Technological Progress and Ownership Structure

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Abstract

Innovation processes under patent protection give rise to 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 patent investment and more patent success as measured by future citations. The positive innovation effect is strongest for concentrated overlapping ownership and for the cases when the overlapping shareholders are dedicated investors.

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1 Introduction

Although technological progress has been 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 gives a new empirical perspective on the role of equity ownership structure in attenuating hold-up problems induced by patent protection in the corporate innovation process.

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

The property rights literature (Hart and Moore, 1990; Grossman and Hart, 1986) argues that joint ownership of complementary assets enhances (ex-ante) investment incentives. Applying this insight to the patent process, we conjecture that joint equity ownership (i.e. shareholder overlap) between an innovating firm and other firms controlling complementary patents can similarly attenuate the hold-up problem and contribute to the patent success of the innovating firm. Two separate channels could promote the internalization of such patent hold-up:

[1] Recent economic research has documented a negative impact of recent patent proliferation on R&D investment and follow-on innovation (Heller and Eisenberg, 1998; Bessen and Maskin, 2009; Galasso and Schankerman, 2015) and highlighted abusive patent enforcement by so-called "non-practicing entities" (Cohen, Gurun, and Kominers, 2015).

First, investors with joint ownership in the downstream and upstream firms could influence management of the downstream firm to internalize future patent rent transfers to the upstream firm and avoid the underinvestment in downstream patents. Second, if such patent rent transfer can only be obtained at an efficiency loss (for example, due to potential patent litigations that retard the commercial adoption of the patent), overlapping investors could contribute to a swift conflict resolution about patent rents, which should also increase ex-ante investment incentives.

Anecdotal evidence for the role of overlapping shareholders in legal conflict resolution is provided by Hansen and Lott (1996), who cite Albert J. Wilson, Vice President and Secretary for TIAA-CREF, stating that his large pension fund was actively involved in applying pressure to ensure that the Pennzoil v. Texaco and Apple v. Microsoft conflicts were resolved, and claiming that this pressure resulted in Pennzoil and Texaco settling their suit much sooner than they would have otherwise.

To subject this property-right perspective of patent success to a systematic 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 1991–2007. In particular, we track stock ownership not only for the innovating firms, but also for firms owning complementary patents. The complementarities are identified directly from patent filings that explicitly list important precursory patents owned by other firms. By law, each newly filed patent must list precursory (upstream) patents

that are technologically related and material to the patentability of the new application.[2] Cited precursory patents thus identify rival property rights which are often complementary assets to the downstream patent. These upstream patents then have to be licensed to the (downstream) innovators for the latter to realize the full value of the new patents (Ziedonis, 2004; Galasso and Schankerman, 2010; Noel and Schankerman, 2013).[3] Our analysis identifies potential patent hold-up based on this list of precursory patents and assumes that the list is exogenously determined by the technology to be patented. Patent examiners frequently add precursory patents to the reference list, suggesting a limited scope in manipulating the reference list of precursory patents by the patent filing firms (Alcácer, Gittelman, and Sampat, 2009).[4]

Our main hypothesis states that joint equity ownership between the downstream innovator and the upstream firms controlling complementary patents attenuates the hold-up problem, increases R&D investment, and contributes to the long-run patent success of an innovating firm. Following the existing literature, we measure patent success by the cumulative citation count $cites_{p,t}$ of each granted patent p that is filed in year t. The corresponding firm average $\overline{cites}_{s,t}$

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

[3]Ziedonis (2004) argues that owners of the (upstream) cited patents are reasonable proxies for the potential licensors of the citing patent. Noel and Schankerman (2013) and Galasso and Schankerman (2010) also suggest that a greater number of upstream assignees can signal a greater number of negotiations and disputes required to commercialize the downstream patent.

[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; 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.

for all patents firm s successfully files in year t represents the intensive margin of patent production; whereas the extensive margin of patent production is simply the number $N_{s,t}$ of successfully filed patents (i.e., patent applications that are eventually approved by USPTO). Overall patent success (at the firm level) is denoted as $CITES_{s,t}$ and aggregates all future patent citations for the entire cohort of patents successfully filed by firm s in year t.[5] Our new explanatory variable is *shareholder overlap* (SOL) and characterizes the percentage of equity ownership for which investors own an equally large equity share in the downstream innovating firm and the upstream firm owning the precursory patents. Consider a patent p owned by the downstream firm $O(p)$ which cites a precursory patent p^u owned by the upstream firm $O(p^u)$. If two investors A and B own 3% and 5% in a downstream firm $O(p)$, and 2% and 6% in the upstream firm $O(p^u)$, respectively, their combined shareholder overlap for the patent pair (p, p^u) amounts to 7% $[= min(3\%, 2\%) + min(5\%, 6\%)]$. The *patent-level shareholder overlap* (sol) follows by aggregating over all upstream patents cited in the patent filings of patent p and the *firm-level shareholder overlap* (SOL) by jointly aggregating over all patents and corresponding upstream patents.

Institutional ownership in U.S. listed stocks has grown rapidly from 25% in 1991 to 49% in 2006. The corresponding share is considerably larger for patent filing firms and has risen from 41% in 1991 to 71% in 2006. Patent filing firms tend to be larger and institutional investors prefer large caps. Figure 1, Graphs A and B depict the distribution of both institutional ownership and firm-level share-

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

holder overlap with upstream patent owning firms for the period 1991 to 2006. Parallel to the rise in institutional ownership, the firm-level shareholder overlap increases from 5.6% in 1991 to 7.4% in 2006. Cross-sectionally, shareholder overlap is positively related to institutional ownership in the downstream firm and even more strongly with its market cap as shown in Graphs C and D of Figure 1. Yet, shareholder overlap varies substantially across firms with similar levels of institutional ownership and market cap. Such a large heterogeneity in firm's indirect control over complementary upstream patents via overlapping shareholders could condition patent hold-up and determine a firm's long-run patent success.

Consistent with this *hold-up attenuation hypothesis* of shareholder overlap, we find that SOL emerges as a statistically and economically significant positive covariate of patent success, and the effect is more pronounced in the top three R&D-intensive sectors. The SOL measure is most strongly related to the extensive margin of patent production: approximately 14% more patents are filed by the downstream innovator if the shareholder overlap with the upstream firms increases by one standard deviation. The results are qualitatively robust to the inclusion of various firm controls, industry or firm fixed effects and measurement of SOL (for the same upstream patents) with ownership data lagged by two or three years.

We also explore two refinements of our basic hypothesis. First, we decompose SOL in the dimension of shareholder activism. A casual effect of shareholder overlap on patent success is most plausible for dedicated investors characterized by concentrated portfolio positions and a long-term investment horizon, but much

less so for other investors types. Consistent with this intuition, we find a much stronger effect of shareholder overlap on patent success when such overlap or joint ownership originates in dedicated fund holdings. Second, the concentration of overlapping equity stakes should also matter: If the downstream innovating firm and upstream firms are jointly owned by only a few relatively large shareholders, coordinated action should be easier to organize, and shareholders might have stronger incentives to resolve a potential hold-up. In accordance with this prediction, we find that the Herfindahl-Hirschman index of (overlapping) shareholder ownership concentration correlates positively with the firm-level patent success beyond the shareholder overlap itself.

We pursue four different strategies to convince the reader that neither omitted variables nor reverse causality is likely to explain the empirical relationship between shareholder overlap and patent success. We first saturate the regression analysis with interacted firm and time fixed effects. These control for all unobservable omitted factors at the level of the downstream firm. Effectively, we compare the patent success of two patents filed by the same firm in the same year as a function of their patent-level shareholder overlap *sol* with the respective upstream firms. We find that this *within firm* patent success is again positively correlated with patent-level variations in shareholder overlap at a high level of statistical significance.

Any remaining omitted variable effect now needs to operate at the patent level of the downstream firm and simultaneously influence the ownership structure of the upstream firms. To further seperate such an omitted variable effect from

affecting the ownership of the upstream firms, we instrument the patent-level shareholder overlap *sol* with the weighted market capitalization of the patent-specific cited upstream firms. Again, we confirm that *within-firm* variation of patent success covaries strongly with the patent specific shareholder overlap even if the latter is instrumented by the average market capitalization (or size) of the upstream firms.

To further probe for omitted variables operating across firms, we design two placebo tests. We replace the shareholder overlap based on true patent citations with a placebo shareholder overlap $SOL\_Placebo$ where we replace any cited upstream firm with a "similar firm" which is not cited by the downstream firm in a given year. Similarity is defined as belonging to the same industry ($SOL\_Placebo1$) and sharing the same firm characteristics or alternatively as technological proximity ($SOL\_Placebo2$). In both cases, the placebo shareholder overlap features no statistically significant effect on hold-up mitigation and patent success.

Fourth, the placebo measures of shareholder overlap also allow us to address concerns about reverse causality. If investors anticipate patent rents and strategically acquire overlapping ownership shares to benefit from such rents, then patent success may cause shareholder overlap rather than vice versa. Yet event evidence for the evolution of shareholder overlap around the patent filing year shows that shareholder overlap evolves identically for the true SOL and two placebo measures, $SOL\_Placebo1$ and $SOL\_Placebo2$. This suggests that future patent filings do not have a discernible effect on shareholder overlap. This finding may

not be surprising as patent developments are generally kept secret and trading on insider information is sanctioned by law.

