CESIS Electronic Working Paper Series

Paper No. 252

Learning by doing in science linkages

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June 2011

The Royal Institute of technology

Centre of Excellence for Science and Innovation Studies (CESIS)

http://www.cesis.se

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Abstract

Since the contribution of Cohen et al. (2002), it is well established that linkages between firms and public research organisations (PROs) serve purposes of both suggesting new R&D projects and completing existing projects. However, the extant literature has little to say about whether these two types of outcomes are linked or independent effects. This paper examines how a firm's ability to absorb useful impulses to new R&D projects from interaction with public research organisations depends on how and how well the firm is able to utilise such linkages in project completion. An analysis of Swedish firms suggests that interaction provides impulses to further R&D primarily when it is successfully linked to achieving objectives in ongoing R&D projects of the firm. However, linkages which are focused on contributions to short-term projects are less likely to generate useful impulses. Moreover, not only are linkages which support both long-term and short-term objectives better than linkages which solely serve short-term objectives; firm-PRO linkages in which short-term objectives play a less accented role are most likely to facilitate valuable impulses to further R&D and innovation.

Keywords: university-industry; externalities from public research; impulses to innovation
JEL-codes: O32; O33; O38

1. Introduction

In recent years a rich variety of literature has focused on the role of public research organisations (PROs) in innovation (Rothermael et al., 2007; Breznitz and Feldman, 2011). This interest has been motivated by a recognition of public science as an important complement to private firms in innovation processes, based on arguments of underinvestment in science by private firms due to the "free-good" nature of scientific knowledge. It has been suggested that direct interaction between firms and PROs greatly facilitates knowledge flows from publicly funded research, motivating both theoretical and policy-driven interest in such linkages. These arguments are not primarily based in mainstream neoclassical economic theory, but rather on considerations of the characteristics of knowledge. The recognition of the 'tacit' nature of certain types of knowledge (Polanyi, 1966; Dosi, 1988) suggests that direct contacts between firms and academic researchers are needed to facilitate relevant knowledge flows. A complementary argument for the importance of collaborative interaction between firms and universities is that it may counteract tendencies to underinvestment in early stage R&D by allowing firms to reduce the costs and risks they face (Link & Scott, 2001; Veugelers & Cassiman, 2005). Arguments supporting this view have been provided by management scholars, who argue that increasing international competition, increasing complexity of technology and continued shortening of development lead times and product cycles push firms away from extensive in-house-only research – in particular from early stage R&D (Gerybadze & Reger, 1999; Tidd et al, 2001).

Despite the analytical guidelines offered by these frameworks, the analysis of to what extent different firm-PRO linkages are congruent with the underlying rationalisation for why public investments in science can be expected to give positive economic returns remains challenging in the study of direct university-industry linkages. While different linkages can be expected to create different amount of knowledge spillovers, it remains unclear what factors, if any, predict the level of externality generation. As a consequence, while an extensive literature has engaged in the analysis of which types of firms that establish linkages to public research (Laursen and Salter, 2004), what different channels that are used (Arvanitis et al., 2008) and what the main barriers to further linking between firms and PROs are (Hall et al., 2001), the study of direct firm-PRO interaction remains unfortunately detached from the theoretical foundations for its economic importance. In this paper, it is argued that an important means to connect the empirical study of the performance of firm-PRO linkages to the generation of spillovers is found in the seminal study by Cohen et al. (2002), where effects of linkages to PRO in terms of idea generation (linkages generating suggestions for new R&D projects) and project completion (linkages helping firms reaching internally defined R&D objectives) are clearly differentiated.

