. $cites^{F1}_{p,t}$ is the same as $cites_{p,t}$ but exclusive of citations coming from firms quoted in the patent application of patent p. [Source: NBER Patent database and Kogan et al. (2014)]
$ln(1+cites^{F2}_{p,t})$	The natural logarithm of one plus $cites^{F2}_{p,t}$. $cites^{F2}_{p,t}$ is the same as $cites_{p,t}$ but exclusive of citations coming from firms that patent p's innovator has ever quoted previously. [Source: NBER Patent database and Kogan et al. (2014)]
$PSOL(p,p_d)$	Pairwise (institutional) shareholder ownership overlap between the citing patent p and its downstream cited patent p_d at the end of year t. We first identify all the overlapped (institutional) shareholders between firm s and the assignee of patent p_d. For each overlapped shareholder i, we calculate the minimum ownership overlap $min[w_{i,O(p)}, w_{i,O(p_d)}]$. $w_{i,O(p)}$ denotes the share holding of investor i (relative to the aggregate institutional ownership) in the corporate assignee of patent p. $w_{i,O(p_d)}$ is defined analogously. Then, we calculate the sum of $min(w_{i,O(p)}, w_{i,O(p_d)})$ over all of the overlapped institutional shareholders in the two firms. When calculating $PSOL$, we ignore any downstream patent p_d whose assignee is not a publicly listed firm or whose assignee is the same as the assignee of the citing patent p. [Source: NBER Patent database, Kogan et al. (2014), and Thomson Reuters 13F database].
$sol_{p,t}$	Shareholder overlap for patent p, filed in year t. It is calculated as the "importance" weighted average $PSOL(p,p_d)$ of all cited downstream patents p_d, with $d = 1, 2, .., N_p$. We measure the importance of a downstream patent p_d by its future citations relative to the aggregate future citations of all cited downstream patents. In cases in which multiple cited patents are assigned to the same firm, we aggregate the citation count of these patents and treat them as one single downstream patent. We exclude all expired downstream patents (i.e., those patents that are filed more than 20 years ago). [Source: NBER Patent database, Kogan et al. (2014), and Thomson Reuters 13F database]
$SOL_{s,t}$	Shareholder overlap for firm s in year t. It is calculated as the "importance" weighted average $sol_{p,t}$ of all patents filed by firm s in year t. We measure the "importance" of a patent p by its future citation count relative to the aggregate citation count of all patents filed by the firm in the year. [Source: NBER Patent database, Kogan et al. (2014), and Thomson Reuters 13F database]

Variable	Description
$SOL^{CAP}_{s,t}$	An alternative measure of shareholder overlap for firm s in year t. It is exactly the same as $SOL_{s,t}$ except that institutional ownership shares are calculated relative to the total shares outstanding instead of the aggregate share holdings of all institutions. [Source: NBER Patent database, Kogan et al. (2014), and Thomson Reuters 13F database]
$SOL\_HHI_{s,t}$	Herfindahl-Hirschmann index (HHI) of the overlapping equity shares. Firstly, we calculate the HHI of minimum ownership overlap $min[w_{i,O(p)}, w_{i,O(p_d)}]$ across all overlapped investors within $PSOL(p, p_d)$. $w_{i,O(p)}$ denotes the share holding of investor i (relative to the aggregate institutional ownership) in the corporate assignee of patent p. $w_{i,O(p_d)}$ is defined analogously. Secondly, we importance weighted average HHI in the first step of all cited downstream patents p_d, with $d = 1, 2, .., N_p$. We measure the importance of a downstream patent p_d by its future citations relative to the aggregate future citations of all cited downstream patents. In cases in which multiple cited patents are assigned to the same firm, we aggregate the citation count of these patents and treat them as one single downstream patent. We exclude all expired downstream patents (i.e., those patents that are filed more than 20 years ago). Lastly, we importance weighted average the result obtained in the second step of all citing patents filed by firm s in year t. We measure the "importance" of a patent p by its future citation count relative to the aggregate citation count of all patents filed by the firm in the year. [Source: NBER Patent database, Kogan et al. (2014), and Thomson Reuters 13F database]
Period dummy	Dummy variable that identifies year intervals of 1992-1996 ($D^{1992-1996}$), 1997-2001 ($D^{1997-2001}$), and 2002-2007 ($D^{2002-2007}$). [Source: Compustat-CRSP merged database]
$D^{High}_{s,t}$	Dummy variable of 1 for firms with more concentrated overlapping shareholders, and 0 otherwise. At the end of each year t, we measure the weighted portfolio concentration ($WHHI_{s,t}$) of all investors who have joint ownership in an innovating firm s and its downstream patent owning firms. An investor's portfolio concentration is measured by the Herfindahl-Hirschman Index (HHI). We then run the median regression for a total of 18,066 firm-year observations: $ln(1 + WHHI_{s,t}) = \beta_0 + \beta_1 \times SOL_{s,t} + \beta_2 \times SOL^2_{s,t} + \beta_3 \times SOL^3_{s,t} + \epsilon_{s,t}$. We obtain the following estimates: $\beta_0 = 0.032$ ($t = 3.89$), $\beta_1 = -0.202(t = 1.34)$, $\beta_2 = 20.892$ ($t = 27.88$), and $\beta_3 = -20.30$ ($t = -19.09$). The $Pseudo\ R^2$ is 0.519. Conditional on a given level of $SOL_{s,t}$, we can segregate firms into above the median and those below the median value of $WHHI_{s,t}$. We define $D^{High}_{s,t}$ to be 1 if $WHHI_{s,t}$ is above the median value for a given level of $SOL_{s,t}$, and 0 otherwise. [Source: NBER Patent database, Kogan et al. (2014), Thomson Reuters 13F database, and Compustat-CRSP merged database]
