Paper to be presented at the Summer Conference 2009

on

CBS - Copenhagen Business School
Solbjerg Plads 3
DK2000 Frederiksberg
DENMARK, June 17 - 19, 2009

WHEN DO FIRMS USE PUBLIC RESEARCH? THE DETERMINANTS OF KNOWLEDGE FLOWS FROM UNIVERSITIES AND GOVERNMENT LABS TO INDUSTRIAL R&D

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This paper examines the use of public research in firm R&D while accounting for endogeneity arising from self-selection. Comparing a survey measure of knowledge flows to backward citations to patent and non-patent references (e.g., scientific publications), I find that the probability of using public research increases with firm basic and applied research, while firm scientific capabilities and new ventures are associated with greater exploitation of knowledge flows. More specifically, while firm basic research increases the probability that a firm uses public research, it has little effect on knowledge flows from public research perhaps suggesting the role of public research as a substitute for firm basic research activity. On the other hand, firm applied research activity is positively related with the use of public research, indicating the role of public research as a complement to applied research. Furthermore, a firm s scientific capabilities are a key driver the exploitation of knowledge flows, and entrepreneurial ventures exploit more knowledge flows than established firms. By unpacking a firm s scientific absorptive capacity, this paper provides a nuanced view of the specific roles of firm research activity and capabilities in the exploitation of extramural knowledge.

JEL - codes: O31, O32, I23

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ABSTRACT
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Keywords: public research, industrial R&D, knowledge flows, spillovers, patent citations
JEL Codes: O32, O34, I23, I28, M13

I would like to thank Wes Cohen for access to the Carnegie Mellon Survey and for extensive comments and suggestions. I would also like to thank Jim Adams, Shane Greenstein, Mike Lenox, David Ridley, Scott Rockart, Henry Sauermann, John Walsh, and Charlie Williams for their valuable suggestions, as well as seminar participants at Duke University, the University of North Carolina, and the 9th Annual Wharton Technology Conference. All errors are my own. This research was partially funded by a grant from the John W. Hartman Foundation for Small and Medium Enterprises at Duke University.

I. INTRODUCTION

In recent years that has been increasing interest in the impact of knowledge flows from universities and government labs (i.e., public research) on firm innovative performance. While prior research has demonstrated that nonpecuniary spillovers from public research and collaborative research with university scientists have a substantial impact on firm innovative performance (Jaffe 1989; Adams 1990; Cockburn and Henderson 1998; Zucker, Darby, and Armstrong 2002), little is known regarding the conditions under which firms use knowledge flows more broadly from public research in their R&D activities. Furthermore, much of the empirical research neglects potential endogeneity associated with firms' decisions to use public research in the first place. As a consequence, our understanding of the key antecedents of knowledge flows from universities and government labs to firm R&D and the subsequent impact on innovative performance remains incomplete.

In this paper we investigate the conditions under which firms use knowledge flows from public research as inputs to their innovative activities. We argue that the anticipated benefits of using public research are driven largely by a firm's need for scientific knowledge that is relevant to its own R&D activities and the availability of scientific knowledge emanating from public research institutions. The costs of using public research, on the other hand, can be prohibitive and are associated with identifying, acquiring and exploiting extramural knowledge. However, these costs can be mitigated by a firm's scientific capabilities and its collaborative relationships with academic scientists. In addition to these general benefits and costs, entrepreneurial ventures possess unique attributes that enable them to exploit greater knowledge flows from public research relative to established firms. In addition to the substantive questions identified above, this study explicitly recognize that the use of public research is driven at least in part by a firm's decision to use public research, and thus accounts for the presence of potential endogeneity by correcting for self-selection.

Using a novel data set that combines survey responses from R&D managers with patents and publications at the R&D unit level, this study examines when firms use public research by utilizing two measures of knowledge flows: a survey measure of the fraction of R&D projects that use public research and backward patent to citations to both patent and non-patent references (e.g., scientific publications authored by university scientists). We find dramatic differences between the factors that determine the probability that a firm uses public research on the one hand and the factors that condition knowledge flows from public research on the other. In addition, we find that patent citations to patent and non-patent references exhibit little significant relationship with the determinants of the use of public research once corrected for self-selection, especially coauthored publications. These findings illustrate not only substantive differences between how knowledge flows influence firm innovation, but also highlight the need to account for self-selection in this setting.

More specifically, we find that while firm basic research activity increases the probability that a firm will use public research, contrary to conventional wisdom it has no effect on the amount knowledge flows to firm R&D projects. Surprisingly, firm basic research activity is negatively related with backward patent citations to public research. Instead, it is a firm's internal scientific capabilities that are most strongly associated with knowledge flows from public research. Across industries the overall level of public research activity available to firms is positively associated with both the probability and greater use of public research. However, we find no evidence of the greater use for geographically proximate public research activity. In addition, we find that in the life sciences firms utilize public research as a complement to their internal basic and applied research, while in chemical and engineering technology groups public research appears to be a substitute for internal basic research and a complement to applied research.

This unpacking of a firm's absorptive capacity (Cohen and Levinthal 1989; Cohen and Levinthal 1990) suggests a more nuanced view of the specific roles of firm research activity and capabilities in the exploitation of extramural knowledge. This research contributes to the innovation literature by advancing our understanding of the foundational factors that drive the firm use of public research in industrial R&D, factors which are often omitted in empirical studies of the impact of public research on firm innovative performance.

The layout of this paper is as follows. In Section II we review the literature on knowledge flows from public research and develop a simple cost-benefit framework to examine the drivers of a firm's use of public research in its innovative activities. Section III introduces the data and variables, while Section IV discusses the empirical specification and econometric issues associated with the use of public research in firm innovation. The empirical results are presented in Section V, followed by Section VI which concludes the paper by discussing the implications of these findings for management and policy, and proposes directions for future research.

II. THE USE OF PUBLIC RESEARCH IN INDUSTRIAL R&D

Research conducted in publicly funded institutions such as universities and government labs typically addresses questions of a fundamental, or basic, nature with the aim of developing a deeper understanding of the underlying properties or mechanisms of natural and artificial materials and organisms. Characteristically, the success and commercial value of basic research is highly uncertain at the time of project initiation, and as such firms typically have less incentive to invest in such projects relative to applied research or development projects that may result in more readily commercializable innovations (Nelson 1959; Rosenberg 1990; Thursby and Thursby 2003). As a result, public research can serve as a potentially valuable source of extramural knowledge that can either complement or substitute a firm's own R&D activities (Mansfield 1991; Rosenberg and Nelson 1994; Mowery and Rosenberg 1998).

