Private Equity and Long-Run Investment:

The Case of Innovation

Josh Lerner, Morten Sørensen, and Per Strömberg*

January 2010

Abstract: A long-standing controversy is whether LBOs relieve managers from short-term pressures from public shareholders, or whether LBO funds themselves sacrifice long-term growth to boost short-term performance. We examine one form of long-term activities, namely investments in innovation as measured by patenting activity. Analyzing 472 LBO transactions, we find no evidence of any decrease in these activities. LBO firm patents are more cited (a proxy for economic importance), show no shifts in the fundamental nature of the research, and become more concentrated in important areas of companies' innovative portfolios. These findings are inconsistent with the hypothesis that LBOs sacrifice long-run investments.

---

* Harvard University and National Bureau of Economic Research; Columbia University, NBER, and SIFR; and Institute for Financial Research, CEPR, and NBER. We thank Geraldine Kim, Jodi Krakower, Sanjey Sivanesan, and especially Sarah Woolverton for assistance with this project. The World Economic Forum and Harvard Business School's Division of Research provided financial support for this research. We are grateful for helpful comments from participants in the American Economic Association, European Finance Association, NBER Summer Institute, and Western Finance Association meetings, the World Economic Forum "Global Economic Impact of Private Equity" project, and various seminar participants, especially Bronwyn Hall, Laura Lindsey, Paul Oyer, Mark Schankerman and John van Reenen. Many thanks also to Campbell Harvey (the editor) and two anonymous referees, whose comments greatly improved the paper. All errors and omissions are our own.

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 add value more effectively and make long-run investments without catering to the market's demands for steadily growing quarterly profits, which Stein [1988] and others argue can lead firms to myopically sacrifice such expenditures.[1] In this case, it would not be surprising that the efficiency of R&D expenditures improves after buyouts, consistent with the suggestions of Hall [1990].

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

---

[1] Consistent with Stein's arguments, Graham, et al. [2005] in a survey of 400 public company executives find that 78% admit to sacrificing long-term value to smooth earnings. Similarly, Bushee [1998] finds that firms with a high fraction of ownership by short-horizon institutional investors are more likely to reduce R&D in order to reverse an earnings decline. By way of contrast, Atanassov, et al. [2007] document that firms relying on public equity and bond financing, as opposed to bank debt financing, have a larger number of patents and that these patents are more cited.

abrogating explicit and implicit contracts with workers (e.g., Shleifer and Summers [1988] and, for a more popular view, Kosman [2009]). More specifically, they queried whether private equity-backed firms actually focus on adding value and 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—that enable private equity groups to extract fees and raise new funds more quickly.

Ultimately, the nature of the changes in corporate time horizons 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 would be 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. Finally, our focus is consistent with the argument of Zingales [2000] that more emphasis should be devoted to issues that go beyond firms' investments in physical assets.

We examine the changes in patenting behavior of 472 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. 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. 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" or "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 improvement 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 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

---

[2] One anecdote consistent with this finding is from a practitioner who described 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.

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. Recently, Atanassov, et al. [2007] examine the relation between capital structure and patenting activity. They find that firms relying on primarily on bank financing have fewer and less-cited patents compared to firms relying on outside equity or bond financing. They interpret this as evidence that banks are less able to evaluate novel technologies and therefore discourage investment in innovation.

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 addition, 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 digitization 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 dataset. 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.

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-

[3] Strömberg [2008] shows that public-to-private transactions account for roughly 6% of all private equity-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.

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 closed 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), 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.

---

[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 (rather than LBOs) until the mid-1990s. Strömberg [2008] compares the CIQ LBO data during the 1980s with the samples from older LBO studies using 1980s data and estimates the CIQ coverage to be somewhere between 70% and 85% for this period. The CIQ sample is likely to be biased towards deals for larger, surviving, and more established private equity firms before the mid-1990s. Only 7 out of the 472 LBO transactions analyzed in this paper occur before 1995, however, and our results are robust to dropping these observations from the sample.

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 (i.e., when the private equity fund divests the portfolio company, typically by selling the company or taking it public), which are useful for matching the data to patent records. Finally, we use a variety of databases, including Capital IQ, SDC VentureXpert, Dealogic, 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. 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.[5] We search the HBS database for each of

[5] The database is constructed in a similar manner to the NBER data, but is more updated. The database builders did a concerted effort to consolidate variant spellings of the same assignee, but did not attempt to match assignee names to Compustat. The database is documented in Lai, et al. [2009].

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 473 entities with at least one U.S. utility 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.[6]

The seemingly small number of patentees likely reflects two facts. First, in many instances the companies 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 would be unlikely to be issued by May 2007, and we only see patent applications that have been successful granted by the USPTO (not

---

[6] 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]).

pending applications). An additional concern arises since more than one-quarter (2,540) of the 8,938 utility 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 main analyses. Instead, we provide a separate case study of the Seagate Technologies transaction in section 4A below. Thus, our final sample consists of 6398 patents from 472 firms granted from 1984 through May 2007. For most our analysis, however, we calculate the number of citations a patent receives over the three years following the grant date. Hence, for these parts of the analysis, we exclude patents granted after 2005, restricting the sample to 4207 patents.

In Table 1, Panel A, we first 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 before January 1986 and after December 2005 reflects the construction of the sample, which only includes buyout transactions completed during this period. Exits, not surprisingly, lag the transactions by several years.

Panel A also 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.

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 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]).

Panels D and E present 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 industry 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) firms. In Panel E, the sample is compared to the overall population of leveraged buyouts (as defined by the CapitalIQ data set from Strömberg [2008]). Our sample is overrepresented in manufacturing industries and underrepresented in non-manufacturing industries such as distributors, hotels, restaurants, and publishing, which is not surprising given the lower propensity to patent in these industries.

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, were the bulk of transactions occur towards the later years of our 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.[7]

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, et al. [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 less cited patents. 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

---

[7] 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 the later 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.[8]

In addition to the truncation problem delineated above, we also face challenges around divisional buyouts and cases where the target firm was subsequently 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

---

[8] 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 compute these measures as one minus the Herfindahl index 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. We map the primary U.S. patent class into the aggregated patent categories used in Hall, et al. [2001] and Jaffe and Trajtenberg [2002], and use these categories to undertake the calculations. We use the bias correction of the Herfindahl measures, developed by Hall, and described in Jaffe and Trajtenberg [2002] as well.

