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The Impact of Private Equity on Firms' Innovation Activity

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April 2015

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Abstract

The paper analyses the impact of private equity (PE) backed leveraged buyouts (LBOs) on innovation output (patenting). Using a sample of 407 UK deals we find that LBOs have a positive causal effect on patent stock and quality-adjusted patent stock. Our results imply a 6% increase in quality-adjusted patent stock three years after the deal. The increase in innovation activity is concentrated among private-to-private transactions with a 14% increase in the quality-adjusted patent stock. Further analysis supports the argument that PE firms facilitate the relaxation of financial constraints. We also rule out alternative explanations for portfolio firms' higher patenting activity. Our findings suggest that PE firms do not promote short-term cost-cutting at the expense of entrepreneurial investment opportunities with a long-term pay-off.

JEL Classification: D22, G32, G34, L26

Key words: private equity, leveraged buyout, entrepreneurial buyouts, innovation

1. Introduction

Private Equity (PE) firms have emerged as an important part of the entrepreneurial finance landscape. PE firms establish funds in order to raise capital that is then put towards the acquisition of a portfolio of mature firms (Kaplan and Stromberg, 2009). The 'portfolio firms' are acquired via a Leverage Buyout (LBO) because the PE firm will raise debt finance, secured against portfolio firms' assets and/or future cash flows, in order to facilitate the transaction (Gilligan and Wright, 2014). An LBO can improve corporate governance, reducing the managerial agency problem, and so better aligning managers' objectives with those of owners (Jensen, 1986). Key features of the LBO governance structure are: active PE investors with board representation, debt bonding, and strong management incentives derived from their equity ownership (Jensen, 1986; Thompson and Wright, 1995). Evidence of post-LBO performance improvements is consistent with the view that LBOs create managerial incentives to improve firm performance (Lichtenberg and Siegel, 1990; Amess, 2003; Harris et al., 2005).

There is controversy, however, concerning the source of the documented performance gains. Proponents argue that an improved system of corporate governance creates incentives to reduce sub-optimal discretionary expenditures (Jensen, 1986). In contrast, critics generally point to two features of an LBO that create incentives for management to focus on short-term cost-cutting, foregoing entrepreneurial investment opportunities that benefit the firm in the longer-term. First, there is the transitory nature of PE firms' investment practices. PE firms have an incentive to promote short-term cost cutting in order to generate short-term profit because they typically promise to repay fund investors' capital, along with any profit generated, about 5-10 years after the capital is invested in a PE fund. Second, high leverage means cash is used to service the debt rather than make investments that yield a longer-term pay-off. See Rappaport (1990) and Kaplan (1991) for a discussion of these issues.

While this early literature largely focused on the cost-cutting aspect of incentive realignment, more recent research addresses the issue of entrepreneurial growth incentives (Wright et al, 2000; Boucly et al., 2011). It is well-recognized that established firms may engage in entrepreneurial activities (e.g. Morris, Kuratko and Covin, 2008; Miller, 1983) and LBOs may create incentives to pursue entrepreneurial growth opportunities for a variety of reasons. First, an LBO replaces internal labor market and managerial labor market incentives with market-based incentives (Thompson and Wright, 1992, 1995). Management equity ownership creates entrepreneurial incentives to pursue profitable growth opportunities (Meuleman et al., 2009). Second, PE firms use incentive mechanisms (e.g. equity ratchets) and encourage management to behave entrepreneurially and pursue growth as a means of creating firm value (Valkama, et al., 2013). Third, PE firms can facilitate access to finance and increase targets' debt capacity, alleviating possible financial constraints (Boucly et al., 2011; Engel and Stiebale, 2014). Finally, public corporations are criticized for their short-term investment horizons because senior management focus on delivering short-term profit for shareholders (Stein, 1988); an LBO takes firms private, away from public scrutiny, permitting them to make entrepreneurial investments that yield a return in the longer-term.

Whether LBOs create financial incentives to make entrepreneurial investments with a longer-term payoff or focus on short-term cost-cutting is a long-standing controversy. The issue is crucial for investment in innovation activity because it benefits the firm in the longer-term. While Lichtenberg and Siegel (1990) find that an LBO has no significant impact on R&D expenditure, Long and Ravenscraft (1993) report reductions in R&D expenditure, consistent with the short-term cost-cutting argument. A problem with analyzing R&D expenditure, however, is that it is not clear whether a reduction in productive or unproductive R&D

expenditures is being observed. Zahra (1995), for example, finds that LBOs are followed by a more effective use of R&D expenditure. It is therefore better to measure firms innovation output, specifically patenting activity (Lerner et al., 2011). They find no evidence that LBOs impact the level of patenting but do find evidence consistent with patent quality improving. They acknowledge, however, that their analysis might well suffer from endogeneity, i.e. they are unable to determine whether LBOs cause changes in patent activity or whether PE firms select LBO targets that already have forthcoming improvements in patent activity.

Using a sample of 407 UK PE-backed LBOs observed over the 1998-2008 period, we provide new insight and evidence concerning the impact of LBOs on innovation activity. First, we establish that LBOs increase patent activity and quality-adjusted patents (measured as patents weighted by forward citations). By using propensity score matching combined with a difference-in-differences approach, we seek to account for the selection problems that afflict previous research in the area. Second, we seek to provide novel insight on the role of PE firms in relaxing financial constraints. Financial constraints are notoriously difficult to measure and so we adopt various approaches to build a picture of LBOs relaxing financial constraints. Particularly, we provide evidence that post-LBO increases in innovation are concentrated among portfolio firms that are *a priori* more likely to be financially constrained; such firms are privately owned pre-LBO, operate in industries with a high dependency on external finance, and have a relatively low credit score. Extensions to our analysis rule out management equity ownership, leverage, equity ratchets, and PE experience as alternative mechanisms through which LBOs impact on innovation activity.

The remainder of the paper is organized as follows. Section 2 summarizes the theoretical arguments in the related literature, section 3 describes the empirical strategy, and section 4 provides a description of the data. Results of the empirical analysis are presented in section 5 and section 6 concludes.

2. Theoretical considerations

This paper is concerned with the effect of PE firms on financial constraints and therefore the funding of innovation. Hence, we focus on the role of PE firms as a source of entrepreneurial finance in the capital market.

2.1 PE firms can reduce external capital market imperfections

Capital markets are fraught with information asymmetries. The suppliers of finance are confronted with an adverse selection problem leading to the rationing of finance (Stiglitz and Weiss, 1981). In such a scenario firms underinvest (Hubbard, 1998). Since asymmetric information problems are probably more pronounced for R&D than for tangible investment, and the collateral value of intangible assets is limited, financial constraints are arguably especially relevant for the financing of innovation (Brown et al., 2012). Further, the riskiness of R&D makes debt financing particularly difficult to obtain, since in contrast to equity market investors, creditors do not benefit from upside returns (Brown et al., 2009; Hsu et al., 2014).

The extent to which different types of firms are financially constrained and suffer from underinvestment varies. Expectations regarding listed corporations are somewhat ambiguous. Listed corporations are generally expected to experience little underinvestment due to financing constraints resulting from the problem of information asymmetry for investors. However, some listed corporations may face financing constraints because short-term investors are unwilling to allow them the time and resources they need to innovate in order to achieve longer-term pay-offs. Going private through an LBO may relieve these financing constraints as PE investors have a longer time horizon than stock market investors (Lerner et al., 2011). The argument for going private in order to innovate also rests on the assumption that PE investors have specialist expertise that gives them both better information and the ability to act on that information than stock market investors.

In contrast, private firms suffer from underinvestment due to their reliance on internal finance (Carpenter and Petersen, 2002) and difficulties in accessing finance from banks (Behr et al., 2013). This is because private firms find difficulty in conveying information to finance providers (Behr et al., 2013). Further, the goals and behavior of private firm owners may also constrain access to external finance to fund innovation. For instance, private firm owners may seek to retain control and hence be reluctant to dilute ownership through opening up their share capital to external investors.