In this difference between new ideas and project assistance lies an opportunity to provide a more nuanced view on the discussion of PRO-industry linkages as oriented towards either "basic" or "applied" R&D. This distinction is a fundamental key to connecting the study of firm-PRO linkages to the theory of knowledge externalities. However, the classic definition of "basic R&D", which is associated with low degrees of appropriability and conceptualised as related to the knowledge involved (Nelson, 1959; Arrow, 1962) is notoriously difficult to operationalise in empirical research. In this paper, following Aghion et al. (2008), the "basicness" of R&D – i.e. the potential of R&D to generate knowledge spillovers – is considered to be determined by the distance between the innovation phase and a marketable product. In particular, firm-PRO linkages are evaluated after the extent to which they contribute to the very first phase of an innovation cycle, i.e. to what extent links provide the firm with valuable impulses to new R&D projects and future innovation. This approach allows us to discuss and empirically investigate interaction outcomes from the market-oriented perspective of the firm, while maintaining a connection to the notion of firm-PRO links as mediators of knowledge spillovers. This connection is based on two interrelated arguments. First, since innovation activities in very early phases are typically characterised by high uncertainty and the results produced are in general more generic than the results of late-stage innovation activities (see e.g. Larsen, 2006), early-stage results are firmly linked to the classical argument of reduced appropriation opportunities. Second, successful knowledge sourcing from PROs in the form of impulses to further R&D and innovation paves the way for increased R&D expenditures of the firm (Veugelers, 1997), and hence generates further knowledge spillovers over time.

This paper explores the connections between project completion benefits and innovation impulse benefits from firm-PRO linkages. An analysis of Swedish firms shows that interaction provides impulses to further R&D primarily when it is successfully linked to achieving objectives in ongoing R&D projects of the firm. However, linkages which are focused on contributions to short-term projects are less likely to generate useful impulses. Moreover, not only are linkages which support both long-term and short-term objectives better than linkages which solely serve short-term objectives; firm-PRO linkages in which short-term objectives play a less accented role are most likely to facilitate valuable impulses to further R&D and innovation.

The remainder of this paper is organised as follows: Section 2 illustrates that the relationship between project completion benefits and innovation impulse benefits varies considerably between firms, even when limiting the analysis to the engineering sector. Section 3 derives three hypotheses about the relative frequency of occurrence of the four types of relationship identified in the previous section and section 4 delineates the data set on Swedish engineering firms used to test these

hypotheses. Section 5 reports the results of econometric modelling using this data and section 6 concludes, offering a discussion of the policy implications of these findings.

2. Connecting innovation impulses and project completion

The influential study "Links and impacts" by Cohen et al. (2002) has established the insight that firm-PRO linkages may not only – as suggested by the so called linear view of science and innovation – serve as a source of impulses to innovation, but also serves to help firms complete existing R&D efforts. However, this insight has older roots. Academics have over the last decades repeatedly been reported to support innovation efforts in private firms by offering advice and new perspectives, enabling access to advanced equipment for prototype testing and engaging directly in projects as consultants etc (see e.g. Gibbons and Johnston, 1974; Kline and Rosenberg, 1982). However, in spite of significant research interest in the phenomenon of firm-PRO interaction, the wider economic effects of such linkages remain unclear. While the economic case for promoting learning and impulses over the industry-PRO organisational borders is relatively straightforward, the consequences of more exploitation-based interaction is still disputed. It has been argued that to the extent that such linkages affect public science, pushing it away from its unique role in economic systems towards a more development-centred role, firm-PRO interaction may in fact have negative long-term consequences for economic returns to public science. In essence, this debate centres on a reduction in knowledge of a free-good character; both caused by imposed secrecy conditions (Florida and Cohen, 1999; Nelson, 2004) and by a shift of academic scientists attention from generic problems and theory to short-term problem solving related to firm-specific needs (Calderini et al., 2007). In light of this debate, it is important to connect the two kinds of firm benefits from PRO interaction – impulses and project completion – more closely to each other in order to tie the study of firm-PRO interaction closer to the theory of knowledge spillovers. If firms gain impulses for innovation from public research independently from their use of such links for project completion purposes, the concerns raised above may imply that public returns to investment in science can be maximised when firm-PRO linkages are focused on learning aspects only. The implications for public policy would be to strongly encourage firm-PRO linkages of "listening post" character, whereas public funds should be clearly separated from private needs for project assistance. If, on the other hand, firms are more likely to absorb impulses to further R&D and innovation when also deploying links to public science for project completion purposes, such linkages may also be considered to have positive economic effects in terms of knowledge spillovers. An optimal public policy may then involve supporting such linkages, either by encouraging them by means of shifting the incentive systems of PROs or by directly co-funding firm-PRO interaction. In making such design choices, it seems important to distinguish between at least two types of interaction geared

