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Private Equity and Long-Run Investment:

The Case of Innovation

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Abstract: A long-standing controversy is whether LBOs relieve managers from short-term pressures from public shareholders, or whether LBO funds themselves are driven by short-term profit motives and sacrifice long-term growth to boost short-term performance. We investigate 495 transactions with a focus on one form of long-term activities, namely investments in innovation as measured by patenting activity. We find no evidence that LBOs are associated with a decrease these activities. Relying on standard measures of patent quality, we find that patents granted to firms involved in private equity transactions are more cited (a proxy for economic importance), show no significant shifts in the fundamental nature of the research, and are more concentrated in the most important and prominent areas of companies' innovative portfolios.

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1. Introduction

In his influential 1989 paper, "The Eclipse of the Public Corporation," Michael Jensen predicted that the leveraged buyout would emerge as the dominant corporate organizational form. With its emphasis on corporate governance, concentrated ownership and monitoring by active owners, strong managerial incentives, and efficient capital structure, he argued that the buyout is superior to the public corporation with its dispersed shareholders and weak governance. These features enable managers to proceed without catering to the market's demands for steadily growing quarterly profits, which Stein [1988] and others argue can lead firms to myopically sacrifice long-run investments.

These claims excited much debate in the subsequent years. Critics questioned the extent to which private equity creates value, suggesting that funds' profits are instead driven by favorable tax treatment of corporate debt, inducing senior executives of publicly traded firms to accept deals that go against the interests of the shareholders, or abrogating explicit and implicit contracts with workers (e.g., Shleifer and Summers [1988]). They also queried whether private equity-backed firms actually take a longer-run perspective than their public peers, pointing to practices such as special dividends and "quick flips"—that is, initial public offerings (IPOs) of firms soon after a private equity investment, which enable private equity groups to extract fees and raise new funds more quickly. Given their incentives to undertake and exit deals, private equity funds may well promote policies that boost short-run performance at the expense of more sustained long-term growth.

Ultimately, the nature of the changes in corporate policies associated with private equity transactions is an empirical question. In this paper, we present evidence about one form of long-run investment, namely changes in innovative investments around the time of private equity transactions. This presents an attractive arena to examine these issues for a number of reasons. R&D expenditures have typical features of long-run investments. Their costs are expensed immediately, yet the benefits are unlikely to be observed for several years: several studies of managerial "myopia" (e.g., Meulbroek, et al. [1990]) have examined R&D expenditures for this reason. Second, an extensive body of work about the economics of technological change documents that patenting activity and the characteristics of patents reflect the quality and extent of firms' innovations, allowing us to measure firms' innovative output rather than merely R&D expenditures. Since not all research expenditures are well spent, and some critics of major corporations (e.g., Jensen [1993]) suggest that many corporate research activities are wasteful and yield a low return, changes in R&D expenditures are more difficult to interpret. While the literature acknowledges that patents are not a perfect measures of innovation—for example, many inventions are protected as trade secrets—the use of patents as a measure of innovative activity is widely accepted. Moreover, unlike many other measures of corporate activity, patents are observable for both public and privately-held firms, which is important when studying private equity transactions.

We examine the changes in patenting behavior of 495 firms with at least one successful patent application filed in the period from three years before to five years after being part of a private equity transaction.[1] Our main finding is that firms pursue more influential innovations, as measured by patent citations, in the years following private equity investments. Firms display no deterioration in their research, as measured either by patent "originality" and "generality," and the level of patenting does not appear to change after these transactions. We find some evidence that the patent portfolios become more focused in the years after private equity investments. The increase in patent quality is greatest in the patent classes where the firm has been focused historically and in the classes where the firm increases its patenting activity after the transaction. The patterns are robust to a variety of specifications and controls. Collectively, these findings are largely inconsistent with the hypothesis that private equity-backed firms sacrifice long-run investments. Rather, private equity investments appear to be associated with a beneficial refocusing of firms' innovative portfolios.[2]

One limitation is that we cannot formally distinguish whether private equity investors cause these changes or selectively invest in firms that are ripe for an increase in innovative activity. We do not have an instrumental variable to help us resolve the causation question. However, our findings related to the timing of the changes and the

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[1] Throughout this paper, when we refer to private equity transactions or investments, we are referring to equity investments by professionally managed partnerships that are leveraged buyouts or other equity investments with a substantial amount of associated indebtedness.

[2] One anecdote consistent with this finding is from a practitioner who described to us a major corporation where scientists and engineers received badges identifying the number of patent filings they had made. Having a platinum or gold badge—awarded only to the most prolific inventors—was very prestigious. One can imagine the effect of this incentive scheme on the filing of infra-marginal patents.

predominantly "old economy" nature of the firms in our sample suggest that selection plays a relatively minor role in our results. Nonetheless, this alternative interpretation should be kept in mind below.

There are two main related literatures. A number of studies consider the impact of leverage, which is a prominent feature of private equity investments, on innovation. These studies typically examine publicly traded firms with differing debt levels and reach somewhat ambiguous conclusions. There is a clear association between greater leverage and lower levels of R&D spending, as documented by Hall's [1992] examination of over 1,200 manufacturing firms and Himmelberg and Petersen's [1994] more targeted study of 170 small high-technology firms. However, the direction of causality is unclear. It is difficult to determine whether debt leads to R&D reductions or if struggling firms simply have more debt and less spending on innovation. Hao and Jaffe [1993], who carefully grapple with this question, conclude that more debt reduces R&D spending only for the very smallest firms. For larger firms, the causal relationship is ambiguous.

A second set of papers examines the impact of leveraged buyouts on innovative activity generally. Focusing on buyouts of manufacturing firms during the 1980s, Hall [1990] looks at 76 public-to-private transactions, i.e., transactions where a publicly traded firm is purchased and taken private. She finds that the impact of these transactions on cumulative innovation is likely slight. While these firms represent four percent of manufacturing employment in 1982, they only account for one percent of the R&D spending. Lichtenberg and Siegel [1990] examine 43 LBOs during the 1980s where the firms participate in the Bureau of the Census's survey about research activities prior to and after the transaction. They find that these firms increase research spending after the LBO, both on an absolute basis and relative to their peers.

There are a several reasons to revisit the questions in the earlier studies. The private equity industry is more substantial today than it was in the 1980s. This growth not only means that we have a larger sample, but changes in the industry–such as the increased competition between and greater operational orientation of private equity groups–suggest that the earlier relationships may no longer hold. In particular, transactions involving technology-intensive industries have become more common recently. It is also desirable to look beyond public-to-private transactions, since these transactions represent a fairly small fraction of the private equity universe.[3] Finally, the computerization of patent records in the past two decades has substantially enhanced our ability to measure and study the impact on innovation.

The plan of the paper is as follows. In Section 2, we describe the construction of the data-set. Section 3 reviews the methodology employed in the study. We present the empirical analyses in Section 4. The final section concludes the paper and discusses future work.

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[3] Strömberg (2008) shows that public-to-private transactions account for roughly 6% of all PE-sponsored LBO activity in terms of numbers, and roughly 27% in terms of total enterprise value of firms acquired. Moreover, R&D intensive industries such as Information Technology, Telecom, Medical equipment, and Biotech account for roughly 14% of all LBO activity in 2000-2007 (both on an equal- and value-weighted basis), compared to around 7% in the pre-1990 period.

2. The Sample

To construct the dataset, we identify a comprehensive list of private equity transactions and match the involved firms to U.S. patent records. This section describes this process.

A. Identifying Private Equity Transactions

To identify private equity investments, we start from the Capital IQ database. Since 1999, Capital IQ has been specialized in tracking private equity deals on a world-wide basis. Through extensive research, it attempts to "back fill" information about investments prior to this period.[4]

Our starting point is the universe of transactions in Capital IQ that close between January 1980 and December 2005. We eliminate two types of transactions. First, Capital IQ contains some transactions by private equity groups that did not entail the use of leverage. Capital IQ captures a considerable number of venture capital investments by traditional venture funds, and many buyout groups made some venture capital investments in the late 1990s. Hence, we eliminate transactions that are not classified in the relevant categories (which involve the phrases "going private," "leveraged buyout," "management buyout," "platform," or slight variants of these). Second, the data contain a number of transactions that do not involve a financial sponsor (i.e., a private equity firm),

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[4] Most data services tracking private equity investments were not established until the late 1990s. The most geographically comprehensive exception, SDC VentureXpert, was primarily focused on capturing venture capital investments until the mid-1990s.

and we eliminate these deals as well. While transactions in which a management team takes a firm private using their own resources and/or bank debt are interesting, they are not the focus of this study. We also remove investments by private equity groups in companies that remain traded in public markets after the transaction (so called PIPES). After these eliminations, the data contain approximately eleven thousand transactions.