One of the proximate causes of patent success is R&D investment and the property rights literature has emphasized the negative effect of hold-up on firm investment. We therefore examine if shareholder overlap is related to higher R&D expenditure and find an economically strong relationship. This robustness check is important because patent citations are used in firm valuation (Harhoff, Narin, Scherer, and Vopel, 1999); overlapping institutional owners could potentially promote cross-citations between firms in which they also have a joint equity stake and distort the patent citation counts.[6] By contrast R&D expenditure is an accounting measure sourced from Compustat and should not be subject to the same measurement problems.

The relationship between shareholder overlap and R&D expenditure suggests an additional falsification test: If the governance influence of the overlapping shareholders is the true cause of higher R&D expenditure, then all non-overlapping institutional shareholders have an opposing interest. From their perspective, internalization of rent transfers to upstream patent owners implies R&D overinvestment. Accordingly, we can test if a higher share of non-overlapping institutional investors IO^{NOL} is negatively correlated to R&D expenditure—suggesting that they counterbalance the corporate policy influence of the overlapping shareholders. We find that shareholder overlap (SOL) and non-overlapping institutional ownership (IO^{NOL}) indeed feature opposite correlations with patent

[6] As a robustness check, we filter patent citations to exclude those coming from firms cited by the patent filing firm in any of its current or previous filings. Our results remain robust.

investment. This finding highlights the fact that institutional investors can have opposing interest with respect to firm policy and that aggregate institutional ownership itself may not be a very meaningful variable to characterize agency conflicts with respect to patents investment.

2 Related Literature

Notwithstanding its prominence in economic theory, the property rights view of the boundaries of the firm has seen very few empirical applications. A variety of empirical problems explain the scarcity of evidence. First, non-contractible hold-up problems are often difficult to identify in a complicated business environment. Explicit citation of precursory patents in the patent documents provides a unique opportunity in this respect. Second, underinvestment at the project level is difficult to measure because a firm can shift investments to other projects for which hold-up problems are less severe. Such an analysis requires a level of disaggregation typically not available for investment data. Third, investments may involve intangibles resources (such as managerial attention) that pose additional measurement problems[7]. 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.

[7] One of key assumptions in Hart and Moore (1990) is investment has to be specific to an asset/product such that the realization of the investment cannot be used for other purposes. In the setting of corporate innovation, such applied research is usually done with a product in mind and is asset-specific in this sense.

Can firms avoid patent conflicts? Previous studies on patent hold-up problems (e.g., Shapiro, 2001; Ziedonis, 2004; 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 might involve substantial royalty fees and their negotiation may not be 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 firm merger involves high transaction costs and might be challenged in court for anti-competitive reasons (Creighton and Sher, 2009). Our evidence suggests that in liquid equity markets, partial ownership integration via ownership overlap may be achieved at lower costs or may already exist if large institutional shareholders happen to hold shares in both firms concerned.

Recent work has also highlighted that shareholder overlap induced by increasing institutional ownership can soften product market competition (Azar, Schmalz, and Tecu, 2015). But our result cannot be caused by the reduced market competiton because it doesn't explain any within-firm variation of patent success. Hansen and Lott (1996) and He and Huang (2014) discuss the coordination role of common shareholders in internalizing conflicts between firms in their investment portfolio. The extent to which passive institutional shareholders contribute to intra-industry coordination is still debated (Harford, Jenter, and Li, 2011). Doidge, Dyck, Mahmudi, and Virani (2015) present direct

evidence that institutional investors in Canadian equity market coordinate to improve corporate governance collectively. In some cases, activist investors are found to coordinate (otherwise passive) institutional investors in pursuit of common objectives—making the dichotomy between activist and passive investors less clear-cut (Appel, Gormley, and Keim, 2015).

Our paper also speaks to the widely debated policy issue of patent reform. President Obama in his 2014 State of the Union address singled out the patent system as a priority for economic reform. The U.S. administration has pushed USPTO to examine patent requests more rigorously and define their patentable component more narrowly ex ante in order to reduce the reliance on courts to make those determinations ex post.[8] However, Galetovic, Haber, and Levine (2015) argue that there is no evidence that more patent litigations are associated with patent holders stymieing the commercialization of complex technologies or hindering innovation. The evidence in our paper suggests a significant hold-up effect in the corporate innovation process. We argue that shareholder overlap represents an important palliative to hold-up problems with respect to patent investment—a benefit that accrues mostly to large firms.

Other empirical work on the determinants of patent success focuses on the role of institutional shareholders. Aghion, Van Reenen, and Zingales (2013) and Bena, Ferreira, Matos, and Pires (2015) argue that a large share of institutional shareholders is conducive to patent investment as these shareholders tend to pur-

[8] A deterioration in the patent environment is sometimes attributed to the growing role of non-practicing entities (NPEs) or "patent trolls," which specialize in the enforcement of patent rights without having a commercial activity of their own. (See, e.g., Cohen, Gurun, and Kominers, 2015.)

sue a long-run objective. Our evidence shows that it is important to decompose institutional ownership into the overlapping and non-overlapping components as the latter correlates negatively with long-run patent success. Generally, institutional investors may have opposing interests in R&D investment depending on their ownership stakes in upstream firms which benefit from licensing rents.

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

3 Hypotheses

Patent history is about the extension of ownership rights to new ideas, products and processes. The aspect of novelty implies that the scope for ex-ante contracting (prior to patent investment) is limited. The property rights view of the firm is therefore a natural starting point for thinking about patent investment and development.

Common shareholder ownership between downstream and upstream firms can

mitigate the patent hold-up through two channels: First, a *transfer internalization channel* implies that management of the downstream firm will only account for the portion of the transfer payments received by the overlapping shareholders but not the portion paid to the upstream firms' other shareholders in its value maximization. Second, a *transfer reduction channel* suggests that if the rent extraction by upstream firms involves frictions that generate costs for overlapping shareholders without a commensurate benefit, overlapping investors would exercise their influence over the upstream firms in favor of swift conflict resolution and therefore reduce the overall patent transfer payments by the downstream firm. Both channels imply that ex-ante investment incentives and patent success are restored through *shareholder overlap*. We state this prediction as our first hypothesis:[9]

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 filed in year t should increase in the *firm-level shareholder overlap* $SOL_{s,t-1}$ between the firm itself and all other firms owning cited upstream patents that pose potential hold-up problems.

Empirically, any correlation between (lagged) shareholder overlap and patent success may originate in a variety of observable and unobservable firm characteristics which influence both variables. We therefore use firm fixed effects to

[9] A simple model of hold-up attenuation through shareholder overlap is provided in the Web Appendix B to this paper.

control for omitted variables at the firm level. In addition, we undertake two placebo tests to check if bilateral industry characteristics or technological similarity simply drive the observed correlation.

Our second hypothesis decomposes the effect of shareholder overlap on patent production:

> **H2: Extensive and Intensive Margins of Patent Production**
>
> The extensive margin of patent production (proxied by the number of patents $N_{s,t}$ filed by firm s in year t and eventually granted) correlates positively with the *firm-level shareholder overlap* $SOL_{s,t-1}$. The intensive margin $\overline{cites}_{s,t}$ (which measures the average citation count of a firm's patents) should also correlate positively with $SOL_{s,t-1}$ if patent hold-up involves not only value redistribution but also (inefficient) value destruction.

Patent hold-up can reduce both the intensive and extensive margin of patent production. Patent value destruction (through costly patent litigation or delayed commercialization) diminishes the expected value of each patent proxied by the average citations a patent receives in the future. Value transfer through licensing reduces the extensive margin or number of patents a firm finds profitable to develop. Both effects reduce the overall future patent citation count for a firm, but they are economically different.[10] A second reason for examining the extensive margin directly concerns measurement quality. Whereas the future citation count

[10] Our model of patent hold-up in Web Appendix B identifies different structural parameters driving the intensive and extensive margin of optimal patent production under hold-up.

needs to be measured (with some scope for error or controversy), the number of patent filings is directly reported and provides no judgement with respect to its measurement. Finding qualitatively similar results for the extensive margin circumvents any criticism with respect to the measurement of future citation counts.

An important condition for finding any hold-up attenuation under shareholder overlap is that shareholders seek to influence the corporate decision process. Recent evidence by Soloman and Soltes (2015) has documented the frequency of meetings between institutional investors and corporate managers. Shareholder activism varies greatly with the shareholder type and thus provides a useful dimension through which we refine the shareholder overlap measure. We conjecture that dedicated shareholders characterized by concentrated equity portfolios and a long-term investment horizon should be more willing and/or more capable of exercising their ownership power to resolve patent hold-up than passive shareholders.

H3: Shareholder Type within Shareholder Overlap

Shareholder overlap should feature a more positive correlation with patent success if the respective overlap is contributed by more dedicated shareholders as opposed to other shareholders.