towards project completion objectives: interaction dominated by exploratory, long-term R&D objectives and application-centred, short-term R&D objectives, respectively.

Together, the two distinctions discussed above leave us with four possible modes of firm's interaction with PROs. Firms may use PRO interaction (1) primarily to achieve long-term project completion, (2) primarily to achieve short-term project completion, (3) to achieve both long-term and short-term project completion and (4) to achieve neither long-term, nor short-term objectives. Illustrating that impulses to innovation may be derived from all these four modes of interaction and that the relationship between learning and project completion therefore is a non-trivial issue, four miniature case-studies from the Swedish engineering sector are presented below.

2.1 Learning can occur while achieving both long-term and short-term project completion objectives

Bombardier transportation is a multinational company with strong R&D presence in Sweden, where the firm is active in a number of contacts with public research organisations. Research manager Henrik Tengstrand explains that the firm strives to combine exploratory, technology-driven projects and application-oriented projects in its contacts with public research, so as to enjoy economies of scale in those contacts. Through its strong interfaces towards the academic world, the firm is also able to pick up novel ideas that vitalises in-house R&D.

2.2 Learning can occur while primarily achieving long-term project completion objectives

Sandvik Tooling, a section of the Swedish-based engineering group Sandvik, undertakes substantive R&D efforts in materials technology and related subjects. R&D director Ulf Rolander explains that the firm needs to ensure that its R&D is in constant contact with the research frontier in material science. To that end, Sandvik Tooling gives high priority to contact with academic milieus, e.g. in the form of offering PhD students both funding and access to the firm's facilities to advance research on the characteristics of specific compounds identified as commercially interesting for the firm.

2.3 Learning can occur while primarily achieving short-term project completion objectives

For the KMT group, active in manufacturing of advanced machinery, contacts to public research is primarily considered an alternative to technical consultancies for applied R&D contracts. Former CEO Lars Bergström states that the advantage of engaging public researchers is that the results tend to be less predictable, offering the firm's engineers the opportunity to learn by serendipity.

2.4 Learning can occur while achieving neither short-term nor long-term objectives

In the late 1990s Indexator, a small manufacturer of hydral engines located in northern Sweden, engaged in a joint research project at Luleå University of Technology. CTO Anders Jonsson describes the outcome of the project as non-successful, in the sense that the firm was not able to utilise any of the results of the project in its R&D processes. Nonetheless, the contacts with the university provided inspiration and opened new R&D venues for the firm. Newly initiated R&D around the issues of material choice led to improved competitiveness, allowing the firm to grow from 100 to 200 employees within a few years.

3. A pattern of Connecting innovation impulses and project completion

Having acknowledged that all four possible relationships between learning and project completion exist in contemporary university-industry linkages, the question becomes which of these four types that are most typical. First let us consider whether case 2.4 above, where learning occurred in the absence of project completion benefits, can be generalised to the wider setting of engineering firms' interaction with PROs.