We supplement the Capital IQ data with data from Dealogic, another data vendor. The Dealogic data often contain more comprehensive information about the characteristics of the transactions, such as the multiple of earnings paid and the capital structure employed. It also frequently records information about alternative names of the firms, add-on acquisitions, and exits, which are useful for matching the data to patent records. Finally, we use a variety of databases, including Capital IQ, SDC VentureXpert, and compilations of news stories, to identify the characteristics of the transactions and the nature of the exits.

B. Capturing Patent Data

We restrict our sample to firms with at least one successful patent application from three years before the transaction to five year afterwards, and we match the firms involved in buyout transactions to their patenting records based on their name and location. To do this, we employ the Harvard Business School (HBS) patent database. The HBS data contain all electronic records of the U.S. Patent and Trademark Office (USPTO) through May 2007, but these records have been researched and consolidated, which is important, since the names of assignees in the original USPTO database are riddled with misspellings and inconsistencies. We search the HBS database for each of the firms, using both the original name and any alternative names from Dealogic. The firms' location is contained in Capital IQ, and the patent data contain the location of both the inventor(s) and the entity to which the patent is assigned at the time of issue, which is typically the inventor's employer. There are ambiguous situations where the names are similar, but not exactly identical, or where the location of the patentee differs from the records of Capital IQ. In these cases, we research the potential matches, using historical editions of the Directory of Corporate Affiliations, Hoover's Directory, the Factiva database of news stories, and web searches. An observation is only included when we are confident of a match. In total, we identify 496 entities with at least one patent grant in the period from the calendar year starting three years before to the calendar year starting five years after the year of the private equity transaction.[5]

The seemingly small number of patentees likely reflects two issues. First, in many instances the firms are "old economy" firms in which intellectual property is less central and which have a greater reliance on trade secrets or branding to protect intellectual property. Second, the acceleration of private equity activity means that many transactions are undertaken in 2004 and 2005. In cases of divisional buyouts, where new firms are created, this leaves only a short time for observing any patenting activity. Even if these new entities filed for patents, they are unlikely to be issued by May 2007, and we only see patent applications that have been successful granted by the USPTO (not pending

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[5] We follow the literature in focusing only on utility patents, rather than other awards, such as design or reissue awards. Utility patents represent about 99% of all awards (Jaffe and Trajtenberg [2002]).

applications). An additional concern arises since more than one-quarter (2,440) of the 8.938 patents we identify are assigned to Seagate Technologies. In contrast, the second largest patentee accounts for less than 5% of the sample. Since Seagate would dominate our sample, we do not include it in the analyses. Thus, our final sample consists of 6,938 patents from 495 firms.

In Table 1, Panel A, we summarize the annual private equity investments and exits. The transactions are concentrated in the second half of the 1990s and the first half of the 2000s. This reflects both the increasing volume of transactions during these years and the growing representation of technology firms, which have more patents. The absence of transactions during 2006 and 2007 reflects the construction of the sample, which only includes buyout transactions completed by December 2005. Exits, not surprisingly, lag the transactions by several years.

Panel B shows the distribution across types of transactions. Buyouts of corporate divisions are most common, followed by private-to-private deals (investments in independent unquoted entities), secondary deals (firms that were already owned by another a private equity investor), and public-to-private deals. These patterns mirror private equity investments more generally, as does the preponderance of exits by trade sales (i.e., acquisitions by non-financial buyers), revealed in Panel C (see also Strömberg [2008]).

Panel D presents the industry composition of firms and patents. Patents are assigned to the primary industry of the parent, as reported by Capital IQ. In later analyses, we use the patent-specific information from its classification by the USPTO.

Notably, no single industry dominates and the sample contains a mixture of “old economy” (e.g., auto parts and building products) and “new economy” (for instance, application software and healthcare equipment) sectors.

Panel E displays the timing of the patent applications and awards. Each patent is associated with two dates: the application date and the grant date. The application dates extend from 1983 (three years before the first private equity investment) to 2006. No applications from 2007 appear because we only examine successful applications that have already been granted by the USPTO. Moreover, the number of awards falls sharply in 2007, because we only identify grants through May 2007. The growth in private equity investments and patent grants is also captured in Figure 1.

Panel F shows the distribution of the lag between the patent applications and the private equity transactions, and it illustrates one of the challenges faced by our methodology. The patents we observe are disproportionately applied for in the years before and immediately after the buyout. This reflects the “back-end loaded” nature of the sample and the lags associated with the patent granting process. Obviously, we cannot see successful patents filed five years after a buyout undertaken in 2005, and we do not yet observe most of the patents filed five years after a buyout in 2000, since patents, on average, take more than 30 months to issue, with a substantial minority taking considerably longer.[6]

We capture a variety of information about the patent awards. Over the past two decades, several quantitative measures of patent quality have become widely adopted (Jaffe and Trajtenberg [2002]; Lanjouw, Pakes and Putnam [1998]). These measures rely on the citations either to or by the patent to characterize the nature of the grant (also called forward and backward citations). Citations are extremely important in patent filings, since they serve as "property markers" delineating the scope of the granted claims.

Patents that are more cited are typically interpreted as having more impact or as being more important than other awards. However, the distribution of citations is also important. Patents that cite other patents in a broader array of technology classes are often viewed as having more "originality." Patents that are themselves cited by a more technologically dispersed array of patents are viewed as having greater "generality." Both

[6] Statistics available at http://www.uspto.gov/web/offices/com/annual/2006/50304_table4.html (accessed October 21, 2007). It is natural to ask why we only examine successful patent applications, rather than all patent filings. Unfortunately, the USPTO did not publish information on applications for patents filed prior to November 2000, and even these data are imperfect: not all applications in the U.S. are published and information on unsuccessful applications is often removed from the database of applications.

“originality” and “generality” have been interpreted as measures of the fundamental importance of the research being patented.[7]

In addition to the truncation problem delineated above, we also face challenges around divisional buyouts and cases where the target firm was ultimately acquired by another corporation. In these instances, the firm’s patents may not be assigned to the target but rather to the corporate parent. For instance, consider a divisional buyout. Many of the patents applied for three years before the buyout are likely to be issued before the private equity investment. In most instances, these will be assigned to the corporate parent, and even some patents applied for by employees of the bought-out division that are issued after the buyout may nonetheless be assigned to the corporate parent rather than to the target corporation.

While we are unable to comprehensively solve this problem, we can partially address this issue. In unreported analyses, we repeat the analyses, capturing some, though not all, of the additional patents associated with bought-out firms that are units of larger concerns during part of the period during the period from three years before to five years after the investment. We identify all patents assigned to the corporate parent prior to the private equity investment or assigned to the target’s acquirer after the private equity

[7] Each patent is assigned to a primary (three-digit) patent class as well as a subclass using the USPTO’s classification scheme. These classifications are important to the USPTO as they are used to search subsequent awards. We follow the literature in computing these measures as one minus the Herfindahl index of the primary patent class of the cited or citing patents. Thus, a higher measure of originality or generality means that the patent is drawing on or being drawn upon by a more diverse array of awards.

investment that have the same assignee as one of the patents assigned to the target. We believe that this criterion is conservative. It will lead us to some, though not all, of the missing patents associated with the target, but identify few "false positives," or patents assigned to the parent that are not associated with the target. When we include these supplemental patents in the analysis, the statistical and economic significance of the results do not change materially.