Despite the popular notion that scientific discoveries emanating from universities and government labs flow downstream to stimulate industrial R&D (Bush 1945), the interplay between science and technology is complex (Kline and Rosenberg 1986). In addition to the role of universities and government labs as a source of scientific and technical knowledge that both stimulates technological opportunities as well as facilitates a firm's own R&D activities, public research also contributes more directly through collaborative research between academic and industrial scientists and faculty consulting. This study focuses on one dimension of this interplay: the factors that condition the use of knowledge flows—both non-pecuniary knowledge flows and private market-oriented knowledge transfers—from university and government labs to firm innovative activities.

Although knowledge flows from universities and government labs are an increasingly important source of extramural knowledge in firm innovation, relatively little is known regarding the factors that condition the use of knowledge flows by firms. The central premise of this study is that firms use public research when the net expected benefits to its use exceed the costs, where the costs and benefits are associated with both firm characteristics such as the nature of R&D activity and the firm's scientific capabilities, as well as the external availability of relevant public research. In general, as these benefits of exploiting knowledge flows from public research accrue to the firm it should observe an increase in both the probability and the amount of public research utilized by a firm in its R&D activities. Similarly, as the costs of identifying and internalizing public research increase, a firm should not only be less likely to utilize public research, but also use less of it in its R&D.

A. The Benefits of Knowledge flows from Public Research

The anticipated benefits of using public research are driven largely by two factors: a firm's need for scientific knowledge as an input to its own R&D activities and the availability of such knowledge emanating from public research institutions. The composition of a firm's R&D activities determines the type of knowledge useful to a firm, and thus conditions the sources and nature of knowledge useful to a firm. Research-intensive firms, for example, are widely regarded as engaging in activities that are not only more science-oriented, but also more uncertain (Rosenberg 1985; Henderson and Cockburn 1996; Hall, Link, and Scott 2003; Branstetter and Ogura 2005). As a result, research-intensive firms may benefit from public research not only as a direct input to their own activities, but also as a guide to shape the direction of R&D and thereby reduce uncertainty and cost to achieve R&D objectives (Kline and Rosenberg 1986; Mansfield 1991). Development activities, on the other hand, are less uncertain and tend to be oriented toward solving well-defined problems (Jewkes, Sawers, and Stillerman 1958; Mansfield, et al. 1977). At the same time, firms may utilize public research as a substitute for their own internal research activity. *Thus, when knowledge flows are a complementary input to firm R&D we expect a positive relationship between firm research activity and the use of public research, and a negative relationship when knowledge flows are a substitute.*

In addition to a firm's R&D activity, the availability of relevant knowledge emanating from public research institutions also conditions the benefits of knowledge flows from public research. A primary role of public research is as a source of scientific and technical knowledge that both stimulates new technological opportunities for firms (Griliches 1979; Rosenberg and Nelson 1994; Klevorick, et al. 1995) as well as provides a repository of scientific knowledge upon which firms may draw for solutions to problems encountered in their R&D activities (Gibbons and Johnston 1975; Brooks 1994). Greater levels of public research activity in a given field leads to an increase in the frequency and number of discoveries which may lead to technological opportunities (Klevorick, et al. 1995). In addition, greater public research activity also increase the underlying body of knowledge available to firms, thereby increasing the potential for firms to benefit from scientific theories, principles and insights. In this way public research not only benefits the firm by aiding to more clearly define a problem and reduce uncertainty regarding the set of possible solutions and guide a firm's R&D activity, but also as an immediate solution to such problems (Gibbons and Johnston 1975; Brooks

1994; Klevorick, et al. 1995). *Thus, as the level of public research activity in fields relevant to a firm's R&D activities increases, the firm will use more public research.*

B. Costs of Identifying, Acquiring, and Exploiting Public Research

Despite the potential benefits of utilizing knowledge flows from public research, the costs associated with successfully identifying, acquiring, and exploiting public research can be quite costly, even prohibitively so. Firm's can mitigate these costs through an ability to recognize and absorb extramural knowledge (Cohen and Levinthal 1989; Arora and Gambardella 1994; Cockburn and Henderson 1998; Fabrizio 2006). In particular, a firm's absorptive capacity for scientific knowledge, or its scientific capability, enables the firm to understand fundamental scientific knowledge and principles that can facilitate the use of public research (Brooks 1994; Rosenberg and Nelson 1994). For example, the employment of academically trained scientists can allow a firm to quickly identify, comprehend and utilize scientific and technical knowledge embodied in publications, patents, and products, which can then be exploited in firm's own R&D. *Thus, firms with greater scientific capabilities should use more public research.*

The costs associated with using public research can also be mitigated through collaborative relationships with academic scientists. Collaborative research provides strong links that facilitate the flow of knowledge from academic institutions, thereby reducing the costs of using extramural scientific research (Cockburn and Henderson 1998; Zucker, Darby, and Brewer 1998). In addition, collaborative research often reflects interactions with university and government scientists related to leading-edge research and the creation of new scientific knowledge (Hall, Link, and Scott 2003). Such research may be a firm's attempt to stay abreast of the frontiers of science, or they may be direct inputs to a firm's R&D and thus substitute for internal research. *Thus, firms that engage in greater collaborative research activity will use more public research.*

C. The Relative Advantage of New Ventures

Public research, and in particular university research, is widely believed to be an important source of extramural knowledge for entrepreneurial ventures (Acs, Audretsch, and Feldman 1994; Rosenberg and Nelson 1994; Audretsch and Feldman 1996; Zucker, Darby, and Brewer 1998; Mowery, et al. 2001; Shane 2001; Cohen, Nelson, and Walsh 2002; Shane and Stuart 2002). Entrepreneurial ventures (i.e., small and young firms) face unique, and at times conflicting, conditions regarding both the benefits and costs of using public research. For example, new ventures may be formed to exploit opportunities emanating from public research (Zucker, Darby, and Brewer 1998; Shane 2001), thereby increasing the relevance and importance of public research to their attempts to commercialize university discoveries. In addition, new ventures often possess dramatically fewer resources than established firms, and thus may benefit more upon public research as a substitute for costly internal research activity (Shane and Stuart 2002). On the other hand, new ventures may face lower costs of using public research as they are more likely to be linked to universities and thus possess an advantage in exploiting public research (Mansfield 1991; Acs, Audretsch, and Feldman 1994; Zucker, Darby, and Brewer 1998; Cohen, Nelson, and Walsh 2002; Zucker, Darby, and Armstrong 2002). While this might suggest that new ventures are more likely to use public research than established firms, new ventures may also lack the routines necessary to effectively exploit public research in their innovative activities (Stinchcombe 1965;

Nelson and Winter 1982; Sorensen and Stuart 2000). *Taken together it is unclear whether new ventures use more public research than established firms.*

It is important to note that in much of the literature firm size is confounded with being a new venture, in particular when firm age is excluded as a featured variable. For example, work on the relationship between firm size and innovative performance suggests that small firms posses an advantage in exploiting public research (Link and Rees 1990; Acs, Audretsch, and Feldman 1994). However, it is not clear from these studies whether this advantage relates strictly to firm size or both firm size and age, which is particularly important given the high correlation between size and age. For example, research on the effects of firm age on innovation found that as firms age they are less adapt at exploiting extramural knowledge (Sorensen and Stuart 2000), perhaps suggesting that the advantage of new ventures to use public research relates more with age than size. In this study new ventures are conceptualized as being both small and young, and thus are distinct from small but established firms as well as larger firms.