A second dimension in which we can predict heterogenous effects of shareholder overlap on patent hold-up mitigation is the very concentration of such overlap. A large finance literature has regarded ownership concentration as a

proxy for shareholder influence over management decisions. Hence, if the overlapping shares are concentrated among a few institutional investors, coordination and free-rider problems are smaller and lobbying for hold-up internalization should be easier.

H4: Concentration of Shareholder Overlap

Coordination among overlapping shareholders should make concentrated overlapping equity ownership more effective in internalizing patent hold-up and therefore correlate positively with patent success.

An additional way to address endogeneity concerns about (unobservable) characteristics of the downstream firm is to undertake patent-level regressions and compare the patent success of different patents obtained by the same firm in the same year. These patents are still subject to different hold-up attenuation because of different bilateral overlaps with their respective upstream firms, while all firm characteristics as well as the ownership of the downstream firm are identical and thus cannot influence the inference. Accordingly, we can formulate the following within-firm hypothesis:

H5: Patent Success within the Firm

Within a firm's cohort of patents filed in the same year t, those with the largest *patent-level shareholder overlap* (denoted by $sol_{p,t-1}$ and measured with respect to each individual patent p's cohort of upstream cited patents) should feature the largest patent-level success

(denoted by $cites_{p,t}$) in terms of the total future citations for the patent.

We can test hypothesis H5 using a rich set of interacted firm-year fixed effects—thereby controlling for time-varying unobservable firm heterogeneity for the downstream firm. Any omitted variable effect is reduced to factors influencing *within-firm* patent success of the downstream firm and simultaneously affecting the ownership structure of the upstream firms. To reduce the potential endogeneity of ownership further, we can instrument $sol_{p,t-1}$ with the average market capitalization of all upstream cited firms of any patent.

The proximate cause of patent success is patent investment. As the property rights literature emphasizes the negative effect of hold-up on firm investment, we also examine the direct effect of shareholder overlap on the investment behavior of the firm. Using R&D expenditure as an alternative dependent variable allows us to discard patent data from the left-hand-side of the regression; instead we use the common corporate data compiled independently from patent data. This should also alleviate concerns about measurement error or biases related to the patent data.

H6: Firm R&D Expenditure

A firm's (log) R&D expenditure (denoted by $R\&D\ Exp_{s,t}$) increases in the firm-level *shareholder overlap* $SOL_{s,t-1}$.

Finally, we want to consider the shareholder conflict created by hold-up internalization. Generally, the interests of the overlapping shareholders in high R&D

investment is not shared by other shareholders of the downstream firm who do not profit from patent rent transfers to the upstream firm. To non-overlapping shareholders such hold-up internalization is simply an overinvestment and we expect them to oppose the lobbying of the overlapping shareholders. It is therefore important to distinguish the interests of overlapping institutional investors from the opposite interest of the non-overlapping institutional owners as highlighted in our last hypothesis:

H7: Non-Overlapping Institutional Ownership

Non-overlapping institutional shareholders in the downstream firms should oppose patent rent internalization by the overlapping shareholders because for them it leads to R&D overinvestment. Hence the institutional ownership share of non-overlapping shareholders (IO^{NOL}) should correlate negatively with R&D expenditure conditional on SOL.

4 Data

4.1 Patent Information

We collect patent and citation information from the data set provided by Kogan, Papanikolaou, Seru, and Stoffman (2014). The data set provides annual patent and citation information for patents granted over the period 1926–2010.[11] Our measurement of innovation success follows the existing literature (Griliches,

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

Pakes, and Hall, 1988). To distinguish influential innovations from incremental technological discoveries, we use the total number of a patent p's future citations ($cites_{p,t}$) from the patent filing year t to 2010 as our proxy for patent success. A patent will start to receive citations only after it becomes known to others. USPTO currently publishes patent applications 18 months after their filing dates. Such publications generally are not issued for earlier patents (filed before November 29, 2000); therefore, they typically start to receive citations only after they are granted. According to Hall, Jaffe, and Trajtenberg (2001), it takes on average 18 months for a patent's application to be approved and about 95% of successful patent applications are granted within three years of application. So the lag between patent filing and the first citation ranges from zero to three years in most cases.

We examine the firm-level patent metrics by summing up the patent metrics by patent filing year instead of grant year as the former is closer to the date of invention. We aggregate the count statistic $cites_{p,t}$ to the total number of future patent citations generated by granted patents filed by firm s in year t, denoted by $CITES_{s,t}$. Self-citations are excluded. Patent and citation counts are set to zero whenever there is no patent or citation information provided in the data. We also examine the extensive margin of patent production $N_{s,t}$, defined as the number of successful patent filings (i.e., patent applications that are eventually granted) by firm s in year t. The corresponding intensive margin is measured by the average cites per patent $\overline{cites}_{s,t}$ (which equals the ratio of $CITES_{s,t}$ to $N_{s,t}$). Because most of these patent-related measures feature highly right skewed

distribution, we generally apply a log transformation $ln(1+X)$ in order to obtain more normally distributed variables for regression analysis.

We adjust carefully for two truncation problems commonly associated with patent data. First, the patent data set only includes those patents that are eventually granted, so many patent applications filed in 2009 and 2010 and eventually granted beyond 2010 are not included in the data set. To mitigate this patent truncation bias, we use only patent applications up to 2007 in our empirical analysis. 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.

4.2 Ownership Data and Shareholder Overlap

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

A key explanatory variable in our analysis is *shareholder overlap* which we

define as follows: Let $O(p)$ designate the firm owning patent p. The *pairwise (institutional) shareholder overlap* between the downstream patent p and an upstream patent p_u (listed in the patent filings) is defined as

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

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

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

where we sum over the N_p (complementary) upstream patents of patent p. The *firm-level shareholder overlap* can be defined as

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

where we sum over all the N_s patents filed by firm s in a given year.

A final measurement issue concerns the choice of weights reflecting the relative importance of any patents p and p_u. Empirically, we measure the relative

importance by the relative (log) citation count as follows:

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

The use of citation based measures for the construction of explanatory variables (even if only as weights) could raise concerns about spurious correlations with the dependent variable which for most regression specifications is also based on patent citations. But we can show that alternative weighting scheme using a (non-parametric) rank measure of future citations $rank(p)$ delivers very similar results. The results are even robust to equal weights for which citation counts are completely discarded.

Because expired patents should not create any hold-up problems, we ignore cited patents that are filed 20 years before the application date of the citing patents in constructing SOL.[12] A limitation of our analysis is that we can measure ownership only for publicly listed firms. Our working assumption is that institutional ownership in private firms is generally small and that the resulting ownership overlap should also be negligible. We therefore set the pairwise shareholder overlap with any privately owned upstream firm to zero. The measurement error may become larger if the share of privately owned upstream firms in the construction of SOL is also large. To control for this effect, we track the (weighted) share of privately owned upstream firms and include it as a control

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

variable (*Private Patent Share*). As this variable captures potential "underestimation" of the true SOL, we expect it to have a positive sign.[13]

The citation count variable as a proxy for patent success has the important advantage that it can be measured both at the firm level and also at the patent level. Analogously, we can also measure shareholder overlap at both the firm level (SOL) and the patent level (sol). The weighted sum of the *patent-level shareholder overlap sol* amounts to the *firm-level shareholder overlap SOL*.

Shareholder overlap correlates positively with institutional ownership (Figure 1, Graph C) and firm market cap (Figure 1, Graph D). But particularly the former cannot be considered any more exogenous than shareholder overlap itself. By contrast, index inclusion (of either the upstream or downstream firm) may represent a relatively exogenous instrument for increased shareholder overlap. Yet such index events are rare and effectively reduce the sample to a rather small subset of firms. A more promising empirical strategy deals with the omitted variable problem through the construction of placebo measures of shareholder overlap ($SOL\_Placebo$). These measures replace the true citation link to the upstream firm with an incorrect link to a firm similar to the true upstream firm.

Our final sample includes all U.S. publicly listed firms that have more than one successful patent application over the sample period $1992-2007$. We require each firm to have at least two valid observations because we control for firm fixed effects in our main regression specifications. Our final sample includes $2,964$ firms.

[13] We also check robustness of our results to an alternative procedure in which privately owned upstream firms are generally ignored in the construction of SOL. The results are qualitatively similar.

We exclude all firm-year observations with missing values for the explanatory variables or control variables. The control variables such as firm market capitalization $ln(1 + MktCap_{s,t-1})$, the cumulative R&D investment $ln(1 + R\&D\ Stock_{s,t-1})$, a measure for capital intensity $ln(1 + K/L_{s,t-1})$, and sales $ln(1 + Sales_{s,t-1})$ are drawn from Compustat database.

