Private Equity and Innovation: Evidence from Sweden

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Abstract

Whether private equity owners create long-term value or if these investors neglect investing for the longer run in order to boost short-term returns has for long been a widely debated topic. This paper aims to investigate how long-run investments in innovation are impacted by LBO transactions on the Swedish market. We examine investments in innovation as measured by patents on a sample of 87 Swedish firms which have been private equity owned some time in the period between 1994 and 2019. More specifically, we investigate how the quality of patents, the number of patents applied for and the productivity of innovation activities evolve in the period surrounding an LBO transaction. Our findings suggest that both the quality and the number of patents applied for by Swedish firms that undergo an LBO transaction seems to decrease in the period following the transaction, however the statistical significance in these tests is low. When extending our analysis to consider what the underlying cause of these potential shifts might be we find that the yield on investments in R&D, as measured by the number of patents applied for and the quality of those patents relative to the R&D expenditure, decreases significantly in the period following the LBO transaction. This suggests that the way in which private equity owners on the Swedish market undertake long-run investments might be different, and perhaps less productive, compared to non-private equity owners.

Supervisor: Ramin Baghai
Keywords: private equity, LBO, innovation, patent

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Contents

1 Introduction

In 1989 Michael C. Jensen published *The Eclipse of the Public Corporation* which claimed that the public corporation had outlived its usefulness and that other organizational forms would emerge as the dominant corporate entities. His critique of the public corporation centered around how agency costs were instrumental in creating poor governance structures within the firm (ibid.). Among these agency costs were the tendency of managers to retain more cash than needed to achieve a decreased dependency vis-a-vis the public capital markets and the tendency for empire building since compensation is highly correlated with the size of the firm (ibid.). Furthermore, managers of public firms have been claimed to be under constant short-term pressures from shareholders. In a survey of 400 executives of public companies, Graham et al. (2005) show that almost four out of five executives admit to having sacrificed long-term value creation to smooth earnings.

Ever since, a new corporate organizational form has emerged; the leveraged buyout (LBO[1]). In an LBO a private equity fund acquires a controlling equity stake in the target company, with substantial amounts of associated indebtedness (Kaplan and Strömberg, 2009). There has since been a long-standing debate whether this alternative ownership model contributes to long-term value creation or if private equity investors sacrifice long-term value to boost short-term returns. Since a private equity fund will typically acquire a controlling position in their portfolio companies and on average hold the company approximately five years before divesting the investment (Kaplan and Strömberg, 2009), critics have argued that the nature of the corporate time horizon changes under the ownership of private equity investors who are incentivized to cut costs and boost short-term profits during their holding period (Dutta et al., 2015). These critics have argued that the private equity model is a "quick flip" construction whereby firms are listed as soon as possible following the investment, in order for the private equity fund to raise new funds and earn fees.

In 2011, Lerner, Sorensen and Strömberg set out to investigate how target companies' long-term investments are impacted by LBOs. By examining one form of long-run activity, namely investments in innovation as measured by patenting activity on the US market, the researchers analyzed 472 LBO transactions between the years 1985 and 2005. They found no evidence that LBOs sacrifice long-term investments, but rather that the quality of patents granted for these firms increased following the LBO transaction (ibid.).

In this paper, we revisit the question of how LBO transactions impact long-run investments in innovation by studying the relationship on the Swedish market. We do so for several reasons. First, the study of Lerner et al. (2011) is based on private equity transactions up until December of 2005 and an analysis of patenting activity until May of 2007. By examining private equity transactions through 2019 in this study, we extend the time horizon of Lerner et al. (2011) study and add transactions from the period during and after the global

[1]Throughout this paper, we refer to an LBO, LBO transaction, private equity transaction or private equity investment synonymously.

financial crisis of 2008 to our analysis. Adding observations from this period is of particular interest given that credit supply was higher before the crisis (Kahle and Stulz, 2013), meaning lower quality investments should have been more likely to receive funding before compared to after the crisis when funding was more scarce.

Second, studies on how long-run investments are impacted by private equity ownership have predominantly been conducted in a US setting and, to the best of our knowledge, no study has been conducted on the Swedish market alone. The choice of investigating the Swedish market is of particular interest given an interesting observation relating to the relationship between Research and Development (R&D) investments and innovative output in Sweden. In 1998 Edquist and McKelvey showed the presence of a so-called R&D paradox in Sweden. The researchers found that while the Swedish ratio of R&D spending to GDP is high in an international comparison, the Swedish economy produces a below average percentage of R&D intensive products seen in relation to total manufacturing (Edquist and McKlevey, 1998). This paradox has been shown to persist in more recent studies as well (Bitard et al., 2008). The aforementioned research suggests that investments in R&D might not easily translate into innovative output, something that could represent an opportunity for private equity investors in the Swedish market to improve the translation of R&D spending into innovation output.

Last, while Lerner et al. (2011) analyze patents, which is a metric measuring the output of innovation, we extend the analysis to also consider the input aspect. We do this by analyzing how investments in R&D translate into innovative output, as measured by the number of patents and the quality of such patents, to see if this relationship changes in the period following the LBO transaction.

Whether the nature of the corporate time horizon changes or not following an LBO transaction, and how that impacts long-run investments in innovation on the Swedish market, is ultimately a question this paper aims to answer. More specifically, we aim to analyze the effect of private equity ownership on an LBO firm's innovation performance, activity and productivity.

First, the performance of innovation is in this paper proxied by the number of citations a patent receives, i.e. the citation intensity of the patent. The number of citations a patent receives has been shown to be positively correlated with the economic importance of the patent (OECD, 2009). A company that has produced a patent that receives many citations[2] has produced high quality, and valuable, innovation (Hall, Jaffe and Trajtenberg, 2005). For this reason, we consider the number of citations a patent receives an indicator of quality and value. In our analysis, we consider how the citation intensity of LBO firms patents change in the period surrounding the LBO transaction.

Second, we analyze the effect on innovation activity by observing how the

[2] A patent can receive two types of citations, forward citations and backward citations (OECD, 2009). While a backward citation is a citation to previous patent documents and thus helps track knowledge spillovers in technology, a forward citation is the number of citations subsequently received by a patent (ibid.) and this is what we analyze in this paper. Throughout this paper, when writing "citations" we refer to "forward citations".

level of patent applications undertaken by the firm evolves in the period before and after a private equity transaction. That is, we analyze if the number of patents applied for differs in the period after the LBO transaction or not. Last, we investigate the productivity of innovation activities. In this part of the analysis we primarily consider how the return on investments in R&D, as measured by the number of patents and the corresponding quality of those patents, changes in the period following the private equity investment.

We formulate three hypotheses based on previous literature. In terms of the performance of innovation activities, as measured by the citation intensity of patents, we formulate a hypothesis in favor of a positive effect from the private equity transaction based on the findings of Lerner et al. (2011):

H1: *The quality of LBO firms patents are higher after an LBO transaction compared to the quality of patents applied for before the transaction*

For the analysis on how the level of patenting is impacted by the private equity transaction, we also rely our hypothesis on the findings of Lerner et al. (2011) who did not find any clear pattern denoting either a decrease or increase in the patenting activity. Since there are no findings providing evidence against this study, we state our hypothesis to be:

H2: *LBO firms produce as many patents after the LBO transaction as they did before the transaction*

With regards to the productivity of innovation activities, we base our hypothesis on studies that point towards a positive effect on corporate governance from private equity ownership, meaning less profitable investments and similar agency costs should be reduced (Harbula, 2015). The hypothesis subsequently becomes as follows:

H3: *The productivity of innovation activities for an LBO firm is higher after an LBO transaction compared to the productivity before the transaction*

We construct a sample of 87 firms on the Swedish market which have been private equity owned some time in the period between 1994 and 2019 and that have applied for at least one patent in the time period between 3 years before the private equity transaction until 5 years after. In total, these 87 firms applied for 1969 patents which we analyze in this study.

Our main findings are not in line with our hypotheses. Although our tests show low levels of statistical significance, the findings of our tests indicate that both the performance of innovation activities and patenting activity is lower in the period following the private equity transaction. Our findings indicate that the patents receive fewer citations and that the patenting level seems to decrease after the LBO transaction.

Given our findings on the quality of patents and the number of patents applied for, we extend the analysis and ask whether private equity owners neglect dedicating resources to long-run investments in innovation, or if it is rather the case that the productivity of these innovation activities deteriorate under the private equity ownership period. We show that while the R&D intensity of private equity backed firms does not seem to change significantly following the private equity investment, the yield on investments in R&D, as measured by the number of patents and the corresponding quality of those patents, seems to decrease. These results on the productivity of innovation activities are generally significant.

Based on the results of our initial tests we choose to redo parts of our tests with a restricted sample which only includes private equity investments and patents from the period before the global financial crisis of 2008. By doing so, the sample in our study should be more comparable to that of Lerner et al. (2011). We now find a positive, and statistically significant, effect on the quality of patents from the private equity transaction, in line with our hypothesis and the results of Lerner et al. (2011). This finding indicates that the studied relationship might have been positive also on the Swedish market for the period up until 2008. Given our results for the full time period are not in line with the above findings, this suggests that the relationship might have been impacted by the global financial crisis of 2008. However, this is by no means a perfect test to infer if the relationship has in fact changed following the crisis and we therefore suggest further research on if, and how, the relationship might have been impacted.

One limitation of the study is the size of our sample. The relatively small sample affects the precision of point estimates and decreases the statistical power of our tests. Although increasing the sample in terms of the number of firms would have been ideal, there is no reason to expect biases in the coefficients resulting from the small sample. Furthermore, the results of our study should not be neglected as a small sample artifact given that the findings of all our tests of the full time horizon are directionally consistent. Additionally, when we consider a similar time horizon as Lerner et al. (2011) our results are in line with the results of this previous study.

Our paper brings valuable insights to managers at target companies who are considering being acquired by a private equity sponsor, private equity firms who want to enhance the value of their portfolio companies as well as policy makers who better want to understand what implications private equity funding might have for innovation in Sweden.

The remainder of this paper is structured as follows. Section 2 provides the relevant theoretical background to this paper. Section 3 presents the sample and descriptive statistics of the data. Section 4 describes the methodology and section 5 presents the results of the study, followed by robustness tests, a discussion of the findings and study limitations. Section 6 concludes the paper and presents suggestions of future research.

2 Theoretical Background

There are four branches of literature related to this study. The first relates to value creation in the private equity ownership model, and the second to the importance and measurement of innovation. Further, the third branch is related to the impact of leverage on innovation and the last on the impact of various ownership models on innovation activity generally.

2.1 The Private Equity Model

The literature on private equity points towards two main drivers of value creation during the holding period of a portfolio company. First, a central element in the private equity model is the use of high levels of outside debt to acquire portfolio companies (Kaplan and Strömberg, 2009). While the use of debt in the capital structure increases the risk of the investment, it also increases the expected return on the equity portion that the private equity firm earns, and provides a tax shield on interest payments on the debt portion (Harbula, 2015). Jensen (1989) further argues that the use of leverage can be a source of value by providing discipline to portfolio companies given the requirement to meet interest payments, thus lowering agency costs. Second, by having one active majority owner which can closely monitor the company, less profitable investments and other similar agency costs are reduced given the improved corporate governance (Harbula, 2015).