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 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. Method

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 calendar year of the patent grant and the three subsequent years (we will refer to this period below as a "three-year window"). 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. Case Study of Seagate Technologies

The case of Seagate Technologies, which as noted above is the largest single patentee in our sample, provides an interesting illustration of the issues confronting private equity investors (this account is based on Andrade, et al. [2003], Gallo and Lerner [2000], and Leslie and Tauber [2004]). Seagate was founded in 1979 by entrepreneurs who were among the pioneers in the development of disk drives. In 2000, Seagate was an industry leader, with total annual revenues of nearly $7 billion and a market share of 21 percent of the worldwide disk drive market.

Seagate employed a strategy of vertical integration, encompassing all phases of the disk drive development and manufacturing operations, and its management believed that this integration would allow it to better adjust to new technological opportunities. In contrast, Seagate's competitors, such as IBM, were increasingly outsourcing manufacturing to specialized outsiders. Seagate's structure attracted criticism from analysts, who claimed that vertically integrated firms had substantially higher fixed costs, and that the strategy was particularly inappropriate in an industry that was rapidly changing from an innovative high-tech industry to a commodity business, increasingly beset by intense price competition. In response, Seagate launched a broad restructuring effort in 1997, involving closing or selling off overseas manufacturing operations, exiting from a number of product lines, and reducing capital expenditures and R&D.

Given the private equity industry's traditional emphasis on mature firms with stable cash flows, Seagate might appear to be an unlikely buyout candidate. But Silver Lake Partners and other private equity groups specializing in technology buyouts saw the firm's transformation to a commodity manufacturing firm, which was a typical buyout candidate, and in March 2000 an investor group led by Silver Lake Partners announced the buyout.[9] Seagate sold its disk drive, tape drive, and software businesses to the investor group in exchange for approximately $2 billion, including $1.1 billion in equity. In return Seagate's shareholders received cash and VERITAS stock, with a total value of

---

[9] The immediate genesis of the transaction, however, was a market anomaly. In 1999 Seagate Technology sold a unit to VERITAS Software, and in exchange it received approximately 40% of VERITAS equity. In the six months following the transaction, VERITAS' stock price increased by more than 200%, while Seagate's value climbed by only 25%. At times the value of Seagate's stake in VERITAS exceeded the entire market value of Seagate. Seagate's ability to sell the shares was limited by an agreement with VERITAS, and the perception that investors would object to such a transaction, as the firm would incur a tax liability.

approximately $77.50 per share, a dramatic improvement from the average price of about $30 at which the stock traded during 1999. Silver Lake's role in Seagate's transformation extended beyond financial engineering. The private equity group was intimately involved in key decisions to improve operations and position for sale Crystal Decisions, the accounting software unit that Seagate had acquired in 1994.

This transition is evident in the summary data for Seagate's patenting and citations presented in Table 2. In this table we compare Seagate to two large independent competitors, Maxtor and Western Digital. (It is difficult to compare Seagate to more diversified manufacturers, such as Hewlett-Packard, given their broad patent portfolios.) Panel A presents three measures of patenting: the number of (ultimately successful) patent applications filed annually between 1985 and 2003, the subsequent citations to these patents through October 2009, and the ratio of citations to patents. The decline in the number of patents and citations partly reflects that more recent applications are less likely to have been issued and garner citations. For this reason, we do not include patent applications filed in 2004 and after.

Panel B presents the percentage changes in the three measures. We report the year-to-year changes in the number of patents. Since these changes may be affected by changes in the industry and the granting and citation lags reported above, we focus on the adjusted changes, calculated as the annual percentage change for Seagate less the average percentage change for Maxtor and Western Digital. Due to substantial year-to-year fluctuations, we compare the averages of these adjusted changes for the years before the buyout (1996 to 1999) and the years after (2000 to 2003).

First, it is clear that Seagate's competitive position was deteriorating prior to the buyout as the above account suggests. While the aggregate numbers of patents and citations were increasing, they were declining sharply relative to the competitors (with average annual adjusted changes of -35% and -41%). Similarly, the relative growth of citations per patent was negative, on average. After the buyout Seagate's position continued to lag behind its rivals', but the rate of decline slowed, particularly in the case of aggregate patents and citations (the three average annual measures are now -8%, -10%, and -4%). Thus, the buyout appears to have partially stemmed the deterioration of Seagate's innovative position.

B. Measuring Patent Importance

We begin the large-sample analysis 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 limits the information loss from ignoring later citations.[10] We examine the sensitivity of the results to this choice in Section 4C below.

Table 3 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 and in the year of 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. Therefore, we define matching patents 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.[11] 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

---

[10] 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.

[11] 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.

citations has increased. Furthermore, as private equity investments in high-technology industries become more common, the representation of patents in technologically dynamic industries has grown. Hence, it is important to control for the timing of the patent grant and its technology class.

To address this concern, Table 3 also 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. Before the transactions, the relative citation counts are 0.065 and 0.075. Neither of these figures is statistically different from zero, suggesting that the buyout firms are not targeting companies with unusual patenting activity. After the transactions, the relative citation counts increase to 0.761 and 1.140, an increase that is highly statistically significant. 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 of the changes 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, which assumes that the three-year citation count is distributed according to a Poisson distribution. However, we find substantial overdispersion in the citation counts, which is typical for patent data, but leads to a rejection of the Poisson model. Following the literature, we turn to the Negative Binomial model instead, which can be interpreted as generalizing the Poisson model with an additional error term in the specification of the citation intensity, capturing the overdispersion. Both models are standard (e.g., Cameron and Trivedi [1998] and Hausman, Hall, and Griliches [1984]).

To control for changes in citation behavior and the industry composition of companies over time, 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

$$\gamma_i = \frac{Total\ Citations}{Number\ of\ Matching\ Patents}, \tag{1}$$

where *Total Citations* is the number of citations received by all matching USPTO patents during the three years following their grant dates. When including this average intensity in the estimation – with a fixed coefficient of one – we control for technology- and year-specific variations in the citation patterns. The resulting estimates reflect *relative* citation intensities of patent granted to companies in our sample compared to the matching patents.

