R&D or R vs. D?
Firm Innovation Strategy and Equity Ownership*

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Abstract

We analyze a unique dataset that separately reports research and development expenditures for a large panel of public and private firms. We establish new empirical facts about how equity ownership status relates to innovation strategy and then compare these facts to equilibrium outcomes predicted by theory. We find public firms have greater research intensity than private firms, inconsistent with theories predicting an equilibrium wherein private firms conduct relatively more exploratory innovation. We also find public firms invest more intensely in innovation of all sorts. These results suggest more innovative firms select into public status, which relaxes financing constraints and provides a more diversified shareholder base more tolerant of high idiosyncratic risk. Reconciling several seemingly conflicting results in prior research, we find private equity held firms, though equally innovative as other private firms, skew their strategies toward development and away from research.

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1. Introduction

While there is a vast amount of empirical literature on firm investment in innovation, due to data limitations, it mostly focuses on firms' combined investments in research *and* development. Thus, the question of how different types of firms vary in their focuses on research *versus* development has gone unexplored.[1] We fill this gap in the literature by using restricted microdata from the Business R&D and Innovation Survey (BRDIS) conducted by the U.S. Census Bureau and the National Science Foundation (NSF). We establish several empirical facts about how the degree to which a firm engages in research *versus* development is associated with its equity ownership type (i.e. public or various types of private ownership).

Following the NSF (2015), we define research as, "The planned, systematic pursuit of new knowledge or understanding," and development as, "The systematic use of research and practical experience to produce new or significantly improved goods, services or processes." These definitions broadly correspond to the innovation theory literature's definition of "knowledge exploration" and "exploitative innovation" (e.g., Chen, Gao, Hsu, and Li, 2019; Ferreira, Manso and Silva, 2014; Gao, Hsu and Li, 2018; Manso, 2011; and March, 1991), respectively. We can thus provide insights into the empirical relevance of these theories by comparing the equilibria they predict with the empirical facts we uncover. We are also able to reconcile several seemingly conflicting empirical findings in prior research on the relation between private equity fund ownership and innovation policy.

We categorize a firm's equity ownership type in one of three ways: public, for publicly listed firms; private equity held, for firms owned by private equity buyout funds structured as limited partnerships and sponsored by specialized firms; or other private. We then examine how ownership

[1] Lee and Park (2019) also disaggregate research and development at Korean firms and study how they are financed. In contrast, we study the relation between disaggregated research and development to equity ownership type in the United States.

type is related to firm exploration and exploitation of knowledge. We also examine differences in the propensity of firms with different types of equity ownership to: apply for patents; be issued patents; introduce new products; and introduce new production and logistics processes, as well as support activities. Finally, we use the survey data to explore how firms with different ownership types differ in how their research and development investments translate into issued patents and new products or processes.

We find that public firms tend to invest *more* in research than private firms of a similar size in the same industry. Since research investment roughly measures investment in "exploratory innovation," this evidence is inconsistent with the theory of Ferreira et al. (2014), which predicts an equilibrium in which private firms primarily engage in exploration, whereas public firms primarily engage in exploitative innovation.[2] Moreover, we find that public firms, in addition to investing more in research, also invest more in development, as well as innovation-related physical capital (e.g. laboratory space and equipment). We also find that public firms are more likely to introduce new processes. These findings suggest public status is associated with more investment in innovation overall, consistent with an equilibrium in which highly innovative firms tend to select into public status. If public firms are more likely to be incumbents, our findings are also consistent with the predictions of Akcigit and Kerr (2018) that incumbent firms invest more in internal (existing product lines) and external (new product lines) innovation. In addition, these findings are in line with recent work in Acharya and Xu (2017), which find external finance dependent public firms innovate more than their private counterparts, and Maksimovic, Phillips, and Yang (2019) and (2020), who report evidence against public firm and market myopia and for selection effects on public firm growth.

[2] Our results are related to Gilje and Taillard (2016), who find no evidence that private natural gas producers drill more "exploration" wells relative to "development" wells. Several papers study the heterogeneity of innovation within public firms. For example, Phillips and Zhdanov (2013) model and show evidence that large public firms may innovate less as part of an optimal decision to access innovation through acquisition.

Theory suggests two reasons to expect such an equilibrium: first, public status comes with lower financing constraints, making the financing of innovation cheaper; second, the greater diversification of public firm shareholders allows them to be more tolerant of the risks inherent to investment in innovation. Our findings suggest that, on average, the benefits to exploratory innovation associated with public status outweigh the incentive problems theorized in Ferrerira et al. (2014) to make private status more conducive to knowledge exploration. Our results are also consistent with Manso (2011), who theoretically shows that innovation-killing incentive problems inherent to public status can be overcome through careful design of executive compensation schemes.

On the surface, the above results appear to be at odds with Asker, Farre-Mensa, and Ljungqvist (2015), Aggarwal and Hsu (2014), Fang, Tian, and Tice (2014) who find that public firms invest and patent less than private firms. Bernstein (2015), Gao, Hsu and Li (2018), and Chen, Gao, Hsu, and Li (2019) also find public status is associated with less novel patents, from which they conclude that public firms engage in less exploration. We note, however, that not all investment is related to innovation, and not all innovation is related to patenting.[3] Because a granted patent entails public disclosure of the technical details of the proposed innovation, it is sometimes optimal to guard innovation as a trade secret rather than attempt to patent it. Hall et al. (2014) provide an extensive review of the literature pertaining to the tradeoffs between formal (e.g. patents, trademarks) and informal (e.g trade secrets, confidentiality agreements, or the use of complexity) intellectual property strategies. For example, Hall et al. (2014) find that only a minority of firms in the U.S. and U.K. that invest in research and development consider formal intellectual property, such as patenting, important, while the majority consider informal intellectual property, such as secrecy, confidentiality agreements, or the use of complexity, as important. Furthermore, there is a significant time lapse between when a patent

[3] Recent studies suggest that trade secrets are important to firm decisions. For example, Klasa et al. (2018) find that when firms face the potential loss of trade secrets they strategically choose more conservative capital structures.

application is filed, when, if at all, the respective patent is issued, and what its claims are and what the assignee intends to do with it (e.g. license, produce or block a competitor, etc.). Therefore, differences in the novelty between firms' patents do not necessarily reflect a difference in the novelty of all their innovative activities. Thus, our finding that public firms are more likely to develop new production and logistics processes than private firms implies that studies comparing the innovation of public and private firms solely by comparing patent data are likely to be underestimating the relative novelty of public firm innovation.

Additionally, we find that private equity-held firms tend to conduct just as much development as public firms, but significantly less research. Furthermore, though private equity-held firms tend to invest as much in research and development combined as do other types of private firms, the former skew their investments toward development. These results suggest an equilibrium in which firms with a more exploitative innovation strategy tend to select into private equity ownership. Since investments in research take longer to produce returns than those in development, such an equilibrium is consistent with the proposition that the short holding periods of private equity funds make this form of ownership more conducive to firms with investment opportunities with shorter horizons (e.g., Kolasinski and Harford, 2014; Barrot, 2017). The finding in Yang and Zhang (2019) that private equity-held firms have fewer new product announcements are also consistent with this proposition. Our finding also resolves the seeming inconsistency between the latter study and Lerner, Sorensen, and Stromberg (2011), who find that firms increase patenting activity after being bought out by a private equity fund. Consistent with both studies, we confirm that private-equity held firms introduce fewer new products, but we also find private equity-held firms have higher patenting activity than other private firms. Since we show that the innovative activities of private-equity held firms skew toward development, our results suggest these patents are mostly a result of exploitative, rather than exploratory, innovation. Finally, we fail to find any evidence that proprietary disclosure cost considerations, related to innovation, influence the selection of firms into different types of equity ownership.

Next, we examine how past and contemporaneous investments in research and development relate to various measures of innovation output: patent application filings, patent grants, and the introduction of new products and processes. We regress each innovation-type output on contemporaneous research and development, as well as three lags of each. Consistent with the NSF definitions of research and development, we find that development has a stronger association than research with all innovation outputs. Curiously, however, we find that it is the contemporaneous value that has the strongest effect.[4] Finally, we find that the association between patent issuances and applications, and contemporaneous research and development, is strongest for public firms. We conclude that public status is positively associated with higher levels of innovation investment quality as well as quantity, suggesting an equilibrium outcome at odds with several theories.

The associations we uncover between innovation strategy and ownership type could reflect a causal effect of ownership type, or could reflect a firm's selection into the ownership type that is optimal for its innovation strategy. To help distinguish between selection and causation, we examine whether innovation strategy changes when firms change their ownership status. That is, we examine how research, development and the propensity to introduce new products and processes changes as firms change status in the following ways: public to private equity-held, private equity-held to public, other private to public, and finally, private equity-held to other private. We find evidence that firms moving from public to private equity-held status significantly increase development expenses. However, we fail to find strong evidence that changes in status are related to other changes in innovation strategy in the short-term. We therefore interpret our main results as evidence that ownership type can

[4] Notably, we find a similar pattern with research. That is, even though research overall has a weaker effect on innovation outcomes than development, the contemporaneous value has a stronger effect than its lags.

significantly impact innovation strategy through changes in development spending, but also that firms select into the ownership type that is optimal for their innovation strategies. Analyses on how the innovation strategy of private equity held firm changes after it exits private equity held status further supports the selection hypothesis.