The degree to which private equity creates value has however caused debate. Critics have questioned the above claimed drivers of value and argued that private equity funds are breaking explicit and implicit contracts with workers (Kosman, 2009) or taking advantage of favorable tax policies for corporate debt (Shleifer and Summers, 1988) in order to create shareholder value. As Lerner et al. (2011) point out, while some argue that private equity owners take a longer-run perspective compared to public market firms, others have claimed that the private equity model rather is a "quick flip" construction whereby firms are listed as soon as possible following the investment in order for the private equity firm to raise new funds and earn fees.

On the one hand, the short holding period of the investment and the use of high levels of debt to realize high returns on equity could be claimed to be a construct to realize short term value. On the other hand, the improved governance and the use of leverage which provides discipline to portfolio companies could be argued to be a source of long-term value creation. As has been made evident, the literature is divided on the topic of private equity and value creation.

2.2 Innovation

Innovation has long been regarded a necessary component for lasting economic growth and prosperity (Solow, 1957). While several studies have established the importance of innovation, a number of different researchers have shown how investments in innovation and long-term growth is sacrificed at times, for instance in order to meet quarterly earnings estimates (Graham et al., 2005). Studies from the global financial crisis of 2008 have also shown that firms stopped ongoing innovation projects during the crisis and that this tendency was strongest for firms without access to public capital markets (Paunov, 2012).

Furthermore, an important body of research relating to this paper is that on the measurement of innovation. The two main metrics in the literature are either input based metrics, such as R&D expenditure or R&D intensity, or output based metrics, such as patents or trademarks. Early research finds a positive effect of both R&D expenditures and the number of patent applications a firm produces on the value of the firm (Griliches, 1981). Regarding the relationship between R&D expenditures and patents, research by Griliches, Pakes and Hall (1986) point to a positive correlation between the two. Not only do firms which spend a lot on R&D also accumulate many patents, changes in the R&D program has been shown to produce similar changes in the level of patenting (Griliches, Pakes and Hall, 1986). Griliches, Pakes and Hall (1986) also show that the positive relationship between R&D and patenting activity is largely contemporaneous.

On the one hand, considering R&D based metrics is a widely adopted method when analyzing innovation, see for instance research by Lichtenberg and Siegel (1990). While R&D based metrics are good indicators of how firms prioritize longer-run investments, this method has been criticized by Jensen (1993) since not all R&D projects necessarily are well spent, and because they do not provide any insights on the quality of the investments.

On the other hand, patent based metrics enable the measurement and analysis of the innovative performance of firms, as has been shown in studies by e.g. Lerner et al. (2011) or Demir and Mohammadi (2019). Research by Trajtenberg et al. (2005) furthermore confirms earlier studies by Griliches (1981) and show that patents have a positive correlation with the value of the firm. Although some innovations may be protected as trade secrets, patents are a widely accepted measure of innovative performance and the metric lends itself well in an analysis of private equity transactions given the availability of patent data on both private and public firms.

2.3 Leverage and Innovation

Given the importance of leverage in the private equity model, we turn to a number of studies which focus on the impact of leverage on innovation. Hall (1989) studies the US manufacturing sector between 1974 and 1987 and finds that high leverage is a determinant of low R&D spending, consistent with the disciplinary effect leverage might have on managers. Similar findings are made in Himmelberg and Petersen's (1991) study on high-tech firms and in Hall and Bronwyns (1992) study on manufacturing firms. While the findings of these papers indicate that more leverage is associated with less R&D spending, it is not established if it is the leverage that leads to less R&D spending or if firms that struggle have more debt in their capital structure and thus invest less in R&D. In terms of the quality of innovations as measured by patents, Atanassova et al. (2007) find that firms with bank financing rather than bonds or externally financed equity hold less patents and that those patents receive less citations. While there seems to be clear evidence that leverage and innovative activities are negatively correlated, the casual direction of the relationship has not yet been established.

2.4 Ownership and Innovation

Another related literature is that on the effect of ownership structures on innovation. Bernstein (2015) analyzes the effect of going public on innovation, by comparing firms that undergo an initial public offering (IPO) with firms that withdraw their IPO-filings. The author finds that the quality of internal innovation declines following the IPO. In a study of 400 executives of public companies, Graham et al. (2005) show that almost four out of five executives admit to having sacrificed long-term value creation to smooth earnings. Lichtenberg and Siegel (1990) analyzes leveraged buyouts on the US market and find that research related spending increased following the LBO transactions. In a European context, Popov and Roosenboom (2009) conduct a cross-country study between 1992 to 2004 and analyze how private equity risk capital affects patent applications and grants. The researchers find that a 1% increase in private equity risk capital investment increases the number of patent grants by between 0.04% and 0.05%[3]. The general direction of these studies suggests that the effect of private equity financing on investments into innovation should be positive and that firms on public markets should experience a decline in the quality of their innovation following their IPOs.

In the aforementioned seminal study from 2011, Lerner, Sorensen and Strömberg analyze investments in innovation as measured by patenting activity and the quality of patents in the years leading up to, and the years following, an LBO transaction. With a sample of 472 LBO transactions on the US market, the researchers do not find that the level of patents changes after the transaction. They do however find that LBO firm's patents receive more citations and that these patents are more focused in the firm's core areas of innovation post the transaction. In a similar study, Demir and Mohammadi (2019) look at a more niche segment of firms which go private. These authors also find that the most important innovations have higher quality (i.e. receive more citations) after going private compared to the most important innovations prior to the transaction. Both studies indicate a positive effect on innovative output from becoming a private equity owned firm on the US market.

[3]The cross-country study by Popov and Roosenboom (2009) includes data on the Swedish market, however, the authors do not specifically consider the effect of an LBO transaction (where debt is a key component) but rather focus on private equity risk capital where venture capital financing is also considered. No country specific results are presented in the paper.

3 Data

In this section we describe the process of identifying private equity transactions and matching the involved firms to data on patent applications and citations, as well as data on the productivity of innovation activities that these firms have undertaken. We also present descriptive statistics of our dataset.

3.1 Private Equity Transactions

We start from the Venture Xpert database provided by the Swedish House of Finance Research Data Center to identify buyout transactions involving Swedish target companies. The database contains information on transactions ranging from 1999 to 2019. Through this database we are able to find 802 such transactions. This list of transactions is complemented with a bottom-up analysis of 53 private equity buyout funds which have been active on the Swedish market. By examining each respective buyout fund's website, we are able to identify an additional 598 private equity transactions which took place between the early 1990s and 2019, and thus have a dataset of approximately 1400 private equity transactions which occurred on the Swedish market.

We eliminate three types of transactions from the initial dataset. First, we exclude all secondary deals, i.e. transactions where the seller of the target firm is another private equity firm. This is done to ensure that our analysis only considers the shift from a non-private equity owner to a private equity owner. Additionally, by doing this we ensure that each firm is only part of the sample once. Second, we exclude all deals where the acquiring firm was not a financial sponsor to ensure all acquirers are in fact private equity companies. Last, deals where the target firm remains traded on a public stock market after the transaction, that is private investments in public equity (PIPE) transactions, are also excluded from the dataset. This is done to make sure that the private equity acquirers have a similar possibility to impact the firms, something which might be limited if a firm remains traded on a public stock market. After having eliminated these transactions we are left with approximately 500 transactions where each transaction relates to one unique firm.

The above data is supplemented with data on corporate identity numbers from Retriever Business. Furthermore, details on the transactions as well as subsequent exits are obtained from company press releases and the website mergr.com, which is a database with information on M&A transactions worldwide (Mergr, 2020).

3.2 Patent Data

Our starting point for the data on patenting activity is the European Patent Office (EPO). The EPO provides data on patents from many of the world's different patent offices through its service PatStat (EPO, 2020). Through the PatStat SQL database, we are able to retrieve information on patents and their corresponding citation data for patents which Swedish firms have applied for through the European Patent Office, Patent- och Registreringsverket (PRV), the Patent Cooperation Treaty (PCT) and the United States Patent and Trademark Office (USPTO).

In order to match the patents retrieved from the PatStat SQL database with the firms in our sample, we use the PatLink dataset provided by the Swedish House of Finance Research Data Center (Swedish House of Finance, 2020). The PatLink dataset connects each unique patent identifier with a corresponding corporate identity number for all patents that belong to Swedish firms and that were applied for between the years 1990 and 2019. The patent identifier originates from PatStat and the corresponding corporate identity numbers are extracted from the Serrano database (ibid).

For the 500 identified transactions, we find 146 firms which have applied for at least one patent. Since we aim to investigate the effect of private equity ownership on innovation activity, we restrict our sample to firms which have applied for at least one patent in the period from three years prior up until five years after the private equity transaction. With this restriction, we identify 87 firms in total which have applied for at least one patent in the [-3;+5] time period. In total, these firms have applied for 1969 patents during this window. These firms and patents subsequently make up the final sample of the main analysis.

One limitation is that if a Swedish firm only has applied for a patent for the Swedish market (from the PRV) there is no record of the number of citations that the patent has received and we therefore choose to excluded the patent from our analysis (Patstat, 2020). However, Swedish firms to a larger degree than ever before apply for patents on the European or world level (through EPO, PCT or USPTO), rather than solely on the national level (Rasch, 2020). Consequently, there is no reason to believe that the exclusion of patents applied for solely on the Swedish market should make the results of our study less representative of the patenting activities of Swedish firms.

Additionally, the fact that we focus our analysis solely on the Swedish market is reflected in the small number of firms and patents in our sample. For this reason, we choose to consider patent applications for both ultimately granted and non-granted patents in the main analysis of this paper. All patent applications which have been published by a patent office such as the EPO can receive citations and we can therefore include published but ultimately non-granted patents as well. In section *5.5 Robustness* we perform a robustness test of our results where we only consider the ultimately granted patents and there end up with a sample of 68 firms with 1098 patents.

3.3 Innovation Productivity Data

We retrieve data on firms' research and development activities from the Serrano database, provided by the Swedish House of Finance research data center. Given that accounting practices for how to register innovation activities differ between firms, not all firms in our sample record R&D. As a result, this part of the analysis is based on a smaller sample of 49 firms and 1113 patents.

Data on R&D costs, depreciation of R&D assets and on the opening and closing balance of R&D assets for each of the years from 3 years prior up until 5 years after the private equity transaction is gathered. This data is used to calculate the R&D expenditure, which is described in further detail in section *4.3 Productivity of Innovation Activities*. Data is matched to the corresponding firm using corporate identity numbers. From the Serrano database, we also retrieve data on sales and number of employees.