3. Methodology

We focus on the *quality, size,* and *structure* of the company's patent portfolios. These features are characterized in four ways. First, following the literature, we use the citation count as a measure of the quality, or economic importance, of the patent. The citation count is the number of times the patent has been cited by other patents in the three-year period subsequent to the grant date of the patent. In particular, we examine whether citation counts change for patents granted before and after the transaction. Second, we examine whether the nature of the patents change after the transactions, measured by the patents' "originality" and "generality," which are computed using the dispersion of the patents that cite or are cited by the awarded patent. Moreover, we examine variations in the propensity of firms to file for patent protection before and after private equity investments. Finally, we explore whether firms alter their patent filing practices after the transactions. In particular, we examine whether the changes in patent quality can be explained by firms increasingly patenting in certain areas.

These patterns provide some indications of the impact of private equity transactions on long-run investments. If indeed we observe a higher quality of patent filings, and a more targeted allocation of innovative activity, the pattern would be consistent with the arguments postulated by Jensen [1989, 1993] about the salutatory effects of private equity transactions. If we find a decrease in these measures of innovative activity, the results would be consistent with the more skeptical views of these transactions.

4. Analysis

A. Measuring Patent Importance

We begin by examining the quality of the patents in the sample. As noted above, the most widely used measure in the literature is patent citations. Implementing this measure requires deciding the number of years over which the citations are counted after the patent is granted. There is a considerable amount of serial correlation in patent citations, and patents that are highly cited in their first few years tend to be cited heavily throughout. Moreover, since our sample is back-end loaded, we prefer a shorter window to reduce the truncation of the sample at the end. Consequently, we use a three-year period of citations to construct our citation counts variable, but the serial correlation means that little information is lost by ignoring later citations.[8] We examine the sensitivity of the results to this choice in Section 4C below.

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[8] In the USPTO data, patents are typically not cited prior to issuance. This reflects the fact that many awards are not published prior to issuance and that the USPTO does not update its records of citations to published patent applications to include the number of the ultimately granted patents. Thus, the grant date is the beginning of the period when a patent can garner citations.

Table 2 presents the first comparison of patents filed for before and after the transactions. The two panels treat patents filed in the calendar year of the private equity investment differently. Focusing on Panel A, we observe that, on average, patents issued before the transactions are cited 1.99 times in the first three years after they are granted. In contrast, patents issued after the transactions are cited 2.49 times over the three years after the grant date, corresponding to a 25% increase in the number of citations.

These comparisons are instructive but coarse, since they are based on the raw citation counts. Figures 2 and 3 plot the number of citations in the three years after the patent grants for each of the patents in the sample as well as the average number of citations for matching patents. These matching patents are defined as follows. For each patent in the sample, we determine all U.S. patents granted in the same year and assigned to the same USPTO technology class.[9] We observe a clear increase in the average number of citations for the patents granted to the private equity-backed firms. In part, this may reflect the increasing importance of patents in later years, but it may also reflect two other changes. As the pace of patenting world-wide accelerates, the frequency of patent citations increases. Furthermore, as private equity investments in high-technology industries become more common, the representation of patents in technologically dynamic industries increases. Figure 3 captures these trends, and this figure shows a clear increase in the average number of citations, as well as the dispersion of citations, for the

[9] Patents are assigned during the application process to one of approximately one thousand technology classes, as well as a more detailed subclass. These classifications are important, since they are the primary way in which the USPTO identifies other relevant patents during the examination process.

matching patents. Hence, it is important to control for the timing of the patent grant and its technology class.

To address this concern, Table 2 reports the relative citation counts. These are calculated as the number of citations in the calendar year of the grant and the three calendar years thereafter (citation count) less the average number of citations during this period to matching patents, which have the same grant year and primary USPTO class. When comparing the relative citation counts, both the absolute and percentage increases in the counts are as great as or greater than the increases for the raw, unadjusted citation counts. For the measures of "originality" and "generality" the economical and statistical magnitudes are smaller when comparing the relative measures to the raw ones.

To provide a more nuanced view of the changes in the patent citations, we turn to a multivariate analysis. A natural starting point is the Poisson count model. The defining property of this model is that, for each patent *i*, the individual citation events are independently distributed over the three years following the grant of the patent with intensity λ_i. This implies that the three-year citation count is distributed according to the Poisson distribution

$$\Pr\left(Y_i = y\right) = \frac{\exp(-\lambda_i)\lambda_i^{\,y}}{y!} \tag{1}$$

and the patent receives on average λ_i citations over the three years following the grant date. To compare the citation intensities before and after the transactions, we estimate the standard Poisson specification

$$\ln\left(\lambda_i\right) = X_i'\beta \tag{2}$$

Here X_i contains observed characteristics, including variables capturing whether the application date is before of after the date of the transaction. Estimates are reported in Table 3, but before discussing these estimates, a limitation of this model should be noted. In the Poisson model, the citation intensity is a deterministic function of the observed characteristics. However, there may be unobserved factors that affect the citation intensity, and such factors would cause overdispersion of the citation counts relative to the Poisson model (see Cameron and Trivedi [1998] and Hausman, Hall and Griliches [1984]).[10] In our sample, when testing for overdispersion, the basic Poisson model is consistently rejected. The Negative Binomial model is a generalization of the Poisson model that addresses this problem. It includes an additional error term to capture unobserved factors, and the distribution of the three-year citation count is a mixture of the Poisson distribution and the distribution of this error term. Using this model, we estimate the specification

$$\ln\left(\lambda_i\right) = X_i'\beta + \varepsilon_i \tag{3}$$

where ε_i is an *i.i.d*. random variable with mean zero.

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[10] Another potential source of overdispersion is a disproportionate number of patents with zero citations (see Cameron and Trivedi [1998]). We repeat the analysis using *zero-inflated* Poisson and Negative Binomial models and find results that are consistently slightly stronger than the reported results.

To control for changes in citation behavior and the industry composition of companies in our sample, we control for the baseline citation intensities, using the matching patents described above. This is implemented as follows. For each patent, we calculate the average citation intensity of the matching patents as

$$\gamma_i = \frac{Total\,Citations}{Number\,of\;\,Matching\;Patents} \tag{4}$$

where *Total Citations* is the number of citations received by all matching USPTO patents during the three years following their grant dates. For patent *i*, γ_i gives the baseline citation intensity. By including this baseline in the estimation, the estimates control for technology and year specific variations in the citation patterns. Hence, we estimate the Poisson and Negative Binomial specifications

$$\ln\left(\lambda_i\right) = X_i'\beta + \ln\left(\gamma_i\right) \tag{5}$$

and

$$\ln\left(\lambda_i\right) = X_i'\beta + \ln\left(\gamma_i\right) + \varepsilon_i \tag{6}$$

To interpret the parameters in these specifications, note that when $X_i'\beta = 0$, the citation intensity equals the baseline intensity for the matching group of patents. When $X_i'\beta$ is greater (or smaller) than zero, the citation intensity is proportionally greater (or smaller) than the intensity for the matched group. Finally, note that the reported coefficients are incidence rates, reflecting the proportional effect of an increase in the underlying characteristic. An incidence rate greater than one corresponds to a positive coefficient and a positive effect of the characteristic on the intensity. For binary variables, the reported incidence rate is the proportional increase in citation intensity following an increase in the variable from zero to one.

The results are reported in Table 3. In the first four regressions, the independent variables are indicators for the individual years of the patent application relative to the year of the private equity transaction. In each case, applications in the second through fifth year after the transaction are cited significantly more frequently. To illustrate, in the first regression, the coefficient of 1.824 for a patent applied for three years after the private equity transaction implies that these patents garner 82% more citations than those applied for in the year of the transaction. Except for the first specification, the coefficients in the first three rows are not significantly different from zero. The coefficient may suggest a decline in citation intensity from years -3 or -2 to the year of the transaction (year 0 is the base year, with a coefficient normalized to one), but this decline is an order of magnitude smaller than the subsequent increase and less significant. For the relative citation intensities, this initial decline largely disappears, meaning that patents filed for before the transaction are cited about as frequently as the patents in the matching group. However, except for the year immediately after the transaction, the coefficients for subsequent years are greater than one and consistently significant, showing that patents filed after the private equity investment are cited significantly more frequently than the patents in the matched group. This pattern is found both for absolute and relative citation intensities, although it is slightly more pronounced for the relative intensities that control for the timing and industry composition of the patents.