2. Data

Our sample begins with all observations in the Business Research, Development and Innovation survey (BRDIS) from 2009-2015, inclusive, from the U.S. Census Bureau. The survey selects a sample of public and private firms, though it oversamples larger firms and firms with positive research and development expenses. Approximately one-third of Compustat firms are included in the survey. Certain firms are also sampled with certainty in any given year. Details of the sample selection procedure can be found at the NSF website.[5] Responding to the survey is required by law, so selection bias due to failure to respond is not a significant concern. Nevertheless, the Census and NSF adjust their data for non-response bias, and we use the adjusted data in all of our tests.

We merge the BRDIS survey with the Census' Longitudinal Business Database (LBD), using internal Census firm identifiers, in order to obtain payroll and employment for each firm-year observation. Since the LBD reports data at the establishment level, we sum payroll and employment to obtain a firm-level number for firms with multiple establishments. We exclude all firm-year observations with zero payroll from our sample. Since the survey includes a large number of extremely small private firms that are not comparable to public firms or private equity-held firms, we drop firms from the sample if payroll is smaller than the first percentile payroll of firms we identify as belonging to a private equity portfolio. (We describe this identification process in depth below). Since both payroll and

[5] https://www.nsf.gov/statistics/srvyindustry/#qs&sd

employment are always positive in our sample, and yet highly skewed, we use the natural logarithmic transformations of these variables to control for firm size in our regressions, along with the natural logarithm of sales from the BRDIS. We also utilize the natural log of a firm's age and its square, to control for life-cycle effects, for each firm. The age variable is from the LBD and measured as the age of a firm's oldest establishment.

From the 2009-2015 BRDIS, we obtain domestic research, domestic development and worldwide combined R&D for each firm-year firm reported. Unfortunately, the survey does not separately collect information on worldwide research and worldwide development. We thus obtain separate proxies for worldwide research and worldwide development by scaling domestic research and domestic development by the ratio of worldwide-to-domestic, combined R&D. However, all R&D is domestic for over 95% of the observations in our sample. If a firm has missing worldwide combined R&D, we assume research and development are both zero. If a firm reports non-zero worldwide R&D, but the values of domestic research or development are missing, we drop the observation. We also obtain the firm's reported domestic expenditures on capital equipment and structures devoted to research or development and label this variable R&D CAPX. If R&D CAPX is missing, we set it to zero. If R&D CAPX is not missing, we scale it by the ratio of worldwide-to-domestic, combined R&D to obtain a proxy for worldwide R&D CAPX. Since the distributions of research, development and R&D CAPX are highly skewed, but also often take the value of zero, we use the inverse hyperbolic sine (asinh) transformation of these variables in all of our tests. Coefficients from regressions using the asinh transformed data have a similar interpretation to coefficients estimated on log-transformed data. However, asinh has the advantage of being defined at zero. In robustness tests, we find our estimates are nearly identical, both in magnitude and statistical significance when we use a started log transformation with one plus the variable of interest (i.e. ln(1+x)).

We also obtain total worldwide sales, the number of patent applications, the number of patents issued in the year, and the number of scientists, engineers and technicians employed by the firm, globally, for R&D activities from BRDIS. These variables are also highly skewed, so as in the case of sales, we take the natural logarithm. For the patent and personnel counts, we add one and take the natural logarithm, as is standard for count data that can take the value of zero (unlike continuous data, for count data, the started log transformation, where one is added to a variable before taking the natural logarithm, has a straightforward interpretation). We also construct dummy variables indicating whether the number of patents issued or applied for is positive, as well as dummy variables for observations where patent count data are missing. If the firm has missing data on patent or personnel count in a given year, we set it to zero. In unreported results, we confirm the external validity of the patent applications and issuances reported in BRDIS and find that the data generally match patent data available through the United States Patent and Trademark Office (USPTO).

We also create dummy variables related to other types of innovation outputs. That is, we define dummy variables to indicate whether the firm reported introducing new products or services, new production processes, new logistics processes, or new support activities. We also define dummy variables indicating whether the firm indicates utility patents, design patents and trade secrets are somewhat important or very important to its business. All these dummy variables take the value of one if the answer is true, and zero otherwise, even if data are missing. For the trade secret and patent importance dummies, we also create dummies where responses are missing.

We use the Preqin database, a global directory of private equity portfolio companies, to identify all firms within BRDIS from 2009-2015, inclusive, that are part of private equity buyout fund portfolios. To identify firms in private equity buyout portfolios, we first merge BRDIS with the LBD and Standard Statistical Establishment List/Business Register (SSEL) to retrieve the names and addresses of each BRDIS firm establishment. Then, for each year, we use text-matching algorithms to compute a similarity score between the name of every BRDIS firm establishment and every firm in Preqin that is designated as part of a private equity portfolio within that year. We strip all firm names of generic words common to firms, such as "Corp," "Corporation," "Company," "Group," "LLC," and "Industries," before computing the similarity score. We then manually check the names for every potential match with a similarity score of 0.5 or greater (on a scale of 0 to 1) and where the Preqin industry matches the NAICS code in the Census datasets. We also consider the state, zip code and street addresses in making this match. If the state and zip code match, and the names are sufficiently close so that the firms are highly likely, in our judgement, to be the same, we manually designate the pair to be a match. Because firms sometimes relocate, we also identify a pair as a match if the names and industries are a near perfect match, even when the addresses do not match. If the states and zip codes match exactly, we manually examine each potential matched pair, even if the similarity score is as low as 0.3, and designate the pair as a match if the names and industries are sufficiently close in our judgement.

Once we identify the BRDIS firms that are in private equity portfolios in a given year from 2009-2015, we use the Compustat–SSEL Bridge file to identify firms that are publicly listed in a given year. Since the bridge file only extends to 2011, we extend it ourselves to 2015. We do this by identifying the firms deleted from Compustat in 2012-2015 and removing them from the bridge file in the appropriate year. We then examine which firms were added to Compustat in each year, from 2012-2015, and match them with firms in the LBD based on employer identification number (EIN). Those that we cannot match on EIN we match using historical names, addresses and NAICS codes from the CRSP-Compustat merged file and the SSEL. Once we match these firms, we add them to the Compustat–SSEL Bridge file in the appropriate year.

Once we obtain the ownership status of every firm in the BRDIS database, we remove firms designated as other private that have sales below the first percentile of firms in the private equity held category. This ensures that there is overlap in firm size between the types, as the very small firms in the other private category are likely to be fundamentally different from the other categories. In Table 1, we present descriptive statistics on all data used in our tests, delineated by the three ownership types: public, private equity held and other private. All variables are as defined in Appendix A.

3. Methods and Results

We first examine how various innovation variables are related to the ownership status of each firm in the BRDIS database. Since ownership status is not randomly assigned, but rather, firms tend to select into the ownership status thought to be best suited to their business, we empirically model ownership status as a function of innovation strategy in our initial analysis (reported in Table 2), rather than innovation as a function of ownership status.[6] In subsequent tests, we study the impact of ownership status and ownership status changes on innovation (equations 2 and 3, as reported in Tables 3 and 5). We thus we run linear probability models of the form:

$$\begin{aligned} Ownership_{i,t} &= \alpha + \beta_1 \operatorname{asinh}(resesarch_{i,t}) + \beta_2 \operatorname{asinh}(development_{i,t}) + \\ &\beta_3 \operatorname{asinh}(R\&D\ CAPX_{i,t}) + \beta_4 Trade\ Secrets\ Important_{i,t} + \beta_5 Design\ Patents\ Important_{i,t} + \\ &\beta_6 Utility\ Patents\ Important_{i,t} + \beta_7 \ln(1 + \#Patents\ Filed_{i,t}) + \beta_8 I(\#Patents\ Filed_{i,t} > 0) + \\ &\beta_9 \ln(1 + \#Patents\ Issued_{i,t}) + \beta_{10} I(\#Patents\ Issued_{i,t} > 0) + \beta_{11} New\ Products_{i,t} + \\ &\beta_{12} NewProductionProcesses_{i,t} + \beta_{13} NewLogisticsProcesses_{i,t} + \beta_{14} NewSupportActivities_{i,t} + \\ &\beta_{15} \ln(sales_{i,t}) + \beta_{16} \ln(payroll_{i,t}) + \beta_{17} \ln(employees_{i,t}) + \beta_{18} \ln(age_{i,t}) + \beta_{19} \ln(age_{i,t})^2 + \\ &\mathbf{\Gamma' MissingVariableDummies} + \varepsilon_{i,t} \qquad (1) \end{aligned}$$

Where *i* indexes the firm, *t* indexes the year. $Ownership_{i,t}$ is a categorical variable indicating a firm is either private equity held, public, or other private. $I(\cdot)$ is an indicator function, taking the value of one if

[6] Modeling the relation this way has the practical advantage of having to run fewer specifications, as there many more innovation strategy variables than ownership status variables, and the need to obtain Census Bureau disclosure approval makes it costly to report a large number of specifications.

the criterion in the parentheses is satisfied and zero otherwise. We report the results of three different versions of this model in Table 2. We run linear probability models because some of the dependent variables of ownership type are sparse in some specifications, and sparse dependent variables can bias coefficients in categorical data specifications (such as logit and probit) that utilize a non-linear link function.