3.4 Descriptive Statistics

Descriptive statistics on patents per firm and citations per patent are presented in Table I. The mean number of patents per firm is 22.6 while the median is 5 patents. The spread between number of patents per firm is large, as can be inferred by the high standard deviation. In terms of the number of citations per patent, the mean is 12.1 and the median 8 citations. Since some patents have not received any citations, the minimum number of citations for some patents in our sample is zero.

The fact that the mean number of patents per firm is considerably higher than the median indicates a positive skew in our dataset, this is confirmed when observing the maximum number of patents for a firm. This skew is primarily driven by the medical technology company *Gambro* which had 749 patents assigned in the time period between three years prior until five years after the LBO by the private equity group *EQT* in 2006. The patents assigned to *Gambro* constitute approximately 35% of the patents we identify, in contrast the second largest patentee accounts for 6% of the sample. However, since the variations in our regressions are at the firm level and we are clustering standard errors on the firm level, the fact that *Gambro* constitutes a large fraction of our sample should not bias the results in our tests. For this reason, we choose to include the company and its patents in our sample. For robustness, we perform additional tests where all patents belonging to *Gambro* are excluded in section *5.5 Robustness*.

Table I
Descriptive Statistics on Patents per Firm and Citations per Patent

Statistics are based on a sample of 1969 patents applied for by 87 firms on the Swedish market between 1991 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction.

Panel A: Patents per firm

n Firms	n Patents	Mean	SD	Min	Median	Max
87	1 969	22.6	81.3	1	5	749

Panel B: Citations per patent

n Patents	n Citations	Mean	SD	Min	Median	Max
1 969	23 813	12.1	13.3	0	8	117

Table II shows correlations between all variables used in our regressions. These correlations are calculated based on 255 firm-year pairs and the variable definitions can be found in section *4.3 Productivity of Innovation Activities.* As can be inferred from the table, the number of patents and citations are strongly positively correlated. This is expected since the number of patents should drive the number of citations. In terms of patents' and citations' correlation with sales and R&D expenditure, we observe a higher positive correlation with sales than with R&D. Interestingly, R&D expenditure is more strongly correlated with the number of citations a patent receives than with the number of patents applied for, suggesting that R&D efforts are rather an input to increase the quality of patents than to increase the number of patents produced.

Table II
Correlation Matrix

Correlations are based on a sample of 255 firm-year pairs for firms that were part of an LBO transaction some time in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction.

	Sales	R&D Expenditure	Employees	Patents	Citations
Sales	1.0000				
R&D Expenditure	0.6572	1.0000			
Employees	0.9652	0.6243	1.0000		
Patents	0.6733	0.3580	0.7638	1.0000	
Citations	0.7208	0.4755	0.7975	0.9276	1.0000

Table III shows the transaction and exit years for all firms in the sample as well as the application and grant year for the patents. Investments are concentrated around the period between years 2000 to 2010. Exits lag transactions by approximately six years on average which is expected given the nature of private equity investment strategies as elaborated on previously.

Table III
Transaction Years, Exit Years and Patent Application and Grant Years For Firms and Patents in Sample

The full sample consists of 1969 patents applied for by 87 Swedish firms that were private equity owned sometime in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. An exit is defined as the private equity fund divesting the LBO firm. Applications are defined as a patentee firm applying for a patent, a grant is defined as the patent ultimately being granted. Not all patents are ultimately granted.

	PE deals		Patents	
Year	Transactions	Exits	Applications	Grants
1991	N/A	N/A	2	0
1992	N/A	N/A	1	0
1993	N/A	N/A	0	0
1994	3	0	4	2
1995	0	0	9	2
1996	2	0	25	1
1997	5	1	88	3
1998	4	1	89	8
1999	5	0	90	21
2000	7	1	124	36
2001	8	0	115	34
2002	7	2	84	56
2003	5	2	150	52
2004	2	5	213	52
2005	3	9	198	26
2006	5	9	119	48
2007	3	6	116	48
2008	7	4	92	64
2009	2	2	137	61
2010	5	4	119	78
2011	3	3	103	81
2012	4	2	23	77
2013	0	3	34	74
2014	2	3	18	83
2015	1	5	6	58
2016	1	8	3	48
2017	2	3	5	35
2018	0	2	2	36
2019	1	1	0	14
Total	87	76	1969	1098

Table IV provides details on the types of investments and exits in our sample. Investments are categorized as being "Private-to-Private", "Divisional", "Public-to-Private" or "Other". The number of firms corresponding to each category is presented in Panel A. The majority of investments are private-to-private, whereby a private equity company acquires a majority stake of a privately held firm from founders or management of the firm. The second biggest category is divisional transactions, whereby a larger corporation sells off a division to a private equity company. This is a growing transaction type according to research by Strömberg and Kaplan (2009). Panel B shows types of exits, where the private equity investor chooses to divest the company. These are categorized as being "Sale to strategic buyers", "Secondary", "Other/Unknown", "No Exit", "IPO" or "Bankruptcy". The largest category is sale to strategic, non-financial, buyers. Given these firms hold patents, one hypothesis is that the firms lend themselves well for acquisitions by strategic buyers. The rationale for this hypothesis would be that the strategic buyer wants to gain access to the innovation that the patent is protecting, and therefore chooses to acquire the firm.

Table IV
Type of Private Equity Investment and Exit with Patenting Within [-3;+5] Window

The full sample consists of 1969 patents applied for by 87 Swedish firms that were private equity owned sometime in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. An investment is defined as the LBO transaction event and an exit is defined as the private equity fund divesting the LBO firm. Data on investment and exit type is based on company press releases and the website mergr.com.

Panel A: Investments

Type	
Private-to-Private	48
Divisional	22
Other	9
Public to private	8

Panel B: Exits

Type	
Sale to strategic (non-financial) buyer	36
Secondary	18
Other/Unknow	13
No Exit	11
IPO	7
Bancruptcy	2

Table V shows the sector composition of firms and patents in our sample. Patents are assigned to the primary sector of the parent company based on the S&P Global Industry Classification Standard (S&P Global, 2020). We observe quite large deviations between the share of firms in each sector and the share of patents assigned to these sectors. One example is the health care sector. While 46% of the patents belong to firms within the health care sector, these patents are held by only 11% of the firms in the sample.

Table V
Sector Composition of Firms and Patents

The full sample consists of 1969 patents applied for by 87 Swedish firms that were private equity owned sometime in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. The sector classifications are based on the S&P Global Industry Classification Standard as reported in Capital IQ. Patents are assigned to the primary sector of the parent company.

Sector	Share of Firms	Share of Patents
Materials	5.7 %	4.1 %
Consumer Discretionary	17.2 %	7.9 %
Consumer Staples	6.9 %	1.2 %
Industrials	44.8 %	31.8 %
Health Care	11.4 %	46.3 %
Information Technology	12.6 %	8.5 %
Communication Services	1.1 %	0.3 %

The same tendency is illustrated in Figure I which illustrates the average number of patents per firm by sector and the average number of citations per patent by sector. Once again, the health care sector stands out with 91 patents per firm on average. With regards to the number of citations per patent, the materials sector stands out with an average of 37 citations per patent. For this reason, we conduct controls for firm fixed effects in our regressions following recommendations of Amir et al. (2015).

Figure I
Average Number of Patents per Firm and Citations per Patent, by Sector

The full sample consists of 1969 patents applied for by 87 Swedish firms that were private equity owned sometime in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. The sector classifications are based on the S&P Global Industry Classification Standard as reported in Capital IQ. Patents are assigned to the primary sector of the parent company. Patents per firm are calculated as the average number of patents applied for by firms belonging to that specific sector. Citations per patent is calculated as the average number of citations received to date by patents belonging to firms in that specific sector.

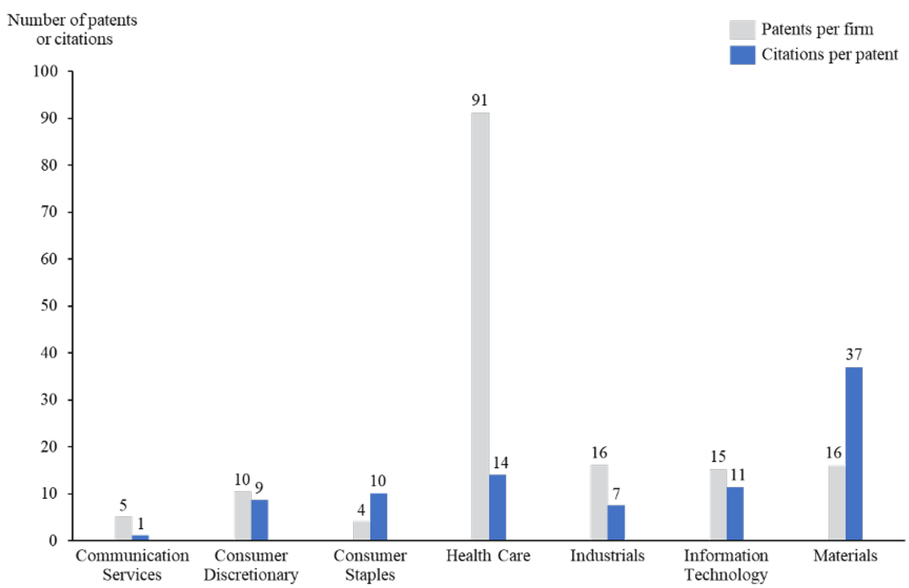
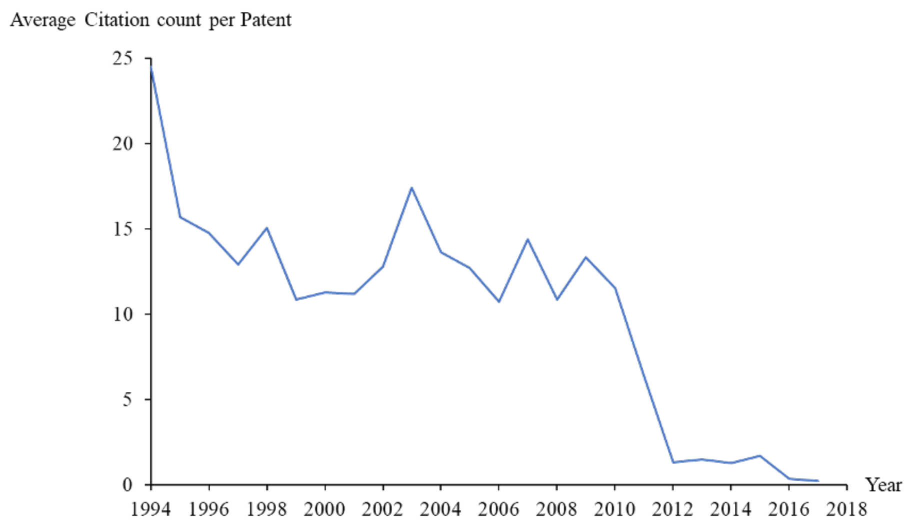


Figure II illustrates one of the key challenges faced by our methodology. The figure shows the average number of citations a patent has received to date depending on its application year. Patents applied for in the beginning of the period have on average received more citations compared to patents applied for in recent years. This tendency comes as no surprise as older patents have naturally had a longer "window of opportunity" to receive citations, meaning there is a truncation bias because of the systematic cross-year differences in citations received by patents in our sample. It is however of crucial importance to account for this difference in the window of opportunity in our tests. For this reason, we control for year fixed effects in our regressions following Jaffe and Trajtenberg (2002).