III. Data, Variables & Estimation

A. Data

The data for this study are drawn from the CMS-Duke dataset, which combines survey responses from R&D managers to patents and publications at the R&D unit level of analysis.[1] The Carnegie Mellon Survey (Cohen, Nelson, and Walsh 2000) contains responses from managers of R&D units regarding their innovative activities and use of

[1] A detailed description of the data collection and measurement construction is available from the author.

public research for the period 1992-1993.[2] Patents were matched to the CMS through the NBER Patent Data File (Hall, Jaffe, and Trajtenberg 2001) and supplemented with non-patent references obtained from Delphion[3] and the Science Citation Index (SCI) database. These novel cross-sectional data allow for not only a direct comparison of survey and patent-citation measures of knowledge flows, but also provide direct measures of many previously unobserved variables such as industrial basic and applied research activity, respectively, the relevance of specific fields of science and engineering to a firm's R&D, and the employment of industrial scientists.

B. *Variables*

From these data we are able to directly compare two distinct, yet complementary measures of knowledge flows from public research. The first is a survey-based measure of the fraction of a unit's R&D projects that use public research findings reported on a 5-point scale ranging from 0-100%.[4]. A considerable strength of this measure is that it reflects knowledge flows from public research through the full array of potential channels, uses, and applications to a firm's R&D. That is, unlike more widely used backward patent citations, the survey measure is not constrained to only those innovations which are patented, while at the same time it reflects both codified and tacit knowledge flows from public research.

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[2] Additional details regarding the CMS may be found in Cohen, Nelson & Walsh (2000).
[3] Delphion is a commercial patent database offered by Thompson Scientific.
[4] While this variable takes on only one of five values and is not continuous between the interval of 0 and 1, it is treated as continuous in this study. A limitation of this measure is that it does not vary as greatly as a firm's true use of public research does, however this leads to more conservative estimates and thus provides more confidence in significant results. Nevertheless, for all regressions in this study using the survey measure, corollary regressions were performed which treat the survey response ordinal data with substantively identical results.

The second measure of knowledge flows from public research is the number of backward patent citations to both patent and non-patent references. While much of the patent citation literature relies exclusively upon citations to university patents (Jaffe, Trajtenberg, and Henderson 1993; Trajtenberg, Henderson, and Jaffe 1997; Mowery, et al. 2001; Mowery and Ziedonis 2001), this study joins a small but growing number of studies that employ patent citations to both patent non-patent references, such as scientific publications, conference proceedings, and other published documents (Narin, Hamilton, and Olivastro 1997; Hicks, et al. 2001; Agrawal and Henderson 2002; Branstetter and Aoki 2005; Branstetter and Ogura 2005; Fabrizio 2006).

In the context of this study non-patent references are particularly important, as they are both the primary form or public research output and arguably more appropriate than citations to patents (Agrawal and Henderson 2002). First, both the incentives and professional norms in academia favor the publication of research findings over more commercial forms of research output such as patents (Cole and Cole 1967; Merton 1969; Etzkowitz 1998; Owen-Smith and Powell 2001; Agrawal and Henderson 2002). Second, non-patent references are unquestionably the most prominent form of public research output (Narin, Hamilton, and Olivastro 1997), while only a small fraction of public research is actually patented (Agrawal and Henderson 2002).

An additional concern when using patent citations is the influence of individuals external to the innovation process such as patent attorneys and patent examiners. For example, recent research on the contributions of patent examiners to the citation record suggests that as many as 90% of citations to non-patent references—including scientific publications—are inserted by the inventors, while approximately 60% of citations to patents are inserted by inventors (Cockburn, Kortum, and Stern 2003; Sampat 2004; Alcacer and Gittelman 2006). Together these suggest that citations to scientific publications and other non-patent references are critical to a comprehensive understanding of firms' use of public research and far more informative than citations to patents alone.

Patent citations to public research are measured as the total number of patent or non-patent references affiliated with a U.S. university, government lab, non-profit research institute, or hospital. Although this citation-based measure more accurately reflects knowledge flows from public research than the widely used measure of patent citations to university patents alone, it does provides an important benchmark to extant literature.

We make a number of assumptions regarding what each measure captures with respect to knowledge flows from public research.[5] First, we assume that the survey-based measure is not directly impacted by firm patenting and citing behavior, and thus it more accurately reflects the full utilization of public research than patent citations. However, the survey-based measure is limited in that unlike citations it does not reflect the intensity or magnitude of utilization, nor does it convey information on the source or direction of knowledge flows from public research. Despite these limitations, we expect the survey-based measure provides a more complete picture of the utilization of public

[5] One obvious question that arises with such a comparison is which measure—survey or patent—more accurately indexes knowledge flows from public research? More precisely, I would like to know which measure is least influenced by systematic error. To examine the validity of the survey measure itself, I compared managers' responses on the fraction of R&D projects that use public research to other survey responses of the use and importance of public research, including the frequency with which the lab received useful information from public research, the importance of public research by fields of science and engineering, and various channels of knowledge flows. The findings suggest that, at least within respondents, the survey measure is highly reliable. As a result, I assume that the survey response is measured with less error than patent citations and, thus, is a more accurate measure of the broad use of public research in a firm's R&D activities. This assumption is less a reflection of the precision of the survey measure than it is a recognition of the numerous factors which can impact patent citations that are not directly related with use.

research across the range of firm R&D activities, while patent citations more accurately reflect the use of public research in a firm's patentable technologies.

Independent Variables To capture differences across firms in the extent to which they are engaged in greater research activity rather than development we include two measures of a firm's share of total R&D activity directed specifically toward basic and applied research, respectively. To measure a firm's ***basic research*** activity we include the share of firm's total R&D activity directed toward scientific research with no specific commercial objectives. ***Applied research*** is measured as the share of a firm's total R&D activity directed toward research with specific commercial objectives.[6] In addition, we control for a firm's overall level of R&D effort by including the log of a firm's annual investment in R&D.