The summary statistics are reported in Table 1. The sample features 19,315 firm-years of patent production involving a total of 582,032 patents. On average, a firm produces 30 patents per year. The average (median) firm-level shareholder overlap (SOL) is 6.2% (4.3%) with a large standard deviation of 6.3%. The patent-level shareholder overlap (sol) shows an average (median) value of 14.4% (11.0%) with a standard deviation of 14.2%. The higher mean and standard deviation for the patent-level shareholder overlap is explained by the fact that firms with many patent filings tend to be both larger and feature a higher level of shareholder overlap. The institutional ownership (relative to the total number of shares outstanding of a firm) and shareholder overlap generally exhibit an upward time trend throughout the sample period. Time fixed effects are included in all regressions to ensure that the documented shareholder overlap effect does not capture any parallel time trend in patent success. We provide the detailed definitions of all variables in the Web Appendix.

5 Evidence on Patent Success

5.1 Baseline Specification

As some firms register patents which are never cited throughout the sample period, we therefore prefer to measure patent success in log terms as $ln[1+CITES]$ rather than $ln[CITES]$.[14] The baseline regression linking patent success to shareholder overlap then becomes

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

where the coefficient of interest is $\beta_1 \geq 0$.[15] More shareholder overlap with firms holding the upstream patents should boost the downstream innovating firm's patent success as hold-up problems are attenuated.

We estimate Eq. (5) over the period 1992–2007. The citation count $CITES_{s,t}$ for patents filed by firm s in year t includes all future citations up to year 2010. *Shareholder overlap* ($SOL_{s,t-1}$) measures the ownership overlap at the end of year $t-1$ between the innovating firm and all other firms controlling complementary patents. For the choice of control variables, we follow Aghion, Van Reenen, and Zingales (2013) and include the cumulative R&D investment $ln(1 + R\&D\ Stock_{s,t-1})$, a measure of relative capital intensity $ln(1 + K/L_{s,t-1})$ and, the firm sales $ln(1 + Sales_{s,t-1})$[16]. We also include firm market cap $ln(1 + MktCap)$ to

[14] 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.

[15] The model developed in the Web Appendix B implies in particular $\beta_1 = (\frac{1}{b} + \frac{\gamma}{b} + \gamma)\delta \geq 0$.

[16] See also Gompers and Metrick (2001) and Hall, Jaffe, and Trajtenberg (2005).

account for firm size and the (weighted) share of private firms in cited upstream firms *Private Patent Share*.

Table 2, Columns 1–3 present the results for all firms and Columns 4–6 for firms in the top three R&D-intensive sectors (pharmaceuticals, computer hardware, and telecommunications equipment).[17] Columns 1 and 4 control for year fixed effects and industry fixed effects based on four-digit SIC codes, whereas Columns 2–3 and 5–6 control for year and firm fixed effects. We report robust standard errors allowing for two-way clustering at the firm and year (i.e., patent filing cohort) level.

The baseline regression shows that *shareholder overlap* SOL represents a statistically and economically significant explanatory variable. The point estimate of 3.726 in Column 1 implies that an increase in shareholder overlap by one standard deviation (or 0.063) increases patent success in terms of log firm citation ($ln[1+CITES]$) by 11.4% of its standard deviation of 2.066, suggesting that shareholder overlap has an economically large attenuation effect on patent success. The point estimate for SOL drops after including firm fixed effects in Column 2 which limits the power of SOL to explain intertemporal variations in patent success within a firm; The point estimate for the SOL coefficient remains highly significant at the 1% level. A one-standard-deviation increase in SOL rises patent success by 4.8% of its standard deviation. This weaker economic significance level is explained by the double inclusion of firm fixed effects and the

[17] We identify the three R&D-intensive sectors following Bloom, Schankerman, and Van Reenan (2013). Specifically, they are firms in the following sectors: Pharmaceuticals (SIC codes 2834 and 2835), computer hardware (SIC codes 3570, 3571, 3572, 3575, 3576, and 3577), and telecommunications equipment (SIC codes 3661, 3663, and 3669).

five firm-level controls, which together absorb much of the variation in patent success. As the control variables in Column 2 may raise endogeneity concerns with respect to the patent process, we also present results with firm fixed effects only in Column 3, which yields indeed a larger regression coefficient of 2.042 for SOL, compared to the coefficient of 1.561 reported in Column 2.

Columns 4–6 repeat these regressions for the top three R&D-intensive sectors. As expected, we find a statistically and economically stronger SOL effect in these sectors. Particularly, the regression specifications in Columns 5-6 with firm fixed effects yield statistically and economically significant point estimates for shareholder overlap. Not surprisingly, shareholder overlap matters most for patent success in those industries which are most patent-intensive.

5.2 Intensive versus Extensive Margins

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

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

where $\theta_1 > 0$ implies that patent hold-up reduces the average success of those patents which are eventually granted. A positive value of θ_1 therefore points to (ex-post) patent value destruction under patent conflict rather than mere rent

redistribution to upstream firm. Frictionless (ex-post) rent redistribution should primarily affect the extensive margin of patent production, but not the intensive one.[18]

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 0.612, implying an increase in shareholder overlap by one standard deviation (or 0.063) corresponds to an increase in the average citation count per patent by about 3.4% of its standard deviation. Inclusion of firm fixed effects in Column 2 restricts the identification of the shareholder overlap effect to intertemporal firm variation. Again, the insignificant coefficient estimate for SOL suggests that much of attenuation effect for the intensive margin of patent success coming from the cross-sectional variation is now absorbed by a combination of firm-level controls and the firm fixed effects.

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

$$ln[1 + N_{s,t}] = \psi_0 + \psi_1 SOL_{s,t-1} + \psi_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \qquad (7)$$

where the coefficient ψ_1 captures the effect of hold-up mitigation through shareholder overlap on the number of successful patent filings. Unlike future citation counts, the patent counts are not subject to much measurement controversy. In

[18] The model in the Web Appendix implies $\theta_1 = \gamma\delta$, where γ represents the degree of patent rent destruction.

particular, they are not subject to the critique that patent citations can be exchanged strategically in order to boost firm valuations (Harhoff, Narin, Scherer, and Vopel, 1999).

The regression results for the extensive margin are presented in Table 3, Columns 3–4. The point estimate of 2.926 in Column 3 suggests a strong economic significance for the shareholder overlap measure; a one-standard-deviation increase in SOL is associated with a 13.8% increase in the number of patents relative to its standard deviation of 2.926. Moreover, the coefficient retains its statistical significance in the specification with firm fixed effects in Columns 4.

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

5.3 Two Dimensions of SOL Heterogeneity

Shareholder overlap could feature a spurious correlation with patent success unrelated to any real governance influence of the overlapping shareholders. As a proxy for *potential influence* on the patent hold-up problem, we predict that shareholder overlap should be inconsequential if the overlapping shareholder are non-

dedicated investors who do not seek to influence the corporate decision process or if the overlapping ownership shares are so fragmented that coordinated action is difficult to organize. We subject both aspects—highlighted in hypothesis H3 and H4, respectively—to further testing.

To test hypothesis H3, we separate institutional investors into (i) dedicated investors, (ii) intermediate investors, and (iii) transient investors based on a combination of portfolio concentration (proxied by Herfindahl-Hirschman Index (HHI)) and portfolio turnover (proxied by churn ratio defined in Gaspar, Massa, and Matos (2005)). At the end of each year, we sort all institutional investors by the HHI (in descending order) and the churn ratio (in ascending order), respectively, and define the combined rank as the sum of HHI rank and churn ratio rank. We label dedicated investors as those in the top tercile of the combined rank (high concentration and low turnover) and transient investors as those in the bottom tercile (low concentration and high turnover). The rest of investors in the middle tercile are labeled as intermediate investors. The distribution of investor types along the two dimensions of portfolio concentration (i.e. HHI) and portfolio turnover (i.e. churn ratio) is shown in Figure 2, where red, pink, and blue points represent dedicated, intermediate, and transient investors, respectively.

Next, we decompose the shareholder overlap of each firm-year according to the three investor types:

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

Shareholder overlap from dedicated investors (with both concentrated equity stakes and a long investment horizon) is expected to attenuate hold-up problems more effectively than shareholder overlap from the other investor groups. The regression result in Table 4, Column 2 confirms this hypothesis. The coefficient estimate for $SOL\_Dedicated$ is at 22.448 more than six times that for SOL in baseline regression (reported in Table 2 and reproduced in Column 1 of Table 4). Shareholder overlap originating in the other two groups of investors with more diversified portfolios and a shorter investment horizon shows a much weaker effect on patent success. In conclusion, what matters most for patent success is shareholder overlap in complementary patents coming from dedicated shareholders.