PE is able to attenuate these capital market imperfections, leading to increased investment after an LBO (Berger and Udell, 1998; Engel and Stiebale, 2014). Boucly et al. (2011) identify mechanisms associated with corporate governance and financial expertise through which PE firms facilitate access to finance; hence, relaxing financial constraints. First, PE firms are active investors who monitor senior management performance and their strategic decisions. This is facilitated by representation on the board of directors. This improvement in corporate governance helps overcome the moral hazard problem, providing creditors with the confidence that funds are used productively. Second, PE firms' financial expertise is a reassurance to creditors, making it more likely they will provide funds for investment. Consequently, portfolio firms are less likely to suffer from underinvestment than private firms with no PE firm involvement. If private firms were underfunding innovation activity prior to an LBO, we expect to observe an increase in innovation activity after an LBO. Correspondingly, for those LBOs that subsequently go through a second buyout (SBO), which involves introducing a new PE firm (Alperovych et al., 2013), we expect to observe little if any increase in innovation activity after SBO. This is especially expected to be the case where the incoming PE firm is performing the same functions as the outgoing PE firm, whereas an incoming PE firm with larger funds available and greater expertise may be able to facilitate more innovation activity.

2.2 Divisional buyouts and internal capital market imperfections

Williamson (1975, 1985) argues that large organizations adopt a divisional organizational structure and use an internal capital market to allocate resources due to the failure of the external capital market in overcoming informational asymmetries. A potential advantage of the internal capital market is its superior access to information compared to the external capital market. The audit function of head office and its ability to gather information enables head office to make superior capital allocation decisions than the external capital market. The divisions, being profit centers, are allocated financial resources on the basis of the return they are able to generate. Efficient decision-making involves operational decisions being taken at divisional level while strategic and capital allocation decisions are taken at corporate head office level. These features allow it to act as an effective hierarchical governance device with divisional managers' focusing on profit maximization (Williamson, 1985).

Williamson (1985) acknowledges that there are limits to the effectiveness of the internal capital market as a control, incentive and governance device. Such limits allow divisional managers to indulge in opportunism and 'politicking', which in turn leads to the misallocation of resources. This could lead to underperformance in the context of superficial investment decision-making (Hill, 1988) and such underperformance can lead to pressure for diversified firms to refocus their activities (Berger and Ofek, 1999). In addition, such firms are more likely to be subject to a takeover because the transfer of financial resources within the internal capital market accommodates the waste of free cash flow (Comment and Jarrell, 1995).

The emergence of PE represents an important development in the external capital market. It facilitates external capital market allocation that might previously have been transacted in an internal capital market. With board representation facilitating the close monitoring of senior management and their strategic decisions, PE firms are active investors in their portfolio firms. As mentioned in section 2.1, this allows PE firms to reduce the information asymmetries associated with external capital market allocation, negating the need for some firms to operate within a divisional structure. Moreover, divisions that once suffered underinvestment due to capital misallocation within the internal capital market can now operate as independent firms and receive financial resources for innovation. If a division suffers from underinvestment while operating within an internal capital market, the LBO of a division is expected to reduce underinvestment. Consequently, profitable investment opportunities are more likely to be funded after the LBO of a division, leading to an increase in innovation activity.

This section has established two competing arguments. First, difficulties in overcoming informational asymmetries in the external capital market can lead to capital allocation and investment occurring in the internal capital market. Second, the internal capital market is a flawed system of capital allocation, leading to underinvestment, and the LBO of a division can reduce underinvestment because a PE firm is able to facilitate access to external finance. The empirical analysis addresses this issue by examining the impact of divisional buyouts on innovation activity. If PE firms reduce external capital market imperfections, making capital allocation superior to the internal capital market and reducing underinvestment, we expect to observe an increase in innovation activity after a divisional buyout.

3. Estimation strategy

Our empirical strategy aims to identify the causal effect of PE-backed LBOs on firms' innovation outcomes. For this purpose, we employ a propensity score matching procedure (to construct the counterfactual) and combine it with a difference-in-differences estimator in order to evaluate the impact of an LBO on portfolio firms.

The evaluation of an average treatment effect on the treated (ATT) *s* periods after a treatment period *t* comprises a comparison between the actual innovation outcome of a firm treated to a PE-backed LBO and the situation had the firm not been acquired. The quantity that is measured is expressed as

$$ATT = E[I^1_{t+s} \mid X_{t-1,} PE_t = 1] - E[I^0_{t+s} \mid X_{t-1,} PE_t = 1] \quad (1)$$

where I^1_{t+s} is the innovation outcome of a portfolio firm in period $t+s$, I^0_{t+s} is the innovation outcome of the portfolio firm would have experienced had it not been subject to an LBO (i.e. the counterfactual), *X* contains a set of control variables, and *PE* is a dummy variable taking the value one if the firm has been subject to an LBO in any respective year.

Causal inference relies on construction of the counterfactual for the last term in equation (1), $E[I^0_{t+s} \mid X_{t-1}, PE_t = 0]$. The construction of the counterfactual is not straightforward if LBO targets are not randomly selected from the population of firms. For instance, PE firms might select LBO targets because there is scope for improvement in innovation activity. In this case, using a randomly selected control sample represents an inadequate approximation of the counterfactual, rendering measures of the ATT subject to sample selection bias. In their study, Lerner et al (2011) identify this problem as a limitation of their analysis.

While there is no straight forward solution to the sample selection problem, we attempt to mitigate it by constructing a control sample using propensity score matching, proposed by Rosenbaum and Rubin (1983). The predicted probability (propensity score) of being subject to an LBO and becoming a portfolio firm, $\hat{\Pr}(PE_t = 1 | X_{t-1})$, is obtained from the estimation of a Probit model. The vector X_{t-1} contains only pre-LBO characteristics in order to avoid reverse causality problems (Caliendo and Kopeinig, 2008). As we exploit a panel data set, we can relax the assumption of selection on observables by combining the matching technique with a difference-in-differences estimator (see, for instance, Blundell and Costa Dias, 2000). Although this assumes that any unobserved differences between firms are constant over time.

Instead of comparing differences in the innovation levels between the two groups, we focus on the growth of the innovation stock (Guadalupe et al., 2012; Seru, 2014). This procedure allows the selection into the group of PE firms to be based on the expected impact on innovation and on time invariant unobservable characteristics (Heckman, Ichimura, and Todd 1997). Nevertheless, unobserved time-varying factors that influence both LBO probability and the innovation outcomes, as well as heterogeneous responses to macroeconomic shocks across treatment and control groups, would lead to biased estimates.

The difference-in-differences estimator, measuring the effect on innovation of a firm being subject to an LBO, is expressed as:

$$E[I_{t+s}^1 - I_{t-1} | X_{t-1}, PE_t = 1] - E[I_{t+s}^0 - I_{t-1} | X_{t-1}, PE_t = 0]. \quad (2)$$

In practice, this difference-in-differences estimator can be obtained by applying weighted least squares to the matched data set, with the change in the innovation stock as the dependent variable:

$$\Delta I^1_{i,t+s} = \alpha + \theta PE_{it} + \eta_t + \varepsilon_{it} \tag{3}$$

θ is the difference-in-difference estimate of the *ATT*, η_t represents time dummies and ε_{it} is an error term. This representation makes the analysis of heterogeneous effects across characteristics of portfolio firms straight forward using the following estimation equation:

$$\Delta I^1_{i,t+s} = \alpha + \theta_0 PE_{it} + \theta_1 PE_{it} Z_{i1t} + ... + \theta_K PE_{it} Z_{iKt} + \eta_t + \varepsilon_{it} \tag{4}$$

where Z_{ikt}, $k = 1,...K$, are characteristics of portfolio firms or PE investors to be considered.

Different estimators are proposed in the matching literature. In this paper we primarily focus on results obtained from nearest neighbor matching without replacement, which means that each portfolio firm has one comparison firm, implying each LBO firm and each matched non-LBO firm is given a weight of one. We have also experimented with a propensity score reweighting estimator (e.g. Imbens, 2004) where we assign a weight equal to $\hat{\Pr}(PE_t = 1 | X_{t-1}) / (1 - \hat{\Pr}(PE_t = 1 | X_{t-1}))$ for all non-LBO firms.