In the first column of Table 2, the dependent variable takes the value of one if the firm is public, and we estimate the model for our full sample. This model estimates how innovation strategy is related to public status relative to both private statuses. In the second column of Table 2, the dependent variable takes the value of one if the firm is private equity held and zero if the firm is public, and we estimate this model on the subsample of firm-year observations that are either public or private equity held. This model estimates how innovation strategy is related to private equity held status versus public status. Finally, in the third column in Table 2, we use an indicator for private equity held status as the dependent variable, and perform the regression on the subsample of firm-year observations that only include private firms. This model estimates how innovation strategy is related to being private equity held versus being held by another kind of private owner. In all cases, we conservatively cluster standard errors at the four-digit NAICS code level, making our inferences robust to arbitrary heteroscedasticity, serial correlation, and cross-sectional correlation within the broad industry group. We also include industry-by-year fixed effects, with industries defined at the six-digit NAICS code level.

As can be seen in column 1 of Panel A, Table 2, firms that engage in more research relative to firms of similar size and in the same industry and year are more likely to be public. (We control for three size measures and industry-by-year fixed effects at the six digit NAICS level.) This finding is inconsistent with Ferreira et al. (2014), whose theory has the empirical implication that public firms are less likely to engage in exploratory innovation. Another interesting finding is that firms that engage in more development and invest more in capital goods and structures necessary to innovate are more likely to be public, as indicated by the positive coefficients on development and R&D CAPX. Overall, then, we find that public firms invest more in innovation across the board, suggesting public status is more conducive to high innovation intensity. While not the focus of this paper, plausible mechanisms for this finding include public firms having fewer financing constraints, as well as a more risk-tolerant shareholder base due to greater diversification. It is also worth noting the lack of firm life cycle effects, as both the natural log of Age and the natural log of Age squared are insignificant in predicting a firm's ownership status.

Turning our attention to the second and third columns of Panel A, Table 2, we see that private equity held firms differ considerably from others in their focus on development. We report results of tests comparing private equity held firms to public firms in column 2. Consistent with the results of column 1, we find that firm research spending significantly decreases the likelihood of being private equity held relative to public. However, we do not find a similar result for development spending. Specifically, we do not find higher firm development spending significantly predicts being a private equity held versus a public firm. Additionally, as shown in column 3 of Panel A, Table 2, development intensity predicts private equity held-status relative to other private status, whereas research intensity predicts the opposite..

Summarily, Panel A, Table 2, reveals a consistent view of the three ownership types. Public firms engage in more investment in all types of innovation relative to private firms. Private firms, that are not private equity held, invest less in innovation than public firms, but conduct roughly equal proportions of exploratory and exploitative innovation. In contrast to other private firms, private equity held firms conduct high levels of exploitative innovation, comparable to that of public firms, but perform less exploratory innovation. This finding is consistent with private equity held firms being less conducive to an exploratory innovation strategy due to the shorter time horizons of private equity investors, as Barrot (2017) reports among venture capital firms. It is also consistent with prior literature finding private equity firms tend to focus on operating improvements (e.g. Bernstein and Sheen, 2016). Indeed, support for operational improvements by private equity held firms is demonstrated by the positive coefficient on the variable "New Support Activities Dummy" in Panel A, column 2, Table 2, where the BRDIS 2009 survey gives examples of support activities as: "… maintenance systems, or operations for purchasing, accounting, or computing."

Further consistent with the differential spending on research and development, we report that a higher level of pay is significantly associated with being privately equity held versus public in column 2 of Panel A, Table 2. This finding is potentially related to the observed higher levels of development by private equity held firms. Specifically, the higher level of pay may be due to the private equity fund seeking to retain key, high-ability employees for development projects, as said employees would most likely positively enhance the firm's patenting activities and the private equity firm's exit prospects.[7]

In addition to the findings discussed above, we also report several novel empirical finding on the relation between other innovation activities and characteristics and equity ownership type. First, we show that firms are less likely to be public if they answer that utility patents are important to their business in column 1 of Panel A, Table 2. Furthermore, firms are more likely to be private equity held if they regard utility patents as important to their business than other private firms in column 3. Second, we also report that a firm is more likely to be public if the firm applies for patents in a given year in column 1, Table 2,. However, a firm is less likely to be public if it is granted patents in a given year and, in column 3, a firm is less likely to be private equity held if it is granted a patent in a given year.[8] Finally,

[7] An increase in compensation could be intended to mitigate any perceived negative wealth-shocks by employees due to an uncertain future and/or career concerns. Thus, an increase in employee compensation could be utilized to induce an employee to continue to supply better quality innovative ideas (e.g. Bernstein, McQuade, and Townsend, 2017) while a firm is private equity held.

[8] It is worth noting that the failure to be awarded a patent in a given year for a private equity held firm, relative to another private firm, may be the result of managerial inefficiencies prior to the private equity held firm becoming part of a private equity portfolio. Thus, the reason for this difference could be former managerial inefficiencies combined with the time lapse between a patent application becoming a granted patent.

we find firms are more likely to be public if they introduce both new production and logistics processes, which may prove difficult-to-patent and/or enforce if a patent is granted.

These results suggest firms more likely to engage in method and/or difficult-to-patent innovation, targeted towards product and process development, find public status advantageous. This suggests that prior research comparing public and private firm innovation, via patenting activity, are missing important aspects of innovation, as well as a firm's goal in obtaining a patent (e.g. production, licensing, blocking a competitor, etc.). Furthermore, columns 2 and 3 of Panel A, Table 2, suggest that private equity held firms are in between public and other private firms in terms of their investments in innovation related to processes and logistics. We find evidence that public firms are more willing to engage in potentially difficult-to-patent innovation, which thereby is more vulnerable to rival imitation. This finding is inconsistent with the hypothesis that disclosure costs associated with innovation are important determinants of public status.

We also run another set of three linear probability regressions in Panel B of Table 2, similar to Panel A of Table 2. Instead of research and development, we use the log count of scientists, technicians and engineers employed at the firm to measure the intensity of investment in innovation. The results, in Panel B of Table 2, are largely consistent with the results in Panel A of Table 2. Specifically, we find that firms with more scientists and firms with more technicians are significantly more likely to be public.

We next study whether different types of equity ownership are associated with divergent levels of innovation outcomes and efficiency in converting innovation input(s) into output(s). To this end, we estimate specifications in which we regress innovation outputs on innovation inputs, as well as three lags of each, along with equity ownership types and size controls:

$$Y_{i,t} = a + \mathbf{B_1}'\mathbf{L}(0,3,\operatorname{asinh}(Research_i)) + \mathbf{B_1}'\mathbf{L}(0,3,\operatorname{asinh}(Development_i))$$

$$+\mathbf{\Gamma}'\mathbf{L}(1,3,Y_i) + \mathbf{Controls_{i,t}} + \varepsilon_{i,t} \qquad (2)$$

Where **L(***s, n***,** *X***)** describes a vector that includes all lags of *X* between *s* and *n*, inclusive*.* A value of *s*=0 indicates the vector includes the contemporaneous value of *X.* Outputs *Y* include: the started log of patents issued, the started log of patent applications, and dummy variables indicating the introduction of new products, processes, and support activities. In the case of the specification for patents issued, we also include three lags of the started log of patents applied. We include controls for size as well as dummies for public and private equity held statuses. Results are in Panel A of Table 3. The specification for patents issued also includes three lags of transformed patent applications, the parameters of which are suppressed for brevity.

As can be seen in Panel A of Table 3, there is a great deal of persistence in innovation outputs, as lags of the dependent variable (*L1.Y*, *L2.Y*, *L3.Y*) are generally significant in all cases. Markedly, only contemporaneous input variables (research and development) appear to significantly increase innovation output, though the effect of development is stronger, as expected. We also see lagged values of development significantly negatively correlated with contemporaneous patenting activity, suggesting development intensity tends to peak during periods of intense patenting, and then revert to lower levels. Point estimates suggest the pattern in research is similar, but not as strong. Additionally, we find that private equity held firms apply for, and are issued, significantly more patents, consistent with Lerner, Sorensen, and Stromberg (2011). However, we also find that private equity held firms introduce fewer new products and new support services, consistent with Yang and Zhang (2019). It is possible that the pursuit of increased patent applications and issuances, as in Lerner *et al* (2011), while not developing new products from new intellectual property, as in Yang and Zhang (2019), is a strategy on the part of the private equity firm to increase the return of their holding's exit by increasing the value of the holding's intellectual property.

Due to the findings in Panel A of Table 3, we only interact the contemporaneous value of the input variables with public and private equity held status in Panels B and C (for development and research, respectively). We only report the interaction term parameters for the sake of brevity, but the same independent variables reported in Panel A are included in these specifications. As can be seen in Panels B and C of Table 3, it appears that public firms are most efficient at turning both research and development spending into patents. Nonetheless, public firms appear to be less efficient at turning research and development into new products, suggesting their investment in innovation is more focused on processes and product improvements. Private equity held firms appear to be more efficient at converting development into patents issued. However, we do not observe a differential for private equity firms on the efficiency of converting development or research spending into other innovation outcomes.