Finally, note that all 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. An incidence rate below one corresponds to a negative effect. For binary variables, the reported incidence rate is the proportional increase in citation intensity following an increase in the variable from zero to one. Note also that all indications of statistical significance do not reflect whether the coefficients are different from zero, as is usual, but whether they differ from one.

Table 4 contains pooled regressions, using the Negative Binomial model, of citation counts on year dummies. In the first two regressions the independent variables are indicators for the individual years of the patent filing relative to the year of the private equity transaction (Event Year 0 is the omitted base category with a coefficient normalized to one). 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 1.786 for patents applied for three years after the transaction implies that these patents garner 78.6% more citations than those applied for in the year of the transaction. The individual coefficients for Event Years -3 to 1 are not significantly different from one. The coefficients may suggest a decline in citation intensity from the years prior to the transaction to the year of the transaction, but this decline is an order of magnitude smaller than the subsequent increase and not significant. In specification two, using 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. The coefficients suggest a gradual increase in the citation intensity starting in the year subsequent to the transaction, progressing through the second year, and peaking in year three, after which the level declines a notch. This post-buyout increase in relative citations is displayed graphically in Figure 1. This shows that patents filed in the years 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.

To confirm this pattern, we consolidate controls into three three-year periods. The first goes from event year -3 to -1. The second period, the base period, runs from period 0 to 2; and the last goes from event years 3 to 5. In specifications three and four we confirm that the citation intensities in the period before the transaction are virtually similar to the intensities for the base period (as also suggested by specifications 1 and 2). For the last period, however, the citation intensities show a substantial increase.

In the last four columns of Table 4, we use even more parsimonious specifications. The dummy variable *Post* equals one if the patent was applied for in the first through fifth year after the private equity investment. The variable *Post Plus One* equals one if the application was in the second to fifth year, to capture the gradual increase seen in the previous specifications. Again, these coefficients are substantially greater than one and statistically highly significant, confirming our finding that the citation count increases 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 investment decisions. Most importantly, as observed both in Table 4 and in Figure 1, the majority of the increase in the citation rate comes in the second and third years 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, making it less likely to having influenced the investors' initial decision to undertake the investment.

The key results are robust to the use of fixed- and random- patentee fixed effects specifications, as reported in Table 5, although the statistical significance naturally declines somewhat. In these specifications we also control for the time variation over the sample period by only estimating relative intensities, as discussed above. In particular, we find that in the specifications with controls for individual years that the coefficients for event years 3 and 4 are significantly greater than one. Dividing the event period into three three-year periods, as above, we confirm that the citation intensity increases in the years following the transaction. This specification also suggests that there is a slight decline in citations from the period before the private equity investment to the base period. This may also explain the somewhat muted coefficients in the final specifications with the *Post* and *Post Plus One* variables. With the slight decline in citations before the transaction and the gradual increase subsequently, the coefficient on *Post* is now close to one and insignificant. The coefficient on *Post Plus One* better captures the gradual increase following the investment and is significantly greater than one albeit muted.

While these coefficients also confirm our main conclusion, the specifications that include only *Post* and *Post Plus One* may be too parsimonious to capture the dynamic pattern in the citation counts that is indicated by the previous specifications in this table.

C. 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 3, we see that when we examine these measures, patents applied for after the private equity investments are similar in terms of generality and originality than those applied for beforehand.

A similar conclusion emerges from the regression analyses in Table 6. When we run regressions akin to those in earlier tables (now employing an ordinary least squares specification with patentee fixed effects), we find that the awards applied for after the private equity investments are somewhat more general and less original.[12] Once we use the relative originality and generality, by subtracting the averages for patents in the same class and grant year, as independent variables, the significance of these differences

---

[12] The sample size is smaller in regressions examining generality because computing this measure requires that patents are subsequently cited.

essentially disappears. Thus, private equity investments do not seem to be associated with a change in the fundamental nature of the (patented) research.

D. 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, which only uses the citation count during the three years after the award. 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 enhances the accuracy of our identification of important patents but reduces 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, and 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 private equity-backed 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 can partially address this concern by using the enhanced sample described above. We also address this issue by rerunning the cross-tabulations and regressions above while excluding the divisional buyouts from our sample. Since the buyouts in the sub-sample are not “carved out” of firms, but involve the purchase of an entire corporation, this problem should not be present. The key results are little changed as a result of this shift.

Another robustness check is to examine the impact of the holding periods of the private equity groups. If private equity groups only affect the companies in their portfolios gradually, we might expect that firms that have been held by private equity investors for longer periods would have a more dramatic increase in innovative output. In unreported regressions analyzing patent citations, we find support for this hypothesis. The pattern is no longer statistically significant, however, when we add firm fixed effects to the specification.

E. Analysis of Level of Patenting

In the last three tables, we move from examining the quality of individual patents to looking 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.

The 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 and the fact may of our companies are not stand-alone entities in the years surrounding the transaction. 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. When no patents are observed in a year, it is difficult to say whether the company did not file for patents or whether it was not operating as an independent entity. Consequently, we exclude divisional buyouts for the analysis below. Moreover, we estimate specifications restricted to buyouts taking place before 1999 and to companies that have patent filings in three years before the transaction and five years after the transaction, suggesting that these companies were independent entities during the entire period.

Moreover, the analysis faces an identification problem. As observed previously, the composition of firms and the citation patterns change during our sample period, making time controls important. Ideally, the specification would also include individual company fixed effects as well as separate indicators for the years surrounding the transactions. However, this specification is not identified, since the company fixed effect defines the event time, which, together with the indicator for the year surrounding the event, uniquely determines the year. (See Berndt and Griliches [1993] and Hall, Mairesse, and Turner [2007] for detailed analyses of this problem). There is no entirely satisfactory solution. We circumvent this problem by replacing the individual indicators for the years surrounding the event with a single *Post* dummy. This identifies the regression, but the identifying assumption is that the patenting levels are constant before and after the transaction (i.e., the full transition takes place in the year of the transaction). To verify the robustness of this assumption, we also report estimates of specifications with a dummy that equals one from year two after the transaction (*Post Plus One*), allowing for a more gradual effect. Note that this identification problem is not a concern for our analysis of citation counts, since we could use the citation rates for matching patents to calculate the relative citation intensities, and in this way avoid including individual year fixed effects.