4. Data and variables

4.1 Data sets

The data set employed is constructed from three sources: the Center for Management Buyout Research (CMBOR), FAME, and PATSTAT. Data on PE firms and portfolio firms comes from the CMBOR, which provides information on LBO deals. The CMBOR database is compiled from a wide range of sources, including biannual surveys of financiers, press releases, stock exchange circulars, and specialist finance and press coverage. The database has no lower size cut-off, enabling the examination of the full size range and vendor type of buyouts; this is especially important for the incorporation of LBOs that were previously under private ownership (private-to-private transactions).

The second data source is the FAME database, which provides financial and accounting data for UK firms.[1] The FAME database provides information on firms' sales, productivity, profitability, capital, wages and industry affiliation. Unconsolidated accounts are chosen to separate economic activity in portfolio firms from parent companies.

The third data source is PATSTAT, developed by the European Patent Office and the OECD, which provides data on patent applications and citations. We extract patent applications for the years 1978-2008 for all firms in our sample. The data on patent applications are merged with the other firm-level data sets using a computer supported search algorithm based on the firms' names, addresses and zip (postal) codes. Every match was checked manually to ensure a good match. We only consider patents that are ultimately granted but date them back to the application year. This is to ensure that our results measure the timing of an innovation but are not affected by the length of the patent granting process. Besides patent applications, the data allows identifying information on patent citations. We weight patent applications by forward citations to construct a quality-adjusted measure of patent counts. In addition, the time dimension allows the construction of an innovation stock for each firm, which we simply define as the cumulative number of (citation-weighted) patent applications.

Our estimation sample is based on the years 1998 to 2008. LBOs take place between 1998 and 2005 as we restrict the analysis to firm-year observations for which information on patenting and citations are available for at least three prospective years after a buyout (we relax this restriction in robustness checks described in section 5.4). The analysis is based on 143,653

[1] The database contains the subset of UK firms from the Amadeus database which has been used in numerous empirical studies (see, for instance, Budd et al., 2005; Helpman et al., 2004; Konings and Vandenbussche, 2005).

firm-year observations in total. The estimation sample includes 35,081 firms and 407 buyouts. 1,689 non-PE backed and 239 buyout firms file at least on patent application during the sample period.

4.2 Variables

Our main outcome variables are based on patent applications and patent applications weighted by forward citations, i.e. changes in innovation stocks over time. These variables have previously been employed as measures of innovation activity (e.g. Lerner et al., 2011; Seru, 2014). The empirical analysis determines and quantifies the causal relationship between LBOs and the innovation outcome variables. We are therefore interested in the change of these variables between the pre- and the post-LBO period in comparison with a matched sample of firms.

Using patents as an innovation indicator has both advantages and disadvantages over alternative measures (see e.g. Griliches, 1998). In contrast to R&D expenditures, patents are (at least an intermediate) innovation output indicator and thus also account for the effectiveness with which innovation is pursued. Further, as the number of patents is derived from administrative data, this indicator does not have to rely on self-reported measures of new products and processes, which are often used in innovation studies. Patenting is costly and a granted patent requires a certain degree of novelty which reduces the risk of counting innovations of little relevance. Finally, the number of patents is a well-established indicator of innovation which has been used in several recent studies[2] and patent applications seem to be highly correlated with other common indicators of innovative performance (e.g. Hagedoorn and Cloodt, 2003; Griliches, 1998).

[2] See, for instance, Aghion et al. (2013), Bena and Li (2014) and Seru (2014).

The downside of taking patents as an innovation indicator is that not every invention becomes patented, and - depending on firms' innovation strategies - firms may make more or less use of formal IP rights protection (e.g. Hall and Ziedonis, 2001; Ziedonis, 2004). It can also be expected that there will be substantial variation in the value of patented innovations. To partly address this problem, the results for patent counts are compared with those using citation-weighted patents, which are likely to be correlated with the importance of innovations. If PE firms induce an increase (decrease) in patenting for purely strategic reasons, we should see an increase (decrease) in the number of non-weighted patents but little change in citation-weighted patents (e.g. Bloom et al., 2011).

The choice of conditioning variables included in the Probit model that generates the propensity score used to select firms into the comparison group is based on recent innovation studies (e.g. Guadalupe et al., 2012). In particular, we construct our comparison group based on pre-buyout characteristics such as firm size (the log of sales, *ln_sales*), labour productivity (the log of sales per employee, *ln_Labprod*), exporting (an exporter dummy, *d_export*), skill intensity (the log of the average wage, *ln_av_wage*), debt (liabilities divided by equity, *leverage*), profitability (profit divided by sales, *profit_sales*) and age (log firm age, *ln_age*). We also control for pre-buyout values of our outcome variables (*patent stock* and *patent citation stock*) to ensure that our results are not affected by PE investors choosing firms based on previous innovation outcomes. Finally, the Probit model includes two-digit industry dummies and time dummies. Table 1 contains summary statistics and variable definitions. The industry distribution of buyouts is depicted in Table A.1 and Table A.2 in the appendix.

5. Results

5.1 Propensity score matching

The results from the Probit regression, used to generate propensity scores, are reported in Table 2. In this model, we regress an indicator of LBOs in time period *t* on control variables in *t*-1. We restrict the analysis to firms for which information on patents in time periods *t*+1, *t*+2 and *t*+3 are available. The results show that PE firms tend to acquire relatively large but unproductive firms. Firm age as well as exporting reduces the likelihood of a buyout. In contrast, profitability, average wages, capital intensity, and previous innovation activity do not have a statistically significant impact on a firm being targeted for an LBO.

While the Probit regression results are interesting in their own right, the principal purpose of the Probit regression is to generate a propensity score that is used to match firms in the LBO sample with firms that have not been subject to an LBO. The propensity score matching method is a reliable and robust method for determining and quantifying the effect of LBOs on innovation outcomes if the potential innovation outcomes of the LBO sample and the comparison group are independent of the incidence of LBOs (conditional independence assumption). Under the ’balancing condition’, the firm-specific variables included in the Probit model should be balanced between the portfolio firms and the comparison group. This is crucial because it ensures that the propensity score obtained from the Probit regression is successful in controlling for firm-specific differences between LBO targets and the comparison group in the pre-LBO period. We test the balancing property by conducting t-tests on each variable included in the Probit model to test for equality of means between LBO targets and the comparison group. The tests are reported in Table 3. While t-tests indicate statistically significant differences between the means of the LBO targets and the unmatched control sample for some variables - and most importantly the propensity score - we cannot reject equality of mean values for all control variables in the matched sample at conventional levels of significance (this is also individually and jointly true for industry and time dummies which are not shown in the table). This suggests that propensity score matching has been successful in controlling for observed firm-specific differences between LBO targets and the comparison group of firms. Figure 1 in the Appendix also shows that the distribution of propensity scores across LBO and non-LBO firms is very similar.

5.2 Estimates from differences-in-differences combined with propensity score matching

Having established that the LBO firms and the comparison group are adequately matched, we report difference-in-difference estimates based on the matched sample. Table 4 presents results showing the effects of a PE-backed LBO on the number of patents and the number of citation-weighted patents. We show the effects for up to three years after an LBO, where *t* is the year of the transaction. Panel A shows that the ATT of an LBO on non-weighted patents. By year *t*+3, the patent stock increases by about one-third of a patent. The average effect of an LBO on quality-adjusted patents is also positive. Panel B shows that by year *t*+3 the quality-adjusted patent stock increases by about 1.3. Table 1 shows that the average number of citation-weighted patent applications each year is about one; the cumulated 1.3 increase after 3 years therefore implies that quality-adjusted patent applications after 3 years are on average about 40% higher due to an LBO. Table 1 also shows that the citation-weighted patent stock is about 20.6 and so the 1.3 increase implies an increase in the citation-weighted patent stock by more than 6% after 3 years. The results in Table 4 suggest that PE-backed LBOs are not only associated with an increase in patenting (Panel A), but quality-adjusted innovation output also increases (Panel B).