Figure II
Average Citations per Patent to Date

The full sample consists of 1969 patents applied for by 87 Swedish firms that were private equity owned sometime in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. Average citation count per patent is calculated as the average number of citations received to date by patents applied for in that specific year.



Last, table VI presents descriptive statistics on the data relating to the productivity of innovation activities for a subset of our sample with 255 firm-year observations. The average firm has 2bn SEK in sales, 82m SEK in R&D expenditures and 1300 employees annually. Again, we observe a positive skew in our sample for all variables since the mean R&D expenditure, sales figure and number of employees figure is substantially higher than the median. To control for this tendency, we include firm fixed effects in our regressions on the productivity of innovation activities.

Table VI
Descriptive Statistics on Productivity of Innovation Analysis Sample

Statistics based on a sample of 255 firm-year pairs for firms that were part of an LBO transaction some time in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. All figures are presented on an annual basis.

	Mean	SD	Min	Median	Max
Sales (mSEK)	2 050	4	1	447	26 617
R&D Expenditure (mSEK)	82	0.3	0.2	22	2 837
Employees	1 331	3 064	3	216	21 391

4 Methodology

In preparing our data for the regressions we construct a number of metrics for analyzing the effect of an LBO transactions on the citation intensity, the level of patenting and the productivity of innovation activities of LBO firms. These metrics are presented below together with model specifications for all the models used in our regressions.

4.1 Citation Intensity

According to previous literature, the number of forward citations a patent accumulates is a key estimator of the economic value of the patent (Hall et al., 2005). Patents which receive a larger number of forward citations are considered more valuable than patents which accumulate a smaller number as elaborated on previously. However, using the unadjusted, absolute, number of citations a patent has received is problematic for two reasons, one related to the timing of the citations received by the patents we analyze and another related to differences among the technical fields of patents.

First, the window of opportunity for a patent to receive citations is directly related to how much time has passed since the application date. This means that older patents will have had a longer time to accumulate citations than more recent ones, a tendency which is confirmed in Figure II in section *3.4 Descriptive Statistics*. This creates a truncation bias given the systematic cross-year differences in the number of citations received by patents in our sample. Second, the propensity to accumulate citations is related to the sector of the patent. In Figure I in section *3.4 Descriptive Statistics* we observed a large dispersion of the number of citations patents receive across different sectors. This means that some patents will accumulate more citations than others because of the nature of the research they pertain to.

We mitigate both problems in two ways. First, we follow Jaffe and Trajtenberg (2002) and incorporate year fixed effects in all our regressions to account for the truncation bias. Furthermore, we construct a relative citation measure following Hall, Jaffe and Trajtenberg (2001) to address the differences between sectors. This measure is calculated as the number of forward citations accumulated by the patent less the average number of citations of the matching patents. The matching patents are defined as all patents applied for by Swedish firms in the years between 1991 and 2019 with the same application year and section as the observed patent. A section is an industry classification defined by the European Patent Office (EPO, 2020) and we use this patent specific classification when calculating the relative citation count. This is further described in section *4.1.2 Relative Citation Intensity* below.

We proceed by defining four models which all serve to estimate the possible shift in citation intensity arising from private equity ownership, two based on the absolute citation intensity and two based on the relative citation intensity. One important consideration is the choice of distribution we use for our models. The number of citations a patent receives could be presumed to follow a count model, such as a negative binomial distribution. However, when we calculate the relative citation measure all patents with citation counts below the average of their matching patents will have a negative value for their relative citation intensity. Because the negative binomial distribution can only incorporate positive values, we cannot directly apply a negative binomial model on our data. By using an OLS model we are able to use both negative and positive realizations of the dependent variable.

4.1.1 Absolute Citation Intensity

Initially, we construct an absolute citation intensity metric based on the raw citation count that a patent receives. This metric serves as the dependent variable in models (1) and (2).

$$Absolute\,citations_i = total\,number\,of\,raw\,citations\,earned\,by\,patent\,i$$

For our independent variables in model (1) we specify dummy variables for each of the periods from 3 years before until 5 years after the private equity transaction. Each of the dummy variables for a specific patent is then assigned a value of 1 if the patent was applied for in that particular period, relative to the transaction year of the patentee firm. For instance, a patent applied for 2 years before the transaction year will hold a value of 0 for all dummy variables except the *Event Year -2* dummy, since this dummy corresponds to the application year for that particular patent relative to the transaction year of the patentee firm. We use the following model for estimating the citation intensity of each patent i.

$$\begin{aligned} Absolute\,\hat{citations}_i = [EventYear-3]_i\hat{\beta}_{[EventYear-3]} + ... \\ +[EventYear+5]_i\hat{\beta}_{[EventYear+5]} \end{aligned} \tag{1}$$

Where:

$$[EventYear{-}3]_i = patent\,is\,applied\,for\,three\,years\,before\,the\,transaction\,year$$

$$[EventYear+5]_i = patent\,is\,applied\,for\,five\,years\,after\,the\,transaction\,year$$

Furthermore, in order to investigate the general effect on the absolute citation intensity in the entire period following the LBO transaction we specify the following parsimonious model.

$$Absolute\hat{\,citations}_i = [PostLBO]_i\hat{\beta}_{[PostLBO]} \tag{2}$$

Where:

$$[PostLBO]_i = patent\,is\,applied\,for\,sometime\,in\,the\,period\,between$$
$$EventYear\,+1\,and\,EventYear\,+5$$

We incorporate year and firm fixed effects in both models (1) and (2) above since the variables might have some group characteristics which are not dependent on the transaction taking place. Furthermore, year fixed effects mitigate the truncation bias associated with patents from different years having different windows of opportunity to accumulate citations, as elaborated on previously. We cluster standard errors at the firm level for all the models above. Our reasoning for using clustered standard errors is that the error terms for the models might not be independent on a firm level. Last, we winsorize the data at a 0.5% and 99.5% level to decrease the effect outliers might have on our regression results.

4.1.2 Relative Citation Intensity

We construct the relative citation metric according to the equations below, in which *Citations* is the total number of raw citations earned by the patent *i*. The average number of citations for matching patents is defined as γ and *Total Citations* is the number of citations received by all matching section patents.

$$Relative\,citations_i = Citations_i - \gamma_i$$

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

Similar to the model on the absolute citation intensity, we specify a dummy variable for each of the periods from 3 years before until 5 years after the private equity transaction. We use the following model for estimating the citation intensity of each patent *i*.

$$Relative\,\hat{citations}_i = [EventYear-3]_i\hat{\beta}_{[EventYear-3]} + ... \\ +[EventYear+5]_i\hat{\beta}_{[EventYear+5]} \tag{3}$$

Where:

$$Relative\,citations_i = total\,number\,of\,relative\,citations\,earned \\ by\,a\,specific\,patent$$

$$[EventYear{-}3]_i = patent\,is\,applied\,for\,three\,years\,before\,the\,transaction\,year$$

$$[EventYear+5]_i = patent\,is\,applied\,for\,five\,years\,after\,the\,transaction\,year$$

Once again, in order to investigate the general effect on the relative citation intensity in the entire period following the LBO transaction we specify the following parsimonious model.

$$Relative\,\hat{citations}_i = [PostLBO]_i\hat{\beta}_{[PostLBO]} \tag{4}$$

Where:

$$[PostLBO]_i = patent\,is\,applied\,for\,sometime\,in\,the\,period\,between \\ EventYear\;+1\,and\,EventYear\;+5$$

As done previously, we incorporate year and firm fixed effects in the models. We cluster standard errors at the firm level and winsorize the data at a 0.5% and 99.5% level, as elaborated on in the previous section.

4.2 Patenting Level

We now proceed to the analysis of the number of patents applied for by LBO firms in order to investigate if the patenting activity changes in the period following the transaction. Each observation in this analysis is a specific firm-year pair where we observe each firm in the sample for nine consecutive periods, from 3 years before the transaction until 5 years after the transaction. Each of these years constitutes one unique period. Although using similar models to those specified in section *4.1 Citation Intensity* would make for a more detailed analysis of the patenting levels among firms before and after a private equity transaction, it would cause an identification problem in our models. Because the patenting pattern differs across firms and years it is ideal to incorporate both firm and year fixed effects into our models. However, this model is not identified because the firm fixed effect variable defines the event time and this together with the indicators for when the firm is observed uniquely determines the year. We mitigate this problem by dividing our time period into three unique periods for model (5) and four periods for model (6) below.

The independent variables for these regressions denote in what period the firm is observed relative to the transaction year. We specify two different models for estimating the effect from a private equity transaction. First, a model with two different dummy variables is specified to investigate the effect in the year of the private equity transaction and in the entire period after the transaction[4]. The model is specified as follows where i denotes the specific firm observed and t denotes in what period relative to the event year it is observed.

$$\begin{aligned} Patent\,app\hat{l}ications_{i,t} = [EventYear]_{i,t}\hat{\beta}_{[EventYear]} + \\ [PostLBO]_{i,t}\hat{\beta}_{[PostLBO]} \end{aligned} \tag{5}$$

Where:

$$Patent\,applications_{i,t} = number\,of\,patents\,applied\,for\,by\,firm\,i\,in\,period\,t$$

$$[EventYear]_{i,t} = company\,observed\,in\,Event\,Year\,0\,i.e.\,the\,transaction\,year$$

$$\begin{aligned} [PostLBO]_{i,t} = company\,observed\,sometime\,in\,the\,period\,between \\ EventYear\,+1\,and\,EventYear\,+5 \end{aligned}$$

Since we also want to investigate whether the effect from a private equity transaction on the patenting activity happens immediately or gradually over the holding period of the private equity company, we specify a model which splits the post transaction period into multiple sequences. This model follows below.

$$\begin{aligned} Patent\,app\hat{l}ications_{i,t} = [EventYear]_{i,t}\hat{\beta}_{[EventYear]} + \\ [EventYear+1]_{i,t}\hat{\beta}_{[EventYear+1]} + [PostLBO+1]_{i,t}\hat{\beta}_{[PostLBO+1]} \end{aligned} \tag{6}$$

Where:

$$[EventYear+1]_{i,t} = company\,observed\,in\,period\,EventYear+1$$

$$\begin{aligned} [PostLBO+1]_{i,t} = company\,observed\,sometime\,in\,the\,period\,between \\ Event\,Year\,+2\,and\,EventYear\,+5 \end{aligned}$$

Similar to the regressions on the citation intensity described in section *4.1.1 Absolute Citation Intensity* and *4.1.2 Relative Citation Intensity* we incorporate firm and year fixed effects into these regressions. We also cluster the standard errors on the firm level and winsorize the data at the 0.5% and 99.5% level.

[4]We provide an illustration of these sequences in Appendix A for clarification.