To understand whether any of the effects we find are due to firms selecting into ownership type most appropriate for their innovation strategies, or whether ownership type is causing the innovation strategy, we examine whether changes in ownership status correlate with changes in innovation strategy. To that end, we take the subsample of firms in our panel for which there are at least three years of consecutive observations. Then, for each observation, we take the difference between the variables in the year after and the year prior to the current year. We then regress these changes of innovation strategy on dummy variables indicating a change in ownership status, along with changes in our log-transformed size measures (i.e. payroll, sales and employment). The resulting specification is:

$$\Delta Y_{i,(t+1)-(t-1)} = \alpha_{k,t} + \beta_1 pub\_to\_pe_{i,t} + \beta_2 pe\_to\_pub_{i,t} + \beta_3 pe\_to\_othpriv_{i,t} + \beta_4 othpriv\_to\_pe_{i,t} + \beta_5 othpriv\_to\_pub_{i,t} + \beta_6 \Delta\ln(sales)_{i,(t+1)-(t-1)} + \beta_7 \Delta\ln(payroll)_{i,(t+1)-(t-1)} + \varepsilon_{i,(t+1)-(t-1)} \quad (3)$$

Where *Y* takes on the following innovation variables, each in a separate specification: $\text{asinh}(research)$, $\text{asinh}(development)$, asinh(R&D CAPX), $\ln(patents\ applied)$, and $\ln(patents\ issued)$. The Δ operator signifies the change between the year $(t+1)$ and the year $(t-1)$. The change in ownership status dummies are all contemporaneous (i.e. year t). Thus, the coefficients on the change in status dummies, represent the estimated effect of a change on the lead value of the dependent variable relative to the lag value. All coefficients are estimated using OLS with industry-by-year fixed effects, with industries defined at the six-digit NAICS code level. Reported t-statistics are conservatively derived from clustered standard errors at the four-digit NAICS code level. Descriptive statistics on the smaller sample of firm-year observations, wherein these regressions are computed, are in Table 4. Results from the lead-lag regressions are in Table 5.

To draw inferences from the specification given in equation 3, we make the identifying assumption that the firm's optimal innovation strategy is somewhat persistent, and does not change radically from year to year. We also assume that if there is a causal effect of ownership type on innovation strategy, it is likely to significantly manifest itself within a year. Thus, where estimates of equation 1 uncover any significant association(s) between ownership type and innovation strategy/strategies, but are not significantly associated in equation 3, we will conclude the effect(s) found in equation 1 are the result of selection. However, if we do find a significant effect, or effects, in equation 3, in a similar direction as the effect(s) found in equation 1, we will infer that ownership type likely has some causal effect, though we will not be able to precisely measure it.

As can be seen by the positive and significant coefficient on the *pub_to_pe* dummy in column 2 of Table 5, we find evidence that development increases as firms move from public to private equity held status. Hence, it is possible that changes in public to private equity status result in more development spending. This consistent with our linear probability models, which suggest that private equity held firms tend to skew their innovation investments toward development. However, most of the changes in status dummies are statistically insignificant. Thus, aside from the development result discussed above, we infer that many of our estimates in Table 2 are likely to reflect a firm's selection into the type of ownership status that best suits its particular innovation strategy, rather than a causal effect of ownership status on innovation.

To further study whether innovative activities have a causal effect on the ownership type of a firm, we study the exit outcomes of private equity-held leveraged buyout investments. We test whether innovative activities are significant determinants of the exit of a private equity held firm to a public operating company (trade sale), to public markets (IPO), to another private equity firm (secondary buyout), to a private operating firm (other private), or a write-off or restructuring (bankrupt). We regress an exit-type indicator on various innovation and control variables in a system of jointly estimated linear probability models for deals exited between 2010 and 2016 that we were able to match to the BRDIS.

We average all innovation and control variables over the period that the firm was in the private equity portfolio, for all years where we have data. We include 3-digit NAICS industry and investment year fixed effects, with standard errors clustered at the 3-digit NAICS code level. As reported in Table 6, we find the innovation activities of a portfolio company significantly impact its exit type. Specifically, we find that private equity held firms that are smaller, have greater research intensity, introduce new products, place low importance on utility patents, and place a higher importance on trade secrets, are significantly more likely to be purchased in a trade sale relative to other outcomes. These results are consistent with public operating companies acquiring firms that are potentially better fits into their established portfolio, as well as research being important to the business of large public operating companies. However, we also find that larger private equity held firms (as measured by payroll) are more likely to go public through an IPO. On the other hand, we find that they are not more innovative, on average, than firms exited through other means. Finally, and somewhat consistent with the findings of Lerner, Sorensen, and Stromberg (2011), we find that private equity held firms that report utility patents are important to their business are more likely to be sold to other private equity firms in a secondary buyout. We also find firms that introduce new products or services and consider design patents more important are less likely to exit via secondary sale. Additionally, and contrary to the disclosure cost hypothesis, we find that a secondary sale is less likely if trade secrets are important to the private equity held firm.

4. Conclusion

The literature on innovation theories has long distinguished between exploration and exploitation of knowledge. Due to the fact that firms generally report aggregated spending of their research and development activities, it has been difficult to empirically test these theories. While prior empirical work has made progress by examining the nature of patents applied for and issued to firms, there are important reasons why firms may not patent innovation and existing evidence suggests that patenting is of secondary importance to other informal intellectual property protection. For example, firms often guard innovation as a trade secret or through confidentiality agreements rather than patent it since a granted patent entails public disclosure of the technical details of the proposed innovation. The competitive costs of disclosing these innovations may outweigh the benefits of patent citation. In addition, there is a significant duration of time between when the patent's subject matter is researched, when the patent is applied for and when the patent is issued, if at all. Thus, the use of informal rather than formal intellectual property, and the significant temporal gap between innovation inputs and outputs, results in patenting activity not reflecting the totality of a firm's innovation.

Utilizing the BRDIS dataset, in which research and development are separately reported, we can distinctly observe firm investment in exploratory and exploitative innovation. Contrary to some prominent theories of innovation, we find public firms have greater investment intensity in exploratory innovation. We also find public firms tend to invest more in innovation of all types, suggesting that several unique features of public firm status make them more conducive to investment in innovation overall. Private equity held firms, consistent with shorter horizons, due to limited holdings periods, tend to skew their innovation activities toward exploitation of knowledge rather than exploration. Finally, analyses of how changes in innovation strategy relate to changes in ownership status suggest our findings are due to firms selecting into the ownership status that best suits their innovation strategies, rather than a causal effect.

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Table 1

Summary Statistics by Ownership Type: Public, Private Equity Held and Other Private Firms.

BRDIS Firm-Year Observations from 2009-2015, inclusive. The number of observations is rounded due to Census Bureau disclosure regulations. All variables are as defined in Appendix A.

Panel A: Public Firms. N = 11,000.

	Mean	Std. Dev.	Skewness	Kurtosis
asinh(Research)	3.948	4.839	0.5750	1.633
asinh(Development)	5.938	5.519	0.01501	1.291
ln(1+Engineers)	0.3681	1.349	3.963	18.80
ln(1+Scientists)	0.1652	0.8299	5.844	39.92
ln(1+Technicians)	1.731	2.213	0.9436	2.680
asinh(R&D CAPX)	3.970	4.487	0.4536	1.568
Trade Secret Important Dummy	0.2222	0.4158	1.336	2.785
Trade Secret Important Missing	0.4019	0.4903	0.4000	1.160
Design Patents Important Dummy	0.4802	0.4996	0.07911	1.006
Design Patents Important Missing	0.4004	0.4900	0.4067	1.165
Utility Patents Important Dummy	0.2545	0.4356	1.127	2.271
Utility Patents Important Missing	0.3994	0.4898	0.4106	1.169
ln(1+Patents Applied)	1.266	1.869	1.355	3.883
Patents Applied > 0, Dummy	0.4037	0.4907	0.3926	1.154
Missing Patent Applications	0.3098	0.4624	0.8225	1.676
ln(1+Patents Issued)	1.085	1.729	1.591	4.745
Patents Issued > 0, Dummy	0.3741	0.4839	0.5205	1.271
Patents Issued Missing	0.3215	0.4671	0.7643	1.584
New Products Introduced Dummy	0.3621	0.4806	0.5737	1.329
New Production Processes Dummy	0.2057	0.4042	1.456	3.120
New Logistics Processes Dummy	0.1530	0.3600	1.927	4.715
New Support Activities Dummy	0.2071	0.4052	1.446	3.090
ln(Sales)	13.79	2.113	-0.5822	4.539
ln(Payroll)	12.07	1.677	0.03700	2.976
ln(Employment)	7.717	1.770	0.04409	3.008
ln(Age)	3.380	0.4555	-2.243	8.634
$\ln(Age)^2$	11.63	2.635	-1.723	5.351

Panel B: Private Equity Held Firms. N = 4,500.