The view of impulses to innovation as independent from project completion benefits is seemingly supported by theories of knowledge which emphasise the transferability of codified knowledge without the need for personal contacts. As academic results are highly codifyable, the need to interact directly with researchers to learn from the outputs of academic research have been argued to be relatively small (Asheim and Gertler, 2005). On the other hand, theory on organisational learning suggests that impulses to innovation from external sources typically arise serendipitously in close contacts characterised by trust (de Wijt et al., 2008). Furthermore, the ability to interpret academic results and to orient in the vast stream of results continuously produced critically depends on specific absorptive capacity of a type that may be difficult to uphold without maintaining some form of operational ties to academic research. Only the most well-resourced firms can be expected to afford such capacity creation if these efforts are not also geared towards ongoing R&D needs of the firm. In light of this, the following hypothesis is suggested:

H1: Firms that successfully use linkages to PROs for R&D project completion are more likely to gain useful impulses to further R&D projects from PROs than other firms

Next, let us consider whether the relationship between the two types of benefits – impulses to R&D and innovation and project completion – can be expected to be mediated by what type of projects to which a firm gains useful assistance from PROs. In particular, does it matter whether firms deploy

PRO links in exploratory projects where innovation and market launch is a long-term ambition, or in exploitative projects close to actual innovation?

There are reasons to expect that a firm that focuses on short-term benefits in interaction are less likely to simultaneously benefit from impulses to further R&D. First, a narrow, well-defined objective of interaction would seem to leave little room for serendipitous learning. Secondly, it can be expected that firms which primarily use PROs in applied, short-term project are less likely to have the resources to benefit from learning that occurs in interaction. However, arguments quite to the contrary have been offered. Perkmann and Walsh (2009) find that interaction channels that are typically used in applied contacts to public research organisations (contract research, consulting) tend to "involve far closer collaboration between academic researchers and industry partners [...] which [...] facilitates interactive learning". Similarly, Cohen et al. (2002) find that firms that use consulting and contract research are more likely to report that PRO linkages are both contributing to both project completion and suggesting new projects. Nonetheless, the following expectation is suggested:

H2: Firms that primarily use PRO linkages for short-term R&D projects are less likely to gain useful impulses to further R&D projects from PROs

It remains to discuss whether links characterised by a balanced mix of long-term and short-term benefits are more likely to generate useful impulses to R&D and innovation than links focused on long-term effects (interaction linked to exploratory R&D projects). Relatively little evidence can be mobilised to produce an expectation in any direction. The literature on ambidexterity has described how the ability to simultaneously explore and exploit is conduit of success in innovation (O'Reilly and Tushman, 2004, 2007). This literature is however less clear about how exploration and exploitation can, or must be combined across all possible types of linkages that firms deploy. Studies on exploration and exploitation in innovation networks have, however, recorded tendencies to "underscore either exploration and exploitation within alliance domains" (Lavie and Rosenkopf, 2006). In lack of further guidance, it can be hypothesised that, controlling for the firm's ability to use PRO linkages for any kind of project completion, impulses to further R&D projects arise more often when a linkage is focused on long-term accomplishments than when a linkage contributes to both long-term and short-term R&D objectives.

H3: Firms that primarily use PRO linkages for long-term R&D projects are more likely to gain useful impulses to further R&D projects from PROs

4. Methodology

The three hypotheses are tested using a dataset collected from Swedish engineering firms. This setting can be expected to be a good choice to study which type of firm-PRO links that generate valuable impulses to further R&D. Since Sweden, among with the other Nordic countries, has higher activity in firm-PRO interaction than other EU countries (as indicated by the Community Innovation Survey), there are reasons to expect Nordic firms to have relatively long experience of collaboration, and to have developed strategies for interaction with public research organisations.

The dataset used in this study is based on a survey of 425 establishments from 397 firms in the Swedish engineering sector which was conducted during the summer of 2007. The establishments were randomly selected and stratified by size. All establishments were contacted by telephone and asked to identify the best respondent for our survey. In declining order of priority, the establishment was asked to identify its R&D manager in charge of external relations, general R&D manager, technology manager, production manager or site manager/CEO. The respondents were then contacted by e-mail and given the opportunity either to respond to the survey electronically or to indicate that they did not want to participate. A reminder e-mail was sent after one week. In parallel, respondents who had not reacted to the survey were contacted by telephone and given the option of responding to the survey questions orally. After three weeks of intensive efforts, a final e-mail was sent. In total, 68 per cent of the respondents completed the survey. A further 6 per cent gave incomplete answers.