To measure the level of ***public research activity*** in fields relevant to a firm's own R&D activity [7] we sum total U.S. academic spending in 1992 by field of science and engineering relevant to a firm's R&D activity. These data are drawn from the NSF CASPAR database[8] and survey responses on the importance of nine fields.[9] Greater levels of this measure reflect more academic spending in the U.S. in fields that a firm considers important to its R&D, and thus reflects not only the potential for greater

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[6] The sum of basic share, applied share, and development share (not included, but measured as technical activity translating research findings into products or processes) accounts for 100% of a firm's R&D activities.
[7] These fields are biology, chemistry, physics, computer science, materials science, medical and health science, chemical engineering, electrical engineering, and mechanical engineering.
[8] CASPAR is a database supported by NSF which provides data resources on science and engineering indicators. The data for this study were obtained specifically from the NSF Survey of R&D Expenditures at Universities and Colleges. Additional information and access to the data may be found at http://webcaspar.nsf.gov.
[9] Although this is not a stock measure, an examination of U.S. academic spending ten years prior indicate a high degree of consistency in academic spending by field, suggesting that there have not been any dramatic changes in spending over time that would such that a stock measure would provide greater information. For each field that a firm reports as being important to their R&D activities we summed the total U.S. academic spending across all universities. To reduce potential endogeneity arising from firms' decisions to use public research from specific fields we include any field that a firm reports as being at least slightly important (i.e., they do not report a field as not being important).

technological opportunities but also the existence of a larger pool of knowledge upon which firms may draw.

We measure a firm's ***scientific capability*** as the fraction of total R&D personnel that are trained as Ph.D. or M.D. scientists (Arora and Gambardella 1994). This measure captures the extent to which a firm possesses in-house expertise necessary to more fully utilize public research. A limitation of this measure is that it does not reflect the quality of a firm's scientists nor the firm's active engagement in research activity. But it is advantageous over other measures in that it is not contingent upon a firm either publishing or patenting to be observed.[10]

A firm's ***collaborative research relationships*** with academic scientists is measured as the fraction of firm scientific publications that were coauthored with at least one scientists affiliated with a university, government lab, non-profit research institute, or hospital (Cockburn and Henderson 1998; Zucker, Darby, and Armstrong 1998). Data on a firm's scientific publications were obtained from the ISI-Science Citation Index (SCI) database of scholarly articles in all fields of science and engineering.

To measure ***new venture*** status we include a dummy variable that equals one if a firm first entered its focal industry within the previous ten years and has no more than 500 employees. The list of firms that meet these criteria were confirmed using VentureXpert to distinguish between de novo ventures and diversified entrants. We also include a control for firm size measured as the log of the number of business unit employees.

[10] Scientific capabilities are costly and require time to develop. Thus, while scientific capabilities are undoubtedly related with a firm's prior use of public research, it is unlikely that firms are able to effectively build scientific capabilities in such as a way that would contribute substantial bias in the regression estimates.

In addition to the variables described above, we also include control variables for industry effects and R&D unit size (unit employees), the number of patents when backward citations are used as the measure of knowledge flows, and industry dummies. Table I presents a list of variables and TABLE II provides descriptive statistics.

C. Estimation

Throughout the extant literature it is implicitly assumed that the use of public research is exogenous to the firm, and thus estimates of the impact of public research on firm innovative performance are interpreted as if they were relatively free of bias. However, this ignores the fact that the use of public research is largely a decision of the firm, and that the factors that influence this decision likely vary across firms in meaningful, and often unobservable, ways. For example, firms that perceive the ex ante benefits of knowledge flows from public research to be positive may implement policies that encourage their R&D personnel to turn to public research as a source of extramural knowledge. In the presence of self-selection, estimates may reflect underlying differences in the decision to use public research that are omitted from the empirical specification, and thus may lead to biased estimates and inaccurate interpretations regarding the determinants of the use of public research.

A number of approaches exist to account for selectivity, yet these data possess a number of unique characteristics which narrow the set of methods available. First, the cross-sectional nature of the survey eliminates commonly used panel techniques such as fixed firm effects and lagged measures of utilization. Second, it is difficult to identify *a priori* those factors that significantly explain whether a firm uses public research but are not related to the amount of public research used, thereby making the existence of suitable instrumental variables unlikely. However, an advantage of the survey is that it provides observations on whether a firm uses public research or not, and thus does not face the problem of unobserved outcome variables more typical of sample selection (Heckman 1979).

While the set of variables that determine the probability and the intensity of a firm's use of public research are likely the same, it is conceivable that coefficient estimates for this set of determinants differ significantly between the two outcomes. As a consequence, available estimation approaches such as the Tobit—which assumes that the process that determines the probability and the intensity of use are the same—would be misspecified, and thus inappropriate.[11] An alternative approach is a two-stage model that first estimates the probability that a firm uses public research, and then includes the predicted probability as a determinant of the level of public research used by a firm.[12] Given that unobserved firm heterogeneity is likely correlated with a firm's decision to use public research or not, this approach is an attempt, albeit a rather crude one, to account for endogeneity that has been used to model both the decision to participate in an activity as well as the level of activity conditional upon participation.[13] The empirical specification is:

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[11] A test for the suitability of the Tobit is to compare estimates with an identically specified probit (Lin and Schmidt 1984; Johnston and DiNardo 1997), and indeed in results discussed below I find differences which suggest the need for an approach that separately accounts for both the decision to use public research and the amount used.

[12] Typically, estimation of two-stage models with limited response variables can create additional estimation challenges that require more sophisticated techniques (Maddala 1983). However, recent simulation and empirical research has shown that in cases where the sample size is sufficiently large a two-step approach actually performs as well as more complicated methods such as GMM and full-information maximum likelihood (Guilkey, Mroz, and Taylor 1992; Bollen, Guilkey, and Mroz 1995). Furthermore, while Maddala (1983) suggests a complex approach to calculating asymptotically correct standard errors when using predicted values, Guilkey et al. (1992) further demonstrate that adjusted standard errors are no more effective than conditional standard errors. Thus, for simplicity robust standard errors are reported throughout this study.

[13] Given the lack of attention in the theoretical literature to variables that meaningfully and uniquely determine the probability and level of use respectively, both equations are specified identically. In principle the two-stage model is identified even when the variables in the probability and intensity specifications are the same, and such an approach is

$$\text{(1)} \quad \begin{aligned} \text{USE}_i &= \beta_1\text{RD}_i + \beta_2\text{ACAD}_i + \beta_3\text{SCICAP}_i + \beta_4\text{COLLAB}_i + \\ &\quad \beta_5\text{VENTURE}_i + \beta_6\text{IND}_i + \varepsilon_i \end{aligned}$$

where i indexes the firm
USE is a measure of the use of knowledge flows from public research (either the decision or intensity of use)
RD is a set of variables that index firm's R&D activity
ACAD is a measure of the level of public research available to the firm in relevant fields
SCICAP is an index of a firm's scientific capabilities
COLLAB is a measure of a firm's collaborative research with academic scientists
VENTURE is a binary measure of whether a firm is a new venture or not
IND is a set of industry dummies

In addition to the variables described above, we account for additional unobservable heterogeneity arising from a firm's prior use of public research by including the stock of a firm's scientific research outputs, measured as the five year lag of firm scientific publications.