Having established that the average LBO has a positive effect on innovation outcomes, we conduct further analysis on the role of PE firms in target firms' financial constraints. The possible presence of financial constraints in the target firm is not directly observable; however, the arguments presented in Section 2 suggest any post-LBO effect on innovation outcomes will depend on pre-LBO ownership type because ownership structure impacts on any financial constraints on investment in innovation. Therefore, following the approach of Boucly et al. (2011), we break our LBO sample into four deal types based on pre-LBO ownership: private-to-private transactions (*Priv2Priv*), public-to-private transactions (*Pub2Priv*), divisional buyouts and secondary buyouts.

The heterogeneous effects of deal types are reported in Table 5. It shows that the private-to-private transaction is the only deal type that has a statistically significant effect on innovation outcomes. By year *t*+3 after the LBO the patent stock has increased by nearly one patent (see Panel A) and the quality-adjusted patent stock has increased by nearly three (Panel B), which implies a 14% increase in the quality-adjusted patent stock. There is limited and weak evidence (significance at the 10% level) that public-to-private transactions and divisional buyouts reduce patent activity.

Overall, these findings are consistent with PE firms alleviating financial constraints in private firms and facilitating investment in increased innovation outcomes. PE firms do not have such an impact on other pre-LBO ownership types, however. The findings for other pre-LBO ownership types are consistent with arguments that for listed corporations, while PE firms may relieve financing constraints they are not able to identify and act on superior information regarding innovation opportunities compared to stock market investors. The findings are also consistent with the argument that incoming PE investors in primary divisional buyouts or SBOs do not alleviate financing constraints that may have constrained innovative activity in either an internal capital of a corporation on one hand or in a primary buyout on the other.

We seek to confirm the finding for private-to-private deals by adopting a model specification that compares private-to-private deal types with all other remaining PE-backed LBO transactions. The results reported in Table 6 confirm that the effects of private-to-private transactions on patent stock and quality-adjusted patents are significantly larger than that for other deal types.[3]

In order to provide additional support for the argument that PE firms alleviate financial constraints we conduct two further sets of analysis using a constructed financial dependence measure and an indicator of riskiness provided by FAME which is labelled “Quiscore” to proxy financial constraints. If the financial constraint hypothesis is true, PE firms will have the largest impact on innovation in industries which are more dependent on external finance. Moreover, we expect this to be more pronounced in private-to-private deals, given our previous results. For this analysis, we construct a measure of industry-level financial dependence proposed by Rajan and Zingales, (1998). It is defined as the difference between investment and internal cash flow from operations. The measure is constructed from Compustat data on listed US firms as in previous empirical analyses (e.g. Kroszner et al., 2007). Using data on listed firms in the US has two possible advantages. First, listed firms in the US arguably have relatively few financing obstacles, thus they allow us to measure an industry’s technical dependence on external finance. Second, using a measure of US industries reduces endogeneity concerns as the UK firms in our sample are unlikely to affect investment and financing decisions of US firms.

[3] As we discuss in section 5.4, an alternative propensity matching approach based on private-to-private transactions only leads to very similar results.

However, we also check the robustness of the results using a measure calculated from UK firms.

Results from the financial dependence analysis are reported in Table 7. The results in Panel A confirm previous findings that LBOs have a positive effect on the innovation outcomes of private-to-private transactions but not for other vendor source types (indicated by the coefficients for *PE* × *Priv2Priv* and *PE* variables, respectively). Importantly, the positive effect of private-to-private transaction increases in innovation is notably larger in the presence of greater financial dependence (indicated by the coefficient of *PE* × *Priv2Priv* × *findep*). These findings are more pronounced for the quality-adjusted patent stock, reported in Panel B. It shows that private-to-private deals taking place in industries with no financial dependence have only a weak positive effect in t+1 and no significant effect in subsequent years. In contrast, the impact of private-to-private LBO transactions on the quality-adjusted patent stock increases considerably and statistically significantly with financial dependence. This is consistent with PE firms increasing innovation outcomes through the relaxation of financial constraints.

A further test on the financial constraint hypothesis is conducted using the *Quiscore*, obtained from FAME. The *Quiscore* is a proprietary index of firms' creditworthiness where a higher score indicates greater creditworthiness. Firms with a score of above 80 are identified as being 'secure' and at the lowest risk of defaulting on loans.[4] For the purpose of our analysis we assume that these firms are less likely to face financial constraints because creditors are more likely to provide finance to these firms. In contrast, we define firms with a *Quiscore* below 80 as likely to be affected by financial constraints. On this basis we construct a dummy variable

[4] For instance, Guariglia and Mateut (2010) find that firms with a relatively low *Quiscore* are more likely to be financially constrained as evidenced by higher sensitivity of investment to the availability of finance. In general, credit ratings are often used to classify firms that are likely to face financing constraints (see, for instance Carreira and Silva, 2010 for an overview and Czarnitzki and Hottenrott, 2011 for an application to R&D).

equal to one for all firms with a *Quiscore* of less than or equal to 80 (in section 5.4 we discuss results using an alternative threshold), zero otherwise. This dummy variable is defined on the basis of the *Quiscore* in the year before the buyout (*t*-1), so that our analysis can capture any effect of PE firms in relaxing financial constraints. Unfortunately, using the *Quiscore* reduces the number of LBO deals in the sample due to incomplete coverage.

The results using the dummy variable constructed from the *Quiscore* are reported in Table 8. Panel A and B indicate that LBO transactions, other than private-to-privates, have no significant impact on patenting in portfolio firms whether or not they have a low *Quiscore*. In contrast, Panel B shows that private-to-private LBO transactions have a positive effect on the quality-adjusted patent stock of firms that are more likely to be financially constrained. This is again consistent with PE firms increasing innovation output through the alleviation of financial constraints.

While it is not possible to directly observe the role of PE firms in relaxing financial constraints, this section has presented three sets of analysis in order to build a consistent picture of PE firms alleviating financial constraints in LBO targets. First, we find that the principal effect of PE firms on innovation outcomes stems from private-to-private LBO transactions. Second, we find that the effects of private-to-private LBO transactions are most pronounced for portfolio firms operating in industries with a high dependence on external finance. Finally, we show that private-to-private LBO transactions of firms with lower creditworthiness, which we argue are more likely to be financially constrained, have the largest effect on quality-adjusted patenting. The results present a general picture of private-to-private LBO transactions having a positive causal effect on patent stock and citation-weighted patent stock. This is consistent with PE firms relaxing financial constraints in private-to-private deals, leading not only to increased patenting but also to an increase in quality-adjusted innovation output.

5.3 What other PE firm and LBO governance characteristics could affect innovation?

While our results support the argument that PE firms relax financial constraints in private-to-private LBO transactions, we cannot rule out that other factors associated with PE firms and the post-LBO governance structure impact innovation output. We therefore augment the model reported in Table 7 with a range of variables previously found to be correlated with portfolio firms' innovation and growth (e.g. Ughetto, 2010; Melueman et al., 2009). PE firms potentially gain organizational experience from their involvement in LBO deals and this experience can be shared with portfolio firms, we therefore include variables capturing experience as equity and debt providers. With some PE firms specializing in specific sectors of the economy, we also include debt and equity experience variables at the sector level to the analysis. Leverage has a role to play in bonding managers to pay out future cash flows in the form of interest payments, so leverage is added to the analysis. PE firms often use equity ratchets, that is performance-contingent contracts, to motivate the management to achieve performance targets. We are able to identify which portfolio firms have equity ratchets and include this variable. Finally, we include two industry characteristics, the level of competition and a binary variable for manufacturing industries.