In the stratified sample, 65 per cent reported collaborative relations with PROs. A further 11 per cent reported that they were interacting with universities exclusively through student projects. For the purpose of this paper, the latter are considered non-collaborators. The data set was further processed to fit the needs of the current analysis. Reflecting the discussion of impulses to R&D in the previous section, it was necessary to cut out only those respondents for whom impulses to R&D would be a relevant objective, and for whom such externally acquired impulses could be expected to trigger further effort in innovation. That is, the analysis must be focused on firms which are potentially advanced enough to pursue some form of organised innovation activities (Veugelers, 1997). The operationalisation of this demand was based on patenting statistics and sector classifications, so that establishments to which none of the following three criteria can be applied are dropped from further analysis. Included are establishments which...

... are classified as R&D performers, or
... are classified as belonging to a sector which, according to the classic taxonomy of Pavitt (1984), is

considered science-based, or
... belong to a firm which applied for at least one patent during 2004-2007

After restricting the dataset, 184 establishments remain in the sample, reporting on 920 PRO linkages.

The opportunity to use the Swedish data to study the three hypotheses of this paper arises from the unique detail concerning assessments of linkage benefits that was provided in the survey. Respondents were presented with questions regarding their formal interactions with five categories of PRO: universities[1] in their own county (administrative region), domestic universities outside their own county, foreign universities, domestic public research institutes and foreign public research institutes. For each of five PRO categories, respondents were asked to state whether his/her establishment had had R&D collaboration with a partner in this category in the period 2004–2006. For each category, respondents were then asked to evaluate three possible benefits from the collaboration on a three-level Likert scale ("not at all" / "to some extent" / "to a significant extent").

A1: Interaction has helped the firm suggest and formulate new innovation projects
A2: Interaction has contributed to the execution of long-term innovation projects
A3: Interaction has contributed to the execution of short-term innovation projects

Guided by a series of interviews with R&D managers in engineering firms, the notion of "short-term innovation projects" was operationalised as "projects which resulted in improved or newly introduced products or processes within 12 months of the termination of the project". The notion of "long-term innovation projects" was accordingly defined as having a time horizon of longer than 12 months.

For each respondent, between 0 and 15 assessments of collaboration have thus been made. From these assessments, the following measures are constructed:

impulses to new projects	= A1	(1)
project completion	= max(A2, A3)	(2)
focus on short-term effects	= 1 if A2 > A3	(3)
focus on long-term effects	= 1 if A3 > A2	(4)

[1] Since respondents were not asked to differentiate between "true" universities and university colleges or polytechnics, the term "higher education institutions" was used in the survey.

Four variables, capturing the predictions of the three hypotheses developed in the previous section, are thus available. *impulses to new projects* and *project completion* are ordinal variables, taking on the values 1, 2 and 3. *focus on short-term effects* and *focus on long-term effects* are dummy variables. As reported in Table 1, a first inspection of these variables provides support for the three hypotheses. Linkages which are assessed as contributing to *project completion* to a significant extent are assessed to contribute to *impulses to new projects* more than other linkages. Linkages which are *focused on short-term effects* are assessed to contribute less and linkages which are *focused on long-term effects* to contribute more to *impulses to new projects*.

	Difference in *impulses to new projects*
project completion=3	.28***
focus on short-term effects=1	-.47***
focus on long-term effects=1	.36***

Table 1: Differences and correlation statistics between the three measures of project completion benefits and learning outcomes. *** denotes 1% significance by Wilcoxon rank-sum test

To allow for generalisation of these results, however, a more thorough analysis is required. In particular, we need to control for factors that, independent of the focus of PRO-contacts, may drive the firm's ability to absorb useful impulses to further R&D from such contacts.