Despite these limitations, in Table 7 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, in the first two columns of Table 7, uses the entire sample. These regressions, like all those reported in this table, include fixed effects for each year and each firm to control for the differing propensity to patent. In these specifications, we include the *Post* dummy, denoting observations after the buyout (or *Post Plus One*, as explained above). The coefficients smaller than one suggest that there is a decline in patenting activity following the buyouts.

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 been 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 private equity investments prior to 1999. In these regressions, effects due to not-yet-issued patent applications should be much less severe. Again, we include both firm and year fixed effects. The trend reverses and we find positive effects of buyouts on patenting activity.

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 reduces the concern that we do not observe patents for the firm in the entire nine-year window. (It does introduce 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.) In the two reported specifications (and other unreported ones), we find that the post-buyout dummy is weakly negative.

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

F. 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 reducing 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 row in Panel A of Table 3. 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 80 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 have more concentrated patent portfolios than beforehand.

We can gain some additional insights as to how these more concentrated portfolios emerge from the cross-tabulations in Table 8. In this table, each patent is an observation, and we examine citations in the years prior to and after the private equity investment, similar to the analysis in Table 3. 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.

In an unreported analysis, we look at self-citations. 18.7% of citations to patents applied for prior to the buyout by the private equity-backed firms are self cites; for the patents filed afterwards, 22.5% are. This difference is significant at the one percent confidence level. This pattern is also consistent with the specialization story, as post-buyout, firms are more likely to build on previously successful innovations rather than to pursue unrelated new ones.[13]

Consistent results emerge from Table 9, which presents Negative Binomial regression analyses akin to that in the fifth and sixth columns of Table 4. 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

---

[13] The self-citation rate cannot be readily compared with those computed in Hall, Jaffe and Trajtenberg [2001]. Not only is the time period quite different, but we use a more detailed screen to identify citations from affiliates, joint ventures and subsidiaries, all of which we code as self-citations.

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 more cited ones. Moreover, the interaction term is greater than one. Not only are these patents more important, but their impact appears to increase substantially after the private equity investment.

The variable "Change in Firm's Patent in Class" presents a less consistent picture. This coefficient is close to one, and the interaction terms are smaller than one. However, if the variable with the change in the share of the patent class (and its interaction with the *Post* dummy) is replaced with an indicator variable for whether the change is positive or negative (and its interaction with the *Post* dummy), the coefficient on the new interaction term becomes 1.6, which is now substantially larger than one and highly statistically significant, consistent with the comparison in Table 8.

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 the patents in these classes to have 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 472 firms that received private equity backing between 1986 and 2005. We find that patents of private equity-backed firms applied for in the years after the investment are more frequently cited. These firms show 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, and the firms' patent portfolios become more focused in the years after the 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 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 (e.g., Baker, Stein, and Wurgler [2003]). If this argument is right, and private equity investors provide insulation against these pressures, we might anticipate that investments in innovation by private equity-backed 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. This issue is particularly relevant given the sharp downturn in financing availability after the 2008 crisis. (Of course, private equity groups were also limited in their ability to access financing, particularly debt.)

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?

References

Andrade, Gregor, Stuart Gilson, and Todd Pulvino, 2003, "Seagate Technology Buyout," Harvard Business School Case no. 9-201-063.

Atanassov, Julian, Vikram Nanda, and Amit Seru, 2007, "Finance and Innovation: The Case of Publicly Traded Firms," Unpublished working paper, University of Oregon.

Baker, Malcolm, Jeremy Stein, and Jeffrey Wurgler, 2003, "When Does the Market Matter? Stock Prices and the Investment of Equity-Dependent Firms," Quarterly Journal of Economics, 118, 969-1006.

Berndt, Ernst R., and Zvi Griliches, 1993, "Price Indices for Microcomputers: An Exploratory Study," in Murry Foss, Marylin Manser, and Allan Young, editors, Price Measurements and their Uses, Chicago: University of Chicago Press.

Bushee, Brian J., 1998, "The Influence of Institutional Investors on Myopic R&D Investment Behavior," The Accounting Review 73(3), 305-333.

Cameron, A. Colin and Pravin K. Trivedi, 1998, Regression Analysis of Count Data, Cambridge, MA: Cambridge University Press

Gallo, David, and Josh Lerner, 2000, "Francisco Partners," Harvard Business School Case no. 9-200-063.

Graham, John R., Campbell Harvey, and Shiva Rajgopal, 2005, "The Economic Implications of Corporate Financial Reporting," Journal of Accounting and Economics, 40, 3-73.

Guo, Shourun, Edie Hotchkiss, and Weihong Song, 2007, "Do Buyouts (Still) Create Value?" Forthcoming, Journal of Finance.

Hall, Bronwyn, 1990, "The Impact of Corporate Restructuring on Industrial Research and Development," Brookings Papers on Economic Activity, (1), 85-136.

Hall, Bronwyn, 1992, "Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?" Working Paper No. 4096, National Bureau of Economic Research.

Hall, Bronwyn H., Zvi Griliches, and Hausman, Jerry, 1986, "Patents and R and D: Is There a Lag?" International Economic Review, 27, 265-283.

Hall, Bronwyn H., Adam B. Jaffe, and Manuel Trajtenberg, 2001, "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools," Working paper no. 8498, National Bureau of Economic Research.

Hall, Bronwyn, Jacques Mairesse, and Laure Turner, 2007, "Identifying Age, Cohort, and Period Effects in Scientific Research Productivity: Discussion and Illustration Using Simulated and Actual Data on French Physicists," Economics of Innovation and New Technology, 16, 159-177

Hao, Kenneth Y., and Adam B. Jaffe, 1993, "Effect of Liquidity on Firms' R&D Spending," Economics of Innovation and New Technology, 2, 275-282.

Hausman, Jerry, Bronwyn H. Hall, and Zvi Griliches, 1984, "Econometric Models for Count Data with an Application to the Patents-R&D Relationship," Econometrica, 52, 909-938

Himmelberg, Charles P., and Bruce C. Petersen, 1994, "R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries," Review of Economics and Statistics, 76, 38-51.