Hypothesis H4 concerns the potential coordination problem among the overlapping shareholders. If the downstream innovating firm and the upstream cited firms are jointly owned by a few relatively large shareholders, coordinated action might be easier to organize, and shareholders might have stronger incentives to resolve a potential hold-up. To test this hypothesis, let's consider a downstream patent p filed by firm s in year t and a related upstream patent p_u owned by firm u. Let $i \in I_{p,p_u}$ denote an overlapping investor who at the end of time $t-1$ owns equity shares (relative to total institutional ownership) $w_{i,s}$ and $w_{i,u}$ in firms s and u, respectively. We can define a Herfindahl-Hirschman Index (HHI) of shareholder overlap based on overlapping ownership shares $\varpi_i = \min[w_{i,s}, w_{i,u}]$ of all overlapping shareholders $i \in I_{p,p_u}$. Then, we aggregate this shareholder overlap concentration index over all downstream patents p filed by firm s in year t and over their respective upstream patents p_u to obtain a weighted Herfindahl-

Hirschman Index of ownership concentration of overlapping shareholders, defined as

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

where $w(p)$ and $w(p_u)$ denote (as before) the relative importance weights for patents p and p_u, respectively, and the ownership shares are measured at year $t-1$, which is one year before the patent p's filing year t. $WHHI$ describes how concentrated the overlapping ownership stakes are at the firm level and thus captures the coordination problem among the overlapping investors.

Table 4, Columns 3 includes $WHHI$ as a separate control variable. The estimated coefficient is statistically significant and positive, suggesting that a concentration of joint ownership shares by overlapping shareholders positively correlates with patent success beyond the shareholder overlap SOL itself. The coefficient estimate of 2.364 in Column 3 implies that an increase in the ownership concentration of shareholder overlap by one standard deviation (or 0.072) generates the same effect on patent success as raising SOL by 58% relative to its mean $(= [0.072 \times 2.364] \ / \ [4.699 \times 0.062])$. This suggests that the coordination problem among dispersed overlapping institutional investors represents an important impediment to the exercise of effective shareholder power.

5.4 Patent-Level Regressions

The firm-level regressions in the previous section control for a variety of observable firm characteristics and include firm fixed effects for some specifications. Yet, time-varying unobservable influences on both patent success and shareholder overlap may still pose a concern for our inference.[19]

In this section, we present the patent-level regression specification by first including the separate firm and year fixed effects and then including the interaction of the firm and year fixed effects $\epsilon_{s,t}$. The latter specification better captures time-varying unobservable influences and identify the hold-up attenuation effect on patent success by relying entirely on the comparison of different patents filed by the same firm in the same year. Different patent filings by the same firm may list different upstream patents, resulting in patent-specific hold-up and shareholder overlap even within the same firm-year. The patent-specific hold-up attenuation is captured by the patent-level shareholder overlap $sol_{p,t-1}$ in the regression specification

$$ln[1 + cites_{p,t}] = \beta_0 + \beta_1 sol_{p,t-1} + \epsilon_{s,t} + \eta_{p,t}, \tag{10}$$

where $cites_{p,t}$ denotes the future citation count of patent p filed in year t. Similar to the firm-level regressions, all independent variables lag the dependent variable by one year.

Any omitted variable problem should be less severe for the patent-level regres-

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

sions which control for all unobservable time-varying effects at the level of the downstream firms. Any remaining omitted variable effect now has to operate on the within-firm patent success of the downstream firm and simultaneously affect the ownership structure (and thus shareholder overlap) for the upstream firms. To address endogeneity concerns with respect to ownership of the upstream firm, we conduct a two-stage least square ($2SLS$) regression by instrumenting *sol* with the average asset size of the patent-specific upstream firms. The size of the upstream firm should be largely exogenous to any endogenous patent-related ownership formation at the level of the upstream firm.

The patent-level citation success $cites_{p,t}$ can capture only the intensive margin of patent production, not the extensive margin, unlike the firm-level measure reported in Table 3. In addition, firm-years that feature only one patent application are discarded from the patent-level regressions; such cases account for about 25% of the firm-years in our overall sample. The patent-level data thus feature a strong selection bias toward those firms with many patents—51% of all patent filings are from the 1% most patent-intensive firms (as measured by the total number of patent filings over the sample period) and the other 49% are from the remaining 99% of firms.

The statistically significant point estimates of *sol* in Column 1-2 of Table 5 indicate shareholder overlap features a hold-up attenuation effect at the patent level. The estimated *sol* coefficient of 0.270 reported in Column 2 implies that an increase in shareholder overlap *sol* by one standard deviation (0.142) is related to an increase in the patent-level citation count by 2.8%. This modest economic

effect mainly represents the hold-up attenuation effect on the intensive margin of the most patent-intensive firms. Compared to OLS specification in Column 2, the $2SLS$ specification in Column 4 yields a very similar point estimate for the coefficient of interest. This suggests that the patent-level shareholder overlap is not endogenous to within-firm variation of patent success. A formal Hausman test rejects such endogeneity. Overall, the result is consistent with hypothesis H5 that patent success within a firm is also correlated with the patent-specific shareholder overlap *sol*, which differentiates different patents within the same firm-year.

5.5 Two Placebo Tests

Finally, we propose two different placebo tests to check whether the relationship between patent success and shareholder overlap is spurious and driven by other unobservable factors. The construction of our first placebo shareholder overlap ($SOL\_Placebo1$) replaces every cited upstream firm with a (placebo) firm of similar characteristics—but one that is *not* cited as the upstream patent owner by a cohort of patents filed by the downstream firm. For any firm patent cohort, the placebo firms are matched to the true upstream firms based on the same four-digit SIC industry code and then on the minimal Euclidean distance of firm size and firm patent filings in past five years.[20] Alternatively, the second placebo shareholder overlap ($SOL\_Placebo2$) defines similarity between the true

[20] If an upstream firm cannot find any proper matching in the four-digit SIC industry code in the same year, we then move to the three-digit SIC industry code. We normalize $ln(1+Assets)$ and $ln(1+CITES)$ by their respective industry average in the same year before minimizing the Euclidean distance.

upstream firm and its matching firm based on technological proximity following Bloom, Schankerman, and Van Reneen (2013). If more than one of matching firms feature identical technological proximity with respect to a true upstream firm, we then follow the same methodology to find the closest matching firm as in the first placebo measure. By design placebo firms are never cited in the (successful) patent cohort of a downstream firm. The falsification test explores if this is a sufficient condition to eliminate any hold-up relief coming from "similar" shareholder overlap.

Column 5-6 of Table 4 confirms this conjecture. Unlike the true shareholder overlap measure, its placebo equivalents ($SOL\_Placebo1$ and $SOL\_Placebo2$) do not feature any statistically significant correlation with patent success. The positive correlation between shareholder overlap and patent success is therefore contingent on picking exactly those firms for the construction of SOL which are cited in the patents of the downstream firm and not an arbitrary groups of similar firms. General unobservable factors influencing both patent success and shareholder overlap are unlikely to account simultaneously for the positive finding for SOL and the negative finding for $SOL\_Placebo$.

5.6 R&D Expenditure and Non-Overlapping Institutional Ownership

So far our analysis has focused on patent success as the main measure of the hold-up attenuation effect of shareholder overlap. But such hold-up attenuation should

equally apply to patent investment as the proximate cause of patent success. At the same time R&D expenditure represents a more tangible and (potentially) more precisely measured variable.

We test hypothesis H6 using the linear panel regression specification

$$ln[1 + R\&D\ Exp_{s,t}] = \kappa_0 + \kappa_1 SOL_{s,t-1} + \kappa_2 Controls_{s,t-1} + \epsilon_s + \mu_t + \eta_{s,t}, \quad (11)$$

where we include the same control variables as in the previous regressions with the exception of $ln(1 + R\&D\ Stock)$, which is excluded because it summarizes past R&D expenditure.[21]

Table 6 reports the regression results. The effect of shareholder overlap is statistically and economically significant in the specifications both without firm fixed effects (Column 1) and with firm fixed effects (Column 2). For example, an increase in shareholder overlap by one standard deviation (or 0.063) in Column 1 increases R&D expenditure by 11.1% of its standard deviation ($= 0.063 \times 3.376/1.912$). The hold-up attenuation effect of shareholder overlap on R&D investment is therefore economically important.

While the patent data enter the construction of the SOL measure and also our measures of (citation based) patent success, the same does not apply to R&D expenditure data sourced from Compustat. Therefore, measurement error is unlikely to present an omitted factor explaining the observed correlation. But the above investment regression suggests one further test to exclude other

[21] The model in the Web Appendix implies for the parameter $\kappa_1 = (1 + \gamma)(1 + 1/b)\delta > 0$.

omitted factors as explanations for the observed correlation. If the higher R&D expenditure for firms with shareholder overlap is driven indeed by the governance influence of the overlapping shareholders, then the ensuing agency conflict implies that non-overlapping shareholders in the downstream firm should have the exact opposite influence on R&D expenditure. For them patent rent internalization is simply an overinvestment that needs to be curtailed (hypothesis H7).

Columns 3 and 4 of Table 6 extend the specification in Eq. 11 to include the non-overlapping institutional ownership IO^{NOL}. Their ownership share is obtained by subtracting from the overall institutional ownership IO those institutions that own equity stakes in both downstream and upstream firms (i.e., the institutions that enter positively into the calculation of SOL). In accordance with hypothesis H7, the coefficient estimate for IO^{NOL} has the predicted negative sign and is statistically highly significant. The evidence is therefore consistent with hypothesis H7, whereby non-overlapping institutional shareholders constrain the hold-up internalization efforts of overlapping shareholders.