Theory on organisational learning suggests that impulses to innovation typically arise serendipitously in close contacts. Face-to-face contacts, trust, and appropriate cognitive distance (Noteboom et al., 2007) have all been found to facilitate organisational learning. Beyond the variables directly related to the three hypotheses above, the influence of these factors is captured by two further characterisations of a specific firm-PRO linkage. First, in linkages extending the borders of Sweden, the firm must put up relatively higher efforts to engage in face-to-face contacts. Furthermore, learning in cross-border interaction may be somewhat hampered by cultural differences and communication barriers (Broström, 2010). To capture these effects, a dummy-variable on describing whether a certain linkage is *foreign* or not is included in the model. Secondly, the different knowledge-bases of different types of PROs can be expected to influence organisational learning. In the context of the present analysis, the main difference is expected to arise between interaction with universities on the one hand and industrial research institutes on the other. In the context of Swedish engineering, the latter group is dominated by a number of application-oriented institutions. A dummy-variable describing whether a specific linkage involved a university or an *institute* is included as a further control.

A number of establishment-level and firm-level factors are also expected to influence the likelyhood that a particular firm-PRO link gives rise to valuable impulses to innovation. Such effects are most

likely to arise in firms which command appropriately advanced technological and innovation-related competences. Not only are more advanced firms, and firms which pursue some kind of R&D activities in general more likely to be receptive to impulses to innovation from all kinds of sources (Cohen and Levinthal, 1989); advanced firms can be expected to be particularly well positioned to benefit from impulses from public research. In the terminology of Nooteboom (2000), they are at more appropriate cognitive distance from scientific researchers than unadvanced firms are. At more advanced firms, personnel who participate in science-based 'communities of practise', and who therefore are able to exchange knowledge more efficiently than outsiders to such a community (Brown and Duguid, 1991, 1996), can be engaged to manage PRO links. Two types of controls are applied to incoproate the above discussion in the model. The technology level of the firm is proxied by the number of *patent applications* filed at the Swedish patent bureau and the European Patent Office (EPO) in 2004-2006. This data was obtained from the PATSTAT database of the EPO. The second type of control related to the discussion of advanced vs. un-advanced establishments is the sector classification of the establishment, which was provided from public registers by Statistics Sweden.

Furthermore, three variables capturing the corporate structure of the establishment (*group*, *number of establishments*, *firm size*) are constructed from register data. For these controls, expectations on total impact is relatively unclear. On the one hand, the ability to source knowledge from within a larger group and to manage the division of innovation labour across a larger group can be expected to negatively affect the likelyhood that a particular establishment generates valuable impulses to innovation from PROs. On the other hand, establishments embedded in larger groups may be better provided with resources for R&D and innovation, as larger firms may have higher market power and enjoy economies of scale and scope. To improve the precision of these controls, data on the *profit margin* of the firm in 2006 is added from auditing records.

Finally, following the literature utilising the CIS, controls capturing two types of barriers to interaction with PRO are included as controls. The variables *financial obstacle* and *miss-match obstacle* are constructed based on survey responses. Both types of barriers are expected to inhibit learning and impulses from PROs.

Table 2 provides an overview of the variables with their respective means and standard deviation. Beyond the variables discussed above, dummy variables capturing establishment size and the expectancy that linkages to PROs will have *increased priority* in ten years time, compared to the present time, are included in the table as they are used as instruments in robustness tests, as discussed in the following section.