Jaffe, Adam B., and Manuel Trajtenberg, 2002, Patents, Citations, and Innovations: A Window on the Knowledge Economy, Cambridge, MA: MIT Press.

Jensen, Michael C., 1989, "The Eclipse of the Public Corporation," Harvard Business Review, 67 (September-October), 61-74.

Jensen, Michael C., 1993, "The Modern Industrial Revolution, Exit, and the Failure of Internal Control Systems," Journal of Finance, 48, 831-880.

Kaplan, Steven N., and Jeremy C. Stein, 1993, "The Evolution of Buyout Pricing and Financial Structure in the 1980s," Quarterly Journal of Economics, 108, 313-357.

Kosman, Josh, 2009, The Buyout of America: How Private Equity Will Cause the Next Great Credit Crisis, New York: Penguin.

Lai, Ronald, Alexander D'Amour, and Lee Fleming, 2009, "The Careers And Co-Authorship Networks of U.S. Patent-Holders, Since 1975," Unpublished Working Paper, Harvard University.

Lanjouw, Jean O., Ariel Pakes, and Jonathan Putnam, 1998, "How to Count Patents and Value Intellectual Property: The Uses of Patent Renewal and Application Data," Journal of Industrial Economics, 46, 405-432.

Leslie, Mark, and Alexander Tauber, 2004, "Crystal Decisions," Stanford Graduate School of Business Case no. E-169.

Lichtenberg, Frank R., and Donald Siegel, 1990, "The Effects of Leveraged Buyouts on Productivity and Related Aspects of Firm Behavior," Journal of Financial Economics, 27, 165-194.

Muelbroek, Lisa K., Mark L. Mitchell, J. Harold Mulherin, Jeffry M. Netter, and Annette B. Poulsen, 1990, "Shark Repellents and Managerial Myopia: An Empirical Test," Journal of Political Economy, 98, 1108-1117

Seru, Amit, 2007, "Do Conglomerates Stifle Innovation?" Unpublished Working Paper, University of Chicago.

Shleifer, Andrei, and Lawrence Summers, 1988, "Breach of Trust in Hostile Takeovers," in Alan J. Auerbach, editor, Corporate Takeovers: Causes and Consequences. Chicago: University of Chicago Press.

Stein, Jeremy C., 1988, "Takeover Threats and Managerial Myopia," Journal of Political Economy, 96, 61-80.

Strömberg, Per, 2008, "The New Demography of Private Equity," Unpublished Working Paper, Institute for Financial Research.

Zingales, Luigi, 2000, "In Search of New Foundations," Journal of Finance, 55, 1623-1653.

Table 1: Summary Statistics

Panel A: Transaction and exit years for PE deals involving companies with patents in our sample and application and grant years for those patents.

	PE Deals		Patents	
	Transactions	*Exits*	*Applications*	*Grants*
1983	N/A	N/A	52	0
1984	N/A	N/A	52	17
1985	N/A	N/A	56	55
1986	1	0	60	58
1987	0	0	42	54
1988	0	0	37	56
1989	2	0	25	48
1990	0	0	19	23
1991	0	0	17	21
1992	0	0	16	14
1993	3	0	30	19
1994	1	0	64	20
1995	10	0	99	30
1996	18	1	153	57
1997	23	4	313	79
1998	30	2	456	166
1999	51	2	593	309
2000	43	5	805	412
2001	36	3	968	587
2002	52	4	1035	683
2003	69	22	869	680
2004	82	28	462	819
2005	51	42	155	801
2006	N/A	44	20	996
2007	N/A	26	0	394
Total	472	183	6,398	6,398

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: Top Industries in Sample

	Top ten industries in sample	
	% of sample firms	% of sample 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: Industry Distribution of Private Equity Investments with Patenting in [-3,+5] Window and Associated Patents: Top Industries in Overall LBO Populations

	Representation of sample in the top ten industries in the overall LBO population		*Industry share in overall LBO population*
	% of sample firms	% of sample patents	
Industrial Machinery	9.9%	8.3%	4.4%
Application Software	3.4%	3.2%	3.3%
Office Services and Supplies	1.6%	2.5%	2.5%
Distributors	0.8%	0.2%	2.3%
Packaged Foods and Meats	1.4%	0.5%	2.2%
Commodity Chemicals	4.8%	4.8%	2.0%
Hotels, Resorts and Cruise Lines	0.0%	0.0%	1.9%
Publishing	0.6%	0.1%	1.9%
Restaurants	0.8%	0.1%	1.9%
Building Products	4.2%	1.9%	1.9%

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 full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. Firms are only included in the sample if they applied for patents in the period between three years before and five years after the private equity investment. Exit is defined as the private equity fund eventually divesting the LBO. “Secondary” exit refers to the LBO-backed firm subsequently being sold to another private equity fund. “Initial Public Offering” the LBO-backed firm subsequently going public. “Trade Sale” refers to the LBO-backed firm subsequently being acquired by another strategic (i.e. non-financial) buyer. “Bankruptcy” refers to the LBO-backed firm subsequently filing for bankruptcy and/or going out of business. The industry shares in the overall population used for comparisons in the bottom half of panel D consists of 9659 LBOs of U.S. firms included in the Capital IQ database between 1970 and 2007. The industry classification is based on CapitalIQ and contains 160 different industries.