In the fifth and sixth columns of Table 3, we use a more parsimonious specification, in which a dummy variable equals one if the patent was applied for in the first through fifth year after the private equity investment. Again, this coefficient is greater than one and statistically highly significant, confirming our finding that citation count increase following private equity transactions.

One concern is that buyout funds "cherry pick" companies and focus their investments in companies with stronger innovation potential. In this case, our findings may reflect this "selection" rather than the investors' effect on the companies. While we do not have an instrumental variable that would allow us to definitively resolve this issue, we believe that this is a small concern for two reasons. As mentioned above, the majority of the companies in our sample are "old economy" companies where innovation and intellectual property are less central to their businesses. The innovation potential of these companies is unlikely to be an important factor for the private equity funds when they make the investment decision. Moreover, as observed in Table 3, the majority of the increase in the citation rate comes in the second year after the transaction. Hall, Griliches, and Hausman [1986] study the lag between R&D activities and patent applications and find that they move virtually simultaneously, suggesting that most of the change in the patent quality does not take place until sometimes after the transaction.

The key results are robust to the use of fixed- and random-effects specifications. In particular, we find that in the four Poisson specifications (with random and fixed effects, and the controls for individual years and the more parsimonious specification with the post-investment dummy), the years after the private equity investment are associated with consistently more significant patents. The magnitudes of the coefficients do not change appreciably from those in Table 3. The results are weaker but quantitatively similar when we employ the Negative Binomial specification with fixed and random effects in columns five and six, due to the additional flexibility of this model.

B. The Fundamental Nature of the Patents

One possibility is that the patents awarded to the firms are more economically important, but the firms are sacrificing more basic or fundamental research that will not yield commercial benefits for some time going forward.

We thus turn to examining the fundamental nature of the patents awarded to these firms, using the measures of patent originality and generality described above. In Table 2, we see that when we examine these measures, patents applied for after the private equity investments are somewhat more general but less original than those applied for beforehand. Once we adjust for the average generality and originality of awards in the same patent class and with the same grant year, these differences essentially disappear.

A similar conclusion emerges from the regression analyses in Table 5. When we run regressions akin to those in earlier tables (now employing an ordinary least squares specification), we find initially that the awards applied for after the private equity investments are somewhat more general and less original.[11] Once we add the originality

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[11] The sample size is smaller in regressions examining generality because this measure requires that patents be subsequently cited to compute this measure.

and generality of the average patent in the same class and grant year as independent variables, the significance of these differences essentially disappears. Thus, private equity investments do not seem to be associated with a change in the extent to which the (patented) research being pursued is fundamental.

C. Robustness Checks of the Patent Quality Analyses

In undertaking the analyses of patent quality, we needed to make a number of assumptions. In this section, we summarize the results of unreported supplemental analyses, where we relax these assumptions.

One issue was posed by private equity investments where there was already an existing investor. These investments are typically secondary buyouts, where one sponsor buys out the stake of another. As a result, some patents may be double-counted: they may be simultaneously prior to one transaction and after another. We repeat the analysis, employing these patents only the first time they appear and then dropping them entirely. The results are little changed.

A second concern was posed by our measure of patent citations, using only the citation count during a three-year window. As mentioned above, the number of citations to a given patent in each year is strongly serially correlated, so we should identify the same patents as heavily cited ones whatever window we use. Using a long window to identify citations, though, will enhance the accuracy of our identification of important patents but reduce our sample size. We repeat the analysis, using citations through the end of the second calendar year after the patent grant, as well as after the fourth year. The results are qualitatively similar.

A third concern has to do with what we term “cherry picking” in divisional buyouts. In particular, we worried that corporate parents, when they determine which pending patent applications will be assigned to the firm at the time of the buyout, will select only low quality patents: the best patents, even if very relevant to the target firm, will be retained by the corporate parent. This tendency might lead to an apparent increase in quality in the patents applied for after the award, while all we are really seeing is an unbiased sample of the unit’s patents.

We will be able to partially address this concern by using the enhanced sample described above. We also address this issue by rerunning the cross-tabulations and regressions above, dropping the divisional buyouts from our sample. Since the other cases are not “carve out” parts of firms, but rather involve the purchase of the entirety of a corporation, this problem should not be present. The key results are little changed as a result of this shift.

D. Analysis of Level of Patenting

In the last two analyses, we move from examining the quality of individual patents and instead look at the mixture of the overall patenting activity generated in the years before and after the private equity investments.

A natural first question is how the level of patenting activity changes around the time of a private equity investment. If the average number of successful patent filings falls dramatically, our interpretation of the earlier finding that the importance of the issued patents rises considerably might be quite different: it would suggest cutbacks of unproductive innovative activities rather than repositioning of research from lower to higher impact topics.

An analysis of patenting prior to and after the private equity investment is problematic, however, for several reasons. While we can adjust for the truncation associated with the timing of the patent applications (the fact that, in many cases, not all patents in the five years after the private equity investments in our sample have been applied for, much less awarded), it is very difficult to control for the assignment of patents to corporate parents. As noted above, we will be able to see some but not all of patents assigned to targets that were units of larger firms prior to divisional buyouts or else were ultimately acquired by other concerns. The reliability of the algorithm that identifies these hidden patents is almost impossible to assess. Consequently, we exclude divisional buyouts for the analysis below.

Despite this limitation, in Table 6 we undertake an analysis of the level of patenting. An observation is a target firm-year pair: that is, for each transaction in 2000 and before, we use nine observations for each transaction, from three years prior to five years after the transaction. (For transactions in subsequent years, we use smaller number of observations, reflecting our inability to see patent filings made after 2005.) The dependent variable is the number of ultimately successful patent filings made in the given calendar year.

The initial analysis is in the first two columns of Table 6, which use in turn fixed effects for each year and firm to control for the differing propensity to patent. In this analysis, the results suggest that there is a marked decline in patenting.

We might worry, however, that this result is an artifact of our sample construction: in particular, while we observe some successful patent filings in the final years of the sample, there are likely to be many applications that were filed in these years that had not issued as of May 2007. (Recall the average patent pendency today is about 30 months.) Because observations of patent filings in 2004 and 2005, where this selection bias will be the worst, are disproportionately likely to be in the years after private equity transactions, this effect may bias our counts of patent filings.

We thus repeat the analyses restricting the sample in two ways. First, in columns 3 and 4, we limit the analysis to using only private equity investments prior to 1999. In these regressions, effects due to not-yet-issued patent applications should be much less severe. We find that when we use firm fixed effects, the trend of patenting over time is negative; when we use year fixed effects, the trend is insignificant.

A remaining worry is that these results may be affected by some firms not being stand-alone firms in the years before or after this transaction, even if the transaction itself is not a divisional buyout. To ensure we have patenting information about the individual firms in the years surrounding the transaction, specifications (5) and (6) condition on the firm having received a patent both in the years three years before and five years after the transaction, i.e. we require that the firm had received a patent both in Event Year -3 and in Event Year +5. This reduced the concern that we do not observe patents for the firm in the entire nine-year window. It also introduces a concern that companies that are stand-alone entities before and remain stand-alone entities after the transaction are special in other ways, which may affect our results as well. However, as expected, the main effect of conditioning on this subsample is to reduce the below one coefficients in the years before the transaction, consistent with the concern that specifications (3) and (4) may underestimate these coefficients.

In the final set of analyses, we use a dummy variable for patents filed after the private equity investment, rather than separate ones for each year. When we do so, we now can estimate regressions with both year and firm fixed effects (in earlier estimations, when we tried such specifications, the regressions failed to converge). Here, we find that as before, with firm effects, the time trend in patenting is negative; with year effects, it is greater than one; and with both sets of dummy variables, it is not significantly different from zero.

Taken together, the results do not suggest any clear change in patenting. While our conclusions must be somewhat tentative due to the discussed difficulties in measurement, questions of causation, and the remaining uncertainties, the lack of a consistent pattern once we control for the biases is evident.