5.7 Reverse Causality?

Asset ownership structure might dynamically adjust to patent hold-up and evolve toward an efficient combination of complementary assets. Under private information about future patent hold-up, investors have an incentive to achieve this joint ownership through shareholder overlap—thus internalizing the hold-up problem. We might therefore expect the shareholder overlap between downstream and upstream firms owning complementary patents to increase prior to the public dis-

closure of patent filings. For each yearly cohort of patents filed between 1991 and 2007, we measure evolution of the average firm-level shareholder overlap relative to the year of the patent filing. For a cohort of downstream patents filed in year t, let $SOL(t,k)$ represent the average shareholder overlap measured based on ownership data at the end of year $t+k$, where $k=-5,-4,...,4,5$. For example, $SOL(t,-3)$ denotes the average shareholder overlap between downstream and upstream firms measured based on ownership in year $t-3$ for all patents filed in year t. The average aggregate ownership overlap (measured at lag/forward k) for all patent filing years follows

$$\overline{SOL}(k)=\begin{cases} \frac{1}{17-|k|}\sum_{t=1991+|k|}^{2007} SOL(t,k), & if \ \ -5\leq k\leq -1 \\ \frac{1}{17-|k|}\sum_{t=1991}^{2007-|k|} SOL(t,k), & if \ \ 0\leq k\leq 5 \end{cases}$$

and is plotted in Figure 3[22]. As a benchmark, we also plot the evolution of the (average) placebo shareholder overlap $\overline{SOL}\_Placebo(k)$, which is defined similar to $\overline{SOL}(k)$.

Around a patent filing year ($k=0$), the average aggregate shareholder overlap $\overline{SOL}(k)$ depicted in red evolves similar to the average aggregate shareholder overlap of the placebo benchmark $\overline{SOL}\_Placebo(k)$ depicted in blue. The vertical line marks two standard deviations around the mean value for each of the measures. Importantly, we find no evidence the shareholder overlap $\overline{SOL}(k)$ endogenously reacts in anticipation of patent rents of future patent filing. Instead its

[22]We note that the full set of $SOL(t,k)$ cannot be calculated for all years. For example, for patents filed in 1992, we can only calculate $SOL(t,k)$ for $k=-1,0,...,5$. Similarly, for patents filed in 2007, $SOL(t,k)$ can only be calculated for $k=-5,-4,...,0$.

evolution mimics that of the placebo shareholder overlap which is by construction devoid of future patent rents.

In conclusion, we find no evidence for an endogenous dynamic adjustment of shareholder overlap in the run-up to patent filings. This finding may not be surprising for at least two reasons: First, patent developments are generally kept secret so that public information should be extremely scarce. Second, legal restrictions on insider trading limit the scope for stock trading on private information.

5.8 Robustness Issues

We subject our analysis to a variety of robustness checks which are discussed in more details in the Web Appendix C.

First we examine two alternative hypotheses which could account for the evidence. Aghion, Van Reenen, and Zingales (2013) argue that R&D investments have a long-term horizon, and a high share of institutional investors allows management to focus on the long-term return on the investments. Following their specification, we measure the share of *institutional ownership* (IO) as the relevant proxy for investor patience. As institutional ownership share also correlates with our shareholder overlap measure, it could potentially account for the firm-level evidence, though not for the within-firm variation of patent success. While we are able to reproduce the results in Aghion, Van Reenen and Zingales (2013), we find no evidence that their results carry over to the extended data sample used in this paper. In particular, we highlight that institutional investors tend to have

the opposing interests with respect to the firm's investment policy depending on their ownership stakes in the upstream firm.

A second alternative explanation concerns the role of institutional investors with a technology focus on their investment portfolio. Even if technology funds tend to be smaller in size, their investment policy may generate more shareholder overlap in patent filing firms. At the same time such funds may provide governance input which is beneficial to patent success independently of any hold-up problem. We therefore create a measure of *shareholder innovation focus* which calculates the investment bias of each institutional investor towards patent filing firms and then aggregates this measure for all institutional investors of the downstream firm. However, controlling for the average innovation focus of a firm's shareholders does not reduce the economic or statistical significance of the SOL measure.

A variety of robustness tests concern the measurement of patent citations. Our baseline measure of $CITES$ follows Hall, Jaffe, and Trajtenberg (2001) in scaling the raw future citation count of each patent by a specific factor (see Table 5 of Hall, Jaffe, and Trajtenberg, 2001) that increases in the time span until the terminal year of our sample. We reproduce our results using the alternative proxy for patent success proposed by Lerner, Sorensen, and Stromberg (2011). These and other robustness checks are documented in the Web Appendix C of this paper.

6 Conclusion

This paper provides a property rights perspective on the success of corporate innovation. We argue that the success of patents often depends on access to complementary patents not under the direct control of an innovating firm. From a property rights perspective, the "extended boundary" of the innovating firm includes such complementary patents if both the downstream innovator and the upstream firms owning these complementary patents are linked by joint equity ownership.

Our identification strategy is based on patent documents that directly list related precursory 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 upstream firms controlling the complementary patents; an innovating firm with a large SOL value can be interpreted as having an extended firm boundary.

We document the role of *shareholder overlap* for patent success at both the firm level and the patent level; it correlates positively with both the intensive and extensive margins of patent production in an economically significant manner. This finding is robust to a variety of control variables and the inclusion of time and firm (or industry) fixed effects. Using interacted firm and time fixed effects, we show that two patents from the same yearly cohort filed by the same firm perform differently depending on their respective (patent-level) shareholder overlap. In addition, we instrument the latter with the average size of the upstream firms

(holding the precursory patents to the downstream patent) and find no qualitative effect on the estimated relationship. We also apply placebo tests to document that the citation link to the upstream patent is crucial for the hold-up attenuation effect of shareholder overlap and that it is not driven by reverse causality.

Two additional dimensions of ownership structure are also highlighted: First, shareholder overlap coming from more dedicated investors tends to contribute more to the hold-up attenuation—suggesting that the "extended boundary" of the innovating firm also depends on the type of institutional shareholders. Second, the ownership concentration of shareholder overlap matters independently of the overlap level. This could be explained by the existence of coordination and free-rider problems among a large group of overlapping shareholders.

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Table 1: Summary Statistics

Reported are the summary statistics for all regression variables. 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) $R\&D\ Exp_{s,t}$ 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 received by patent p successfully filed in year t. The explanatory variables $SOL_{s,t-1}$ and $sol_{p,t-1}$, refer to the shareholder overlap for firm s or patent p, respectively. We separate shareholder overlap into SOL contributed by dedicated investors ($SOL\_Dedicated$), intermediate investors ($SOL\_Intermediate$), and transient investors ($SOL\_Transient$). $IO^{NOL}_{s,t-1}$ is the institutional ownership share excluding institutions that enter into the calculation of SOL. $WHHI_{s,t-1}$ represents the weighted HHI of shareholder overlap concentration for firm s in year $t-1$. The control variables include the (log of) lagged market capitalization, $ln(1+MktCap)$; lagged cumulative R&D investment, $ln(1+R\&D\ Stock_{s,t-1})$; lagged capital to labor ratio, $ln(1+K/L_{s,t-1})$; lagged sales, $ln(1+Sales_{s,t-1})$; and the weighted share of cited upstream patents owned by private firms, *Private Patent Share*. 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)									
$ln(1+CITES)$	19,315	3.933	3.898	2.066	0.118	0.000	1.287	6.602	11.640
$ln(1+N)$	19,315	1.952	1.609	1.335	1.365	0.693	0.693	3.892	8.395
$ln(1+\overline{cites})$	19,315	2.386	2.457	1.145	−0.175	0.000	0.874	3.777	6.643
$ln(1+R\&D\ Exp)$	19,315	2.569	2.532	1.912	0.488	0.000	0.000	5.101	9.408
$ln(1+cites)$	582,032	1.900	1.962	1.357	0.121	0.000	0.000	3.662	7.129
Independent Variables (measured in year $t-1$)									
SOL	19,315	0.062	0.043	0.063	1.498	0.000	0.000	0.149	0.541
$SOL\_Dedicated$	19,315	0.002	0.000	0.004	9.433	0.000	0.000	0.004	0.174
$SOL\_Intermediate$	19,315	0.026	0.019	0.027	1.619	0.000	0.000	0.063	0.248
$SOL\_Transient$	19,315	0.031	0.020	0.034	1.710	0.000	0.000	0.078	0.289
$SOL\_Placebo1$	19,315	0.049	0.037	0.048	1.520	0.000	0.000	0.114	0.483
$SOL\_Placebo2$	19,315	0.047	0.035	0.046	1.616	0.000	0.000	0.110	0.546
sol	582,032	0.144	0.110	0.142	1.171	0.000	0.000	0.342	0.850
$WHHI$	19,315	0.057	0.035	0.072	3.268	0.000	0.000	0.134	1.000
IO^{NOL}	19,315	0.100	0.037	0.158	2.648	0.000	0.000	0.282	1.000
Controls (measured in year $t-1$)									
$ln(1+MktCap)$	19,315	19.888	19.732	2.085	0.317	13.644	17.330	22.725	27.124
$ln(1+R\&D\ Stock)$	19,315	3.751	3.886	2.224	0.058	0.000	0.000	6.547	10.714
$ln(1+K/L)$	19,315	4.416	4.328	0.904	0.611	0.000	3.395	5.535	10.296
$ln(1+Sales)$	19,315	5.425	5.420	2.479	−0.045	0.000	2.117	8.667	12.722
$Private\ Patent\ Share$	19,315	0.736	0.771	0.200	−0.895	0.000	0.467	1.000	1.000

Table 2: Baseline Regressions

Reported are the firm-level OLS regressions of patent success (measured as the (log) future citation count, $ln(1 + CITES_{s,t})$ 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. Shareholder overlap measures the average shareholder ownership overlap between the innovating firm and other firms owning the precursory complementary patents. Column 1–3 report full sample results whereas Column 4–6 report subsample results based on the top three R&D-intensive industries. Industry fixed effects are based on four-digit SIC codes. All regressions report robust standard errors clustered at firm and year levels in parentheses. The variable definitions are described in more detail in the Appendix.