	Mean	Std. Dev.	Skewness	Kurtosis
asinh(Research)	1.974	3.335	1.321	3.224
asinh(Development)	3.696	4.368	0.5210	1.626
ln(1+Engineers)	0.1333	0.6845	5.789	38.33
ln(1+Scientists)	0.04490	0.3599	9.323	99.08
ln(1+Technicians)	0.8282	1.456	1.947	6.687
asinh(R&D CAPX)	2.220	3.318	1.092	2.787
Trade Secret Important Dummy	0.2216	0.4153	1.341	2.798
Trade Secret Important Missing	0.5474	0.4978	-0.1904	1.036
Design Patents Important Dummy	0.3656	0.4816	0.5582	1.312
Design Patents Important Missing	0.5474	0.4978	-0.1904	1.036

Utility Patents Important Dummy	0.3009	0.4587	0.8684	1.754
Utility Patents Important Missing	0.5463	0.4979	-0.1859	1.035
ln(1+Patents Applied)	0.3838	0.9567	3.127	14.39
Patents Applied > 0 Dummy	0.1928	0.3946	1.557	3.424
Missing Patent Applications	0.4137	0.4926	0.3503	1.123
ln(1+Patents Issued)	0.2734	0.8118	4.004	22.60
Patents Issued > 0 Dummy	0.1484	0.3556	1.978	4.911
Patents Issued Missing	0.4374	0.4961	0.2525	1.064
New Products Introduced Dummy	0.2622	0.4399	1.081	2.169
New Production Processes Dummy	0.1279	0.3340	2.228	5.965
New Logistics Processes Dummy	0.08063	0.2723	3.081	10.49
New Support Activities Dummy	0.1378	0.3448	2.101	5.415
ln(Sales)	12.12	1.709	-0.2636	5.781
ln(Payroll)	10.68	1.420	0.7673	3.701
ln(Employment)	6.539	1.492	0.7908	3.934
ln(Age)	3.191	0.6338	-1.651	5.382
$\ln(\text{Age})^2$	10.59	3.421	-1.150	3.260

Panel C: Other Private Firms. N = 132,000.

	Mean	Std. Dev.	Skewness	Kurtosis
asinh(Research)	1.607	2.880	1.535	4.022
asinh(Development)	2.781	3.738	0.8056	2.043
ln(1+Engineers)	0.1090	0.5562	6.163	47.02
ln(1+Scientists)	0.03452	0.3066	11.38	159.0
ln(1+Technicians)	0.5314	1.052	2.333	8.786
asinh(R&D CAPX)	1.588	2.632	1.399	3.742
Trade Secret Important Dummy	0.2580	0.4375	1.106	2.224
Trade Secret Important Missing	0.5598	0.4964	-0.2410	1.058
Design Patents Important Dummy	0.3724	0.4834	0.5279	1.279
Design Patents Important Missing	0.5602	0.4964	-0.2426	1.059
Utility Patents Important Dummy	0.3212	0.4670	0.7657	1.586
Utility Patents Important Missing	0.5588	0.4965	-0.2370	1.056
ln(1+Patents Applied)	0.2149	0.6847	4.022	21.82
Patents Applied > 0 Dummy	0.1242	0.3298	2.279	6.194
Missing Patent Applications	0.3806	0.4855	0.4919	1.242
ln(1+Patents Issued)	0.1452	0.5492	4.975	32.68
Patents Issued > 0 Dummy	0.09285	0.2902	2.806	8.873
Patents Issued Missing	0.4078	0.4914	0.3754	1.141
New Products Introduced Dummy	0.2583	0.4377	1.104	2.220
New Production Processes Dummy	0.1497	0.3568	1.964	4.856
New Logistics Processes Dummy	0.06834	0.2523	3.421	12.71
New Support Activities Dummy	0.1315	0.3380	2.181	5.755
ln(Sales)	10.26	1.859	0.09808	5.673
ln(Payroll)	9.034	1.375	1.155	4.650
ln(Employment)	4.857	1.397	0.9422	4.567
ln(Age)	2.950	0.7377	-1.070	3.452
$\ln(\text{Age})^2$	9.246	3.821	-0.5837	2.128

Table 2

Linear Probability Models of Ownership Status

Linear probability model parameter estimates, and t-statistics, summarizing the relation between innovation strategy variables and equity ownership types for BRDIS firm-year observations from 2009-2015, inclusive. Panel A includes research and development variables; whereas, Panel B includes counts of scientists, engineers and technicians. Every firm-year observation is labeled by ownership type as: "Public," "PE Held," or "Other Private." In each model, the sample consists of firm-year observations that belong to the groups specified in the title of the model. The dependent variable in each model is an indicator, taking a value of zero or one, that specifies whether a firm-year observation belongs to the first listed group of the model's title. All regressions include six-digit NAICS industry-by-year fixed effects. Standard errors are clustered at the four-digit NAICS code level. The number of observations is rounded due to Census Bureau disclosure regulations. All variables are as defined in Appendix A. Statistical significance: 1% = ***, 5% = ** and 10% = *.

Panel A

	Public vs. All Others	PE Held vs. Public	PE Held vs. Other Private
asinh(Research)	0.001326**	-0.004994***	-0.001559***
	(1.985)	(-2.947)	(-3.264)
asinh(Development)	0.001936**	-0.0005823	0.001036**
	(2.557)	(-0.2925)	(2.343)
asinh(R&D CAPX)	0.02699***	-0.01109	-0.000661
	(4.073)	(-0.6820)	(-0.1517)
Trade Secret Important Dummy	0.005334	0.0002060	-0.002588
	(0.6260)	(0.004190)	(-0.4172)
Trade Secret Importance Missing	-0.008997*	0.06432***	0.006643*
	(-1.710)	(3.714)	(1.890)
Design Patents Important Dummy	-0.005904	0.08593*	0.002896
	(-0.5354)	(1.814)	(0.5457)
Design Patent Importance Missing	0.01820***	0.005768	-0.003575
	(2.955)	(0.5604)	(-1.150)
Utility Patents Important Dummy	-0.01466*	-0.02321	0.01585***
	(-1.900)	(-0.8344)	(3.041)
Utility Patents Importance Missing	0.01699***	-0.04205	0.004453
	(3.877)	(-1.440)	(1.460)
ln(1+ Patents Applied)	0.04821***	0.02343**	-0.00627
	(8.519)	(2.254)	(-1.528)
Patents Applied > 0 Dummy	-0.03090***	-0.1060***	0.007482
	(-3.412)	(-4.327)	(1.365)
Missing Patent Applications	-0.009067**	0.02444	0.0004747
	(-2.535)	(0.9011)	(0.1666)
ln(1+ Patents Issued)	-0.01352***	0.007850	-0.002666
	(-4.745)	(0.5733)	(-1.296)
Patents Issued>0 Dummy	-0.008243**	-0.03258*	-0.01342***
	(-2.325)	(-1.763)	(-4.404)
Patents Issued Missing	0.01899***	-0.02369	0.003631

	(4.579)	(-1.370)	(1.378)
New Products Introduced Dummy	-0.003485	0.02491	0.0003114
	(-1.187)	(1.650)	(0.1447)
New Production Processes Dummy	0.009303***	-0.01680***	0.002320***
	(7.766)	(-2.889)	(3.330)
New Logistics Processes Dummy	0.04591***	-0.1556***	0.01392***
	(12.72)	(-7.388)	(6.507)
New Support Activities Dummy	0.003943	0.1049***	0.01353***
	(1.345)	(5.653)	(6.996)
ln(Sales)	0.008456	-0.2341***	-0.0009916
	(0.9041)	(-3.365)	(-0.1305)
ln(Payroll)	0.001483	0.02782**	0.0006968
	(0.7398)	(2.021)	(0.4368)
ln(Employment)	0.001074	0.001508	0.0001024
	(1.388)	(0.7191)	(0.2145)
ln(Age)	-0.002395	-0.01452	-0.003054
	(-0.7067)	(-0.8770)	(-1.199)
$\ln(\text{Age})^2$	0.01289	-0.01120	0.003656
	(1.540)	(-0.2492)	(0.5675)
Constant	-0.5443***	2.017***	-0.1917***
	(-17.22)	(13.03)	(-10.27)
Adj. R-Squared	0.3174	0.3571	0.07389
Obs.	148,000	15,500	137,000

Panel B

	Public vs. All Others	PE Held vs. Public	PE Held vs. Other Private
ln(1+Scientists)	0.001526**	-0.0004361	0.0002346
	(2.327)	(-0.2459)	(0.5661)
ln(1+Engineers)	-0.001702	-0.01707	-0.003591
	(-0.5054)	(-1.046)	(-1.429)
ln(1+Technicians)	0.01462*	-0.006922	0.002821
	(1.718)	(-0.1532)	(0.4396)
asinh(R&D CAPX)	0.02616***	-0.01071	-0.0003525
	(4.012)	(-0.6675)	(-0.08231)
Trade Secret Important Dummy	0.004537	-0.0008660	-0.002299
	(0.5333)	(-0.01746)	(-0.3716)
Trade Secret Important Missing	-0.008642*	0.06699***	0.006658*
	(-1.683)	(3.832)	(1.884)
Design Patents Important Dummy	-0.005440	0.08390*	0.001972
	(-0.4948)	(1.750)	(0.3706)
Design Patent Dummy Missing	0.01671***	0.004822	-0.003954
	(2.736)	(0.4834)	(-1.277)
Utility Patents Important Dummy	-0.01179	-0.02224	0.01645***
	(-1.506)	(-0.8203)	(3.227)
Utility Patents Important Missing	0.01691***	-0.04431	0.003869
	(3.935)	(-1.550)	(1.268)
ln(1+ Patents Applied)	0.04587***	0.02195**	-0.006158