A final econometric concern is that the survey measure of a firm's use of public research is a fractional response variables bound between 0 and 1. As such, estimates from OLS may lie outside this interval, and other approaches such as the log-odds ratio require complex adjustments if the outcome variable equals 0 or 1 or if the proportions are from variable group sizes (Papke and Wooldridge 1996). A simple and robust alternative is fractional logistic regression (Papke and Wooldridge 1996), which is easily

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commonly used in practice (Johnston and DiNardo 1997). In addition, while other variables included as determinants of the use of public research may themselves be endogenous, the same challenges of identifying suitable instruments for the decision to use public research hold. However, to the extent that endogeneity in the determinants of use are correlated with unobservable factors related with a firm's decision to use public research in the first place, then including the predicted probability of use should mitigate, although not eliminate, potential bias due to endogeneity. This approach is similar to that used in the classic example of a woman's decision to participate in the workforce and her wages in Gronau (1974). For a recent example of this approach see Gruber & Zinman (2000) regarding the decision to smoke and the number of cigarettes smoked by teenagers. Regressions were also performed that included an Inverse Mills Ratio with substantively identical results.

implemented using most standard statistical packages. Fractional logistic estimates are presented when the measure of use is the fraction of projects that use public research (survey) [14], while negative binomial regression is used with the dependent variable is the number of patent citations to public research (Hausman, Hall, and Griliches 1984).[15]

IV. RESULTS

To understand the conditions under which firms use public research, TABLE III presents aggregate cross-industry results of the decision to use public research and the level of public research used in a firm's R&D projects. Column 1 illustrates that firms that conduct more basic and applied research activity are more likely to use public research. In addition, as the level of public research activity in fields relevant to a firm increases so too does the probability of using public research. Surprisingly, a firm's scientific capabilities as measured by the employment of PhDs has no effect, perhaps suggesting the industrial scientists may act as an internal source of scientific knowledge that reduces the need to turn to extramural sources such as universities and government labs. Finally, entrepreneurial ventures do not appear to be more likely to use public research than established firms.

Column 2 presents results of the determinants of the intensity of knowledge flows to firm R&D for the full sample and Column 3 includes the predicted probability of using

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[14] As discussed in the variables section, given that the survey measure is a 5-point response on the fraction of R&D projects that use public research multinomial logistic regressions were also performed with consistent results. These results are available from the author upon request.

[15] Given that approximately 60% of firms do not cite public research, a concern is that excess zeros could result be an additional source of overdispersion not accounted for through negative binomial regression. One alternative is a zero-inflated negative binomial model (Cameron and Trivedi 1998). However, given that the observation of citations is driven in part by several different processes—including whether firms use public research or not, their innovative productivity resulting in patentable innovations, and patenting and citing activity—it is difficult to discern precisely which latent group is never at risk. Addressing these different processes through a structural model is an objective of a future related paper.

public research from Column 1 to correct for self-selection. Columns 4 and 5 replicate these results for the sample conditioned upon using public research. Once care is taken to account for self-selection we find a more nuanced picture emerges, one which highlights key differences between the factors that determine whether a firm uses public research and those that determine how much public research it uses. More specifically we find that after accounting for self-selection a firm's basic and applied research activity has little association with the amount of public research used in its R&D projects, which is strikingly different from results in Column 2 which do not account for self-selection. Rather, it appears that firms use more public research when the overall level of public research activity and a firm's own scientific capabilities are greater. In addition, for the conditional sample (Column 5) new ventures are also associated with greater use of public research.

Across all regressions the level of public research activity appears to be a robust determinant of both the probability of using public research and the amount of public research exploited in firm R&D projects. While these results suggest that more opportunities and a greater knowledge base increase use, there is considerable interest in the spillovers literature on the importance of geographic proximity in facilitating these flows (Jaffe, Trajtenberg, and Henderson 1993; Audretsch and Feldman 1996; Zucker, Darby, and Armstrong ; Mowery and Ziedonis 2001; Adams). To examine this we conducted several regressions that include measures of both total and proximate levels of public research activity and found no significant effects for proximity.[16] Although quite surprising, these results should be interpreted with care. While on the one had they

[16] Results available upon request from the authors.

suggest that greater amounts of proximate public research are not associated greater exploitation of public research in firm R&D, they do not suggest that geographically proximate spillovers are unimportant to firm innovation.

When taken together with the probit results these results suggest that basic and applied research may act as a mechanism for monitoring and recognizing valuable extramural knowledge, but it has little association on the exploitation of public research in firm R&D projects. The effect of scientific capabilities—as measured by the fraction of R&D personnel that are Ph.D. or M.D. scientists—also exhibits a striking difference between firms' actions to monitor versus exploit public research. While possessing greater scientific capabilities does not determine the probability of using public research, the results suggest that industrial scientists are a key driver of a firm's ability to utilize knowledge flows in its R&D. This result is consistent with the notion that industrial scientists are important conduits to a firm's ability to recognize and exploit extramural knowledge (Cohen and Levinthal 1989) as well as contribute to the creation of scientific knowledge within the firm (Brooks 1994; Rosenberg and Nelson 1994).

Contrary to findings on the positive benefits of firm size with respect to the utilization of public research (Mansfield 1991; Acs, Audretsch, and Feldman 1994), we find that it is not size per se, but rather new ventures (i.e., size and age) that are related with greater use of public research. In fact, consistent with recent research (Cohen, Nelson, and Walsh 2002; Hall, Link, and Scott 2003) the results from this study illustrate that new ventures use greater amounts of public research even after controlling for firm size (Column 5). Indeed, contrary to much of the economics literature on the benefits of firm size and the use of public research (Nelson 1959; Cohen and Levinthal 1989) we find that size has no effect on the use of public research. While this may be partly driven by the small number of projects, these results are robust to the inclusion of controls for both R&D expense and unit size. This finding provides additional evidence in support of the importance of knowledge flows from public research to new ventures.

Turning now to the results in TABLE IV which employ patent citations to patent and non-patent references, Column 1 replicates the probit results in TABLE III for reference. Columns 2 and 3 present results for the full sample with the latter correcting for self-selection, while Columns 4 and 5 present similar results for the conditional sample of patenting-only firms. Across all regressions one of the most robust results is the surprising negative association between basic research and citations. One possible explanation for this is that the ways in which public research is utilized in firm basic research do not directly contribute to patentable innovations and thus citations. For example, public research may inform early-stage or more fundamental research, which then in turn influences a firm's applied research and development. Even if public research directly contributes to patentable innovations, it may be that the specific role of public research, particularly as a repository of scientific knowledge, is not fully manifest in patent citations, while the more salient and arguably more impactful role of public research as a source of technological opportunities might be readily cited.