To avoid producing an overwhelming volume of results, we report whether the variables mentioned above have an effect on innovation outcomes for the period t+3 only. We first examine each variable separately to establish if there is a statistical relationship. The final column shows results from the specification including all variables. While there are some significant interaction terms for the effect on non-weighted patenting (see Panel A), none of the additional variables have an impact on citation-weighted patenting (see Panel B). Most importantly, none of these additional variables affects our main results. It is noticeable that private-to-private LBO transactions in financially dependent industries continue to have the largest impact on patent stock and citation-weighted patenting after the inclusion of additional variables that explore alternative mechanisms through which LBOs impact on innovation. The additional analysis allows us to rule out alternative explanations to PE firms relaxing financial constraints.

5.4 Robustness checks

We conduct several sensitivity checks with respect to our estimation method and variable definitions. First, instead of using a balanced panel of buyouts and potential controls for which three years of data on post-LBO patenting are available, we estimate ATT using an unbalanced panel with varying numbers of observations. This also allows us to follow portfolio firms over a longer time period of up to 5 years after an LBO. The results are documented in Table A3 in the appendix. Both the effects on patents and citation-weighted patents increase over time even on a reduced sample of firms. However, due to the smaller number of observations, only the effect on citation-weighted patents is statistically significant in time periods t+4 and t+5. The results confirm our previous estimates and indicate that innovation outcomes are steadily improving after a buyout.

Second, we conduct a propensity score reweighting estimator in which all firms in the potential control group are used but weighted according to the propensity score (as described in the section 3). Results in columns (1)-(3) of Table A4 in the appendix confirm the positive effects of private-to-private transactions on innovation. The remaining transactions have a negative effect on average innovation output which is however only weakly statistically significant and remains relatively small.

A potential concern is that the selection mechanism of private-to-private transactions is different from other buyouts. Therefore, we alternatively consider the treatment to be a private-to-private transaction and conduct a separate propensity score estimation in which non-private firms are eliminated from the sample. Columns (4) to (6) of Table A4 contain the results of the ATT estimation for this sample (results for the propensity score estimation and the balancing property are very similar and are available upon request). The results confirm the positive impact of private-to-private transactions on portfolio firms.

Next, we construct an alternative measure of financial dependence based on UK data instead of US firms. Compared to the measure based on US data, it has the advantage that it may capture the financial situation of UK firms more accurately. A potential disadvantage is that this measure is more likely to be affected by endogeneity problems. Table A5 shows that regressions based on financial dependence of UK firms yields qualitatively similar results. The positive impact of private equity firms mainly stems from private-to-private transactions and is most pronounced in financially dependent industries. Finally, we use 70 instead of 80 as a threshold for the *Quiscore* to classify firms that are more likely to be financially constrained. Results depicted in Table A6 show that this alternative threshold does not affect our main conclusions.

6. Conclusions

This paper conducts an empirical analysis of a particularly contentious aspect of the entrepreneurial finance market. Specifically, we contribute to the debate concerning the role of

PE firms in sacrificing longer-term performance in the pursuit of short-term profit. Critics argue that the necessity for PE firms to generate short-term returns for their fund investors motivates them to promote cost-cutting in order to generate short-term profit in portfolio firms. Entrepreneurial investment opportunities with a long-term pay-off are therefore passed over. We would therefore expect a reduction in innovation activity if short-term cost-cutting is prioritized. In contrast, proponents argue that PE firms are able to alleviate capital market imperfections for entrepreneurial firms that are financially constrained. PE firms are a source of entrepreneurial finance and facilitate portfolio firms' access to external sources of finance. This allows portfolio firms to invest in innovation activity, which would not have been possible pre-LBO.

The results show that PE-backed LBOs have a positive causal effect on both patenting and quality-adjusted patents measured by forward citations. This implies that LBOs cause an increase in innovation activity rather than an increase in strategic patenting. Further analysis shows that the impact is predominantly driven by private-to-private LBO transactions, particularly in financially dependent industries and among firms that are more likely to be financially constrained before the LBO. The findings are consistent with PE firm involvement relaxing financial constraints in firms, facilitating their investment in innovation activity. We are able to rule out other factors having a causal effect on innovation. These findings therefore suggest that PE firms facilitate investment in innovation activity that has a long-term pay-off.

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Table 1
Summary statistics and variable definitions

Variable		Mean	SD
Firm and industry-level variables			
PE	=1 if buyout in year t, 0 else	0.002	
Post_PE	= 1 for all years after a buyout, 0 else	0.010	
Patent count	Number of patent applications in current year	0.048	1.817
Quality-adjusted patent count	Number of patent applications in current year, weighted by the number of citations	0.983	128.1
Patent stock	Cumulated number of patents till current year	0.406	11.078
Quality-adjusted patent stock	Cumulated number of patents till year t, weighted by citations	20.614	1,405.1
Sales	Sales	27,511	204,00
Employees	Number of employees	206.5	1483.1
Capital	Tangible fixed assets	9,481	95,848
Fixed assets	Fixed assets	15,858	31,900
Labprod	Labour productivity, Sales per employee	360.25	4,042
Cap_Emp	Capital per employee	313.95	8,299
Age	Firm age in years	22.014	21.215
Sales growth	Logarithmic yearly sales growth rate	0.09	0.509
d_export	=1 if overseas sales>0, 0 else	0.325	0.469
Av_wage	Average wage per employee	34.20	101.11
Profit_sales	Profits/Sales * 100	0.626	58.26
Leverage	Loans + overdrafts + liabilities / equity *100	304.16	870.06
Quiscore	Inverse indicator of likelihood of default	74.730	22.539
Findep	Industry-level financial dependence (US data)	0.066	0.298
Findep(UK)	Industry-level financial dependence (UK data)	0.217	0.377
Competition	Average of 1-Lerner Index (industry level)	0.943	0.027
Variables at the PE firm / buyout level			
Experience equity	# of previous deals involving equity	11.216	30.746
Experience debt	# of previous deals involving debt	29.283	27.930
Exp equity sector	# of prev. deals involving equity in industry	10.378	15.938
Exp debt sector	# of prev. deals involving debt in industry	15.865	23.617
PE × Pub2Priv	= 1 if public to private buyout	0.091	
PE × Priv2Priv	= 1 if private to private buyout	0.472	
PE × Divisional	=1 if divisional buyout	0.283	
PE × Secondary	=1 if secondary buyout	0.155	
Equity_syndicate	=1 for equity provider syndication	0.025	
Debt_syndicate	=1 for debt provider syndication	0.140	
Ratchet	=1 if PE firm uses an equity ratchet	0.118	

Table 2
Propensity score estimation, Probit model

ln_sales	0.200***
	(0.018)
ln_Labprod	-0.158***
	(0.027)
d_export	-0.091*
	(0.047)
ln_av_wage	0.057
	(0.040)
ln_cap	0.013
	(0.012)
ln_age	-0.060***
	(0.019)
Profit_sales	0.003
	(0.010)
Leverage	-0.00004
	(0.00003)
Patent stock	0.001
	(0.001)
Patent citation stock	-0.00001
	(0.00003)
Observations	143,653
Pseudo R squared	0.110
Log likelihood	-2486.5
LR test (chi squared)	615.11

Notes: (1) Robust standard errors in parentheses; (2) * p<0.1, ** p<0.05, *** p<0.01.