	(7.971)	(2.128)	(-1.567)
Patents Applied > 0 Dummy	-0.02853***	-0.1039***	0.007719
	(-3.107)	(-4.341)	(1.426)
Missing Patent Applications	-0.009099**	0.02601	0.0008493
	(-2.580)	(0.9751)	(0.3012)
ln(1+ Patents Issued)	-0.01296***	0.004444	-0.001868
	(-4.919)	(0.3301)	(-0.9317)
Patents Issued > 0 Dummy	-0.008617**	-0.03.865**	-0.01359***
	(-2.459)	(-2.109)	(-4.604)
Patents Issued Missing	0.01872***	-0.02255	0.003600
	(4.459)	(-1.290)	(1.373)
New Products Introduced Dummy	-0.003912	0.02859*	0.0002537
	(-1.312)	(1.914)	(0.1203)
New Production Processes Dummy	0.009186***	-0.01723***	0.002393***
	(7.594)	(-2.981)	(3.493)
New Logistics Processes Dummy	0.04704***	-0.1611***	0.01408***
	(12.49)	(-7.619)	(6.693)
New Support Activities Dummy	0.001707	0.1106***	0.01351***
	(0.5737)	(5.998)	(7.141)
ln(Sales)	0.007406	-0.2168***	-0.0003666
	(0.7838)	(-3.140)	(-0.04818)
ln(Payroll)	0.001679	0.02428*	0.0005692
	(0.8344)	(1.775)	(0.3569)
ln(Employment)	0.004971*	0.00104	-0.002982
	(1.761)	(0.2177)	(-1.472)
ln(Age)	0.01115***	-0.01287***	-0.001332
	(7.496)	(-4.858)	(-1.572)
$\ln(Age)^2$	0.009703***	-0.001208	-0.0008422
	(4.462)	(-0.2842)	(-0.4544)
Constant	-0.5415***	2.022***	-0.1927***
	(-17.09)	(13.07)	(-10.23)
Adj. R-Squared	0.3195	0.3569	0.07371
Obs.	148,000	15,500	137,000

Table 3
Efficiency of Innovation

Coefficient parameter estimates and t-statistics from regressions of innovation outcomes on: Transformed contemporaneous and lagged research and development variables; three lags of the dependent variable; and controls. Panel A presents specifications without interactions. The specification for patents issued includes three lags of patents applied, whose parameters are suppressed. Panels B and C present specifications with the same independent variables and include interactions between ownership status (i.e. public, private and private equity held) with contemporaneous development and research, respectively. Only the interaction terms are reported in Panels B and C for brevity. All specifications are estimated using OLS. Standard errors are clustered at the four-digit NAICS level. All variables are as defined in Appendix A. Statistical significance: 1% = ***, 5% = ** and 10% = *.

Panel A

	ln(1+Patents Issued)	ln(1+Patents Applied)	New Product	New Production Process	New Logistics Process	New Support Service
asinh(Dev)	0.04662***	0.06252***	0.03798***	0.01748***	0.009419***	0.01525***
	(18.31)	(19.00)	(22.75)	(9.469)	(12.65)	(16.09)
L1.asinh(Dev)	-0.01754***	-0.02273***	-0.01607***	-0.008013***	-0.003651***	-0.006198***
	(-8.692)	(-8.920)	(-13.51)	(-6.770)	(-5.051)	(-7.949)
L2.asinh(Dev)	-0.01066***	-0.009945***	-0.001660	-0.001056	-0.001103	-0.001136
	(-5.338)	(-4.958)	(-1.394)	(-1.299)	(-1.549)	(-1.414)
L3.asinh(Dev)	-0.006809***	-0.007732***	-0.001854*	-0.001094	-0.0004931	-0.001440**
	(-3.567)	(-3.825)	(-1.678)	(-1.570)	(-0.8102)	(-2.180)
asinh(Res)	0.01779***	0.02354***	0.008714***	0.009550***	0.004963***	0.007892***
	(5.536)	(4.772)	(7.790)	(8.912)	(6.268)	(7.348)
L1.asinh(Res)	-0.007165***	-0.007705***	-0.0006570	-0.002600**	-0.002138***	-0.002186**
	(-3.309)	(-2.609)	(-0.4737)	(-2.297)	(-2.920)	(-2.224)
L2.asinh(Res)	0.001525	0.001869	0.00005288	0.0006429	0.0003988	-0.00004081
	(0.5937)	(0.7174)	(0.04851)	(0.7369)	(0.5332)	(-0.04690)
L3.asinh(Res)	-0.002181	-0.004078	-0.001990*	-0.0009399	0.0002418	-0.0002078
	(-0.8121)	(-1.459)	(-1.686)	(-0.9587)	(0.3284)	(-0.2881)
Public	-0.01902	-0.01663	-0.01259	-0.02031**	-0.007243	-0.02209***
	(-0.9931)	(-0.7117)	(-1.268)	(-2.310)	(-1.036)	(-2.704)
PE Held	0.06537***	0.06669***	-0.01747**	-0.01172	0.002229	-0.01381*
	(3.194)	(3.085)	(-2.040)	(-1.500)	(0.3612)	(-1.809)
L1.Y	0.3038***	0.4326***	0.3730***	0.4130***	0.4108***	0.3845***
	(13.40)	(27.52)	(38.04)	(47.37)	(36.72)	(40.68)
L2.Y	0.1079***	0.2043***	0.08724***	0.09217***	0.1090***	0.09773***
	(5.524)	(14.44)	(5.768)	(8.251)	(12.04)	(9.831)
L3.Y	0.1146***	0.1447***	0.09419***	0.09456***	0.07355***	0.06864***
	(8.252)	(11.16)	(11.59)	(11.05)	(7.419)	(8.595)
ln(Payroll)	0.07269***	0.09978***	-0.003580	-0.01325**	0.0009905	-0.002209
	(4.919)	(5.992)	(-0.5*216)	(-2.562)	(0.2363)	(-0.4273)
ln(Employment)	-0.03684***	-0.04995***	0.0006737	0.01825***	0.003867	0.006692
	(-2.904)	(-3.245)	(0.0887)	(3.409)	(0.9399)	(1.305)
ln(Sales)	0.006236	0.007733	0.001048	-0.001608	0.002034*	0.003192
	(1.447)	(1.630)	(0.5549)	(-1.129)	(1.789)	(1.544)
Constant	-0.6468***	-0.8611***	0.06429*	0.06927***	-0.04958**	-0.03027

	(-7.261)	(-8.638)	(1.908)	(3.053)	(-2.432)	(-1.193)
Adj. R-Squared	0.7126	0.7018	0.4272	0.3862	0.3328	0.3055
Obs.	28,000	28,000	28,000	28,000	28,000	28,000

Panel B

	ln(1+Patents Issued)	ln(1+Patents Applied)	New Product	New Production Process	New Logistics Process	New Support Service
asinh(Dev) x PE Held	0.01156**	0.01017	-0.004127	-0.002532	0.0003574	-0.001711
	(2.275)	(1.553)	(-1.544)	(-1.437)	(0.2179)	(-0.9752)
asinh(Dev) x Public	0.04043***	0.04048***	-0.005931***	-0.002273	0.001358	-0.001331
	(9.763)	(9.537)	(-3.723)	(-1.561)	(1.261)	(-1.093)
Constant	-0.5970***	-0.8010***	0.05023	0.06361***	-0.04627**	-0.03377
	(-7.208)	(-8.176)	(1.441)	(2.812)	(-2.336)	(-1.361)
Adj. R-Squared	0.7163	0.7048	0.4277	0.3863	0.3328	0.3055
Obs.	28,000	28,000	28,000	28,000	28,000	28,000

Panel C

	ln(1+Patents Issued)	ln(1+Patents Applied)	New Product	New Production Process	New Logistics Process	New Support Service
asinh(Res) x PE Held	0.009224	0.01120	-0.005332	-0.003443	-0.001524	-0.002021
	(1.176)	(1.250)	(-1.391)	(-1.346)	(-0.6805)	(-0.7736)
asinh(Res) x Public	0.03530***	0.03689***	-0.004933***	-0.003051**	0.0002676	-0.001367
	(7.997)	(7.851)	(-2.872)	(-2.133)	(0.1875)	(-0.7936)
Constant	-0.6229***	-0.8272***	0.05639	0.06426***	-0.04932**	-0.03265
	(-7.200)	(-8.268)	(1.612)	(2.839)	(-2.471)	(-1.328)
Adj. R-Squared	0.7149	0.7039	0.4275	0.3863	0.3328	0.3055
Obs.	28,000	28,000	28,000	28,000	28,000	28,000

Table 4

Summary Statistics for Sample where Lead Minus Lag Changes can be Computed

Summary statistics for BRDIS firm-year observations from 2009-2015, inclusive, where at least one lead and lag of an innovation input and output variable are observed. The change operator, Δ[·] is the lead minus the lag of the specified variable. N = 37,500. The number of observations is rounded due to Census Bureau disclosure regulations. All variables are as defined in Appendix A.