$D^{Low}_{s,t}$	Dummy variable of 1 for firms with more diversified overlapping shareholders, and 0 otherwise. $D^{Low}_{s,t}$ is equal to 1 if $WHHI_{s,t}$ is below the median value for a given level of $SOL_{s,t}$, and 0 otherwise. [Source: NBER Patent database, Kogan et al. (2014), Thomson Reuters 13F database, and Compustat-CRSP merged database]
$d^{High}_{p,t}$	Dummy variable of 1 for patents with more concentrated overlapping shareholders, and 0 otherwise. For each patent-year, we measure the weighted portfolio concentration ($whhi_{p,t}$) of all investors who have joint ownership in the innovating firm owning patent p and its downstream patent owning firms. We then run the median regression for a total of 683,021 patent-year observations: $ln(1 + whhi_{p,t}) = \beta_0 + \beta_1 \times sol_{p,t} + \beta_3 \times sol^2_{p,t} + \beta_3 \times sol^3_{p,t} + \epsilon_{p,t}$. We obtain the following estimates: $\beta_0 = 0.048$ ($t = 20.83$), $\beta_1 = 2.527(t = 87.49)$, $\beta_2 = 8.472$ ($t = 86.41$), and $\beta_3 = -7.889$ ($t = -83.26$). The $Pseudo\ R^2$ is 0.568. Conditional on a given level of $sol_{p,t}$, we can segregate firms into above the median and those below the median value of $whhi_{p,t}$. We define $d^{High}_{p,t}$ to be 1 if $whhi_{p,t}$ is above the median value for a given level of $sol_{p,t}$. [Source: NBER Patent database, Kogan et al. (2014), Thomson Reuters 13F database, and Compustat-CRSP merged database]
$d^{Low}_{p,t}$	Dummy variable of 1 for patents with more diversified overlapping shareholders, and 0 otherwise. $d^{Low}_{p,t}$ is equal to 1 if $whhi_{p,t}$ is below the median value for a given level of $sol_{p,t}$, and 0 otherwise. [Source: NBER Patent database, Kogan et al. (2014), Thomson Reuters 13F database, and Compustat-CRSP merged database]
$FIF_{s,t}$	Firm innovation focus for firm s at year t. It is the sum of $ln(1 + CITES_{s,t})$ of all patents filed by firm s in year t, relative to the industry average (based on two-digit SIC codes) over the same period. [Source: NBER Patent database, Kogan et al. (2014), and Compustat-CRSP merged database]

Variable	Description
$IIF_{i,s,t}$	Investor innovation focus for investor i of firm s at year t. It is calculated as the portfolio value-weighted patent share of all stocks $s\prime$ (except for stock s) invested by shareholder i. The portfolio value of shareholder i is measured at the end of year t. [Source: NBER Patent database, Kogan et al. (2014), Thomson Reuters 13F database, and Compustat-CRSP merged database]
$SIF_{s,t}$	Shareholder innovation focus for firm s at year t. It is calculated as the value-weighted average of $ISIF_{i,s,t}$ across all shareholders of firm s. The weight for each shareholder i is proportional to her investment value in the firm at the end of year t. [Source: NBER Patent database, Kogan et al. (2014), and Compustat-CRSP merged database]
$IO_{s,t}$	Aggregate institutional ownership of firm s at year t. It is calculated as the total number of shares of firm s held by institutional investors relative to the total shares outstanding. [Source: Thomson Reuters 13F database and Compustat-CRSP merged database]
$ln(1 + R\&D\ Stock_{s,t})$	The natural logarithm of one plus $R\&D\ Stock_{s,t}$, where $R\&D\ Stock_{s,t} = R\&D\ Expenditure_{s,t} + (1-\delta) \times R\&D\ Stock_{s,t-1}$. Following Hall, Jaffe and Trajtenberg (2005), we set $delta = 0.15$ to represent the private depreciation rate of knowledge. $R\&D\ Expenditure$ (Compustat mnemonic: XRD) is based on the latest fiscal year-end value prior to the end of calendar year t and is measured in million U.S. dollars. [Source: Compustat-CRSP merged database]
$ln(1 + K/L_{s,t})$	The natural logarithm of one plus the ratio of $Capital$ (Compustat Mnemonic: $PPENT$) to *Labor* (Compustat Mnemonic: EMP). Both variables are based on the latest fiscal year-end values prior to the end of calendar year t. *Capital* is measured in million U.S. dollars and *Labor* in thousands. [Source: Compustat-CRSP merged database]
$ln(1 + Sales_{s,t})$	The natural logarithm of one plus *Sales* (Compustat Mnemonic: $SALE$), which is based on the latest fiscal year-end value prior to the end of calendar year t and is measured in million U.S. dollars. [Source: Compustat-CRSP merged database]
Pre-sample mean citation count	The aggregate future citations received by patents filed over the pre-sample period $(1976 - 1991)$ divided by the number of pre-sample years. For firms without patents during this period, we set the value to 0. [Source: NBER Patent database and Kogan et al. (2014)]