4.3 Productivity of Innovation Activities

Next, we investigate the input side of innovation activities, and consider whether the productivity of innovation activities changes following the private equity transaction. We start by analyzing whether private equity owned companies dedicate a different amount of resources to R&D relative to sales in the same period. The unit of observation in these regressions is similarly to the ones in section *4.2 Patenting Level* a specific firm-year pair. To estimate the R&D intensity of firm i in period t the following model is defined.

$$R\&D\,In\hat{tensity}_{i,t} = [PostLBO]_{i,t}\hat{\beta}_{[PostLBO]} \tag{7}$$

Where:

$$R\&D\,Intensity_{i,t} = \frac{R\&D\,Expenditure_{i,t}}{Sales_{i,t}}$$

$$\begin{aligned} R\&D\,Expenditure_{i,t} = R\&D\,Costs_{i,t} + (CB(Capitalized\,R\&D\,Expenditures_{i,t})\\ -OB(Capitalized\,R\&D\,Expenditures_{i,t})\\ +Depreciation\,of\,Capitalized\,R\&D\,Expenditures_{i,t}) \end{aligned}$$

$$\begin{aligned} [Post\,LBO]_{i,t} = company\,observed\,sometime\,in\,the\,period\,between\\ Event\,Year\,+1\,and\,Event\,Year\,+5 \end{aligned}$$

The model above compares the R&D expenditure of LBO firms after a private equity transaction to the expenditure levels before the transaction. We have calculated R&D expenditure as the sum of R&D costs in a given year plus the difference between the opening and closing balance of capitalized R&D expenditure while excluding depreciation of capitalized R&D expenditures. This model aims to answer whether the private equity transaction has any effect on the R&D intensity of the company.

To answer the question of whether private equity ownership impact the productivity of innovation activities for the LBO firms we specify four additional models. The two first models consider how the level of patenting activity and the corresponding number of citations of those patents per 10 mSEK in R&D expenditure are impacted by the private equity transaction. We define the models for each firm i observed in period t.

$$\frac{Patent\,\hat{applications}_{i,t}}{10\,mSEK\,in\,R\&D\,Expenditure_{i,t}} = [Post\,LBO]_{i,t}\hat{\beta}_{[Post\,LBO]} \tag{8}$$

$$\frac{Cit\hat{ations}_{i,t}}{10\,mSEK\,in\,R\&D\,Expenditure_{i,t}} = [Post\,LBO]_{i,t}\hat{\beta}_{[Post\,LBO]} \tag{9}$$

Where:

$$Patent\,applications_{i,t} = number\,of\,patents\,applied\,for\,by\,firm\,i\,in\,period\,t$$

$$Citations_{i,t} = total\,number\,of\,absolute\,citations\,earned\,by\,patents\,applied\,for\,by\,firm\,i\,in\,period\,t$$

One could theorize that there would be a lag between when an R&D investment is made and when there is an effect on the patenting activity. We choose not to incorporate such a lag since several studies suggest a contemporaneous effect of R&D spending and patenting activity, see for instance Hall, Griliches and Hausman, 1984 or Gurmu and Pérez-Sebastián, 2008.

The last two models measure the effect a private equity transaction has on the number of patents the firm applies for and the corresponding number of citations for those patents per 100 employees working at firm i in period t.

$$\frac{Patent\,\hat{applications}_{i,t}}{100\,Employees_{i,t}} = [Post\,LBO]_{i,t}\hat{\beta}_{[Post\,LBO]} \tag{10}$$

$$\frac{Cit\hat{ations}_{i,t}}{100\,Employees_{i,t}} = [Post\,LBO]_{i,t}\hat{\beta}_{[Post\,LBO]} \tag{11}$$

Similar to previous models we incorporate firm and year fixed effects into these regressions. We also cluster the standard errors on the firm level and winsorize the data at the 0.5% and 99.5% level. By examining these models we should be able to judge what effect a private equity investment has on the productivity of innovation activities. Furthermore, we should be able to draw conclusions about how this compares to the resources private equity owned firms dedicate to innovation.

5 Results

In the following we present the results of our tests. First, we start by examining the change in citation intensity of patents after a private equity transaction. Second, we conduct an analysis of how the level of patenting activity changes after the private equity transaction, followed by a test of how the productivity of innovative activities is impacted. These tests are then redone with a sample where observations from the period after the global financial crisis of 2008 are excluded in order to analyze a sample that is more comparable to that of previous studies. We then perform robustness tests on our regressions to make sure our results are not biased by controllable factors. The robustness tests are followed by an overall discussion of our findings and we conclude the section with a discussion of study limitations.

5.1 Citation Intensity

Table VII below shows the results of our four different models for analyzing the effect of a private equity transaction on the quality of innovative output of an LBO firm. The purpose of the analysis is to investigate whether private equity ownership has any effect on the quality of the patents which the portfolio company applies for by comparing the citation intensity in the period before and after the private equity investment. The first two models, (1) and (2), use a year dummy for each year in the period between 3 years before and 5 years after the private equity transaction as independent variables. The dependent variables are the absolute citation count and the relative citation count, respectively. The two latter models, (3) and (4), are parsimonious model specifications where the independent variable is a dummy variable indicating whether the patent was applied for after the transaction and the dependent variables are the absolute and relative citation counts.

Table VII
OLS Estimates of Citation Intensity with Year and Firm Fixed Effects

The full sample consists of 1969 patents applied for by 87 Swedish firms that were private equity owned sometime in the period between 1994 and 2019. The regressions below use the full sample. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. The dependent variable is the number of citations a patent received. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the citation intensity. Standard errors are clustered on the firm level and reported below the coefficients. Data is winsorized at the 0.5% and 99.5% level.***, ** and * indicate statistical significance at the 10%, 5% and 1% levels.

	(1) Absolute	(2) Relative	(3) Absolute	(4) Relative
Event Year -3	6.878***	5.287***		
	(1.971)	(1.957)		
Event Year -2	4.437**	4.044**		
	(1.854)	(1.863)		
Event Year -1	3.472**	2.849*		
	(1.541)	(1.552)		
Event Year +1	0.489	0.276		
	(1.452)	(1.482)		
Event Year +2	-1.296	-1.425		
	(1.783)	(1.851)		
Event Year +3	0.819	1.102		
	(1.769)	(1.821)		
Event Year +4	-6.085***	-5.941***		
	(1.982)	(1.999)		
Event Year +5	7.552***	8.069***		
	(2.475)	(2.449)		
Post LBO			-1.698	-2.150
			(1.537)	(1.555)
Constant	11.217***	-4.180***	12.898***	-2.790***
	(0.860)	(0.833)	(0.436)	(0.440)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	1969	1969	1969	1969

The reported coefficients are citation counts relative to the event year, i.e. the transaction year. A coefficient greater (smaller) than zero indicates that patents applied for in the relevant year on average received correspondingly more (less) citations compared to the average for the transaction year patents. For instance, the coefficient of 6.878 for *Event Year -3* in model (1) means that patents applied for three years before the transaction year are expected to have 18.095 citations, or 6.878 more citations than the average patent in the transaction year (11.217 citations).

From model specifications (1) and (2), we observe that coefficients decrease in the years leading up to the event of the private equity transaction, meaning the quality of patents as proxied by the citation count gradually decrease up until the investment year. This is true for both absolute and relative citation intensity measures, meaning the effect persists even when we control for patent section and year. All these coefficients are statistically significant at the 10% level or lower.

Apart from *Event Year +5*, we observe lower coefficients in the period after the private equity transaction compared to the period before the transaction, meaning patents are cited less and thus should be of lower quality compared to the period prior to the private equity transaction. However, not all these coefficients are statistically significant, and the observed pattern is not entirely clear when considering results from model (1) and (2). We thus turn to the parsimonious models in specifications (3) and (4). The results from these models are not statistically significant, but are however directionally consistent. Both coefficients are negative, indicating that the citation count for patents applied for after the private equity backing in our sample seems to be decreasing. This indicates that patents applied for after the transaction year could be of lower quality than the patents applied for within and before the transaction year and these results are similar for both absolute and relative citation intensity measures, meaning the effect seems to persists when we control for patent section and year. However, since the coefficients in these two models are not statistically significant we cannot draw any strong conclusions for the full population.

In the fifth year following the private equity investment we observe a sharp increase in the citation count for both the absolute and relative citation measures in models (1) and (2). This increase does not follow the pattern of lower coefficients after the transaction. Since we cannot observe the fifth year after the private equity transaction for investments made after 2014, the results are based on fewer observations meaning results for this year should be interpreted with some caution.

Although the results of our tests of citation intensity on the Swedish market generally show low levels of statistical significance, they do not seem to support the hypothesis which expects that the quality of LBO firms patents should be higher after an LBO transaction compared to the patents applied for before to the transaction[5]. We will return to this finding in section *5.6 Discussion.*

[5] We redo these tests based on the smaller sample of 49 firms and 1113 patents that report R&D related data and find similar results.

5.2 Patenting Level

We proceed to our analysis on the number of patents applied for to gain insights on whether the level of patent applications that firms file for is affected by the private equity investment. An observation is a firm-year pair meaning we use nine observations per firm, one for each of the years from 3 years before until 5 years after the transaction. Table VIII below shows four different models which all incorporate the number of patents applied for by a specific firm in a specific time period as the dependent variables. The independent variables consist of dummy variables for when we observe the firm-year pair in relation to the event year. The *Post LBO* dummy includes observations for the entire period between the first year following the private equity investment until five years after, while the *Post LBO + 1* dummy includes observations from two year following the private equity investment until five years after. The Event year dummy only includes the observations for the event year (year 0) and the *Event year + 1* dummy only includes the observations for the first year following the private equity investment[6].

The first models, (1) and (2), are based on the entire sample of firms. In the latter models, (3) and (4), we have limited the sample to exclude divisional buyouts. The reason for excluding divisional buyouts is that we cannot control for the assignment of patents to corporate parents, rather than a division which is bought out by a private equity company, meaning the level of patenting pre versus post a divisional buyout might not be comparable. By excluding divisional buyouts, we ensure that the patenting activity data is comparable in the period before and after the private equity investment.

The reported coefficients are patent counts relative to the period before the private equity investment year. A coefficient greater (smaller) than zero indicates that the level of patent applications firms filed for on average increased (decreased) a corresponding amount compared to the average number of patent applications in the period before the private equity transaction.

[6]We provide an illustration of these windows in Appendix A for clarification.

Table VIII
OLS Estimates of Patent Counts with Year and Firm Fixed Effects

The full sample consists of 1969 patents applied for by 87 Swedish firms that were private equity owned sometime in the period between 1994 and 2019. Model (1) and (2) use the full sample whereas model (3) and (4) excludes divisional buyouts and thus consists of 1463 patents applied for by 65 firms. Firms are only included in the full sample if patents were applied for between 3 years before and 5 years after the private equity investment. The unit of observation is the number of patents applied for by a company each year during the period from 3 years before to 5 years after the private equity transaction. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the patenting level. Standard errors are clustered on the firm level and reported below the coefficients. Data has been winsorized at the 0.5% and 99.5% level. *, ** and *** indicates that the coefficient is statistically different from zero at the 10%, 5% and 1% levels, respectively.