	Mean	Std. Dev.	Skewness	Kurtosis
Public to PE	0.0008319	0.02883	34.63	1,200.
PE to Public	0.0006977	0.02641	37.82	1,431.
PE to Other Private	0.002335	0.04826	20.62	426.3
Other Private to PE	0.005018	0.07066	14.01	197.3
Other Private to Public	0.001.878	0.04330	23.01	530.3
Δ[ln(Sales)]	0.09938	1.036	-0.1110	33.61
Δ[ln(Payroll)]	0.09078	0.4228	-4.760	97.29
Δ[ln(Employment)]	0.04271	0.4049	-3.795	69.75

Table 5

Effect of Changes of Ownership Status on Changes in Innovation Strategy.

Regressions of lead-minus-lag changes of innovation strategy variables on dummies indicating changes in equity ownership status. Research, development and R&D CAPX are all asinh transformed before changes are computed. Patents applied and patents issued are started-log transformed before changes are computed. Size control variables (sales, payroll and employment) are log transformed before changes are computed. T-statistics are in parentheses. Standard errors are clustered at the four-digit NAICS level. All variables are as defined in Appendix A. Statistical significance: 1% = ***, 5% = ** and 10% = *.

	Model 1	Model 2	Model 3	Model 4	Model 5
	Research	Development	R&D CAPX	Patents Applied	Patents Issued
Public to PE	0.08565	0.8390**	0.1036	0.07039	-0.08703
	(0.2023)	(2.444)	(0.2161)	(0.2561)	(-0.3297)
PE to Public	0.9449	0.2418	-0.5003	0.1344	-0.02130
	(1.447)	(0.4403)	(-0.8110)	(0.8795)	(-0.1414)
PE to Other Private	0.3143	-0.04972	0.1662	-0.06352	-0.1071
	(0.8262)	(-0.1157)	(0.3959)	(-0.5437)	(-1.107)
Other Private to PE	0.2355	-0.1675	0.2691	0.07542	0.06682
	(0.8111)	(-0.5225)	(0.9417)	(1.416)	(1.486)
Other Private to Public	-0.4500	-0.1477	-0.6087	0.07559	-0.05334
	(-0.932)	(-0.3207)	(-1.233)	(0.6667)	(-0.3960)
Δ[ln(Sales)]	0.1026***	0.1226***	0.1293***	0.02038***	0.01116**
	(5.306)	(3.795)	(5.633)	(4.539)	(2.208)
Δ[ln(Payroll)]	0.2623***	0.5086***	0.3884***	0.09567***	0.05851***
	(3.444)	(6.678)	(4.176)	(4.533)	(3.398)
Δ[ln(Employment)]	-0.02130	-0.1759*	-0.1557*	-0.008789	-0.004689
	(-0.2260)	(-1.930)	(-1.872)	(-0.4618)	(-0.2597)
Constant	-0.05505***	-0.1150***	0.02041	-0.04379***	-0.01325***
	(-2.972)	(-4.912)	(0.6443)	(-4.894)	(-2.806)
Adj. R-Squared	0.002140	0.003507	0.003136	0.002638	0.001210
Obs.	37,500	37,500	37,500	37,500	37,500

Table 6
Exit Outcomes of Private Equity Investments

Parameter estimates and t-statistics of linear probability models of exit outcome types for a private equity portfolio company. Five models are jointly estimated for five exit outcomes (trade sale, IPO, secondary buyout, bankruptcy, or still held as of 2015), but only the first three models are reported due to disclosure limits. Independent variables include measures of a firm's innovation strategy averaged over all the years for which we have data, where the firm was part of the private equity portfolio. Industry-by-year fixed effects are included in all regressions. Industry is defined at the 3-digit NAICS level. Standard errors are clustered at the 3-digit NAICS level. All variables are as defined in Appendix A. Statistical significance: 1% = ***, 5% = ** and 10% = *.

	Trade Sale	IPO	Secondary Buyout
asinh(Research)	0.008317*	-0.004403	-0.001189
	(1.855)	(-1.482)	(-0.3390)
asinh(Development)	-0.004843	-0.0008669	0.004457
	(-0.771)	(-0.2956)	(0.7671)
asinh(R&D CAPX)	0.0008797	0.003523	-0.006436
	(0.1256)	(0.9772)	(-1.007)
New Products Introduced Dummy	0.09327**	-0.007794	-0.06001*
	(2.219)	(-0.3759)	(-1.664)
New Production Processes Dummy	0.04413	-0.009012	-0.03438
	(0.9548)	(-0.4372)	(-0.8034)
New Logistics Processes Dummy	-0.01734	X	0.01575
	(-0.2854)	X	(0.3176)
New Support Activities Dummy	-0.04122	0.01343	0.03914
	(-0.7457)	(0.4821)	(0.8938)
Trade Secret Important Dummy	0.1060***	-0.00738	-0.08574**
	(3.013)	(-0.3530)	(-2.053)
Trade Secret Important Missing	0.3209**	-0.05900	-0.3897***
	(2.435)	(-0.9912)	(-5.732)
Design Patents Important Dummy	0.09508	0.007311	-0.1477***
	(1.502)	(0.2689)	(-3.754)
Design Patents Important Missing	-0.1583	-0.05427	0.2450
	(-0.398)	(-1.038)	(0.6764)
Utility Patents Important Dummy	-0.1375***	-0.03172	0.1935***
	(-3.058)	(-1.283)	(4.338)
Utility Patents Important Missing	-0.1582	0.08722	0.1584
	(-0.3759)	(1.139)	(0.4197)
ln(Employment)	-0.05137***	-0.01450	0.04886***
	(-3.108)	(-1.435)	(3.063)
ln(Payroll)	0.01133	0.05172***	-0.05086**
	(0.6066)	(4.383)	(-2.495)
ln(Age)	-0.04956	-0.04831	0.1634*
	(-0.5496)	(-1.258)	(1.811)
$\ln(\text{Age})^2$	0.007124	0.006614	-0.02769
	(0.4173)	(0.9101)	(-1.610)

asinh(Patents Applied)	0.03219*	0.005097	-0.06838***
	(1.792)	(0.3154)	(-4.720)
Patents Applied > 0, Dummy	-0.06888	-0.01235	X
	(-1.485)	(-0.4321)	X
ln(Years Held)	0.08787**	-0.04743*	-0.03043
	(2.114)	(-1.913)	(-0.6860)
Syndicated	-0.02281	0.03756**	-0.01877
	(-1.216)	(2.470)	(-0.8111)
R-Squared	0.1071	0.1755	0.1147
Obs.	1,800	1,800	1,800

Appendix A

Variable Definitions

Variable	Variable Description	Variable Description in Survey (Form/Year/Location) or Other Data
asinh(Research) or asinh(Res)	Firm-year level observation. A firm's domestic research is scaled by the firm's ratio of worldwide-to-domestic R&D to provide a proxy for worldwide research. The proxy for worldwide research is transformed using the inverse hyperbolic sine function to alleviate skewness.	"Research—the planned, systematic pursuit of new knowledge or understanding." (BRDI-1/2015/Domestic)
asinh(Development) or asinh(Dev)	Firm-year level observation. A firm's domestic development is scaled by the firm's ratio of worldwide-to-domestic R&D to provide a proxy for worldwide development. The proxy for worldwide development is transformed using the inverse hyperbolic sine function to alleviate skewness.	"Development—the systematic use of research and practical experience to produce new or significantly improved goods, services, or processes." (BRDI-1/2015/Domestic)
ln(1+Engineers)	Firm-year level observation of the started natural logarithm of a firm's number of domestic engineers in an annual BRDIS survey.	"Engineers and their managers." (BRDI-1/2009/Domestic)
ln(1+Scientists)	Firm-year level observation of the started natural logarithm of a firm's number of domestic scientists in an annual BRDIS survey.	"Scientists and their managers (not already reported in line a)." (BRDI-1/2009/Domestic)
ln(1+Technicians)	Firm-year level observation of the started natural logarithm of a firm's number of domestic technicians in an annual BRDIS survey.	"Technicians and technologists." (BRDI-1/2009/Domestic)
asinh(R&D CAPX)	Firm-year level observation. A firm's domestic R&D CAPX is scaled by the firm's ratio of worldwide-to-domestic R&D to provide a proxy for worldwide R&D CAPX. The proxy for worldwide R&D CAPX is transformed using the inverse hyperbolic sine function to alleviate skewness.	"What was the amount of your company's capital expenditures in the domestic United States in 2009?" (BRDI-1/2009/Domestic)
Trade Secret Important Dummy	Firm-year level observation. An indicator variable that is equal to zero if a firm reports that trade secrets are not important to its business practices in a given year, or if the value is missing, and one if a firm reports that trade secrets are somewhat important or very important to its business practices in a given year.	"During 2009, how important to your company were the following types of intellectual property protection? e. Trade secrets. Very Important, Somewhat important, or Not important." (BRDI-1/2009/All)
Trade Secret Important Missing	Firm-year level observation. An indicator variable that is equal to zero if a firm answers this question; otherwise, this variable is equal to one if the firm does not report on trade secret importance in a given year.	Constructed from Trade Secret Important Dummy variable.
Design Patents Important Dummy	Firm-year level observation. An indicator variable that is equal to zero if a firm reports that design patents are not important to its business practices in a given year, or if the value is missing, and one if a firm reports that design patents are somewhat important or very important to its business practices in a given year.	"During 2009, how important to your company were the following types of intellectual property protection? b. Design patents (patents for appearance). Very Important, Somewhat important, or Not important." (BRDI-1/2009/All)