Table 2: Disk Drive Innovation: Comparison of Seagate, Western Digital (WD), and Maxtor

Panel A: Summary Statistics on Patenting and Citations

	Patents			Total Citations to Patents			Citations/Patent		
App. Year	*WD*	*Maxtor*	*Seagate*	*WD*	*Maxtor*	*Seagate*	*WD*	*Maxtor*	*Seagate*
1985	3	1	13	70	26	209	23.3	26.0	16.1
1986	14	1	24	198	44	337	14.1	44.0	14.0
1987	10	4	35	133	112	827	13.3	28.0	23.6
1988	9	8	63	354	199	1255	39.3	24.9	19.9
1989	11	4	54	365	68	1240	33.2	17.0	23.0
1990	5	5	88	62	134	2144	12.4	26.8	24.4
1991	13	7	58	440	124	1201	33.8	17.7	20.7
1992	4	17	64	115	348	1307	28.8	20.5	20.4
1993	3	28	78	62	341	1507	20.7	12.2	19.3
1994	3	17	104	66	174	1407	22.0	10.2	13.5
1995	11	18	148	237	154	1936	21.5	8.6	13.1
1996	25	17	150	360	136	1897	14.4	8.0	12.6
1997	54	9	269	679	67	2537	12.6	7.4	9.4
1998	46	27	346	222	105	2343	4.8	3.9	6.8
1999	54	100	354	320	390	1787	5.9	3.9	5.0
2000	92	63	387	253	178	1535	2.8	2.8	4.0
2001	114	83	497	198	196	1004	1.7	2.4	2.0
2002	162	58	310	194	52	284	1.2	0.9	0.9
2003	97	48	275	46	25	97	0.5	0.5	0.4

Panel B: Change in Seagate Patenting and Citations

	Patents		Total Citations to Patents		Citations/Patent	
	Change	*Adjusted Change*	*Change*	*Adjusted Change*	*Change*	*Adjusted Change*
1986	85%	-99%	61%	-65%	-13%	-28%
1987	46%	-90%	145%	85%	68%	89%
1988	80%	35%	52%	-70%	-16%	-108%
1989	-14%	0%	-1%	30%	15%	39%
1990	63%	78%	73%	66%	6%	9%
1991	-34%	-134%	-44%	-345%	-15%	-85%
1992	10%	-26%	9%	-45%	-1%	-2%
1993	22%	2%	15%	39%	-5%	29%
1994	33%	53%	-7%	15%	-30%	-25%
1995	42%	-94%	38%	-86%	-3%	6%
1996	1%	-60%	-2%	-22%	-3%	17%
1997	79%	45%	34%	15%	-25%	-16%
1998	29%	-64%	-8%	-2%	-28%	26%
1999	2%	-142%	-24%	-182%	-25%	-37%
2000	9%	-7%	-14%	24%	-21%	19%
2001	28%	1%	-35%	-29%	-49%	-22%
2002	-38%	-44%	-72%	-34%	-55%	-8%
2003	-11%	17%	-66%	-2%	-61%	-10%
Avg., 1986-99	32%	-35%	24%	-41%	-5%	-6%
Avg., 2000-03	-3%	-8%	-47%	-10%	-47%	-5%

NOTE**:** Adjusted changes are calculated as the annual percentage change for Seagate less the average percentage change for Maxtor and Western Digital.

Table 3: Univariate Tests of Differences of Patents in Sample

Panel A: Comparing Patents Filed in Years [-3,0] and [1,5] (Post)

	Mean [-3,0]	Obs.	Mean [1,5]	Obs.	Diff.	p-val. t-test
Citations	1.987	[3076]	2.486	[1131]	0.499	0.000
Relative Citations	0.065	[3075]	0.761	[1130]	0.695	0.000
Self-citations	0.303	[3076]	1.046	[1131]	0.743	0.000
Generality	0.384	[1819]	0.387	[649]	0.003	0.849
Relative Generality	-0.024	[1795]	-0.030	[642]	-0.006	0.719
Originality	0.451	[4195]	0.458	[2012]	0.007	0.372
Relative Originality	0.011	[4143]	0.002	[1999]	-0.009	0.218
Herfindahl of Patent Classes	0.220	[80]	0.264	[80]	0.044	0.022

Panel B: Comparing Patents Filed in Years [-3,1] and [2,5] (Post Plus One)

	Mean [-3,0]	Obs.	Mean [1,5]	Obs.	Diff.	p-val. t-test
Citations	1.983	[3508]	2.817	[699]	0.835	0.000
Relative Citations	0.075	[3506]	1.140	[699]	1.064	0.000
Self-citations	0.328	[3508]	1.383	[699]	1.056	0.000
Generality	0.383	[2059]	0.394	[409]	0.011	0.565
Relative Generality	-0.027	[2030]	-0.021	[407]	0.005	0.765
Originality	0.452	[4897]	0.459	[1310]	0.006	0.481
Relative Originality	0.011	[4840]	0.000	[1302]	-0.011	0.223

NOTE: The full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. Citation counts are calculated for the subsample of 4207 patents awarded before December 2004. Firms are only included in the sample if they applied for patents in the period 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 at the firm level. The latter calculations are only undertaken if the firm had at least four patents applied for before and after the private equity transaction. The originality, generality, and Herfindahl measures are calculated using the HJT industry classification, using the Hall bias correction. Relative Citations are constructed by subtracting the average number of citations for all patents in the same USPTO class and with the same grant year. Similarly, the Relative Originality and Generality measures are constructed by subtracting the average (bias corrected) Originality and Generality measures of the patents in the same USPTO class and with the same grant year.

Table 4: Negative Binomial Estimates of Citation Intensity

	(1) Absolute Intensity	(2) Relative Intensity	(3) Absolute Intensity	(4) Relative Intensity	(5) Absolute Intensity	(6) Relative Intensity	(7) Absolute Intensity	(8) Relative Intensity
Event Year -3	1.089	1.035						
	(0.0853)	(0.0774)						
Event Year -2	1.107	1.060						
	(0.0895)	(0.0818)						
Event Year -1	1.029	1.024						
	(0.0848)	(0.0805)						
Event Year 1	1.042	1.092						
	(0.0985)	(0.0986)						
Event Year 2	1.300**	1.375***						
	(0.135)	(0.135)						
Event Year 3	1.786***	1.919***						
	(0.210)	(0.213)						
Event Year 4	1.574***	1.714***						
	(0.219)	(0.225)						
Event Year 5	1.473**	1.787***						
	(0.281)	(0.323)						
Event Years -3 to -1			0.994	0.931				
			(0.0502)	(0.0448)				
Event Years 3 to 5			1.538***	1.639***				
			(0.127)	(0.128)				
Post					1.251***	1.381***		
					(0.0637)	(0.0668)		
Post Plus One							1.421***	1.569***
							(0.0849)	(0.0886)
Constant	1.871***	1.001	2.026***	1.118***	1.987***	1.033	1.983***	1.040*
	(0.116)	(0.0591)	(0.0826)	(0.0434)	(0.0533)	(0.0265)	(0.0497)	(0.0249)
Observations	4207	4205	4207	4205	4207	4205	4207	4205