Dependent Variables:	$ln(1 + CITES)$					
	Full Sample			Top 3 R&D-Intensive Industries		
	(1)	(2)	(3)	(4)	(5)	(6)
SOL	3.726	1.561	2.042	4.814	2.958	3.675
	(0.373)	(0.370)	(0.282)	(0.677)	(0.673)	(0.512)
Controls:						
$ln(1 + MktCap)$	0.300	0.141		0.353	0.147	
	(0.012)	(0.015)		(0.021)	(0.026)	
$ln(1 + R\&D\ Stock)$	0.318	0.146		0.276	0.223	
	(0.009)	(0.025)		(0.020)	(0.047)	
$ln(1 + K/L)$	0.035	−0.069		0.113	−0.027	
	(0.019)	(0.030)		(0.033)	(0.052)	
$ln(1 + Sales)$	−0.008	0.003		0.017	0.005	
	(0.010)	(0.021)		(0.017)	(0.032)	
Private Patent Share	0.411	0.112		0.583	0.159	
	(0.093)	(0.093)		(0.157)	(0.157)	
Year FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	NO	NO	YES	NO	NO
Firm FE	NO	YES	YES	NO	YES	YES
Obs.	19,315	19,315	19,315	6,089	6,089	6,089
Adj. R^2	0.524	0.725	0.721	0.563	0.744	0.739

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. Industry fixed effects are based on four-digit SIC codes. All regressions report robust standard errors clustered at firm and year levels in parentheses. The variable definitions are described in detail in the Appendix.

Dependent Variables:	$ln(1+\overline{cites})$		$ln(1+N)$	
	(1)	(2)	(3)	(4)
SOL	0.612	0.233	2.926	1.178
	(0.207)	(0.236)	(0.237)	(0.201)
Controls:				
$ln(1+MktCap)$	0.084	−0.004	0.180	0.126
	(0.007)	(0.010)	(0.007)	(0.007)
$ln(1+R\&D\ Stock)$	0.026	−0.014	0.260	0.151
	(0.005)	(0.015)	(0.005)	(0.014)
$ln(1+K/L)$	−0.031	−0.090	0.058	0.021
	(0.012)	(0.021)	(0.010)	(0.015)
$ln(1+Sales)$	−0.066	−0.057	0.059	0.052
	(0.007)	(0.014)	(0.005)	(0.011)
Private Patent Share	0.069	0.039	0.345	0.056
	(0.060)	(0.065)	(0.051)	(0.044)
Year FE	YES	YES	YES	YES
Industry FE	YES	NO	YES	NO
Firm FE	NO	YES	NO	YES
Obs	19,315	19,315	19,315	19,315
Adj. R^2	0.424	0.592	0.613	0.834

Table 4: The Structure of Shareholder Overlap and Placebo Measures

The baseline regression in Table 2 is repeated for a split of *shareholder overlap* ($SOL_{s,t-1}$) based on the concentration and turnover of institutional investors' fund holding. The investors are evenly separated into dedicated investors, intermediate investors, and transient investors. The regression in Column 3 expands the baseline regression by including the Weighted Herfindahl-Hirschman index of shareholder overlap, $WHHI_{s,t-1}$. Column 4-5 report results on two placebo tests where we replace SOL in our baseline regression with one of our two placebo measures, $SOL\_Placebo1$ and $SOL\_Placebo2$. Industry fixed effects are based on four-digit SIC codes. All regressions report robust standard errors clustered at firm and year levels in parentheses. The last row of the table reports p-values for the null hypothesis that the estimated regression coefficients are the same for $SOL\_Dedicated$, $SOL\_Intermediate$, and $SOL\_Transient$. The variable definitions are described in more detail in the Appendix.

Dependent Var.:	$ln(1+CITES)$				
	(1)	(2)	(3)	(4)	(5)
SOL	3.726		4.699		
	(0.373)		(0.392)		
$SOL\_Dedicated$		22.448			
		(5.337)			
$SOL\_Intermediate$		2.259			
		(0.822)			
$SOL\_Transient$		4.265			
		(0.697)			
$WHHI$			2.364		
			(0.225)		
$SOL\_Placebo1$				−0.377	
				(0.428)	
$SOL\_Placebo2$					0.625
					(0.451)
Controls:					
$ln(1+MktCap)$	0.300	0.292	0.319	0.342	0.335
	(0.012)	(0.012)	(0.012)	(0.011)	(0.011)
$ln(1+R\&D\ Stock)$	0.318	0.316	0.319	0.327	0.327
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
$ln(1+K/L)$	0.035	0.036	0.041	0.042	0.040
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
$ln(1+Sales)$	−0.008	−0.008	−0.006	0.003	0.001
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Private Patent Share	0.411	0.378	1.093	−0.305	−0.158
	(0.093)	(0.094)	(0.118)	(0.097)	(0.097)
Year FE	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES
Firm FE	NO	NO	NO	NO	NO
Obs	19,315	19,315	19,315	19,315	19,315
Adj. R^2	0.524	0.524	0.527	0.521	0.521
$p-value$		0.001			

Table 5: Patent-Level Regressions

This table presents the correlation between patent success measured at the patent level and the lagged patent-level *shareholder overlap*, $sol_{s,t-1}$, for the sample period $1992-2007$. Patent success is proxied by $ln(1+cites_{p,t})$ as the (log) future citation count received by patent p filed in year t. The patent-level shareholder overlap measures the average shareholder ownership overlap between patent p's owner and the patent-specific cited upstream firms owning the complementary patents. Technology field fixed effects are based on 37 technological categories classified by Hall, Jaffe, and Trajtenberg (2001). All regressions report robust standard errors clustered at firm and year levels in parentheses. The variable definitions are described in more detail in the Appendix.

	OLS		2SLS	
			1^{st} Stage	2^{nd} Stage
	(1)	(2)	(3)	(4)
sol	0.192	0.270		0.281
	(0.019)	(0.019)		(0.014)
$ln(1+MktCap^{up})$			0.017	
			[0.000]	
Tech. FE	YES	YES	YES	YES
Firm FE	YES	NO	NO	NO
Year FE	YES	NO	NO	NO
Year × Firm FE	NO	YES	YES	YES
Obs	582,032	582,032	582,032	582,032
Adj. R^2	0.312	0.334	0.828	

Table 6: R&D Expenditure and Shareholder Overlap

Reported are OLS regressions of R&D expenditure on the lagged *shareholder overlap,* $SOL_{s,t-1}$, for the sample period $1992-2007$. Shareholder overlap measures the average shareholder ownership overlap between the innovating firm and other firms owning the complementary patents. We also include the non-overlapping institutional ownership share, IO^{NOL}, in regression specifications. Industry fixed effects are based on four-digit SIC codes. All regressions report robust standard errors clustered at firm and year levels in parentheses. The variable definitions are described in more detail in the Appendix

Dependent Variable:	$ln(1+R\&D\ Exp)$			
	(1)	(2)	(3)	(4)
SOL	3.376	1.362	2.536	1.140
	(0.309)	(0.257)	(0.309)	(0.264)
IO^{NOL}			−1.036	−0.285
			(0.063)	(0.054)
Controls:				
$ln(1+MktCap)$	0.434	0.236	0.439	0.240
	(0.009)	(0.010)	(0.009)	(0.010)
$ln(1+K/L)$	0.155	−0.007	0.153	−0.006
	(0.015)	(0.019)	(0.015)	(0.019)
$ln(1+Sales)$	0.156	0.213	0.159	0.214
	(0.008)	(0.014)	(0.008)	(0.014)
Private Patent Share	0.127	0.174	0.226	0.205
	(0.067)	(0.055)	(0.066)	(0.055)
Year FE	YES	YES	YES	YES
Industry FE	YES	NO	YES	NO
Firm FE	NO	YES	NO	YES
Obs	19,315	19,315	19,315	19,315
Adj. R^2	0.656	0.863	0.662	0.863