	Full Sample		Excluding Divisional	
	(1)	(2)	(3)	(4)
Event Year	-0.084	-0.084	-0.985	-0.985
	(0.495)	(0.496)	(0.677)	(0.677)
Post LBO	-0.339		-0.858*	
	(0.360)		(0.497)	
Event Year +1		0.238		-0.338
		(0.437)		(0.702)
Post LBO +1		-0.484		-0.988*
		(0.372)		(0.466)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	783	783	585	585

The results of our tests on the full sample, models (1) and (2), are not statistically significant for any of the coefficients. This is not surprising since it would support our hypothesis that LBO firms should not produce a significantly different number of patents following the LBO transaction. However, all coefficients except for the *Event Year +1* coefficient in model (2) are directionally consistent and negative, which could indicate that the private equity ownership has an adverse effect on the level of patenting undertaken by the firm.

Model (3) and (4) consist of the same specification but are applied to a sample where divisional buyouts have been excluded. In these models we see a more pronounced effect on the patenting activity following the private equity transaction. All coefficients are negative and both the *Post LBO* and *Post LBO + 1* coefficients are statistically significant on the 10% level. The negative relationship between the private equity transaction and the patenting activity of the private equity backed firm indicates that firms apply for less patents in the period following an LBO transaction, compared to the period before the transaction.

Given that it is reasonable to exclude divisional buyouts from the sample since the level of patenting otherwise might not be comparable before and after the transaction, we rely on the results from model (3) and (4). The results of these tests do not confirm our hypothesis that LBO firms should produce as many patents after the LBO transaction as it did prior to the transaction, but rather indicate that the patenting activity seems to decrease following the transaction[7].

5.3 Productivity of Innovation Activities

In Table IX we study how the productivity of innovation activities evolve after the private equity transaction. The table shows five specifications where the dependent variable for model (1) is the amount of R&D expenditure relative the sales of the firm, for model (2) and (3) are citations and patents applied for per 10M SEK in R&D expenditures and for model (4) and (5) are citations and patents applied for per 100 employees at the firm. In all specifications, the independent variable is a dummy denoting observations after the transaction.

Table IX
OLS Estimates of Productivity of Innovation with Year and Firm Fixed Effects

The below subsample consists of 1113 patents applied for by 49 Swedish firms that were private equity owned sometime in the period between 1994 and 2017. Firms are only included if patents were applied for between 3 years before and 5 years after the private equity investment. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the productivity measure. Standard errors are clustered on the firm level and reported below the coefficients. Data has been winsorized at the 0.5% and 99.5% level. *, ** and *** indicates that the coefficient is statistically different from zero at the 10%, 5% and 1% levels, respectively.

	(1) R&D/ Sales	(2) Patents/ R&D	(3) Citations/ R&D	(4) Patents/ Employees	(5) Citations/ Employees
Post	0.001	-0.996***	-10.248***	-0.402	-5.689**
	(0.075)	(0.314)	(2.964)	(0.302)	(2.292)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	255	255	255	255	255

In model (1) we observe that there is little evidence in favor of a shift in the R&D intensity of a firm after the transaction. The coefficient is very close to zero which indicates that the R&D intensity of the firm is generally unchanged after the private equity transaction has taken place. Private equity firms thus do not seem to significantly change the relative level of R&D investment for their acquired portfolio companies.

[7] We redo these tests based on the smaller sample of 49 firms and 1113 patents that report R&D related data and find similar results.

In model (2) and (3) we observe that per 10mSEK in R&D expenditures, the number of patents applied for and the number of citations received per patent, decreases following the private equity transaction. Both these relationships are significant at the 1% level. This result indicates that private equity owners receive a lower return on their R&D investments, as measured by the number of patents applied for and the quality of those patents compared to a similar investment for the same firm before the firm was private equity backed.

Last, model (4) indicates a negative relationship between the number of employees at the private equity backed firm and the number of patent applications filed by the firm. In model (5) we observe that the number of employees is also negatively correlated with the number of citations patents receive, and this relationship is significant at the 5% level. The findings of these two models suggest that following the private equity investment, the productivity in terms of patent applications and corresponding patent citations decreases per employee.

Once again, the findings of this test are not in line with the hypothesis that the productivity of innovation activities for an LBO firm is higher after an LBO transaction compared to the productivity prior to the transaction and these results are generally significant. This indicates that private equity owners do not seem to neglect dedicating resources to innovation, but rather that the allocated resources are utilized less efficiently under their ownership. We will elaborate on this finding under section *5.6 Discussion*.

5.4 Analysis Before the Global Financial Crisis

Given the differences in results between our study and the results of Lerner et al. (2011), who finds a positive effect on innovation from a private equity investment, we in this section focus on a key difference between the studies. While our sample includes data from both the period before and after the global financial crisis of 2008, the sample used by Lerner et al. (2011) was solely based on private equity transactions up until December of 2005 and an analysis of patents through May of 2007. Given the results we find, a natural question that arises is whether the studied relationship between private equity ownership and investments in innovation have changed following the crisis. The findings of Paunov's (2012) aforementioned study would support a shift in the relationship, at least during the crisis. Furthermore, given the difference in credit supply before and after the crisis (Kahle and Stulz, 2013), lower quality investments should be more likely to receive funding before, compare to after, the crisis when funding was more scarce. Based on this theory, the quality of patents should on average increase following the crisis. An ideal way of testing this would be to divide the sample in our study in two parts, one pre and one post the crisis and compare the results. For the period after the financial crisis, the natural starting point for the analysis would be transactions from 2012. That would ensure that the three year time horizon for analyzing patenting activity pre the transaction would not fall in the period before the crisis, i.e. before 2008. However, given the small sample of this paper, this would leave us with very few private equity transactions and patent applications to analyze in the period after the crisis.

For the reason stated above, we rather choose a sub-sample that includes transactions and patents that fall in the time period before the global financial crisis. The sample considers private equity transactions from 1994 through 2003, meaning the analysis of investments in innovation after the transaction are not impacted by the global financial crisis. By doing this, the results of our study should be more comparable to results of previous studies by Lerner et al. (2011) and enable us to compare our findings, while providing a high-level indication whether the relationship might have been impacted by the financial crisis.

We redo our tests on citation intensity and patenting levels which Lerner et al. (2011) perform, but with a sample of 46 firms which were acquired by private equity companies sometime in the years between 1994 and 2003. These firms in total applied for 1427 patents between 3 years before and 5 years after their transactions.

Table X
OLS Estimates of Citation Intensity with Year and Firm Fixed Effects, Pre Global Financial Crisis

The sample consists of 1427 patents applied for by 46 Swedish firms that were acquired by a private equity company sometime in the period between 1994 and 2003. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the citation intensity. Standard errors are clustered on the firm level and reported below the coefficients. Data is winsorized at the 0.5% and 99.5% level.***, ** and * indicate statistical significance at the 10%, 5% and 1% levels.

	(1) Absolute	(2) Relative	(3) Absolute	(4) Relative
Event Year -3	-3.369	-8.117**		
	(3.700)	(3.604)		
Event Year -2	-4.206	-5.944*		
	(3.296)	(3.302)		
Event Year -1	-4.188*	-5.326**		
	(2.303)	(2.312)		
Event Year +1	2.483	3.369		
	(2.151)	(2.205)		
Event Year +2	3.495	5.191*		
	(2.610)	(2.742)		
Event Year +3	5.825**	8.878***		
	(2.825)	(2.927)		
Event Year +4	5.339	9.205***		
	(3.280)	(3.338)		
Event Year +5	9.659**	15.606***		
	(4.861)	(4.823)		
Post LBO			1.550	0.904
			(1.831)	(1.860)
Constant	12.184***	-5,389***	11.993***	-5.442***
	(1.436)	(1.240)	(0.690)	(0.728)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	1427	1427	1427	1427

Table XI
OLS Estimates of Patent Counts with Year and Firm Fixed Effects, Pre Global Financial Crisis

The sample consists of 1427 patents applied for by 46 Swedish firms that were acquired by a private equity company sometime in the period between 1994 and 2003. Model (1) and (2) use the full sample whereas model (3) and (4) excludes divisional buyouts and thus consists of 479 patents applied for by 34 firms. Firms are only included in the full sample if patents were applied for between 3 years before and 5 years after the private equity investment. The unit of observation is the number of patents applied for by a company each year during the period from 3 years before to 5 years after the private equity transaction. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the patenting level. Standard errors are clustered on the firm level and reported below the coefficients. Data has been winsorized at the 0.5% and 99.5% level. *, ** and *** indicates that the coefficient is statistically different from zero at the 10%, 5% and 1% levels, respectively.

	Full Sample		Excluding Divisional	
	(1)	(2)	(3)	(4)
Event Year	0.290	0.290	-0.245	-0.245
	(0.721)	(0.721)	(0.572)	(0.573)
Post LBO	-0.228		-0.592	
	(0.556)		(0.504)	
Event Year +1		0.833		0.461
		(0.658)		(0.648)
Post LBO +1		-0.493		-0.855*
		(0.582)		(0.505)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	414	414	306	306

Observing the results from our test on citation intensity in table X, we see that these results indicate that the citation intensity increases following the private equity transaction. This pattern is particularly evident in model (2) where the reported coefficients are negative in the years prior to the transaction and then become positive throughout the coming five years. The results from model (2) are generally significant. These results, which solely consider the period prior to the global financial crisis, are in line with the hypothesis that the quality of LBO firms patents should be higher after an LBO transaction compared to the patents applied for prior to the transaction. The results are also in line with the findings of Lerner et al. (2011).

Proceeding to the analysis of patenting levels in table XI, the results are somewhat inconclusive given that coefficients are both positive and negative and that only one coefficient is significant on the 10% level. These results more resemble the results of Lerner et al. (2011) who similarly could not draw any firm conclusions with regards to the effect on patenting activity in their study.

5.5 Robustness

We perform two different robustness tests of our results. First, we perform the tests listed in the sections 5.1 through 5.3 while excluding patents which were ultimately not granted. Second, we perform the same tests while excluding the single largest contributor of patents, *Gambro*.

5.5.1 Excluding Ultimately Non-granted Patents

Because of our limited sample size we included patents which were ultimately not granted but only applied for in our main regressions. Even though these ultimately non-granted patents are independent work which can be cited and thus represent innovative output, one might worry that patents which were not ultimately rewarded differ from patents that were. In response to this critique we redo the tests in section 5.1 through 5.3 on a sample which excludes ultimately non-granted patents. These regression results can be found in Appendix B.

