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Does Knowledge Diffusion between University and Industry Increase Innovativeness?

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CONTENTS

ABSTRACT

Empirically this paper seeks to assess the effect of firms' R&D collaboration with universities on innovation. A cross-sectional propensity score matching estimator is applied to the Swedish Community Innovation Survey data over 1998-2000, which provides information about cooperation on innovation reported by 790 R&D or innovation investing firms with at least 10 employees. Approximately 25 percent of these firms collaborated with universities on innovation projects. The results shows that university/industry collaboration has a significant and positive influence on three measures of innovative activity. First, the average R&D firm that cooperate on innovation with universities spend more money on R&D compared to an almost identical R&D firm (constructed by the two nearest neighbours) witch has no collaboration with academic researchers. Second, collaborating firms have a larger propensity to apply for patents than other R&D firms. Finally, income from new product sales is considerable greater for a firm that have joint research projects with universities than for a non-collaborating twin firm.

Keywords: R&D investment, innovation, patents, industry-university link, matching methods.
JEL Classification: C24; L10; O30; O31; O38; 040

1. INTRODUCTION

The diffusion of technology and knowledge is a salient feature in more recent literature on technological change, innovation and growth. Much attention has been given to the role of universities. Although there is considerable variety across industries, many studies give evidence on a strategic importance of the university-industry link in modern economies. Main empirical indicators of the growing relationships between universities and firms are (i) industrial funding of university research and partnering projects, (ii) patenting by universities, (iii) start-up companies from universities and (iv) joint authorship of articles by university and industry research. Counts of patent or innovations, market to book value and stock return are common variables for measuring impact of academic knowledge on firm performance.

The Cohen and Levinthal (1989) formulation of absorptive capacity and the 'non-linear model' by Pavitt (2003) and others[i] contributes to our understanding of the firms interactions with universities. Pasteur's quadrant (Stokes, 1997), with Boor, Pasteur and Edison as metaphors for pure basic research, use-inspired basic research and pure applied research, has facilitated a broader understanding of the academia's interaction with commercial firms.

Most of the empirical research on science, universities and firm relations focuses on the U.S. However, it has been shown that experiences on the university-industry link in the American economy often correspond to findings in European and other countries; Hall *et al.* (2001) reports that nearly 60 percent of the research projects funded by the Advanced Technology Program in the U.S. involved firms collaborating with universities. Caloghirou *et al.* (2001) analyzes over 6,000 research joint ventures (RJV) in 42 nations that received funding from European Commission during 1983-1996 and found that the share of RJVs that involved one university or more was 67 percent in 1996. Zucker, Darby and Brewer (1998) study firm formation in biotechnology, which is an industry closely linked to fundamental molecular biology. Their analysis shows that top university researchers in a U.S. region contribute to biotechnology start-ups. Harhoff (1999) studies firm formation in regions of West Germany and report that the nearness to scientific personnel is important mainly for high technology entry. Mansfield (1998) finds that industrial innovations that could not have been developed (without a delay of a year or more) in the absence of academic research accounted for over 5 percent of total sales in major firms in the U.S. in 1994. Through a postal questionnaire survey of 2,300 companies Baise and Stahl (98) replicate Mansfield's survey in Germany and find that approximately 5 percent of new product sales could not have been developed without academic research.

Despite extensive evidence in the literature on the importance of partnering between university and industry, many researchers emphasize that our knowledge on the interaction between universities and the industry is still limited, and when it comes to issues such as systematic data analysis and the economic consequences associated with knowledge diffusion between universities and firms, very little is known. (See, for example Hall, Link and Scott 2003, Jacobsson 2002 and Fontana, Genua and Matt 2003).

Even though the practical benefits for the industry of much, or perhaps most university research probably emerges from indirect and hard-to-measure processes, and even if universities in general are in the business of the creation and free dissemination of knowledge "for its own sake" (see Hendersson, Jaffe and Trajtenberg, 1995) it is naturally unsatisfactory if the largest sector for basic research in the society is not properly evaluated. In particular governments, who in many industrialised countries, fund approximately 70-75 percent (For the case of Sweden, see appendix A) of university research, are interested in the return on these investments.

The present paper is aiming to contribute to the rare quantitative evaluation literature on the practical importance of the industry-university link. Thus, our fundamental research issue is to measure the effect of academic research on firms' innovation performance. Empirically the study seeks to assess possible benefits of academic knowledge on firms' R&D intensity, propensity to apply for patents and their innovation sales. We address this issue by a cross-sectional propensity score matching estimator to the Swedish Innovation Community Innovation Survey data over 1998-2000.