Table 3: Balancing property

Variable	Sample	Treated	Control	t-test, p>|t|
Propensity score	Unmatched	0.0104	0.0024	0.000
	Matched	0.0104	0.0104	0.998
ln_sales	Unmatched	9.9017	8.8335	0.000
	Matched	9.9017	9.8813	0.851
ln_Labprod	Unmatched	4.6661	4.8842	0.000
	Matched	4.6661	4.657	0.887
d_export	Unmatched	0.3123	0.3249	0.616
	Matched	0.3123	0.3381	0.468
ln_av_wage	Unmatched	3.1276	3.2345	0.004
	Matched	3.1276	3.1846	0.196
ln_age	Unmatched	2.7396	2.7341	0.915
	Matched	2.7396	2.7044	0.628
ln_capital	Unmatched	7.8350	6.5577	0.000
	Matched	7.8350	7.7925	0.796
Patent stock	Unmatched	1.0098	0.3787	0.350
	Matched	1.0098	0.5798	0.349
Patent citation stock	Unmatched	25.833	20.599	0.927
	Matched	25.833	17.165	0.712
Profit_sales	Unmatched	-.00893	-.64032	0.829
	Matched	-.00893	-.03416	0.726
Leverage	Unmatched	256.65	303.20	0.280
	Matched	256.65	245.59	0.820

Table 4
ATT from propensity score matching

Panel A: Patent stock			
	t+1	*t*+2	*t*+3
PE	0.166*	0.278**	0.383**
	(0.075)	(0.121)	(0.156)
Number of observations	814	814	814

Panel B: Quality-adjusted patent stock			
	t+1	*t*+2	*t*+3
PE	0.747**	1.127**	1.292**
	(0.338)	(0.518)	(0.581)
Number of observations	814	814	814

Notes: (1) The dependent variable is the change in the cumulated stock of patents in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) PE is a dummy variable taking value one after a private equity financed buyout, zero otherwise; (4) All regressions include time dummies; (5) robust standard errors in parentheses; (6) * $p<0.1$ ** $p<0.05$ *** $p<0.01$.

Table 5
Heterogeneous effects by deal type

Panel A: Patents			
	t+1	*t*+2	*t*+3
PE × Priv2Priv	0.401**	0.691**	0.940***
	(0.162)	(0.269)	(0.350)
PE × Pub2Priv	-0.064	-0.130*	-0.162
	(0.043)	(0.077)	(0.101)
PE × Secondary	-0.006	-0.043	-0.046
	(0.034)	(0.055)	(0.072)
PE × Divisional	-0.047	-0.090*	-0.113*
	(0.030)	(0.049)	(0.061)
Number of observations	814	814	814
Panel B: Quality-adjusted patents			
	t+1	*t*+2	*t*+3
PE × Priv2Priv	1.662**	2.520**	2.902**
	(0.736)	(1.138)	(1.311)
PE × Pub2Priv	-0.021	0.043	0.039
	(0.117)	(0.218)	(0.254)
PE × Secondary	-0.103	-0.205	-0.261
	(0.175)	(0.280)	(0.364)
PE × Divisional	-0.074	-0.131	-0.156
	(0.094)	(0.152)	(0.193)
Number of observations	814	814	814
R-squared	0.033	0.034	0.036

Notes: (1) The dependent variable is the change in the cumulated stock of patents in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) PE is a dummy variable taking value one after a private equity financed buyout, zero otherwise; (4) Priv2Priv is a binary variable for private-to-private deals, Pub2Priv is a binary variable for public-to-private deals, Secondary is a binary variable for secondary buyouts, and Divisional is a binary variable for divisional buyouts; (5) all regressions include time dummies; (6) robust standard errors in parentheses; (7) * $p<0.1$ ** $p<0.05$ *** $p<0.01$.

Table 6
Further analysis of private-to-private transactions

Panel A: Patents			
	t+1	*t*+2	*t*+3
PE	-0.045	-0.093**	-0.116*
	(0.028)	(0.104)	(0.060)
PE × Priv2Priv	0.446***	0.785***	1.055***
	(0.170)	(0.290)	(0.378)
Number of observations	814	814	814

Panel B: Citation-weighted patents			
	t+1	*t*+2	*t*+3
PE	-0.073	-0.123	-0.153
	(0.093)	(0.151)	(0.193)
PE × Priv2Priv	1.735**	2.643**	3.056**
	(0.769)	(1.197)	(1.411)
Number of observations	814	814	814

Notes: (1) The dependent variable is the change in the cumulated stock of patents in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) *PE* is a dummy variable taking value one after a private equity financed buyout, zero otherwise and *Priv2Priv* is a dummy variable indicating private-to-private deals; (4) all regressions include time dummies; (5) robust standard errors in parentheses; (6) * p<0.1 ** p<0.05 *** p<0.01.

Table 7
The effect of LBOs on financially dependent firms

Panel A: Patents			
	t+1	*t*+2	*t*+3
PE	-0.040	-0.082*	-0.100*
	(0.025)	(0.041)	(0.051)
PE × findep	-0.064	-0.130	-0.178
	(0.065)	(0.127)	(0.166)
PE × Priv2Priv	0.297**	0.598**	0.808**
	(0.138)	(0.260)	-0.341
PE × Priv2Priv × findep	1.588***	1.981***	2.624***
	(0.477)	(0.682)	(0.924)
Findep	0.047	0.112*	0.154*
	(0.031)	(0.066)	-0.085
Number of observations	814	814	814

Panel B: Citation-weighted patents			
	t+1	*t*+2	*t*+3
PE	-0.062	-0.110	-0.137
	(0.071)	(0.129)	(0.166)
PE × findep	-0.153	-0.212	-0.261
	(0.246)	(0.459)	(0.602)
PE × Priv2Priv	1.354*	1.717	2.086
	(0.799)	(1.084)	(1.302)
PE × Priv2Priv × findep	4.044**	9.807**	10.282**
	(1.767)	(4.147)	(4.352)
Findep	0.087	0.195	0.231
	(0.078)	(0.144)	(0.179)
Number of observations	814	814	814

Notes: (1) the dependent variable is the change in the cumulated stock of patents in Panel A; in Panel B, patents are weighted by forward citations; (3) *PE* is a dummy variable taking value one after a buyout, zero otherwise, *Findep* is a measure of financial dependence at the industry level, *Priv2Priv* is a dummy variable indicating private-to-private deals; (4) all regressions include time dummies; (5) standard errors in parentheses are clustered at the industry level; (6) * p<0.1 ** p<0.05 *** p<0.01.

Table 8
The effect of LBOs on firms with a low Quiscore

Panel A: Patents

	t+1	*t*+2	*t*+3
PE	0.024	0.015	0.025
	(0.179)	(0.259)	(0.335)
PE × D(quiscore≤80)	-0.028	-0.051	-0.020
	(0.313)	(0.454)	(0.586)
PE × Priv2Priv	0.488**	0.901***	1.250***
	(0.215)	(0.312)	(0.404)
PE × Priv2Priv* D(quiscore≤80)	0.688	0.683	0.642
	(0.438)	(0.636)	(0.822)
D(quiscore≤80)	0.002	0.019	-0.022
	(0.180)	(0.261)	(0.337)
Number of observations	377	377	377

Panel B: Citation-weighted patents

	t+1	*t*+2	*t*+3
PE	0.073	0.228	0.236
	(0.407)	(1.018)	(1.029)
PE × D(quiscore≤80)	-0.031	-0.300	-0.260
	(0.712)	(1.783)	(1.802)
PE × Priv2Priv	0.707	0.851	0.978
	(0.490)	(1.227)	(1.240)
PE × Priv2Priv × D(quiscore≤80)	1.713*	7.517***	7.365***
	(0.998)	(2.499)	(2.525)
D(quiscore≤80)	-0.041	0.069	0.032
	(0.410)	(1.026)	(1.037)
Number of observations	377	377	377

Notes: (1) the dependent variable is the change in the cumulated stock of patents in Panel A; in Panel B, patents are weighted by forward citations; (3) *PE* is a dummy variable taking value one after a buyout, zero otherwise; Quiscore is a measure of credit worthiness and *D(quiscore<80)* takes on a value of one for levels of quiscore below 80, zero otherwise, *Priv2Priv* is a dummy variable indicating private-to-private deals; (4) all regressions include time dummies; (5) standard errors in parentheses are clustered at the industry level; (6) * p<0.1 ** p<0.05 *** p<0.01.