Design Patents Important Missing	Firm-year level observation. An indicator variable that is equal to zero if a firm reports on design patent importance; otherwise, this variable is equal to one if the firm does not report on design patent importance in a given year.	Constructed from Design Patents Important Dummy.
Utility Patents Important Dummy	Firm-year level observation. An indicator variable that is equal to zero if a firm reports that utility patents are not important to its business practices in a given year, or if the value is missing, and one if a firm reports that utility patents are somewhat important or very important to its business practices in a given year.	"During 2009, how important to your company were the following types of intellectual property protection? a. Utility patents (patents for invention). Very Important, Somewhat important, or Not important." (BRDI-1/2009/All)
Utility Patents Important Missing	Firm-year level observation. An indicator variable that is equal to zero if a firm does report on utility patent importance; otherwise, this variable is equal to one if the firm does not report on utility patent importance in a given year.	Constructed from Utility Patents Important Dummy.
ln(1+Patents Applied)	Firm-year level observation. The started natural logarithm of the number of patents applied for in a given year.	"How many patents did your company apply for in 2009 from the U.S. Patent and Trademark Office (USPTO)?" (BRDI-1/2009/All).
Patents Applied > 0, Dummy	Firm-year level observation. An indicator variable that is equal to zero if a firm indicates they did not apply for patents in a given year; otherwise, it is equal to one.	Constructed from Patents Applied in ln(1+Patents Applied).
Missing Patent Applications	Firm-year level observation. An indicator variable that is equal to zero if a firm does report it applied for patents in a given year; otherwise, it is equal to one if a firm does not report it applied for patents in a given year.	Constructed from Patents Applied in ln(1+Patents Applied).
ln(1+Patents Issued)	Firm-year level observation. The started natural logarithm of the number of patents issued to a firm in a given year.	"How many patents were issued to your company in 2009 by the USPTO?" (BRDI-1/2009/All)
Patents Issued > 0, Dummy	Firm-year level observation. An indicator variable that is equal to zero if a firm is not issued patents in a given year; otherwise, it is equal to one if a firm is issued patents in a given year.	Constructed from Patents Issued in ln(1+Patents Issued).
Patents Issued Missing	Firm-year level observation. An indicator variable that is equal to zero if a firm does report issued patents (zero or positive) in a given year; otherwise, it is equal to one if a firm does not report issued patents in a given year.	Constructed from Patents Issued in ln(1+Patents Issued).
New Products Introduced Dummy	Firm-year level observation. An indicator that is equal to zero if a firm has not introduced any new products and/or services within the past three years (inclusive of the survey year), or if the value is missing; otherwise, this variable is equal to one if a firm has introduced new products or services within the past three years.	This variable is constructed from a combination of two BRDIS survey questions, 1-10a and 1-10b. 1-10a: "Did your company introduce any of the following during the three-year period, 2007 to 2009? a. New or significantly improved goods (excluding the simple resale of new goods purchased from others and changes of solely aesthetic nature). Yes or No." 1-10b: "New or significantly improved services. Yes or No." (BRDI-1/2009/All).
New Production Processes Dummy	Firm-year level observation. An indicator that is equal to zero if a firm has not introduced new production processes in the past three years (inclusive of the survey year), or if the value is missing; otherwise, it is equal to one if a firm has introduced new production processes in the past three years.	"Did your company introduce any of the following during the three-year period, 2007 to 2009? c. New or significantly improved methods of manufacturing or producing goods and services. Yes or No." (BRDI-1/2009/All).
New Logistics Processes Dummy	Firm-year level observation. An indicator that is equal to zero if a firm has not introduced new logistics processes in the past three years (inclusive of the survey year), or if the value is missing; otherwise, it is equal to one if a firm has introduced new logistics processes within the past three years.	"Did your company introduce any of the following during the three-year period, 2007 to 2009? d. New or significantly improved logistics, delivery, or distribution methods for your inputs, goods, or services. Yes or No." (BRDI-1/2009/All).

New Support Activities Dummy	Firm-year level observation. An indicator that is equal to zero if a firm has not introduced new support activities in the past three years (inclusive of the survey year), or if the value is missing; otherwise, it is equal to one if a firm has introduced new support activities within the past three years.	"Did your company introduce any of the following during the three-year period, 2007 to 2009? e. New or significantly improved support activities for your processes, such as maintenance systems or operations for purchasing, accounting, or computing. Yes or No." (BRDI-1/2009/All).
ln(Sales)	Firm-year level observation. The natural logarithm of a firm's sales.	"What was the amount of your company's worldwide net sales and revenues during 2009?" (BRDI-1/2009/All).
ln(Payroll)	Firm-year level observation. The natural logarithm of a firm's payroll.	Payroll is obtained from the Longitudinal Business Database (LBD) for all of a firm's establishments. Next, the payroll for all of a firm's establishments are summed to provide a single, firm-level, number and its natural logarithm is computed.
ln(Employment)	Firm-year level observation. The natural logarithm of a firm's number of employees.	Employment is obtained from the Longitudinal Business Database (LBD) for all of a firm's establishments. Next, the employment for all of a firm's establishments are summed to provide a single, firm-level, number and its natural logarithm is computed.
ln(Age)	Firm-year level observation. The natural logarithm of a firm's oldest establishment.	Age is obtained from the Longitudinal Business Database (LBD) for all of a firm's establishments. Next, the maximum age of the establishments is taken, and its natural logarithm is computed.
$\ln(Age)^2$	Firm-year level observation. The natural logarithm of a firm's oldest establishment, squared.	Age is obtained from the Longitudinal Business Database (LBD) for all of a firm's establishments. Next, the maximum age of the establishments is taken, its natural logarithm computed and the resulting number is squared.
Public vs. All Others	Firm-year level observation. An indicator variable that takes a value of one if a firm is public in a given year and is zero otherwise.	Derived from matching firm-year observations to Compustat firm-year observations.
PE Held vs. Public	Firm-year level observation. An indicator variable that takes a value of one if a firm is PE held in a given year and is zero otherwise.	Derived from matching firm-year observations to Compustat firm-year observations and Preqin firm-year observations.
PE Held vs. Other Private	Firm-year level observation. An indicator variable that takes a value of one if a firm is PE held in a given year and is zero only if the firm is another type of private firm (i.e. not in a firm-year observation in Compustat/public).	Derived from matching firm-year observations to Compustat firm-year observations and Preqin firm-year observations.
Public	Firm-year level observation. An indicator variable that takes a value of one if a firm is public in a given year and is zero otherwise.	Derived from matching Compustat firm-year observations to Census data.
PE Held	Firm-year level observation. An indicator variable that takes a value of one if a firm is private equity held in a given year and is zero otherwise.	Derived from matching Preqin firm-year observations to Census data.
asinh(Dev) x PE Held	The interaction of asinh(Dev) and PE Held. See definitions above.	
asinh(Dev) x Public	The interaction of asinh(Dev) and Public. See definitions above.	
asinh(Res) x PE Held	The interaction of asinh(Rev) and PE Held. See definitions above.	
asinh(Res) x Public	The interaction of asinh(Res) and Public. See definitions above.	
Public to PE	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is an indicator variable that takes a value of one if a firm transitions from public status to being private equity held the following year.	Derived from Public and PE Held variables above.

PE to Public	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is an indicator variable that takes a value of one if a firm transitions from private equity held status to public status the following year.	Derived from Public and PE Held variables above.
PE to Other Private	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is an indicator variable that takes a value of one if a firm transitions from private equity held status to other private status the following year.	Derived from Preqin data matched to Census data.
Other Private to PE	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is an indicator variable that takes a value of one if a firm transitions from other private status to private equity held status the following year.	Derived from Preqin data matched to Census data.
Other Private to Public	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is an indicator variable that takes a value of one if a firm transitions from other private status to public status the following year.	Derived from Compustat data matched to Census data.
Δ[ln(Sales)]	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is the difference between the variable ln(Sales) in year t+1 minus ln(Sales) in year t-1, relative to year t.	Derived from ln(Sales) above.
Δ[ln(Payroll)]	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is the difference between the variable ln(Payroll) in year t+1 minus ln(Payroll) in year t-1, relative to year t.	Derived from ln(Payroll) above.
Δ[ln(Employment)]	Firm-year level observation where at least one lead and one lag of an innovation input and output variable is observed. This is the difference between the variable ln(Employment) in year t+1 minus ln(Employment) in year t-1, relative to year t.	Derived from ln(Employment) above.
Trade Sale	Firm-year level observation. An indicator variable that takes a value of one if a private equity held firm is exited via a trade sale and is zero otherwise.	Derived from matching Preqin data to Census data.
IPO	Firm-year level observation. An indicator variable that takes a value of one if a private equity held firm exited via IPO and is zero otherwise.	Derived from matching Preqin data to Census data.
Secondary Buyout	Firm-year level observation. An indicator variable that takes a value of one if a private equity held firm exited via secondary buyout and is zero otherwise.	Derived from matching Preqin data to Census data.
ln(Years Held)	Firm-year level observation. The number of years a firm is held in a private equity portfolio.	Derived from Preqin data.
Syndicated	Firm-year level observation. An indicator variable that takes a value of one if two or more private equity firms held the target firm at the same time and is zero otherwise.	Derived from Preqin data.