NOTE: The full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. The regressions here use the subsample of 4207 patents awarded before December 2004. 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 a patent in the sample with at least three years to be cited. The dependent variable is the number of citations the patent received during the three years after the award. Indicator variables named Event Year equal one for the given year in event time (the base year is year zero with the PE transaction). The indicator Post equals one for event years 1 and forward. The indicator Post Plus One equals one for event years 2 and forward. Reported coefficients are incidence rates. A coefficient greater than one corresponds to a positive relationship between the explanatory variable and the citation intensity. The models are estimated using Maximum Likelihood, and asymptotic standard errors are given in parentheses. *, **, and *** indicates that the coefficient is statistically significantly different from one at the 10%, 5%, and 1% levels, respectively.

Table 5: Negative Binomial Estimates of Relative Citation Intensity with Patentee Fixed and Random Effects

	(1) Fixed Effects	(2) Random Effects	(3) Fixed Effects	(4) Random Effects	(5) Fixed Effects	(6) Random Effects	(7) Fixed Effects	(8) Random Effects
Event Year -3	1.107	1.080						
	(0.072)	(0.068)						
Event Year -2	1.119*	1.105						
	(0.073)	(0.070)						
Event Year -1	1.027	1.015						
	(0.068)	(0.066)						
Event Year 1	0.912	0.924						
	(0.072)	(0.071)						
Event Year 2	1.037	1.041						
	(0.093)	(0.090)						
Event Year 3	1.210**	1.207**						
	(0.118)	(0.115)						
Event Year 4	1.235*	1.242*						
	(0.144)	(0.140)						
Event Year 5	1.218	1.246						
	(0.196)	(0.196)						
Event Years -3 to -1			1.108**	1.086*				
			(0.049)	(0.046)				
Event Years 3 to 5			1.248***	1.246***				
			(0.088)	(0.085)				
Post					0.974	0.993		
					(0.046)	(0.044)		
Post Plus One							1.106*	1.111**
							(0.061)	(0.058)
Constant	0.518***	0.517***	0.506***	0.508***	0.551***	0.543***	0.540***	0.535***
	(0.032)	(0.031)	(0.026)	(0.025)	(0.024)	(0.023)	(0.023)	(0.022)
Observations	4005	4205	4005	4205	4005	4205	4005	4205

NOTE: The full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. The regressions here use the subsample of 4207 patents awarded before December 2004. 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 a patent in the sample with at least three years to be cited. The dependent variable is the number of citations the patent received during the three years after the award. Indicator variables named Event Year equal one for the given year in event time (the base year is year zero with the PE transaction). The indicator Post equals one for event years 1 and forward. The indicator Post Plus One equals one for event years 2 and forward. Reported coefficients are incidence rates. A coefficient greater than one corresponds to a positive relationship between the explanatory variable and the citation intensity. The models are estimated using Maximum Likelihood, and asymptotic standard errors are given in parentheses. *, **, and *** indicates that the coefficient is statistically significantly different from one at the 10%, 5%, and 1% levels, respectively.

Table 6: OLS Estimates of Originality and Generality with Patentee Fixed Effects

	(1) Originality	(2) Relative Originality	(3) Originality	(4) Relative Originality	(5) Generality	(6) Relative Generality	(7) Generality	(8) Relative Generality
Event Year -3	-0.039***	-0.010			0.051**	0.029		
	(0.013)	(0.013)			(0.024)	(0.023)		
Event Year -2	-0.011	0.001			0.010	-0.006		
	(0.013)	(0.012)			(0.024)	(0.023)		
Event Year -1	-0.006	0.001			0.016	0.013		
	(0.013)	(0.012)			(0.024)	(0.024)		
Event Year 1	0.007	-0.008			-0.023	-0.024		
	(0.014)	(0.014)			(0.028)	(0.028)		
Event Year 2	0.000	-0.021			-0.022	-0.019		
	(0.016)	(0.015)			(0.032)	(0.031)		
Event Year 3	0.004	-0.020			-0.068*	-0.044		
	(0.018)	(0.017)			(0.036)	(0.035)		
Event Year 4	0.019	-0.028			-0.073*	-0.053		
	(0.020)	(0.020)			(0.044)	(0.043)		
Event Year 5	0.058**	0.011			0.139***	0.126**		
	(0.024)	(0.023)			(0.052)	(0.051)		
Post			0.023***	-0.013			-0.045***	-0.029*
			(0.008)	(0.008)			(0.017)	(0.017)
Constant	0.465***	0.016	0.450***	0.014*	0.366***	-0.026	0.390***	-0.015
	(0.012)	(0.011)	(0.009)	(0.008)	(0.024)	(0.023)	(0.018)	(0.016)
Observations	6207	6142	6207	6142	2468	2437	2468	2437

NOTE: The full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. The sample size is smaller in regressions examining generality because computing this measure requires that patents are subsequently cited. 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 a patent in the sample for which originality and generality can be computed. The dependent variables are the originality and generality of the patents. Relative originality and generality are computed by subtracting the average originality and generality for patents in the same USPTO class and grant year. Indicator variables named Event Year equal one for the given year in event time (the base year is year zero with the PE transaction). The indicator Post equals one for event years 1 and forward. *, **, and *** indicates statistical significance at the 10%, 5%, and 1% levels, respectively

Table 7: Poisson Model of Patent Counts with Year and Patentee Fixed Effects (excluding divisional buyouts)

	(1)	(2)	(3)	(4)	(5)	(6)
	Full Sample		Before 1999		Early and Late Patenting	
Post	0.854***		1.111		0.924	
	(0.044)		(0.140)		(0.059)	
Post Plus One		0. 814***		1.174		0.982
		(0.042)		(0.150)		(0.067)
Observations	2914	2914	738	738	979	979

NOTE: The full sample consists of 472 firms that received private equity backing between 1986 and 2005. Firms 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 the number of patents granted to a company each year during the period from three years before to five years after the PE transaction. Specifications labeled "Full Sample" include all patents. Specifications labeled "Before 1999" include only companies involved in transactions before 1999 and specifications labeled "Early and Late Patenting" include only companies with patents observed in both event years -3 and 5. The indicator Post equals one for event years 1 and forward. The indicator Post Plus One equals one for event years 2 and forward. Reported coefficients are incidence rates. A coefficient greater than one corresponds to a positive relationship between the explanatory variable and the citation intensity. The models are estimated using Maximum Likelihood, and asymptotic standard errors are given in parentheses. *, **, and *** indicates that the coefficient is statistically significantly different from one at the 10%, 5%, and 1% levels, respectively.