Another robust result is the positive association between scientific capabilities and patent citations, which is consistent with results in TABLE III. Perhaps the most intriguing result is for the association between collaborative research and patent citations. Consistent with a number of influential studies that employ coauthored publications as conduits between firms and public research (Zucker and Darby 1996; Cockburn and

Henderson 1998) we find that coauthored publications are significantly associated with backward citations, but this result disappears once corrected for self-selection. The remarkable change in the significance of this effect may suggest that prior studies that failed to account for firm self-selection to use public research may be based on biased coefficient estimates. Furthermore, given that coauthored publications have no significant association with the survey measure of knowledge flows, the results presented here demonstrate the importance of accounting for endogeneity and draw into question the impact of coauthored publications as a determinant of firm innovative performance.

While the aggregate results just discussed illustrate the need to model the decision to use public research separately from the amount of public research used, they obscure many of the more nuanced differences that may exist across industries and technology groups. For example, in the life sciences where innovations are more closely linked to biology, chemistry, and medicine we might expect that firms exploit greater amounts of knowledge flows from public research in their R&D than other technology groups. In other industries such as information technology and aerospace the applied sciences and engineering fields play an intermediate role in firm innovation and not be directly exploited in industrial R&D.

To examine such differences, we separate the sample into four general technology groups based on research-intensity and the most relevant fields of science and engineering. These groups are the life sciences, chemicals, information technology and aerospace, and all others. TABLE V presents descriptive statistics by these technology groups, which clearly illustrate key differences across these areas. For example, in the life sciences approximately 75% of all firms use public research, compared to 60% in IT

& aerospace, 44% in chemicals, and 40% in all other technologies. Similar differences are also observed for the fraction of R&D projects that use public research, patent citations, basic and applied research, and scientific capabilities.

TABLE VI presents results for the four technology groups. It is important to note that across industries, results for the decision to use public research and the amount used vary considerably. In addition, correcting for self-selection becomes more important to the extent that there is greater variance in the proportion of firms that decide to use public research. Across all technology groups firm basic research has a positive association with the probability of using public research, yet the relationship changes notably for the fraction of R&D projects that use public research. In life sciences firm basic and applied research is positively associated with greater exploitation of public research, suggesting that public research is a complement to firms' internal research activities. In chemicals, however, there is a significant negative relationship with basic research and a positive relationship with applied research, perhaps indicating that in this technology group that public research is a substitute for firm basic research and a complement for applied research.

The importance of firm scientific capabilities and collaborative research to mitigate the costs of using knowledge flows from public research are more varied and complex. For example, across all industry groups the employment of scientists has no bearing on the decision to use public research, but considerable influence on the amount of public research used in chemicals and only a modest effect in life sciences. Although industrial scientists likely play numerous roles in firm innovation acting as both conduits and creators of knowledge, these results highlight the importance of scientific training in a firm's ability to exploit public research conditional upon use. Surprisingly, industrial scientists do not exhibit a strong relationship with the use of public research in the life sciences, perhaps suggesting the importance of alternative mechanisms in this technology group.

In IT and aerospace new ventures do not appear to differ from established firms with respect to their decision to use public research, but somewhat surprisingly they appear to exploit less public research in their R&D projects than do established firms. In the life sciences, however, we find evidence that new ventures both are more likely to use public research and exploit greater amounts of public research, which is consistent with prior research on entrepreneurial activity in the biotechnology and medical devices.

Interestingly, few determinants of the use of public research are significantly associated with patent citations. If patent citations are indeed noisy measures of knowledge flows as has recently been suggested (Alcacer and Gittelman 2004; Sampat ; Thompson 2006), then these results provide further evidence of the potential limitations of patent citations as proxies for knowledge flows from public research.

V. CONCLUSION

While prior research has established a strong link between knowledge flows from public research and firm innovative performance (Jaffe 1989; Adams 1990; Cockburn and Henderson 1998; Zucker, Darby, and Armstrong 2002), this study contributes to the innovation literature by examining the conditions under which firms use knowledge from public research. The results demonstrate that these knowledge flows are driven in no small part by firms' self-selection to using public research, and accounting for this potential l endogeneity has implications on estimates of the exploitation of public research in firm R&D. More specifically, we find that a firm's basic and applied research activity largely determine the probability that a firm uses public research, while a firm's scientific capabilities conditions the exploitation of knowledge flows from public research. We also find that entrepreneurial ventures utilize more knowledge flows from public research in their R&D projects than do established firms, particularly in the life sciences. These results suggest the importance of unpacking the notion of absorptive capacity (Cohen and Levinthal 1989; Cohen and Levinthal 1990) whereby firm basic and applied research activity may help firms to monitor public research for potentially valuable knowledge, while firm scientific capabilities are critical to fully exploiting this knowledge to enhance firm innovation.

This research contributes to the innovation literature by advancing our understanding of the foundational factors that drive the firm use of public research in industrial R&D, factors which are often omitted in empirical studies of the impact of public research on firm innovative performance. Together these results provide evidence that the utilization of public research is largely driven by firm choices, a potential source of endogeneity in studies examining the impact of public research on firm innovative performance. As a consequence, studies relying solely upon patent citations to measure a firm's use of public research may understate the importance of this source of extramural knowledge to a firm's innovative activity and performance. However, this study is not without its limitations. First and foremost, many of the featured determinants of the use of public research are endogenous, and given the lack of structure applied to this analysis it is difficult to make causal statements regarding the direction of the relationship. That is, although we attempt to account for firm characteristics that influence both the decision to use public research and the amount used, it remains possible that many of the determinants included in this study are themselves driven in part by either a firm's prior use of public research or the expected benefits from its use, and thus the potential for reverse causality to influence the results exists.

An additional limitation is that the survey measure of knowledge flows from featured in this study more accurately reflects the breadth of a firm's use of public research in its R&D projects, but not the depth of use within any given project. Thus, we am unable to discern differences across firms in their intensity of use. However, as the measurement analysis demonstrates, the survey measure does capture many of the most important aspects of knowledge flows from public research, especially when compared to the pervasively used measures of patent citations.