Table 9
Additional controls and interaction terms

Panel A: Patents

	t+3	*t*+3	*t*+3	*t*+3	*t*+3	*t*+3	*t*+3	*t*+3
PE	-0.076**	-0.069	-0.093*	-0.361**	-4.392	-0.202	-0.236	0.284
	(0.036)	(0.060)	(0.048)	(0.164)	(2.759)	(0.202)	(0.194)	(2.934)
PE × findep	-0.165	-0.186	-0.170	-1.239*	-0.210	-0.178	-0.236	-1.261*
	(0.148)	(0.170)	(0.159)	(0.660)	(0.170)	(0.175)	(0.215)	(0.665)
PE × Priv2Priv	0.817**	0.788**	0.801**	0.723**	0.801**	0.780**	0.778**	0.657**
	(0.350)	(0.334)	(0.336)	(0.307)	(0.339)	(0.321)	(0.316)	(0.270)
PE × Priv2Priv × findep	2.598***	2.627***	2.629***	3.029***	2.656***	2.644***	2.729***	3.100***
	(0.895)	(0.925)	(0.931)	(1.086)	(0.927)	(0.955)	(1.003)	(1.155)
Findep	0.154*	0.153*	0.142*	0.106*	0.154*	0.153*	0.156*	0.091
	(0.086)	(0.085)	(0.081)	(0.058)	(0.086)	(0.084)	(0.090)	(0.062)
PE × ratchet	-0.244							-0.158
	(0.331)							(0.292)
PE × Equity_syndicate		-0.217**						-0.072
		(0.100)						(0.292)
PE × Debt_syndicate		-0.114						-0.156
		(0.088)						(0.140)
PE × gearing			-0.000					-0.000
			(0.000)					(0.000)
Gearing			-0.000					-0.000
			(0.000)					(0.000)
PE × manufacturing				1.338**				1.355**
				(0.542)				(0.551)
Manufacturing				0.079				0.085
				(0.096)				(0.096)
PE × competition					4.553			-0.747
					(2.936)			(3.307)
Competition					-0.461			-0.456
					(0.991)			(0.988)
PE × Experience_equity						-0.003		-0.007
						(0.005)		(0.009)
PE × Experience_debt						0.005		0.003
						(0.006)		(0.004)
PE × Exper_equity_sector							-0.001	0.001
							(0.002)	(0.002)
PE × Exper_debt_sector							0.010	0.008
							(0.011)	(0.010)
Number of observations	814	814	814	814	814	814	814	814

-Table 9 continued on next page-

Panel B: Citation-weighted patents – Table 9 continued								
	t+3	*t*+3	*t*+3	*t*+3	*t*+3	*t*+3	*t*+3	*t*+3
PE	-0.157	-0.051	-0.074	-0.694	-3.023	-0.798	-0.614	7.818
	(0.197)	(0.176)	(0.157)	(0.604)	(7.381)	(0.931)	(0.740)	(12.792)
PE × findep	-0.272	-0.280	-0.252	-2.531	-0.269	-0.245	-0.478	-2.655
	(0.561)	(0.622)	(0.582)	(2.579)	(0.587)	(0.640)	(0.839)	(2.646)
PE × Priv2Priv	2.079	2.030	2.054	1.904	2.087	1.884	1.948	1.588
	(1.326)	(1.284)	(1.285)	(1.178)	(1.309)	(1.144)	(1.177)	(0.963)
PE × Priv2Priv × findep	10.304**	10.285**	10.296**	11.145**	10.277**	10.418**	10.694**	11.438**
	(4.328)	(4.346)	(4.371)	(4.835)	(4.348)	(4.563)	(4.847)	(5.290)
findep	0.231	0.231	0.204	0.135	0.245	0.225	0.238	0.090
	(0.181)	(0.179)	(0.156)	(0.132)	(0.184)	(0.179)	(0.183)	(0.128)
PE × ratchet	0.202							0.352
	(2.195)							(2.126)
PE × Equity_syndicate		-0.509						0.581
		(0.542)						(0.858)
PE × Debt_syndicate		-0.322						-0.528
		(0.274)						(0.547)
PE × leverage			-0.000					-0.000
			(0.000)					(0.000)
Leverage			-0.000					-0.000
			(0.000)					(0.000)
PE × manufacturing				2.861				3.126
				(2.371)				(2.479)
Manufacturing				0.159				0.199
				(0.312)				(0.315)
PE × competition					3.064			-9.736
					(7.869)			(14.666)
Competition					-3.996			-4.009
					(2.832)			(2.877)
PE × Experience_equity						-0.029		-0.049
						(0.023)		(0.036)
PE × Experience_debt						0.036		0.030
						(0.033)		(0.025)
PE × Exper_equity_sector							-0.006	0.012
							(0.007)	(0.009)
PE × Exper_debt_sector							0.039	0.022
							(0.044)	(0.035)
Number of observations	814	814	814	814	814	814	814	814

Notes: (1) The dependent variable is the change in the cumulated stock of patents (measured at period *t*+3) in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) PE is a dummy variable taking value one after a buyout, *Priv2Priv* indicates private-to-private deals, *Equity_syndicate* (*Debt_syndicate*) is a dummy variable indicating two or more equity (debt) providers, *ratchet* is a dummy variable indicating whether an equity ratchet has been used in the deal, *Manufacturing* indicates manufacturing industries, *leverage* is a debt equity ratio, *experience_equity* is the cumulative number of deals in which a PE firm has provided equity, *experience*_debt is the cumulative number of deals in which a PE firm has provided equity, *findep* measures financial dependence, and *Competition* is measured as 1 minus the average of the Lerner Index (price cost margin) within industries; (4) all regressions include time dummies; (5) Robust standard errors in parentheses; (6) * p<0.1 ** p<0.05 *** p<0.01.

Appendix

Table A1: Industry distribution of number of buyouts

SIC 2007 2-digit code	Number of LBOs	Private-to-private LBOs
1	3	1
2	18	12
3	15	8
9	1	0
10	13	3
13	1	0
14	2	0
15	1	1
16	3	3
17	2	1
18	8	6
19	1	0
20	6	5
22	11	7
23	3	2
24	2	1
25	13	7
26	7	4
27	8	5
28	10	5
29	2	1
30	1	0
32	17	7
36	2	1
38	2	0
41	4	1
43	9	7
45	10	4
46	19	12
47	24	11
49	9	4
50	1	0
51	3	2
52	5	2
53	2	0
55	3	1
56	17	7
58	7	2
59	4	1
61	1	0
62	31	16
64	8	2
65	2	1
66	3	2
68	1	0
70	46	17
72	1	1
77	3	2
82	7	3
85	2	2
86	12	4
87	2	2
88	1	1
90	8	3
92	2	0
93	3	0
96	5	2
all	**407**	**192**

Table A2

Distribution of deals across industry technological intensity

	All buyouts	Private-to-private LBOs
manufacturing high technology	2.0%	2.5%
manufacturing medium high technology	6.3%	8.6%
manufacturing medium low technology	8.0%	9.2%
manufacturing low technology	14.3%	14.1%
Knowledge-intensive services (KIS)	32.4%	30.1%
High-tech (KIS)	25.8%	25.2%
Market KIS	39.2%	36.7%
Less Knowledge-intensive services	24.1%	25.8%
Market services less KIS	22.9%	23.9%

Note: Classification based on Eurostat. Classification of service sectors is partly overlapping

Figure 1:

Distribution of propensity scores across LBO firms and matched controls

(Kernel density estimates)