E. Analysis of Patent Portfolios

In the final section, we turn to considering the structure of the patent portfolios constructed by these firms in the years before and after the private equity investments. Since the previous section shows that the increase in patent importance is not driven by private equity-backed firms cutting back on the number of filings, it is natural to wonder about the dynamics behind the change in quality.

The initial analysis is presented in the final line in Panel A of Table 2. We compare the Herfindahl index, or concentration measure, of the patent classes in which firms' awards are assigned. In this comparison, we restrict the sample to the 59 firms with at least four patent applications in the sample filed prior to the private equity investment and at least four patents applied for afterwards, in order to ensure the computed measures of concentration are meaningful. When we undertake this comparison, we find that firms after private equity investments are likely to have more concentrated patent portfolios than beforehand, but the p-value is just above the 10% threshold.

We can gain some additional insights as to how these more concentrated portfolios emerge from the cross-tabulations in Table 7. We use as observations each patent, and examine citations in the years prior to and after the private equity investment, just as we did in Table 2. We now divide the patents, though, in two ways. In Panel A, we divide the observations into those whose primary patent class assignment was more or less well populated prior to the investments: more precisely, whether the firm, in applications filed in the three years prior to the private equity transaction, had above or below the median share of patenting in that primary patent class. In Panel B, we divide the patents by whether the share of patenting in the primary class increased or decreased after the private equity transaction.

The cross-tabulations provide additional insights into the sources of the increase in patent importance. First, we see from Panel A that awards in the firms' focal technologies—the areas where they had done a disproportionate amount of patenting prior to the transaction—are more likely to increase in quality, whether raw or adjusted patent counts are used. Panel B reveals that patent classes that experience an increase in patenting share are also disproportionately where the increase in patent quality occurred. These patterns are consistent with the private equity-backed firms focusing their innovative investments in their core areas of strength and generating higher-impact patent portfolios as a result.

Consistent results emerge from Table 8, which presents Negative Binomial regression analyses akin to that in the sixth column of Table 3. We now add controls for the share of patenting in the primary patent class prior to the private equity investment (in the first and second regressions) and for the change in the share of patenting in that class from before to after the investment (in the third and fourth regressions), as well as interactions between the patent measure and the dummy denoting an award filed in the first through fifth years after the private equity investment. Because the measures of patent shares may be misleading if there are just a handful of patents assigned to a given firm, we undertake the analysis both using the entire sample (the first and third columns) and only for patents of firms which had at least four patents prior to the private equity investments and four after (the second and fourth columns).

The significantly greater than one coefficient for the variable “Share of Firm's Pre-Investment Patents in Class” suggest that patents in the firms’ “core” areas—the areas where there was more patenting prior to the private equity investment—are disproportionately likely to be important ones. Moreover, the interaction term is greater than one. Not only are these patents likely to be important, but their impact is likely to increase after the private equity investment.

The variable “Change in Firm’s Patent in Class Pre- and Post- Investment” initially presents a more confusing picture. The coefficient is again greater than one—areas where there is growth are more important ones—but the significance is only marginal. In column 3, this interaction term is less than one, but when we restrict the sample to those firms with four patents before and after the transaction (or similar cut-offs), the interaction turns greater than one and significant. Once we exclude firms with only modest patenting activity, an increase in patenting is associated with a sharp (and highly significant) boost in patent quality.

Thus, these analyses suggest that private equity-backed firms tend to focus their patent filings. This focusing process is not indiscriminate, however, but tends to concentrate on core technologies. Moreover, the very process of focusing seems to lead to the patents in these selected classes having greater impact after the private equity investment.

5. Conclusions

This paper examines the changes around the time of investments by private equity groups on firms’ long-run investments, focusing on innovative activities. We examine patents filed by 495 firms that received private equity backing between 1983 and 2005. We find that patents of private equity-backed firms applied for in the years after the investment are more frequently cited. Private equity-backed firms have no deterioration after the investments in patent originality and generality, which proxy for the fundamental nature of the research. The level of patenting does not appear to consistently change in the years after the private equity investment. Patent portfolios of firms become more focused in the years after private equity investments. Breakdowns of the patenting patterns suggest that the areas where the firms concentrate their patenting after the private equity investment, and the historical core strengths of the firm, tend to be the areas where the increase in patent impact is particularly great.

We see three avenues for future research into the relationship of private equity and innovation. While each will require additional data collection, they should deepen our understanding of this important phenomenon: First, is sensitivity of innovative activity to market changes less for private equity-backed firms? Financial economists have argued (e.g., Baker, Stein, and Wurgler [2003]) that the public market can give misleading signals to firms regarding appropriate investments, but that managers nonetheless feel pressured to follow the market's lead. If this argument is right, and the private equity-backed firms provide insulation against these pressures, we might anticipate that investments in innovation by private equity firms would be less sensitive to the shifts in market sentiment. To examine this, we will need to link the patent activity to changes in financial and accounting performance.

Second, do private equity-backed firms differ in their management of patent portfolios? In the past decade, U.S. patentees have needed to pay renewal fees in order to keep their patents active. Some large firms appear to have an automatic policy of renewing patents, even if the bulk of patents have little value. It would be interesting to observe if private equity-backed firms are less likely to renew patents, particularly lightly cited ones, than the norm.

Finally, how do sales of divisions affect innovation by the parent firms? Recent research has suggested that firms that are more reliant on internal capital markets to reallocate resources across divisions produce both a lesser number of innovations and also less novel innovations (Seru [2007]). We can examine patenting not just by target firms, but also of the corporate parents of these targets. Do the changes associated with the sell-off of the target lead the (presumably more focused) parent firm to pursue a more effective innovation strategy?

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Table 1: Summary Statistics

Panel A: Year of Private Equity Investments and Exits with Patenting in [-3,+5] Window

	Number of Investments	*Number of Exits*
1986	1	0
1987	0	0
1988	0	0
1989	2	0
1990	0	0
1991	0	0
1992	0	0
1993	3	0
1994	1	0
1995	11	0
1996	17	1
1997	24	4
1998	32	3
1999	53	2
2000	44	5
2001	37	3
2002	49	6
2003	70	22
2004	87	29
2005	64	41
2006	0	47
2007	0	25

Panel B: Type of Private Equity Investments with Patenting in [-3,+5] Window

	Number of Investments
Public-to-Private	64
Private-to-Private	127
Divisional	219
Secondary	81
Other	4

Panel C: Type of Private Equity Exits with Patenting in [-3,+5] Window

	Number of Investments
No Exit	191
Secondary	59
Initial Public Offering	38
Trade Sale	150
Bankruptcy	3
Other/Unknown	54

Panel D: Industry Distribution of Private Equity Investments with Patenting in [-3,+5] Window and Associated Patents

	Share of Industry	
	Investments	Patents
Industrial Machinery	9.9%	8.3%
Auto Parts and Equipment	5.2%	11.4%
Commodity Chemicals	4.8%	4.8%
Electrical Equipment Manufacturers	4.8%	5.8%
Building Products	4.2%	1.9%
Application Software	3.4%	3.2%
Leisure Products	3.0%	4.5%
Healthcare Equipment	2.6%	3.0%
Specialty Chemicals	2.4%	4.8%
Electrical Components and Equipment	2.0%	1.6%

Panel E: Year of Sample Patent Applications and Grants

	In Each Year, Number of…	
	Applications	Grants
1983	52	0
1984	52	17
1985	56	55
1986	60	58
1987	42	54
1988	37	56
1989	25	48
1990	19	23
1991	17	21
1992	16	14
1993	30	19
1994	64	20
1995	99	30
1996	153	57
1997	313	79
1998	456	166
1999	593	309
2000	805	412
2001	968	587
2002	1035	683
2003	869	680
2004	462	819
2005	155	801
2006	20	996
2007	0	394

Panel F: Lag between Private Equity Investment and Patent Application

	Number of Applications
Three Years Prior	1,131
Two Years Prior	1,163
One Year Prior	1,121
Year of Investment	925
One Year After	721
Two Years After	531
Three Years After	360
Four Years After	264
Five Years After	182

NOTE: The sample consists of 6,398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment.