The results from this first robustness test are very similar to the main results. For models (1) and (2) in Table XII we observe a similar trend of decreasing citation intensity as the firm approaches the transaction year. However, for most of the coefficients the significance of these results is lower than the significance of the coefficients presented in the main regressions. This is somewhat expected given that a smaller sample size will increase the threshold for statistical significance. The coefficients estimated for the years after the transaction year are also decreasing more consistently than the coefficients presented in section *5.1 Citation Intensity*, although the significance of the results is lower. In the parsimonious models (3) and (4) the coefficients are negative but not significant. This robustness test strengthens our findings that private equity ownership is associated with a decrease in the quality of patents produced.

Regarding the level of patenting, we observe the same directional tendency as in the results presented in section *5.2 Patenting Level*. All the coefficients presented in Table XIII are negative except for the *Event Year + 1* estimator in model (2). When excluding divisional buyouts we find that the negative relationship becomes significant. These results suggest that private equity ownership is associated with a decrease in the amount of patents granted which is in line with the results presented in section *5.2 Patenting Level*.

Last, the results regarding the productivity measures of innovation activities in Table XIV all point in the same direction as the main results. The statistical significance actually increases for model (4) and (5) which suggests that these findings are very persistent given that our sample size decreases simultaneously. This supports our findings presented in section *5.3 Productivity of Innovation Activities*, namely that private equity ownership is associated with lower innovative productivity and unaffected R&D intensity. All in all, the results from this robustness test strengthen our findings presented in section 5.1 through 5.3 and indicates that including ultimately non-granted patents does not bias our results.

5.5.2 Excluding Gambro

In section *3.4 Descriptive Statistics* we pointed out that 35% of the patents in our full sample are applied for by the firm *Gambro*. In contrast, the second largest patentee only accounts for 6% of the total number of patents. Because we cluster standard errors on the firm level this should not bias our findings. However, since *Gambro* constitutes such a large fraction of our sample, we want to see whether the company's patents are driving the results in our tests, and thus if the results change if we exclude *Gambro*. Therefore, we apply the same models as in the main regressions but on a sample which excludes *Gambro*. The complete regressions can be found in Appendix C.

When observing the results of the regressions on citation intensity (Table XV) we find a decrease in coefficients leading up to the transaction, whereas the coefficients for the post transaction estimators are mixed but generally decreasing up to the fifth year. The parsimonious model specification (3) and (4) have negative albeit not statistically significant coefficients. These regressions support our findings in section *5.1 Citation Intensity* and suggests that private equity ownership is associated with a decrease in patent quality.

In Table XVI we observe negative coefficients for the dummy variables indicating a post transaction observation. One of the coefficients is significant at the 5% level, namely the *Post + 1* dummy when considering the sample excluding divisional buyouts. These results show that our regression results change little in response to this robustness test. The results of our tests on how the productivity of innovation activities are impacted by the transaction in Table XVII generally point towards a decrease in the productivity of innovation activities. These findings are significant and support our previous conclusions drawn in section *5.3 Productivity of Innovation Activities*. To summarize, this robustness test also provides support for the conclusions reached in section 5.1 through 5.3 indicating that including *Gambro* is not biasing our study.

5.6 Discussion

Although the results of our tests of the full sample show low levels of statistical significance, in particular those on the quality of patents and the level of patenting activity, the results are directionally consistent. Regarding the results on the quality of patents, as measured by the citation intensity of these patents, these findings do not seem to support the hypothesis and indicate that firms in our sample seem to produce lower quality patents in the period following the private equity transaction compared to the period prior. In our analysis of the level of patenting, the findings once again do not seem to support the hypothesis and indicate that the patenting activity also seem to decrease following the private equity investment. We further extend the analysis and investigate whether private equity owners neglect dedicating resources to long-run investments in innovation, or if the productivity of these innovation activities perhaps deteriorate under the private equity ownership period. Our findings indicate that the R&D intensity of private equity backed firms does not seem to change significantly following the private equity investment, suggesting that private equity firms do not significantly change the relative level of R&D investment for their acquired portfolio companies. However, the yield on investments in R&D, as measured by the number of patents applied for and the quality of those patents relative to the R&D expenditure, seems to decrease, as does the productivity of patent production and quality per employee. These results on the productivity of innovation activities are generally significant.

The overall findings indicate that there exists a relationship between private equity ownership and long-run investments in innovation in the time surrounding the private equity transaction. Based on previous studies (see primarily Lerner et al., 2011) conducted on the US market, this relationship was expected to be positive after the private equity investment. Interpreted together, the results from our tests in section 5.1 through 5.3 however do not suggest a positive relationship on the Swedish market. Below, we consider several alternative explanations for why private equity backings might have an adverse effect on investments in innovation on the Swedish market.

One explanation for why the results of this study might differ from previous studies is that our sample considers a different time horizon. As we elaborate on in section *5.4 Analysis Before the Global Financial Crisis*, the difference in results between this study and that of Lerner et al. (2011) could be explained by the fact that our sample includes data from both the period before and after the global financial crisis of 2008, whereas the sample used by Lerner et al. (2011) was solely based on private equity transactions and patents from the period before the crisis. The findings of Paunov's (2012) study, who considers the effect on innovation of the global financial crisis of 2008, would support a shift in the relationship, at least during the period of the crisis, as does the fact that credit supply changed significantly following the crisis (Kahle and Stulz, 2013). As presented in section *5.4 Analysis Before the Global Financial Crisis* the results from our tests on citation intensity for a similar time horizon confirm the findings of Lerner et al. (2011) and finds a positive, and significant, effect on the quality of innovation from the private equity ownership. This means that the studied relationship seems to have been positive also on the Swedish market for the period up until 2008. Given our results for the full time period are not in line with these findings, this suggests that the relationship might have been impacted by the global financial crisis. Important to note is that the findings of these tests are based on fewer observations, and that the test is not an ideal way to investigate differences before and after the crisis. The results of these additional tests should however serve as an indication that the results from our main analysis are not only a small sample artifact given that the results of Lerner et al. (2011) are confirmed when analyzing a similar time horizon.

An alternative explanation is provided when considering previous literature on leverage and innovation. Given that debt is a common denominator in all private equity investments in the studied sample, an alternative explanation to our results could be the findings of related literature which show an adverse effect on R&D spending as debt increases (Hall, 1989; Himmelberg and Petersen, 1991;

Hall, 1992). However, we cannot observe any decrease in R&D spending relative to sales in any of our tests, meaning this explanation finds little support from our findings. Another explanation could be based on the findings of Atanassova et al. (2007) which show that as bank financing increases, the quantity and quality of patents decreases. However, private equity firms tend to use several different debt financing alternatives such as, but not limited to, term loans, bonds or mezzanine debt (Kaplan and Strömberg, 2009) meaning we cannot fully explain our findings with this tendency.

One could also think that our finding could be driven by differences in how the innovation related intellectual property of LBO firms is protected before compared to after the private equity transaction. Rather than applying for a patent, a company can protect an innovation by claiming it to be a trade secret (European Commission, 2016). A theory would thus be that private equity owners prefer that the portfolio companies file for trade secrets to a larger degree rather than patents. This theory would support that the level of patent applications decreases following the private equity transaction, given that some innovations would instead be protected as trade secrets. It could also explain why the quality of patents decreases, since it would be natural not to reveal the most valuable innovations and thus protect these as non-observable trade secrets rather than patents. However, important to note is first that such a theory does not have support from any previous study to the best of our knowledge. Second, private equity owners should in theory not have any different incentives to prefer to apply for trade secrets rather than patents compared to the incentives of the firms' owners prior to being private equity backed. Nonetheless, while no firm conclusion can be drawn, this could be a potential explanation to the findings of our tests.

With regards to the aforementioned R&D paradox on the Swedish market, this does not seem to improve following a private equity investment. Given that the findings indicate that the productivity of innovation activities decreases following the transaction, we find no evidence that private equity firms were to improve the translation of R&D spending into innovation output. Rather, our findings suggest that the innovation output per Swedish krona invested in R&D decreases after the private equity investment. These findings suggest that private equity owners do not neglect dedicating resources to innovation, given that the R&D intensity does not significantly change in the period following the LBO transaction, but rather that the productivity of these investments in R&D deteriorate in the period following the transaction. This finding is important since it highlights the fact that ceteris paribus private equity owners seem to dedicate similar amounts of resources to long-run investments but that the quality, or economic importance, of these investments seem to decrease, as does the number of innovations as measured by the number of patents applied for. Interpreted together, these findings suggest that the way private equity owners undertake long-run investments might be different, and perhaps less productive, compared to non-private equity owners.

Despite these alternative explanations, the fact remains that this study shows directionally consistent results pointing towards a negative effect from private equity ownership on innovation. It could therefore be the case that private equity owners, through their active ownership, cut back on what they consider to be "unnecessary investments" to maximize their returns and by that invest less in innovation, in line with the argument of critics claiming that private equity is a quick-flip construction. However, such a theory does not find support from our findings on the productivity of innovation activities which show that the R&D intensity does not significantly change in the period following the LBO transaction. Rather, the decreased yield on investments in R&D that we find suggests that private equity owners do not neglect the longer run but instead undertake these investments differently, and perhaps less productively, than non-private equity owners. In conclusion, it might be a case of decreased productivity of long-run investments, rather than a shift in the nature of the corporate time horizon, that drive the results observed on the Swedish market.

5.7 Study Limitations

Although our paper provides some clarity on the relationship between private equity ownership and innovation performance, the study has its limitations. First, the analysis would have benefited from a larger data set. The relatively small sample affects the precision of point estimates and decreases the statistical power of our tests. While increasing the sample in terms of the number of firms would have been ideal, there is no reason to expect biases in the coefficients resulting from the small sample. Moreover, it would have been especially interesting to have a larger sample of firms that were acquired by a private equity company in the period after the global financial crisis as this would have enabled a more thorough analysis of if, and how, the relationship between private equity ownership and innovation performance has evolved before vis-à-vis after the crisis.

With regards to causality it is important to point out that even though private equity ownership might have an impact on the innovation performance of the portfolio company, it is not a given that this is the causal direction. In section *5.1 Citation Intensity* we observed that the citation intensity of patents applied for seems to decrease in the three years leading up to the transaction. It could therefore be that firms which experience this pattern have come past the period of high patenting activity, and now seek private equity funding to capitalize on their innovations. This would question the assumed direction of causality, namely that it is the private equity firms that impact the performance of innovation activities, and rather suggest that firms with certain innovation activity and performance are more likely to seek private equity funding in the first place. We do not have an instrumental variable to resolve the causation question, and this ultimately becomes a limitation in our study.

6 Conclusions

This paper set out to investigate how long-run investments in innovation are impacted by LBO transactions on the Swedish market. We base our analysis on a sample of 87 Swedish firms which have been private equity owned some time in the period between 1994 and 2019 and that have applied for at least one patent in the time period between 3 years before and 5 years after the private equity transaction.

We find contrary to our hypotheses that the quality of patents applied for by firms' that undergo an LBO transaction seems to decrease in the period following the transaction and that the number of patents applied for also seems to decrease. The results of these tests are directionally consistent but generally show low levels of statistical significance.