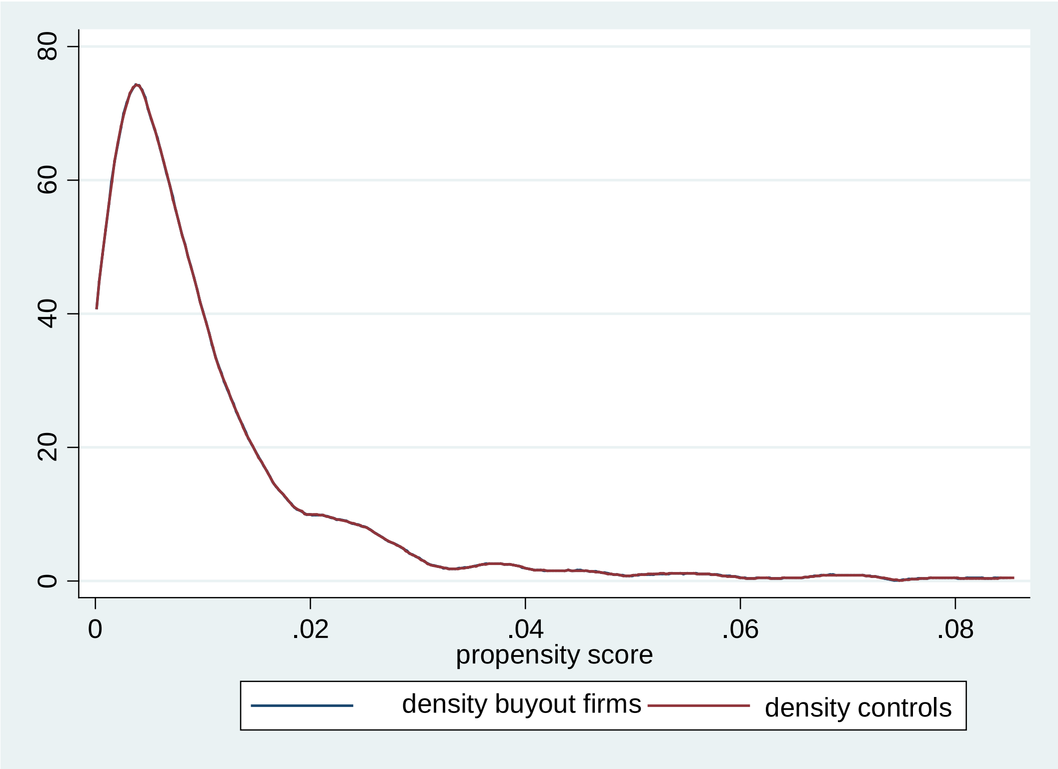

Table A3
Unbalanced Panel. Longer time horizon

Panel A: Patents					
	t+1	*t*+2	*t*+3	*t*+4	*t*+5
PE	0.131**	0.220*	0.383**	0.401	0.421
	(0.056)	(0.114)	(0.156)	(0.258)	(0.363)
Number of observations	1224	1034	814	628	536

Panel B: Citation-weighted patents					
	t+1	*t*+2	*t*+3	*t*+4	*t*+5
PE	0.539**	0.890**	1.292**	1.759**	2.337**
	(0.228)	(0.391)	(0.581)	(0.765)	(1.070)
Number of observations	1224	1034	814	628	536

Notes: (1) the dependent variable is the change in the cumulated stock of patents in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) PE is a dummy variable taking value one after an LBO, zero otherwise; (4) all regressions include time dummies; (5) robust standard errors in parentheses; (6) * p<0.1 ** p<0.05 *** p<0.01.

Table A4
Robustness checks

Panel A: Patents

	Reweight *t*+1	Reweight *t*+2	Reweight *t*+3	Pscore1-1 *t*+1	Pscore1-1 *t*+2	Pscore1-1 *t*+3
PE	-0.070**	-0.143**	-0.210**			
	(0.031)	(0.058)	(0.084)			
PE × Priv2Priv	0.446***	0.777***	1.044***	0.400**	0.647**	0.867**
	(0.172)	(0.290)	-(0.380)	(0.173)	(0.303)	(0.399)
Number of observations	143,653	143,653	143,653	384	384	384

Panel B: Citation-weighted patents

	Reweight *t*+1	Reweight *t*+2	Reweight *t*+3	Pscore1-1 *t*+1	Pscore1-1 *t*+2	Pscore1-1 *t*+3
PE	-0.455**	-0.644**	-0.861*			
	(0.204)	(0.303)	(0.447)			
PE × Priv2Priv	1.651**	2.539**	2.902**	1.711**	2.625**	2.988**
	(0.778)	(1.216)	(1.429)	(0.764)	(1.199)	(1.410)
Number of observations	143,653	143,653	143,653	384	384	384

Notes: (1) the dependent variable is the change in the cumulated stock of patents (measured 3 years after an LBO relative to the year before the LBO) in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) in columns (1-3), observations are weighted according to the propensity score and standard errors are clustered by firm; (4) in columns (4-6), only private-to-private buyouts are included; (5) PE is a dummy variable taking value one after an LBO, zero otherwise; (6) Priv2Priv indicates private-to-private deals; (7) robust standard errors in parentheses; (8) * p<0.1 ** p<0.05 *** p<0.01.

Table A5
The effect of LBOs on financially dependent firms (UK measure)

Panel A: Patents			
	t+1	*t*+2	*t*+3
PE	-0.045	-0.087	-0.109
	(0.036)	(0.064)	(0.082)
PE × findep(UK)	0.003	-0.025	-0.024
	(0.066)	(0.129)	(0.173)
PE × Priv2Priv	0.220**	0.400**	0.533**
	(0.090)	(0.158)	(0.215)
PE × Priv2Priv × findep (UK)	0.906**	1.542**	2.093**
	(0.349)	(0.618)	(0.825)
Findep(UK)	0.037	0.112	0.143
	(0.038)	(0.074)	(0.100)
Number of observations	814	814	814

Panel B: Citation-weighted patents			
	t+1	*t*+2	*t*+3
PE	-0.092	-0.151	-0.201
	(0.146)	(0.231)	(0.301)
PE × findep(UK)	0.098	0.149	0.247
	(0.287)	(0.460)	(0.604)
PE × Priv2Priv	1.034**	1.526**	1.745**
	(0.476)	(0.693)	(0.811)
PE × Priv2Priv × findep (UK)	2.804**	4.474**	5.243*
	(1.365)	(2.211)	(2.723)
Findep(UK)	0.081	0.078	0.102
	(0.122)	(0.217)	(0.253)
Number of observations	814	814	814

Notes: (1) the dependent variable is the change in the cumulated stock of patents in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) *PE* is a dummy variable taking value one after a LBO, zero otherwise, *Findep(UK)* is a measure of financial dependence at the industry level, *Priv2Priv* is a dummy variable indicating private-to-private deals; (4) all regressions include time dummies; (5) standard errors in parentheses are clustered at the industry level; (6) * p<0.1 ** p<0.05 *** p<0.01.

Table A6

Heterogeneous effects by initial *Quiscore*, alternative threshold

Panel A: Patents

	t+1	*t*+2	*t*+3
PE	0.017	0.007	0.022
	(0.161)	(0.234)	(0.303)
PE × D(quiscore≤70)	-0.038	-0.073	-0.056
	(0.382)	(0.556)	(0.718)
PE × Priv2Priv	0.471**	0.890***	1.214***
	(0.201)	(0.293)	(0.378)
PE × Priv2Priv* D(quiscore≤70)	1.112**	1.057	1.190
	(0.519)	(0.755)	(0.975)
D(quiscore≤70)	-0.039	-0.020	-0.070
	(0.209)	(0.304)	(0.393)
Number of observations	376	376	376

Panel B: Citation-weighted patents

	t+1	*t*+2	*t*+3
PE	0.059	0.150	0.165
	(0.366)	(0.912)	(0.922)
PE × D(quiscore≤70)	-0.056	-0.382	-0.349
	(0.869)	(2.164)	(2.187)
PE × Priv2Priv	0.657	0.786	0.905
	(0.458)	(1.140)	(1.152)
PE × Priv2Priv* D(quiscore≤70)	2.832**	11.297***	11.143***
	(1.180)	(2.938)	(2.969)
D(quiscore≤70)	-0.142	-0.210	-0.244
	(0.476)	(1.184)	(1.197)
Number of observations	376	376	376

Notes: (1) The dependent variable is the change in the cumulated stock of patents in Panel A; (2) in Panel B, patents are weighted by forward citations; (3) PE is a dummy variable taking value one after an LBO, zero otherwise; (4) Quiscore is a measure of credit worthiness and D(quiscore≤70) takes on a value of one for levels of quiscore below or equal to 70, zero otherwise; (5) Priv2Priv is a dummy variable indicating private-to-private deals; (6) all regressions include time dummies; (7) standard errors in parentheses are clustered at the industry level; (8) * p<0.1 ** p<0.05 *** p<0.01.

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