Table 8: Comparing Patent Citations in More or Less Active Classes

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	2.10	3.27	0.00	2801
In Poorly Populated Classes	1.68	1.69	0.93	1254
Relative Citations in First 3 Years				
In Well-Populated Classes	0.36	1.52	0.00	2801
In Poorly Populated Classes	-0.07	-0.06	0.93	1254

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	1.85	2.84	0.00	2256
In Shrinking Classes	2.11	1.71	0.03	1951
Relative Citations in First 3 Years				
In Growing Classes	0.11	1.10	0.00	2256
In Shrinking Classes	0.36	-0.04	0.03	1951

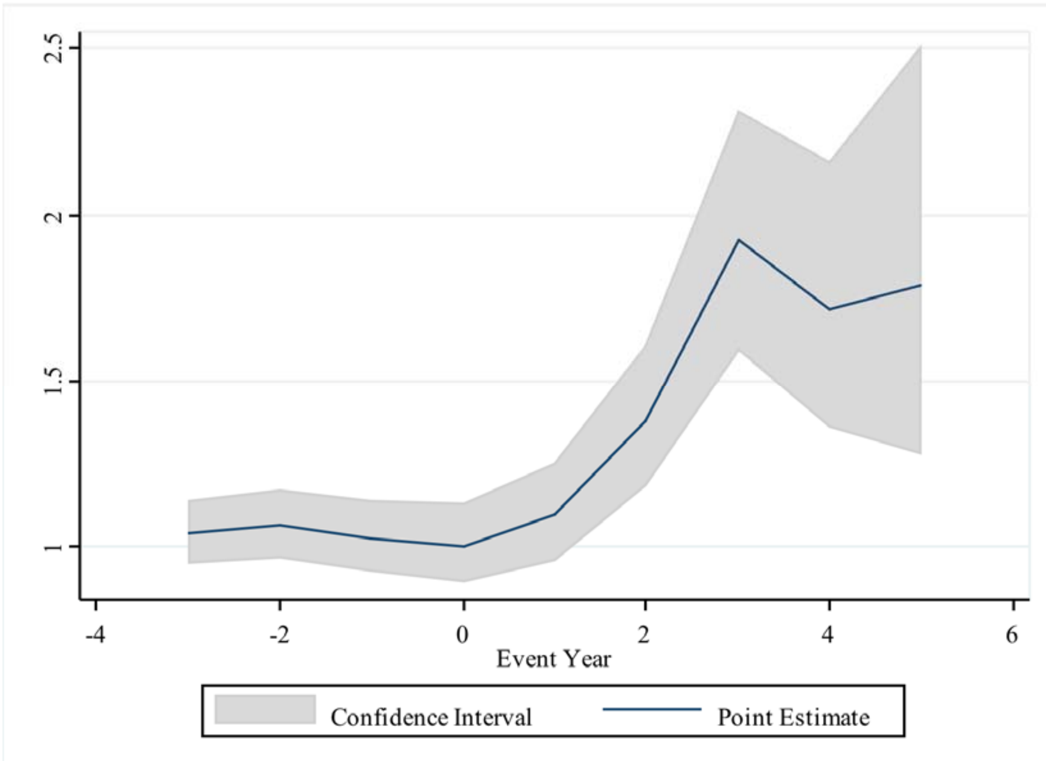
NOTE: The full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. The cross-tabulations here use the subsample of 4207 patents awarded before December 2004. The comparisons in the table are made at the individual patent level using HJT industry classification of the patents. 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 share (15.3%), and by whether the share of the firm's patents in the class after the buyout was greater or smaller (or equal) to the share in the class prior to the transaction.

Table 9: Negative Binomial Regressions of Citation Counts Controlling for Patent Class Share

	Full Sample (1)	With Patenting (2)	Full Sample (3)	With Patenting (4)
Post	0.980	0.886	1.480***	1.530***
	(0.077)	(0.076)	(0.078)	(0.088)
Share of Firm's Pre-Investment	1.110	1.274**		
Patents in Class	(0.097)	(0.155)		
Post x Share …	2.819***	3.769***		
	(0.464)	(0.749)		
Change in Firm's Patent in			0.932	0.957
Class			(0.120)	(0.202)
Post x Change…			0.473***	0.275**
			(0.121)	(0.117)
Observations	4054	2956	3587	2956

NOTE: The full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. The regressions here use the subsample of 4207 patents awarded before December 2004. 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 subsample named "With Patenting" only includes patents in firms that had, at least four successful patents before the transaction and four after the transaction. The unit of observation is a patent in the sample with at least three years to be cited. The dependent variable is the number of citations the patent received during the three years after the award. Share of Firm's Pre-Investment Patents in Class is the fraction of the firms' pre-transaction patents that are in the same HJT industry class. Change in Firm's Patent in Class is the difference in the share of patents in the class between the pre- and post-transaction periods. The Post x Share and Post x Change variables are interaction terms. Reported coefficients are incidence rates. A coefficient greater than one corresponds to a positive relationship between the explanatory variable and the citation intensity. The models are estimated using Maximum Likelihood, and asymptotic standard errors are given in parentheses. *, **, and *** indicates that the coefficient is statistically significantly different from one at the 10%, 5%, and 1% levels, respectively.

Figure 1: Citation Intensities from Negative Binomial Regression



NOTE: The full sample consists of 6398 patents awarded through May 2007 to 472 firms that received private equity backing between 1986 and 2005. The chart uses the subsample of 4207 patents awarded before December 2004. 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 estimated incidence rates and confidence intervals from the patent timing variables in the second specification in Table 4.