Name	Description	Mean	Std. Dev.
Link-specific variables			
impulses to new projects	assessment of to what extent the link is contributing to impulses for innovation	2.02	.66
project completion	assessment of to what extent the link is contributing to project completion	2.40	.63
focus on short-term effects	the link is assessed as contributing more to the execution of short-term R&D projects than to R&D projects with a long-term perspective (=1)	.14	.35
focus on long-term effects	the link is assessed as contributing more to the execution of long-term R&D projects than to R&D projects with a short-term perspective (=1)	.48	.50
institute	link to public research institute (=1) rather than university (=0)	.40	.49
foreign	link to foreign (=1) or domestic (=0) partner	.40	.49
Establishment-specific variables			
metals sector	classified as a producer of basic metals (=1)	.07	.26
metal products sector	classified as a producer of simple metal products (=1)	.05	.26
machinery sector	classified as a manufacturer of machinery (=1)	.23	.42
equipment sector	classified as a manufacturer of electrical and optical equipment (=1)	.19	.39
transport sector	classified as a manufacturer of transport equipment (=1)	.14	.34
r&d sector	classified as a performer of technical R&D (=1)	.35	.48
financial obstacle	lack of public co-funding or insufficient internal resources is reported to be a major obstacle for further interaction (=1)	.25	.43
miss-match obstacle	lack of competences and interests matching those of the company is reported to be a major obstacle for further interaction (=1)	.25	.43
group	the establishment is a part of a multi-establishment firm	.29	.45
local availability	number of engineering faculty active in the county of the establishment	482	489
e-size1	the establishment has 20–49 employees (=1)	.25	.43
e-size2	the establishment has 50–99 employees (=1)	.17	.37
e-size3	the establishment has 100–199 employees (=1)	.19	.39
e-size4	the establishment has 200–499 employees (=1)	.25	.44
e-size5	the establishment has 500+ employees (=1)	.14	.35
increased priority	links to PROs are expected to become more highly prioritised than today in ten years	.41	.40
urban	establishment is situated in an urban region (seven largest cities of Sweden) (=1)	.15	.35
Firm-specific variables			
firm size	the number of employees in the firm	667	721
number of establishments	number of establishments in firm	3.63	5.27
patent applications	the number of applications registered in PATSTAT database	767	2515
profit margin	profit margin in 2006	5.58	45.30

Table 2: Summary of the variables used. N=920.

5. Results

The assessment of impulses is for each link modelled as a function of the variables listed in the previous section. Table 3 reports estimates from an ordered probit model.

	impulses to new projects
project completion	.400 ***
	(.114)
focus on short-term effects	-.593 ***
	(.218)
focus on long-term effects	.464 ***
	(.143)
institute	-.233 *
	(.133)
foreign	-.341 ***
	(.132)
metal products sector	.179
	(.383)
machinery sector	-.096
	(.256)
equipment sector	-.617**
	(.311)
transport sector	.412
	(.301)
r&d sector	-.233
	(.267)
log firm size	-204**
	(.081)
group	.368***
	(.153)
number of establishments	.012
	(.011)
log patent applications	.064**
	(.032)
financial obstacle	-.240*
	(.129)
miss-match obstacle	-.431***
	(.142)
log profit margin	-.084
	(.064)
Wald chi2(17)	95.8 ***
Pseudo-R2	0.1337

Table 3: Estimation results, ordered probit model. Base-case for sectors is *metals*.
Heteroskedasticity-robust standard errors reported.

In support of Hypothesis 1, the assessment that a particular linkage has contributed to *project completion* is positively related to the assessment of learning outcomes. A linkage reported to be *focused on short-term effects* is furthermore less likely and a linkage reported to be *focused on long-term effects* is more likely to provide impulses to further R&D projects, providing support for Hypotheses 2 and 3.

This specification of an ordered probit model potentially suffers from a number of problems. First, the analysis potentially suffers from selection bias. Of 920 potential linkages included in the data, only 369 are realised, and hence assessment of link outcomes can only be reported for about 40% of the observations. The results must therefore be carefully examined for selection bias. Such examination has been made with a sample selection model, demonstrating that the model reported in Table 3 and a model which appropriately captures the selection mechanism through which links are realised are independent of each other, indicating that sample selection is not applicable in the current setting, and that the results are not biased by such a phenomenon.[2]

Second, we must consider the possibility the relationship between the two assessments of *project completion* and *impulses to new projects* are determined simultaneously, and that the reported estimate of the former variable therefore will be biased. To account for this potential problem, a two-equation instrumental variable version of the ordered probit model was estimated, utilising the CMP package for the STATA software (Roodman, 2006). Utilising the variables *urban*, the five dummies capturing establishment size and *increased priority* to instrument *project completion*, no indications of endogeneity bias are found.