Table 2: Univariate Tests of Differences of Patents in Sample

Panel A: Comparing Patents Filed in [-3,0] and in [+1,+5]

	Mean for [-3,0]	*Mean for [+1,+5]*	*p-Value, t-Test*
Citations in First Three Years	1.99	2.49	0.000
Relative Citations in First 3 Years	0.24	0.74	0.000
Generality	0.71	0.69	0.332
Relative Generality	0.00	-0.02	0.047
Originality	0.51	0.49	0.006
Relative Originality	-0.05	-0.05	0.594
Herfindahl Index of Patent Classes	0.29	0.33	0.113

Panel B: Comparing Patents Filed in [-3,-1] and in [0,+5]

	Mean for [-3,-1]	*Mean for [0,+5]*	*p-Value, t-Test*
Citations in First Three Years	2.01	2.27	0.028
Relative Citations in First 3 Years	0.27	0.53	0.020
Generality	0.69	0.71	0.100
Relative Generality	0.00	-0.01	0.390
Originality	0.51	0.50	0.110
Relative Originality	-0.05	-0.05	0.853

NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The comparisons in the table above are made at the individual patent level, except for the calculation of the Herfindahl index of firms' patent classes, which is done on the firm level. The latter calculations are only undertaken if the firm had at least four patents applied for before and four patents applied for after the private equity investment.

Table 3: Count Models of Citation Intensity

	(1) Absolute Intensity	(2) Relative Intensity	(3) Absolute Intensity	(4) Relative Intensity	(5) Absolute Intensity	(6) Relative Intensity
	Poisson Model	Poisson Model	Negative Binomial Model	Negative Binomial Model	Negative Binomial Model	Negative Binomial Model
Event Year -3	1.089**	1.012	1.089	1.035		
	(0.041)	(0.038)	(0.085)	(0.077)		
Event Year -2	1.107***	1.037	1.107	1.060		
	(0.043)	(0.040)	(0.090)	(0.082)		
Event Year -1	1.029	1.021	1.029	1.024		
	(0.041)	(0.041)	(0.085)	(0.081)		
Event Year 1	1.042	1.064	1.042	1.092		
	(0.048)	(0.049)	(0.099)	(0.099)		
Event Year 2	1.300***	1.401***	1.300**	1.375***		
	(0.062)	(0.067)	(0.135)	(0.135)		
Event Year 3	1.786***	1.942***	1.786***	1.919***		
	(0.088)	(0.095)	(0.210)	(0.213)		
Event Year 4	1.574***	1.750***	1.574***	1.714***		
	(0.093)	(0.104)	(0.219)	(0.225)		
Event Year 5	1.473***	1.805***	1.473**	1.787***		
	(0.120)	(0.147)	(0.281)	(0.323)		
Post LBO Dummy					1.251***	1.381***
					(0.064)	(0.067)
Observations	4207	4205	4207	4205	4207	4205

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The unit of observation is each patent in the sample with at least three years to be cited. The dependent variable is the number of citations received in the three years after the award. The table reports incidence rate ratios. A coefficient greater than one corresponds to an increasing relationship between the explanatory variable and the citation intensity.

Table 4: Relative Citation Intensity with Patentee Fixed and Random Effects

	(1)	(2)	(3)	(4)	(5)	(6)
	Poisson Model	Poisson Model	Poisson Model	Poisson Model	Negative Binomial Model	Negative Binomial Model
	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects
Event Year -3	1.145***	1.131***			1.107	1.080
	(0.048)	(0.046)			(0.072)	(0.068)
Event Year -2	1.192***	1.185***			1.119*	1.105
	(0.050)	(0.049)			(0.073)	(0.070)
Event Year -1	1.080*	1.069			1.027	1.015
	(0.045)	(0.045)			(0.068)	(0.066)
Event Year 1	1.045	1.044			0.912	0.924
	(0.050)	(0.050)			(0.072)	(0.071)
Event Year 2	1.446***	1.426***			1.037	1.041
	(0.073)	(0.072)			(0.093)	(0.090)
Event Year 3	1.779***	1.761***			1.210**	1.207**
	(0.093)	(0.092)			(0.118)	(0.115)
Event Year 4	1.720***	1.703***			1.235*	1.242*
	(0.110)	(0.108)			(0.144)	(0.140)
Event Year 5	1.689***	1.704***			1.218	1.246
	(0.147)	(0.146)			(0.196)	(0.196)
Post LBO Dummy			1.244***	1.243***		
			(0.035)	(0.034)		
Observations	4005	4205	4005	4205	4005	4205

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The unit of observation is each patent in the sample with at least three years to be cited. The dependent variable is the number of citations received in the three years after the award. The table reports incidence rate ratios. A coefficient greater than one corresponds to an increasing relationship between the explanatory variable and the citation intensity.

Table 5: OLS Estimates of Originality and Generality

	(1) Originality	(2) Originality	(3) Originality	(4) Originality	(5) Generality	(6) Generality	(7) Generality	(8) Generality
Event Year -3	0.029**	0.006			-0.115***		-0.037**	
	(0.012)	(0.012)			(0.017)		(0.017)	
Event Year -2	0.002	-0.010			-0.078***		-0.031*	
	(0.012)	(0.012)			(0.016)		(0.016)	
Event Year -1	-0.004	-0.009			-0.045***		-0.024	
	(0.012)	(0.011)			(0.017)		(0.016)	
Event Year 1	-0.020	-0.014			0.036*		0.006	
	(0.013)	(0.013)			(0.019)		(0.019)	
Event Year 2	-0.021	-0.007			0.029		-0.017	
	(0.015)	(0.014)			(0.022)		(0.022)	
Event Year 3	-0.020	-0.001			0.108***		0.017	
	(0.017)	(0.017)			(0.024)		(0.024)	
Event Year 4	-0.041**	-0.004			0.120***		0.006	
	(0.019)	(0.019)			(0.029)		(0.029)	
Event Year 5	-0.095***	-0.059**			0.056		-0.090**	
	(0.022)	(0.023)			(0.036)		(0.036)	
Post LBO Dummy			-0.033***	-0.008		0.114***		0.017
			(0.008)	(0.008)		(0.012)		(0.013)
Peer Average Originality		0.794***		0.802***				
		(0.041)		(0.041)				
Peer Average Generality							0.890***	0.908***
							(0.057)	(0.053)
Constant	0.513***	0.072***	0.519***	0.065***	0.731***	0.667***	0.096**	0.059
	(0.009)	(0.025)	(0.004)	(0.024)	(0.012)	(0.005)	(0.043)	(0.036)
R-squared	0.223	0.269	0.220	0.268	0.314	0.298	0.364	0.360
Observations	6346	6089	6346	6089	3416	3416	3413	3413

Standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The unit of observation is each patent in the sample for which originality and generality can be computed. The dependent variables are the originality and generality of the patents.

Table 6: Poisson Model of Patent Counts with Fixed Effects (excluding divisional buyouts)

	(1) Full Sample	(2) Full Sample	(3) Before 1999	(4) Before 1999	(5) Early and late patenting	(6) Early and late patenting	(7) Early and late patenting	(8) Early and late patenting	(9) Early and late patenting
	Year Fixed Effect	Firm Fixed Effect	Year Fixed Effect	Firm Fixed Effect	Year Fixed Effect	Firm Fixed Effect	Year Fixed Effect	Firm Fixed Effect	Year and Firm Fixed Effects
Event Year -3	1.128**	1.177***	0.298***	0.601***	0.865**	1.614***			
	(0.059)	(0.058)	(0.049)	(0.072)	(0.054)	(0.093)			
Event Year -2	1.115**	1.226***	0.512***	0.734***	0.852**	1.403***			
	(0.057)	(0.060)	(0.077)	(0.082)	(0.054)	(0.083)			
Event Year -1	1.078	1.198***	0.632***	0.878	0.930	1.273***			
	(0.055)	(0.059)	(0.084)	(0.094)	(0.059)	(0.077)			
Event Year 1	0.939	0.863***	1.203	0.957	1.016	0.767***			
	(0.051)	(0.047)	(0.141)	(0.100)	(0.074)	(0.054)			
Event Year 2	0.902*	0.857***	1.335**	0.899	1.244***	0.784***			
	(0.052)	(0.050)	(0.167)	(0.095)	(0.098)	(0.060)			
Event Year 3	0.721***	0.649***	1.389**	0.782**	1.462***	0.667***			
	(0.048)	(0.043)	(0.191)	(0.086)	(0.127)	(0.057)			
Event Year 4	0.664***	0.570***	1.438**	0.723***	1.368***	0.515***			
	(0.049)	(0.043)	(0.226)	(0.081)	(0.145)	(0.053)			
Event Year 5	0.613***	0.514***	1.060	0.713***	1.924***	0.726***			
	(0.053)	(0.045)	(0.195)	(0.081)	(0.213)	(0.079)			
Post LBO Dummy							1.373***	0.537***	0.999
							(0.056)	(0.020)	(0.068)
Observations	2953	2956	744	747	972	975	972	975	975

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The unit of observation is each patent in the sample for which originality and generality can be computed. The dependent variables are the originality and generality of the patents. The table reports incidence rate ratios.