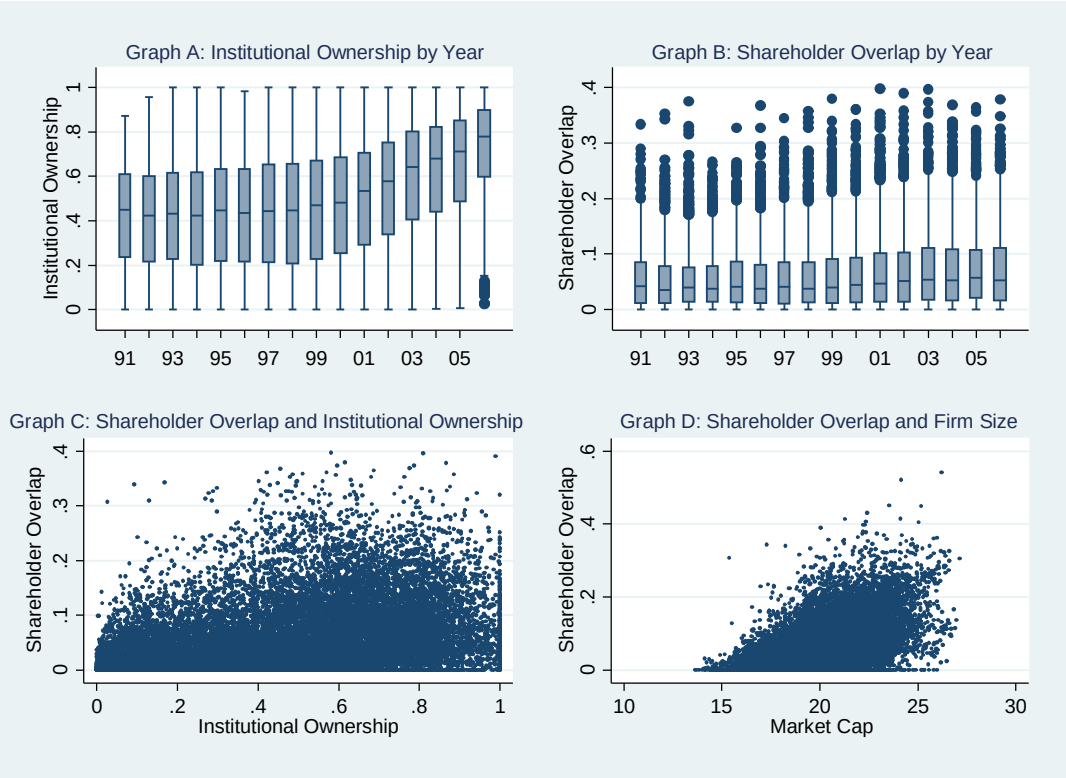

Figure 1: We present four graphs in this figure. Graph A and B depict the evolution of institutional ownership and shareholder overlap over the sample period from 1991 through 2006, respectively. The scatter plots in Graph C and D show the correlation between shareholder overlap and institutional ownership and correlation between shareholder overlap and firm size, respectively.

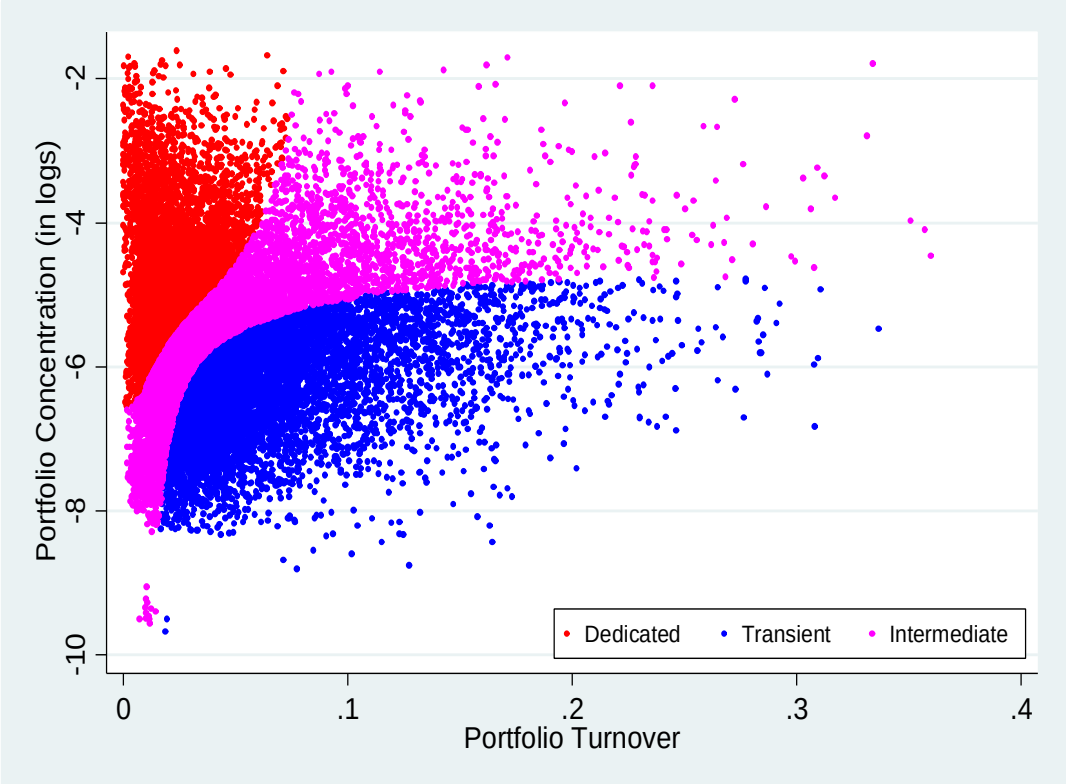

Figure 2: We evenly group funds into (i) dedicated investors, (ii) transient investors, and (iii) intermediate investors based on a ranking of their asset concentration (Herfindahl-Hirschman Index of equity shares) and a ranking of their investment horizon (inverse of the portfolio turnover). The top tercile of the combined rank in both dimensions are labeled as dedicated investors, the middle tercile as intermediate investors, and the bottom tercile as transient investors.

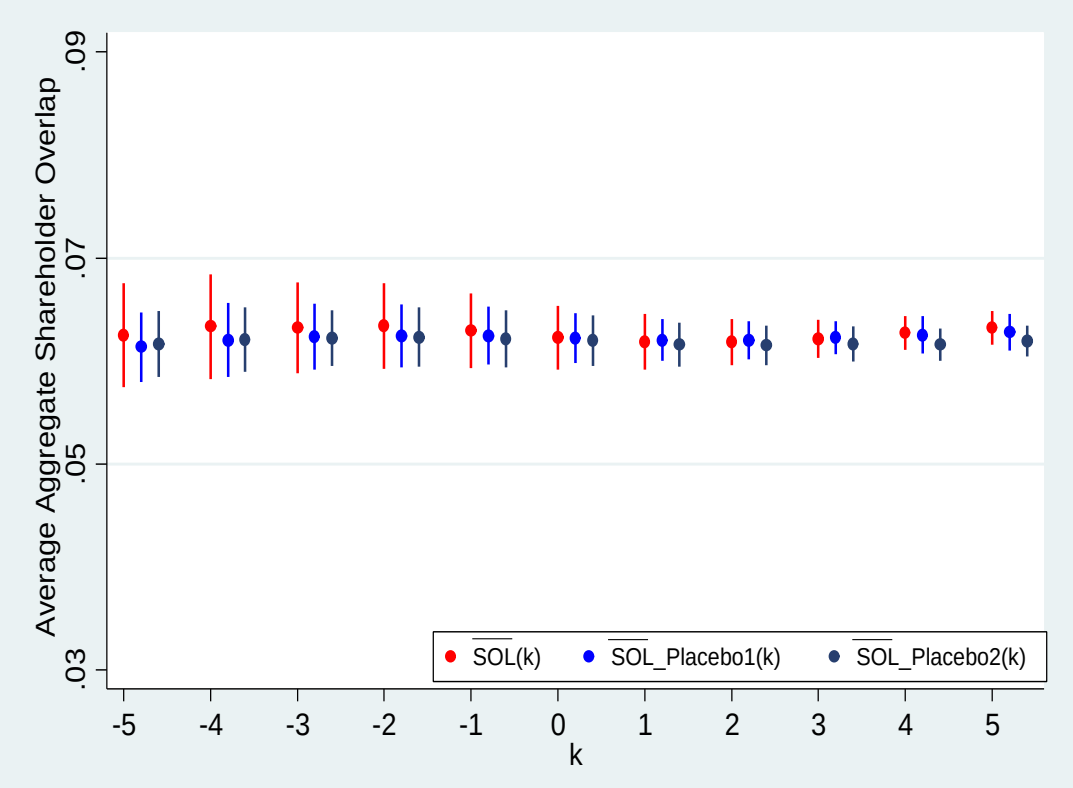

Figure 3: The evolution of the average aggregate (placebo) shareholder ownership overlap is plotted for a lag/forward of k years relative to the patent filing year ($k = 0$). The vertical lines describe a confidence interval of two standard deviations above and below the mean estimate.