Third, we must consider the possibility that responses to the key variables are clustered, in particular between establishment size. We may also suspect that establishment listed as R&D performers are different from other establishment in how they use links to PROs. The model of table 3 has therefore been run with standard errors clustered after establishment size, sectors and a combination of these factors.

Finally, a series of robustness checks have been performed to ensure that the results reported above are not artefacts of the particular ways in which the data set was constructed. It was established that the removal of any one of the three variables directly linked to the study's three hypotheses does not render the other two less significant. It was furthermore tested whether the results reported in table 3 are valid for the unrestricted survey sample. This test confirmed the robustness of the result in the full sample of randomly selected engineering firms, but also indicated that the original reasoning in excluding establishments which cannot be considered sufficiently advanced to benefit from impulses for further R&D and innovation: when testing the model of table 3 for excluded firms only, the entire model is rejected as explaining the independent variable to an insufficient degree.

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[2] In the various robustness tests reported, all three variables which are directly linked to the evaluation of the hypotheses presented in this study remained significant, in the sense that all remained significant at the 5 % level which meets the standard of acceptable significance in a cross-sectional study of this type. However, in some of these models, one or the other of the three estimates was no longer, as the estimates in table 3, significant also at the 1% level.

6. Discussion

This paper reports results on how a firm's ability to absorb useful impulses to new R&D project from interaction with public research organisations depends on how well the firm is able to utilise such linkages in project completion. The insights offered by this analysis allow the study of firm-PRO linkages to be connected to the theory of knowledge spillovers from two directions. From the perspective of the firm, we learn that linkages to public science in which long-term (exploratory) project objectives are accentuated are most likely to generate valuable learning that stimulates further efforts in R&D and innovation. This finding can be related to previous research which, starting from the perspective of the PRO, has found that engagement with firms driven by long-term, exploratory agendas are much less likely to have detrimental effects on the long-term value of academic research than contacts focused on strictly "applied" research (Goldfarb, 2008). Hence, this paper provides a double-sided argument for why firm-PRO interaction driven primarily by long-term R&D objectives of the firm has an important role to play for the public economic returns to investments in academic science.

As it is desirable that considerations of spillover generation are incorporated in the design in public policy on R&D and innovation (Feldman and Kelley, 2006), the findings reported in this paper have significant policy-relevant implications for public efforts to stimulate university-industry linkages. The incentives for interaction should preferably be geared towards interaction on long-term project objectives, as such linkages are most likely to generate learning effects and, in consequence, stimulate further R&D. In designing programs for direct support of university-industry linkages - e.g. through public co-funding - policy-makers should be aware that interaction which primarily serves short-term purposes is less likely to create knowledge spillovers. It should be emphasised that, in particular for non-advanced firms and firms with very limited resources for R&D, short-term objectives may be the only reasonable setting in which links to PROs can be established. The state may potentially seek to engage such firms in linkages to public science, in the idea that linkages driven by short-term objectives over time will stimulate the capacity to innovation and pave the way for future interaction with PROs on long-term objectives. The present study, in its cross-sectional approach, cannot be used to evaluate the effectiveness of such policy. Further research on the dynamics of university-industry linkages and innovation activities would therefore seem most appropriate. By providing further insights on how firms' benefits from linkages to public science vary over time, such research would seem an important step to further tie the study of university-industry linkages to the underlying rationale for the beneficial role of such linkages in the economy.

Acknowledgements

The author is grateful for productive suggestions and comments from Barbara Fuchs and Andrea Fosfuri, none of whom are in any way responsible for remaining limitations of the analysis.

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