Table 7: Univariate Tests of Differences in Patent Citations

Panel A: Comparing Patents in Well- and Poorly Populated Patent Classes Prior to the PE Investment

	Mean for [-3,0]	*Mean for [+1,+5]*	*p-Value, t-Test*	*Obs.*
Citations in First Three Years				
In Well-Populated Classes	2.17	3.60	0.000	2386
In Poorly Populated Classes	1.68	1.69	0.956	1821
Relative Citations in First 3 Years				
In Well-Populated Classes	0.42	1.86	0.000	2386
In Poorly Populated Classes	-0.06	-0.06	0.956	1821

Panel B: Comparing Patents in Growing and Shrinking Patent Classes Around Time of the PE Investment

	Mean for [-3,0]	*Mean for [+1,+5]*	*p-Value, t-Test*	*Obs.*
Citations in First Three Years				
In Growing Classes	2.50	2.76	0.240	1754
In Shrinking Classes	1.77	1.72	0.819	2456
Relative Citations in First 3 Years				
In Growing Classes	0.75	1.01	0.240	1754
In Shrinking Classes	0.02	-0.02	0.819	2456

NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The comparisons in the table above are made at the individual patent level. We divide the patents by whether the share of the firm's patents prior to the private equity investment in the given patent class was above or below the median, and by whether the share of the firm's patents in the class after the buyout was greater or less or equal to that prior to the transaction.

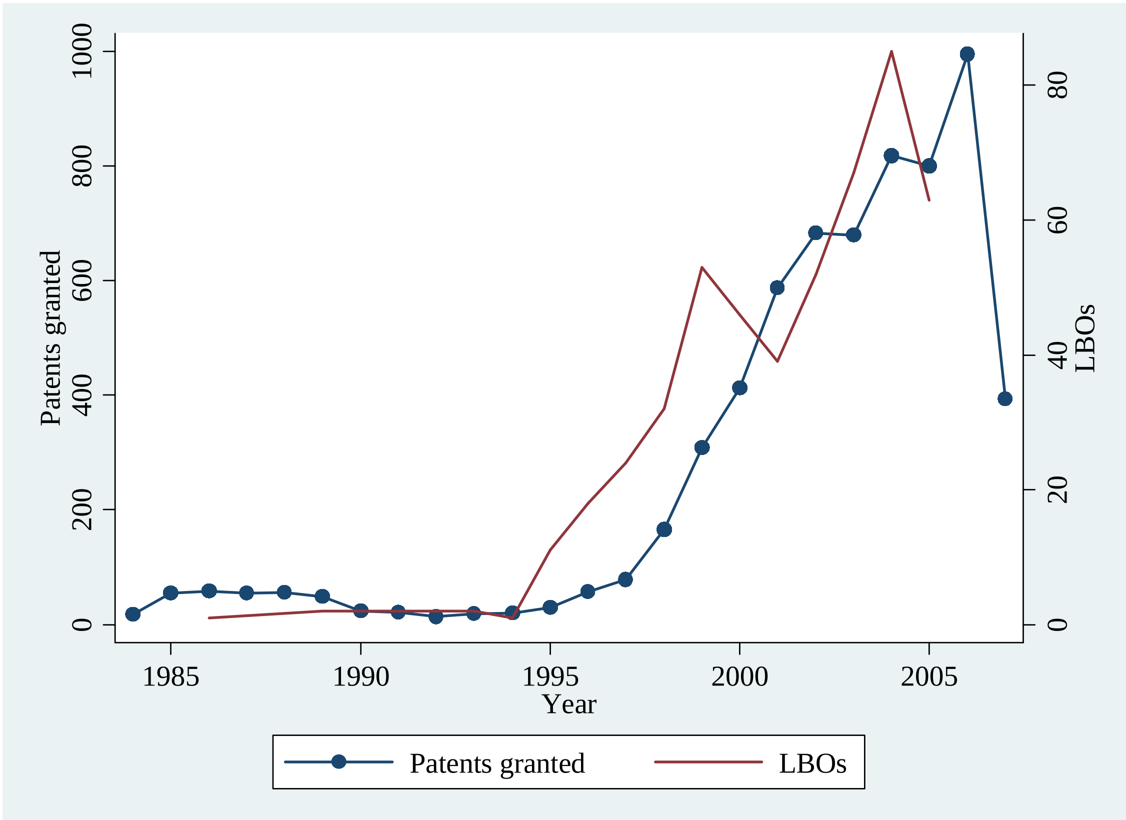
Table 8: Negative Binomial Regressions with Controls for Patent Class share

	(1)	(2)	(3)	(4)
Post LBO Dummy	0.989	0.952	1.414***	1.327***
	(0.066)	(0.073)	(0.077)	(0.081)
Share of Firm's Pre-Investment Patents in Class	1.283***	1.732***		
	(0.118)	(0.229)		
Post LBO * Share…	3.669***	4.389***		
	(0.657)	(0.987)		
Change in Firm’s Patent in Class Pre- and Post-Investment			1.207**	1.323
			(0.109)	(0.288)
Post LBO * Change…			0.570***	2.666**
			(0.106)	(1.214)
Observations	4063	2883	4063	2883

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

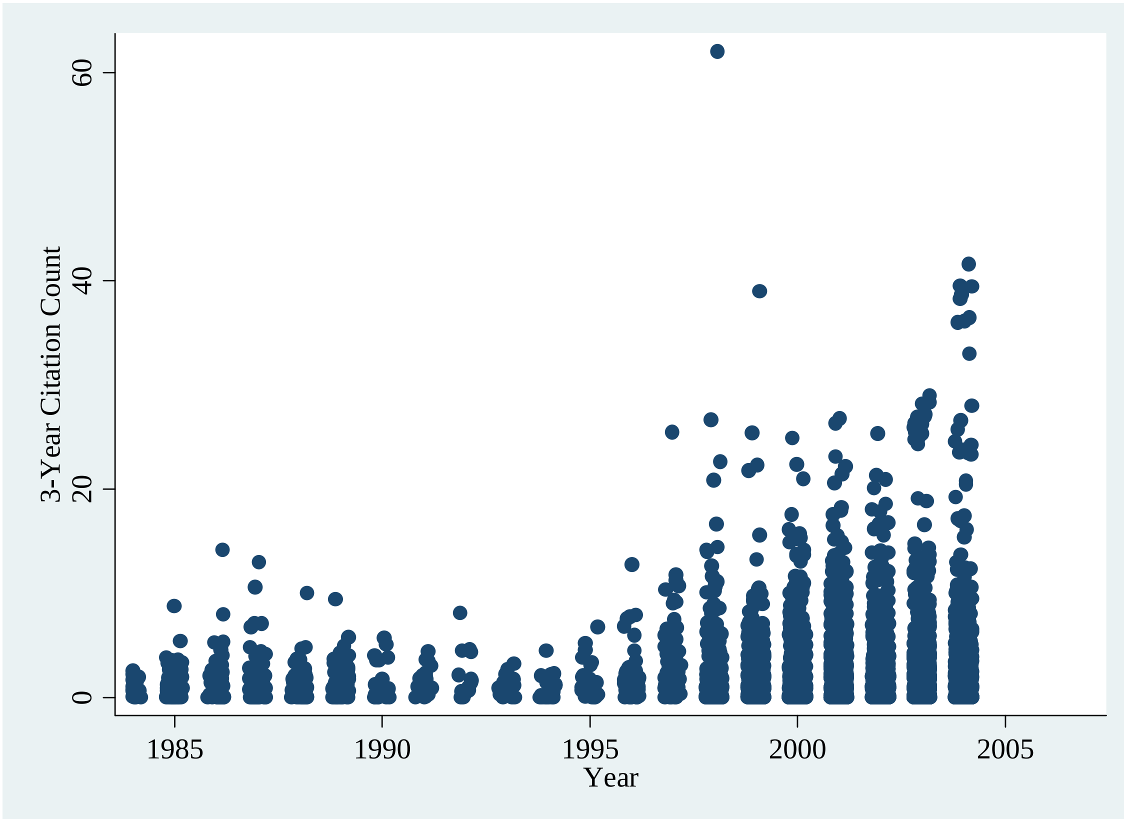
NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The unit of observation is each patent class in which a firm received a patent in the three calendar years prior to that of the investment. The dependent variable is the share of patents in that class after the investment. The table reports incidence rate ratios.