Ongoing and future research will bring the results of the current study to bear on the study of the impact of public research on firm innovative performance. For example, we examine how the drivers of a firm's use of public research and the limitations of patent citations might provide new insights on the existing innovation literature. An important question addressed in this work is how might estimates of the returns to public research in industrial R&D change after accounting for endogeneity arising from a firm's decision to use public research? In addition, in light of the limitations of patent statistics illustrated in the current study how might our understanding of the impact of public research on firm innovation be limited when using patent counts and citation-weighted patent counts as measures of innovative output? Answers to these questions have important implications for not only the management of technology and innovation, but also for the policy debate on the funding of university and public research.

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Table I: Variable Definition and Data Sources

Name	Source	Measure
Knowledge Flows from Public Research		
Decision to use public research	Survey	1 if reported using public research in any R&D project, 0 otherwise
Use of public research in R&D projects	Survey	Reported fraction of R&D projects that use public research findings
Patent citations to public research	NBER, Delphion & SCI	Number of patent citations to patent and non-patent (e..g, scientific publications) reference
Benefits of Using Public Research		
Basic research	Survey	Fraction of total R&D activity directed toward scientific research with no specific commercial objectives
Applied research	Survey	Fraction of total R&D activity directed toward scientific or engineering research with specific commercial objectives
Public research activity	CASPAR & Survey	Log of total academic R&D spending by field relevant to the lab
Mitigating Costs of Using Public Research		
Scientific capabilities	Survey	Fraction of total R&D employees who are PhD or MD scientists
Collaborative research	SCI	Fraction of scientific publications coauthored with university or government scientists
Firm Type		
New venture	Survey & VentureXpert	1 if founded less than 10 years ago, 0 otherwise
Controls		
Level of firm R&D effort	Survey	Log of lab's R&D budget for previous year (1993)
Scientific publication stock	SCI	Log of firm scientific publications for previous five years; lagged measure to account for endogenous propensity to use public research.
Patenting activity	NBER	Log of the number of patents; used when patent citations are measure of knowledge flows to control for the level of patenting activity
Firm/business unit size	Survey	Log of the number of firm employees or business unit employees for multiunit firms
Industry effects	Survey	34 ISIC dummy variables

TABLE II: DESCRIPTIVE STATISTICS

Obs. 838	Mean	Std. Dev	Min	Max
Decision to use public reseach (0/1)	0.50	0.50	0.0	1.0
Fraction of R&D projects that use public research	0.16	0.23	0.0	1.0
Num. of backward citations to public research	6.76	32.57	0.0	493.0
Basic research (share of total R&D)	0.04	0.09	0.0	1.0
Applied research (share of total R&D)	0.36	0.27	0.0	1.0
Public research activity (mil)	5,398	4,874	0.0	14,278
Scientific capabilities	0.16	0.18	0.0	1.0
Coauthored publications	0.14	0.27	0.0	1.0
New venture (0/1)	0.05	0.21	0.0	1.0
R&D budget (mil)	15.12	66.99	0.0	1080.0
Unit employees (1,000's)	2.93	10.68	0.00	200.00

TABLE III: DETERMINANTS OF THE USE OF PUBLIC RESEARCH IN R&D PROJECTS

	(1)	(2)	(3)	(4)	(5)
Measure	Survey	Survey	Survey	Survey	Survey
Sample	Full	Full	Full	Cond.	Cond.
Method	Probit	Flogit	Flogit	Flogit	Flogit
Basic research	1.88***	1.01**	0.93	0.08	0.91
	[0.61]	[0.49]	[0.70]	[0.45]	[0.62]
Applied research	0.46**	0.59***	0.57**	0.28	0.59**
	[0.19]	[0.21]	[0.29]	[0.20]	[0.28]
Public research activity	0.21***	0.43***	0.42***	0.16**	0.33***
	[0.03]	[0.08]	[0.13]	[0.07]	[0.11]
Scientific capabilities	0.31	0.91***	0.89**	0.82***	1.04***
	[0.30]	[0.34]	[0.37]	[0.30]	[0.33]
Coauthored publications	0.19	0.24	0.22	0.07	0.23
	[0.21]	[0.22]	[0.24]	[0.20]	[0.21]
New venture (0/1)	0.44	0.55**	0.53*	0.42*	0.65**
	[0.27]	[0.26]	[0.32]	[0.23]	[0.29]
ln(R&D expense)	0.13***	0.05	0.04	-0.05*	0.03
	[0.03]	[0.04]	[0.07]	[0.03]	[0.06]
Unit size	-0.01	0.01	0.01	0.01	0.01
	[0.02]	[0.03]	[0.03]	[0.02]	[0.02]
ln(publication stock)	0.13**	0.13**	0.13**	0.10**	0.15***
	[0.05]	[0.05]	[0.06]	[0.05]	[0.06]
IMR (Use)			0.11		-1.22*
			[0.79]		[0.72]
Industry controls (33)	Incl.	Incl.	Incl.	Incl.	Incl.
Constant	-3.34***	-6.02***	-5.70**	-2.06***	-6.24***
	[0.68]	[0.96]	[2.43]	[0.62]	[2.28]
Observations	838	838	838	417	417
df	35	35	36	35	36
Log Pseudo-likelihood	-443.06	-250.03	-250.02	-181.88	-181.57

Robust standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%

Column 1 is a probit regression on the full sample where the dependent variable is whether a firm uses public research (1 if yes); Column 2 is the baseline fractional logistic regression for the full sample without accounting for self-selection while Column 3 includes an Inverse Mills Ratio correction based on the probit regression in Column 1; Column 4 conditions the sample on those firms that use public research without accounting for self-selection while Column 5 includes an Inverse Mills Ratio correction.

TABLE IV: DETERMINANTS OF PATENT CITATIONS TO PUBLIC RESEARCH

	(1)	(2)	(3)	(4)	(5)
Measure	Survey	Patent Citations	Patent Citations	Patent Citations	Patent Citations
Sample	Full	Full	Full	Cond.	Cond.
Method	Probit	NegBin	NegBin	NegBin	NegBin
Basic research	1.88***	-1.36**	-2.46***	-1.03	-1.77**
	[0.61]	[0.62]	[0.70]	[0.68]	[0.80]
Applied research	0.46**	0.69***	0.24	0.85***	0.53
	[0.19]	[0.21]	[0.25]	[0.27]	[0.32]
Public research activity	0.21***	0.03	-0.26***	0.07	-0.12
	[0.03]	[0.02]	[0.10]	[0.05]	[0.13]
Scientific capabilities	0.31	0.97***	0.61**	0.98***	0.75*
	[0.30]	[0.28]	[0.30]	[0.37]	[0.41]
Coauthored publications	0.19	0.53***	0.30	0.57***	0.41*
	[0.21]	[0.19]	[0.20]	[0.20]	[0.22]
New venture (0/1)	0.44	0.65***	0.26	0.41*	0.14
	[0.27]	[0.25]	[0.28]	[0.24]	[0.31]
ln(R&D expense)	0.13***	0.19***	0.06	0.07	-0.01
	[0.03]	[0.04]	[0.06]	[0.05]	[0.07]
Unit size	-0.01	-0.02	-0.01	-0.05	-0.04
	[0.02]	[0.03]	[0.03]	[0.04]	[0.04]
ln(publication stock)	0.13**	0.13***	0.04	0.12***	0.06
	[0.05]	[0.05]	[0.05]	[0.04]	[0.05]
ln(num. patents)			1.85***		1.35
			[0.59]		[0.88]
IMR (Use)		1.03***	1.04***	0.98***	0.99***
		[0.06]	[0.06]	[0.06]	[0.06]
Industry controls (33)	Incl.	Incl.	Incl.		
Constant	-3.34***	-4.73***	0.77	-3.33***	0.99
	[0.68]	[0.69]	[1.90]	[0.92]	[2.85]
Observations	838	838	838	331	331
df	35	36	37	36.00	37.00
Log Pseudo-likelihood	-443.06	-1115.58	-1111.91	-696.79	-695.70