Most interestingly however, when we extend our analysis to understand what might be the underlying cause of these potential shifts we find that the yield on investments in R&D, as measured by the number of patents applied for and the quality of those patents relative to the R&D expenditure, decreases significantly in the period following the LBO transaction. These findings suggest that the way private equity owners on the Swedish market undertake long-run investments might be different, and in fact less productive, compared to non-private equity owners.

Last, we redo parts of our tests to make our study comparable to similar past studies on the US market. The results of these tests indicate that the studied relationship between private equity ownership and long-run investment might have been impacted by the global financial crisis of 2008 and we therefore call for further research on if, and how, the relationship might have been impacted.

In conclusion, although the relatively small sample of our study does not enable us to draw too strong conclusions about the studied relationship on the Swedish market, our paper does shed light on a number of so far unexplored effects, such as how the productivity of innovation activities are impacted by an LBO transaction, and brings valuable insights to a number of stakeholders. The findings of this paper are relevant to managers at target companies who are considering being acquired by a private equity sponsor, private equity firms who want to enhance the value of their portfolio companies and to policy makers who better want to understand what implications private equity funding might have for innovation in Sweden.

6.1 Suggestions for Future Research

We observe three possible avenues for future research into the relationship between private equity and innovation. First, the fact that the results for the full sample differ from the results obtained when analyzing transactions which occurred before the global financial crisis of 2008 suggests that the studied relationship might have been impacted by the crisis. In light of this finding one interesting avenue for further research would be to study what potential effect changes in markets conditions, for instance the global financial crisis, has on the innovation activities of private equity owned firms. Furthermore, it would also be interesting to investigate whether this potential effect differs between private equity owned and public market firms.

Second, in section *5.6 Discussion* we suggested that private equity owned firms might choose to protect their most valuable innovations in other ways than through patents. Exploring whether such a tendency exists would be a valuable area of further research to better explain the relationship between private equity and innovation. Last, given that we find unchanged levels of resources dedicated to innovation activities following an LBO transaction, we call for more qualitative research exploring how private equity sponsors prioritize their investments in innovation.

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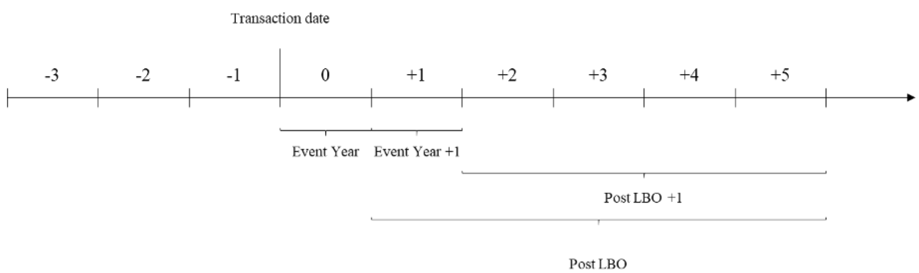
A Figures

Figure III
Transaction Timeline

A detailed illustration of the different independent variables used. The lines indicate where the variable is equal to one. To exemplify, if the patent is granted in the second year after the transaction year (Event Year +2), Post LBO and Post LBO +1 will be equal to one whereas Event Year and Event Year + 1 will be equal to zero.



B Robustness Test Excluding Ultimately Non-granted Patents

Table XII
OLS Estimates of Citation Intensity with Firm and Year Fixed Effects, Only Ultimately Granted Patents

The sample consists of 1098 patents applied for by 68 Swedish firms that were acquired by a private equity company sometime in the period between 1994 and 2017. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction and if the patents were ultimately granted. The dependent variable is the number of citations a patent received. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the citation intensity. Standard errors are clustered on the firm level and reported below the coefficients. Data is winsorized at the 0.5% and 99.5% level.***, ** and * indicate statistical significance at the 10%, 5% and 1% levels.

	(1) Absolute	(2) Relative	(3) Absolute	(4) Relative
Event Year -3	8.086***	6.537**		
	(2.793)	(2.778)		
Event Year -2	4.846*	4.583*		
	(2.722)	(2.737)		
Event Year -1	4.050*	3.563		
	(2.300)	(2.313)		
Event Year +1	0.059	-0.086		
	(2.278)	(2.339)		
Event Year +2	-0.622	-0.584		
	(2.449)	(2.549)		
Event Year +3	-1.606	-1.415		
	(2.856)	(2.905)		
Event Year +4	-7.786***	-7.500**		
	(2.990)	(2.997)		
Event Year +5	8.597**	9.400**		
	(4.368)	(4.271)		
Post LBO			-1.587	-2.136
			(2.377)	(2.426)
Constant	12.817***	-2.669**	14.998***	-0.742
	(1.312)	(1.247)	(0.608)	(0.610)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	1098	1098	1098	1098

Table XIII
OLS Estimates of Patent Counts with Firm and Year Fixed Effects, Only Ultimately Granted Patents

The full sample consists of 1098 patents applied for by 68 Swedish firms that were private equity owned sometime in the period between 1993 and 2017. Model (1) and (2) use the full sample whereas model (3) and (4) excludes divisional buyouts and thus consists of 883 patents applied for by 49 firms. Firms are only included in the full sample if patents were applied for between 3 years before and 5 years after the private equity investment and if the patents were ultimately granted. The unit of observation is the number of patents applied for by a company each year during the period from 3 years before to 5 years after the private equity transaction. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the patenting intensity. Standard errors are clustered on the firm level and reported below the coefficients. Data has been winsorized at the 0.5% and 99.5% level. *, ** and *** indicates that the coefficient is statistically different from zero at the 10%, 5% and 1% levels, respectively. Variable definitions can be found in section 4.2 Patenting Level

	Full Sample		Excluding Divisional	
	(1)	(2)	(3)	(4)
Event Year	-0.098	-0.098	-0.782	-0.782
	(0.304)	(0.305)	(0.505)	(0.505)
Post LBO	-0.304		-0.725*	
	(0.260)		(0.407)	
Event Year +1		0.108		-0.293
		(0.305)		(0.522)
Post LBO +1		-0.407		-0.833**
		(0.267)		(0.393)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	612	612	441	441

Table XIV
OLS Estimates of Productivity of Innovation with Firm and Year Fixed Effects, Only Ultimately Granted Patents

The below subsample consists of 648 patents applied for by 39 Swedish firms that were acquired by a private equity company sometime in the period between 1994 and 2016. Firms are only included if patents were applied for between 3 years before and 5 years after the private equity investment and if the patents were ultimately granted. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the productivity measure. Standard errors are clustered on the firm level and reported below the coefficients. Data has been winsorized at the 0.5% and 99.5% level. *, ** and *** indicates that the coefficient is statistically different from zero at the 10%, 5% and 1% levels, respectively. Variable definitions can be found in section 4.3.

	(1) R&D/ Sales	(2) Patents/ R&D	(3) Citations/ R&D	(4) Patents/ Employees	(5) Citations/ Employees
Post	-0.024	-0.736***	-10.146***	-0.308*	-5.692***
	(0.026)	(0.190)	(2.631)	(0.160)	(1.634)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	219	219	219	219	219

C Robustness Test Excluding Patents Applied for by Gambro

Table XV
OLS Estimates of Citation Intensity with Firm and Year Fixed Effects, Excluding Gambro

The sample consists of 1220 patents applied for by 86 Swedish firms that were acquired by a private equity company sometime in the period between 1994 and 2019. Firms and patents are only included in the sample if patents were applied for between 3 years before and 5 years after the private equity transaction. All patents applied for by the firm Gambro have been excluded. The dependent variable is the number of citations a patent received. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the citation intensity. Standard errors are clustered on the firm level and reported below the coefficients. Data is winsorized at the 0.5% and 99.5% level.***, ** and * indicate statistical significance at the 10%, 5% and 1% levels.

	(1) Absolute	(2) Relative	(3) Absolute	(4) Relative
Event Year -3	4.152**	3.073		
	(1.999)	(2.040)		
Event Year -2	2.535	2.744		
	(2.082)	(2.125)		
Event Year -1	1.572	1.556		
	(1.729)	(1.789)		
Event Year +1	0.432	0.105		
	(1.624)	(1.655)		
Event Year +2	0.625	0.257		
	(1.968)	(2.022)		
Event Year +3	3.901*	4.001**		
	(1.991)	(2.039)		
Event Year +4	0.735	0.676		
	(1.862)	(1.889)		
Event Year +5	9.352***	9.872***		
	(2.705)	(2.663)		
Post LBO			-1.169	-1.573
			(1.597)	(1.622)
Constant	11.268***	-4.857***	10.949***	-5.146***
	(1.101)	(1.056)	(0.539)	(0.548)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	1220	1220	1220	1220

Table XVI
OLS Estimates of Patent Counts with Firm and Year Fixed Effects, Excluding Gambro

The full sample consists of 1220 patents applied for by 86 Swedish firms that were private equity owned sometime in the period between 1993 and 2017. Model (1) and (2) use the full sample whereas model (3) and (4) excludes divisional buyouts and thus consists of 714 patents applied for by 64 firms. Firms are only included in the full sample if patents were applied for between 3 years before and 5 years after the private equity investment. All patents applied for by the firm Gambro have been excluded. The unit of observation is the number of patents applied for by a company each year during the period from 3 years before to 5 years after the private equity transaction. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the patenting intensity. Standard errors are clustered on the firm level and reported below the coefficients. Data has been winsorized at the 0.5% and 99.5% level. *, ** and *** indicates that the coefficient is statistically different from zero at the 10%, 5% and 1% levels, respectively. Variable definitions can be found in section 4.2.

	Full Sample		Excluding Divisional	
	(1)	(2)	(3)	(4)
Event Year	0.050	0.050	-0.318	-0.318
	(0.352)	(0.352)	(0.321)	(0.321)
Post LBO	-0.096		-0.421	
	(0.306)		(0.301)	
Event Year +1		0.574		0.307
		(0.399)		(0.393)
Post LBO +1		-0.264		-0.603**
		(0.315)		(0.305)
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Observations	774	774	576	576

Table XVII
OLS Estimates of Productivity of Innovation with Firm and Year Fixed Effects, Excluding Gambro

The below subsample consists of 570 patents applied for by 48 Swedish firms that were acquired by a private equity company sometime in the period between 1994 and 2003. Firms are only included if patents were applied for between 3 years before and 5 years after the private equity investment. All patents applied for by the firm Gambro have been excluded. A coefficient greater than zero corresponds to a positive relationship between the explanatory variable and the productivity measure. Standard errors are clustered on the firm level and reported below the coefficients. Data has been winsorized at the 0.5 % and 99.5% level. *, ** and *** indicates that the coefficient is statistically different from zero at the 10%, 5% and 1% levels, respectively. Variable definitions can be found in section 4.3.

	(1) R&D/ Sales	(2) Patents/ R&D	(3) Citations/ R&D	(4) Patents/ Employees	(5) Citations/ Employees
Post	-0.007	-1.043***	-10.603***	-0.436	-6.069**
	(0.074)	(0.324)	(3.049)	(0.312)	(2.424)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	249	249	249	249	249