Figure 1: Number of Private Equity Investments and Patents Granted in Sample



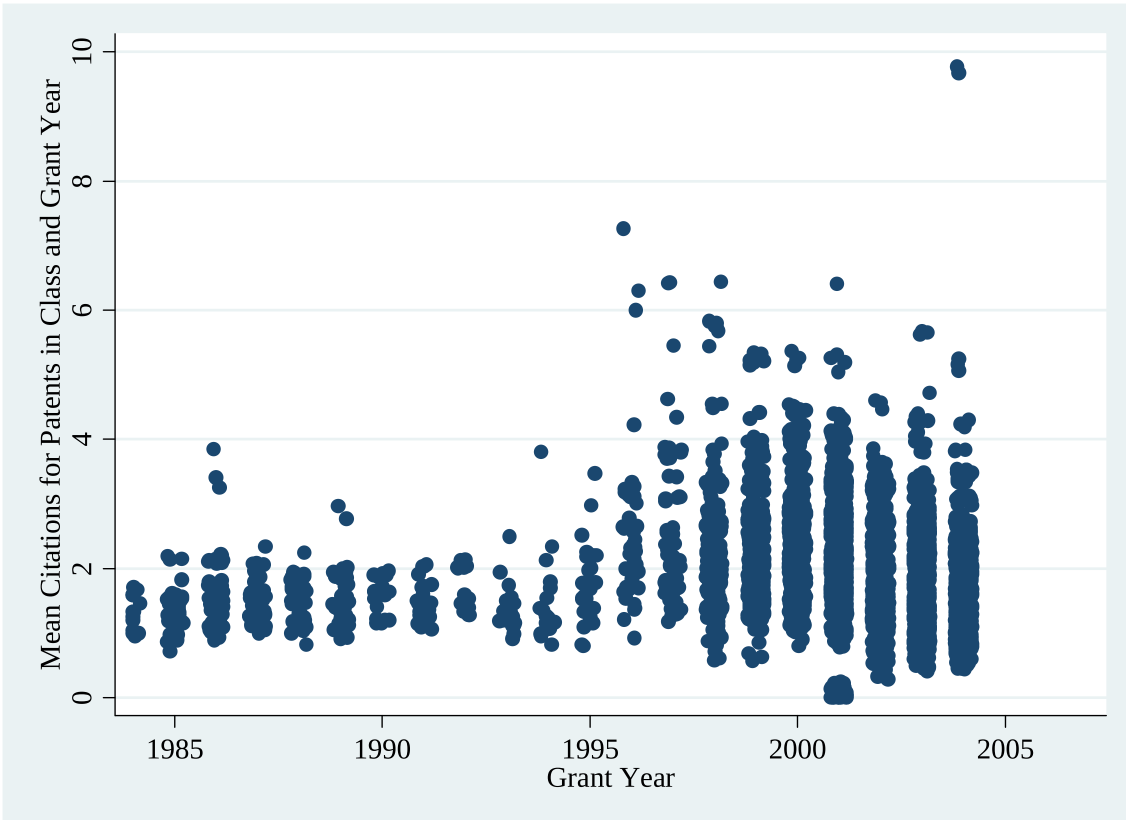
NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment.

Figure 2: Citations in First Three Years, by Grant Year of Patent



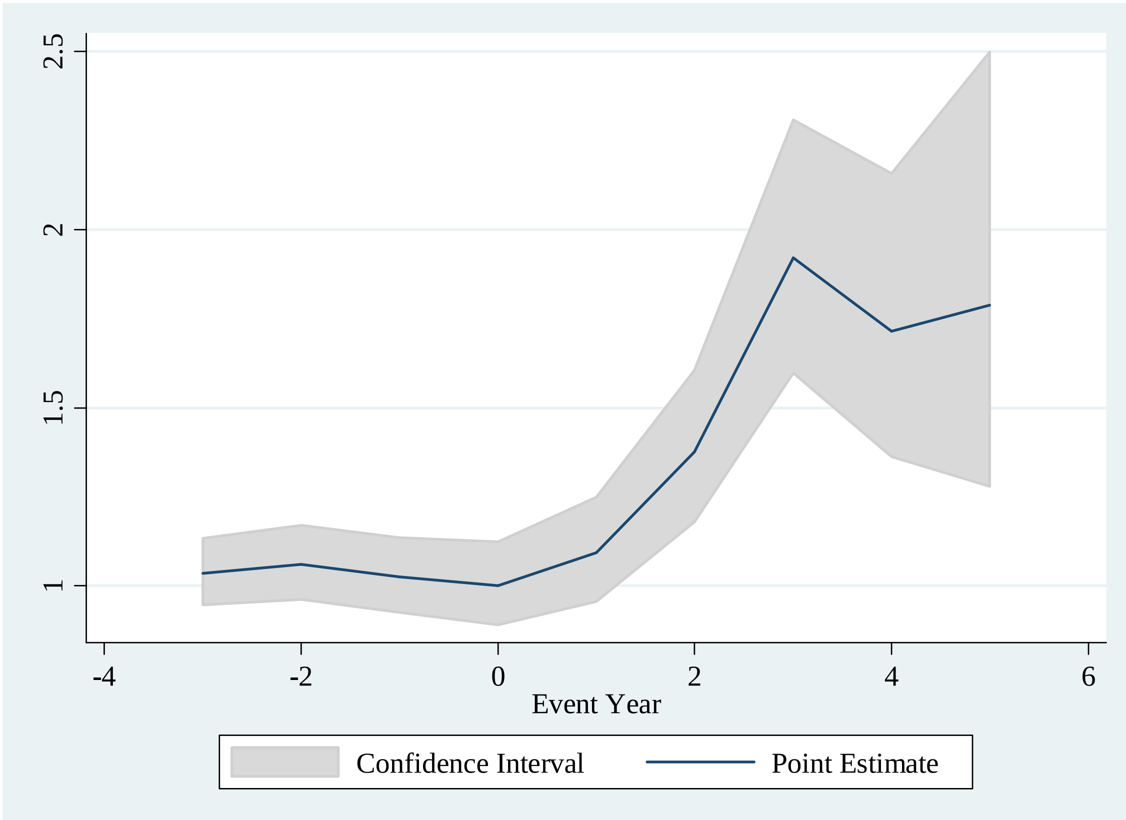
NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment.

Figure 3: Citations in First Three Years for Patents in Same Class and Grant Year



NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment.

Figure 4: Citation Intensities from Negative Binomial Regression



NOTE: The sample consists of 6398 patents awarded through May 2007 to 495 firms that received private equity backing between 1980 and 2005. Firms and patents are only included in the sample if patents were applied for between three years before and five years after the private equity investment. The chart presents the incidence rate ratios and two standard deviation confidence intervals from the patent timing variables in the fourth regression in Table 3.