Robust standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%

Column 1 is a probit regression on the full sample where the dependent variable is whether a firm uses public research (1 if yes); Column 2 is the baseline negative binomial regression for the number patent citations (both patent and non-patent references) to public research for the full sample without accounting for self-selection while Column 3 includes an Inverse Mills Ratio correction based on the probit regression in Column 1; Column 4 conditions the sample on those firms that both use public research and patent (excluding those firms that use public research but do not patent) without accounting for self-selection while Column 5 includes an Inverse Mills Ratio correction.

TABLE V: DESCRIPTIVE STATISTICS BY TECHNOLOGY GROUP

	Life Sciences	Chemistry	IT & Aerospace	All others
Observations	121	168	150	398
Decision to use public reseach (0/1)	0.75	0.44	0.60	0.40
Fraction of R&D projects that use public research	0.31	0.14	0.20	0.11
Num. of backward citations to public research	13.12	7.54	12.68	2.26
Basic research (share of total R&D)	0.08	0.05	0.04	0.03
Applied research (share of total R&D)	0.41	0.44	0.32	0.33
Public research activity (mil)	10,953	5,276	4,470	4,110
Scientific capabilities	0.20	0.20	0.17	0.12
Coauthored publications	0.27	0.14	0.22	0.07
New venture (0/1)	0.17	0.01	0.04	0.01
R&D budget (mil)	15.08	20.65	37.04	4.53
Unit employees (1,000's)	2.26	4.95	11.77	4.47

TABLE VI: DETERMINANTS OF KNOWLEDGE FLOWS BY TECHNOLOGY GROUP

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Industry Group	Life Sciences			Chemistry			Engineering		
Measure	Survey	Survey	Patent Citations	Survey	Survey	Patent Citations	Survey	Survey	Patent Citations
Sample	Full	Cond.	Cond.	Full	Cond.	Cond.	Full	Cond.	Cond.
Method	Probit	Flogit	NegBin	Probit	Flogit	NegBin	Probit	Flogit	NegBin
Basic research	4.01**	2.41**	-2.75*	2.58**	-1.42	-2.92	4.86**	-1.17	-4.63***
	[1.58]	[0.96]	[1.41]	[1.28]	[3.73]	[3.68]	[2.06]	[1.51]	[1.02]
Applied research	0.60	1.19**	0.54	-0.23	0.64	1.06	1.43**	0.19	-0.05
	[0.51]	[0.52]	[0.82]	[0.44]	[0.56]	[0.65]	[0.56]	[0.68]	[0.70]
Public research activity	0.13	0.31***	-0.09	0.21***	-0.02	-0.39	0.20***	0.13	0.10
	[0.09]	[0.11]	[0.11]	[0.08]	[0.34]	[0.48]	[0.07]	[0.09]	[0.17]
Scientific capabilities	-1.25	0.94	1.85	0.11	1.70**	0.58	0.49	0.68	0.52
	[0.80]	[0.84]	[1.23]	[0.67]	[0.72]	[0.74]	[0.70]	[0.49]	[0.49]
Coauthored publications	-0.05	0.64	1.49**	0.18	0.04	0.27	0.72	0.05	0.31
	[0.49]	[0.40]	[0.60]	[0.46]	[0.45]	[0.59]	[0.50]	[0.40]	[0.45]
New venture (0/1)	0.71*	1.55***	0.14				0.69	-1.21**	-0.56
	[0.40]	[0.43]	[0.47]				[0.59]	[0.55]	[0.63]
ln(R&D expense)	0.18**	0.06	0.13	0.22***	-0.27	-0.16	0.18**	-0.07	-0.04
	[0.09]	[0.09]	[0.13]	[0.08]	[0.37]	[0.30]	[0.08]	[0.07]	[0.09]
Unit size	0.04	0.10	-0.12	-0.06	0.10	0.19	0.10	-0.05	-0.12*
	[0.08]	[0.07]	[0.09]	[0.05]	[0.12]	[0.15]	[0.06]	[0.05]	[0.06]
ln(publication stock)	0.24	0.14	-0.13	-0.00	0.02	0.04	0.03	0.14	0.19***
	[0.15]	[0.11]	[0.18]	[0.10]	[0.13]	[0.09]	[0.12]	[0.09]	[0.06]
IMR (Use)		-2.14**	1.71		2.07	4.01		0.51	0.67
		[0.98]	[1.29]		[2.97]	[3.55]		[0.69]	[1.26]
ln(num. patents)			1.37***			0.81***			0.98***
			[0.25]			[0.13]			[0.09]
Industry controls	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Constant	-3.89***	-7.19***	0.49	-4.67***	4.23	5.73	-5.08***	-0.12	0.29
	[1.34]	[2.31]	[2.94]	[1.08]	[10.12]	[10.03]	[1.06]	[2.42]	[3.70]
Observations	121	91	91	168	75	75	150	90	90
df	11	12	13.00	13	14	15.00	13	14	15.00
Log Pseudo-likelihood	-53.38	-40.43	-210.19	-92.14	-33.28	-146.29	-69.04	-39.66	-175.38

Robust standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%

Columns 1-3 are results for the life sciences technology groups (pharmaceuticals, biotechnology, and medical devices), Columns 4-6 are results for chemistry technology groups (e.g., basic chemicals, petrochemicals, plastics, etc., excluding pharmaceuticals), and Columns 7-9 are results for engineering technology groups (computers, semiconductors, telecommunications, and aerospace). For each technology group the first column (1, 4 and 7) is the probability of using public research (use = 1), the second column (2, 5 and 8) is the fraction of R&D projects that use public research conditional on use and accounting for self-selection, and the third column (3, 6 and 9) is the number of citations to public research conditional on use and accounting for self-selection.