A methodological challenge is what in the statistic literature is discussed as the lack of *counterfactual evidence*; we do not what would have happened with the firms' innovation performance in the absence of university collaboration. Following the literature for assessing the outcome of particular treatment effects, we will use the outcomes on noncollaborators to estimate what collaborators would have experienced had they not participated in joint research projects with universities. In doing so, we separate our sample of 790 Swedish firms with respect to participation in common research project with universities in Sweden. The group first consist of 205 firms collaborating on innovation with universities. The other group consists of 585 firms engaged in innovative activities but not participating in any joint research projects with academic researchers. A difficulty in this kind of analysis is when the group of collaborating firms is a selective one. The descriptive statistics shows extensive differences between the groups regarding firms' characteristics than can influence the decision to collaborate with universities.

In order to account for selection bias, initially we calculate a probit model and examine the determinants of firms' likelihood of participating in R&D alliances with universities. Here we include factors such as industry class, firm size, R&D-history, governmental R&D subsidies, export, market orientation, ownership, obstacles to innovation and demand pull indicators. We then apply propensity scores and match collaborators and non-collaborators on their estimated possibility of collaborating with universities. The importance of academic knowledge is finally evaluated by comparing the average level of innovation input and innovation output between the collaborating and non-collaborating twin-firms.

The causal effect identified in the paper is significantly different from zero and quite sizable in order of magnitude, for all three innovation measures. That is, compared with a situation not incorporating academic knowledge in the innovation process, the collaborating firms invest more in R&D, they have a larger propensity to apply for patents, and finally they have larger innovation output in terms of innovation sales.

The rest of the paper is organised as follows. Section 2 briefly reviews some important theoretical and empirical paper on knowledge diffusion and the university/industry link. Section 3 delineates the data. Section 4 introduces the methodological approach. Section 5 states the empirical results, and Section 6 concludes.

2. THE UNIVERSITY-INDUSTRY LINK

In discussing the theoretical foundations for university/industry links Stern, Porter and Fulham (2002) distinguish between three areas of the literature on knowledge diffusion and innovation performance: the cluster-based theory of national competitive advantage (Porter, 1990), knowledge-driven endogenous growth theory (Romer, 1990), and the literature on national innovation systems (Nelson 1993). The first of these three strands of innovation literature emphasizes the microeconomic underpinnings of innovation in country-specific industrial clusters such as local supporting industries, universities and the nature of local competitiveness. In so called endogenous models of knowledge-driven growth, two factors are crucial for the rate of innovation in the economy. They are the prior stock of knowledge accumulated by the economy and the level of R&D effort allocated towards creation of new knowledge in private firms and public research. The literature on national innovation systems tends to emphasize the role of the overall national policy environment, universities and the educational sector, as well as more idiosyncratic institutions that affect innovation.

Many empirical studies support the hypothesis that the use of academic knowledge is beneficial to technological change, innovation and growth in the private sector through new theoretical insights, new techniques, and new skills of a kind that industrial firms find difficult to provide themselves. See for instance Jaffe, 1989, Adams 2002 and 2004, Pavitt 2003, Adams, Chiang and Jensen, 2003 and Adams, Clemmons and Stephan 2004. Conflicting evidence is reported by Medda, Piga and Siegel(2004). Using firm-level data from Italian manufacturing firms they find strong evidence of positive returns to collaborative research companies with companies, while collaborative research with universities does not appear to enhance productivity.

Surveying approximately 400 research ventures in the USA, Lee (1996) found that respondents ranked access to new research and developments of new products as the two most important reasons for collaborating with universities. However, most firms (even R&D firms) do not participate in any R&D cooperation with universities at all. Some main reasons can be identified. Intellectual property rights have been described as an "insurmountable barrier to partnering" (Hall, 2001). In their survey of 38 industry participants in a project funded by the Advanced Technology Program, Hall, Link and Scott (2001) show that about 30 percent of the firms had a university as a research partner and approximately the same proportion reported that IP issues are an obstacle to university collaboration. Pavitt (2003) points out organisational cultural differences as another major problem. He report that managers often complain that universities operate on extended time lines and have little regard for the urgent deadline of business. Geographic limits on knowledge spillover, is a third issue suggested to hamper R&D cooperation with universities. Mansfield and Lee (1996) find that firms prefer to work with local university researchers, usually within 100 miles from the firm's R&D laboratories, though differences are identified between basic research and applied research.

Patent information is often assumed to be a useful indicator on the importance of the university/industry link. When Narin et al (1997) reports a threefold increase in the number of academic citations in industrial patents in the US through the mid 1990s it could be seen as strong evidence on growing integration between academic and private knowledge. Other works, however, give conflicting results on this issue. When assessing the commercial value of academic output measured as knowledge flow, Klevorick et al (1995) finds the direct impact of recent university research to be small in most industries relative to other sources of information or scientific knowledge.[ii]

The relatively few studies trying to evaluate the elasticity of firms' research productivity with respect to academic knowledge or the economic impact of university collaboration have generally shown positive results. Estimating the elasticity of corporate patenting with respect to university results (Jaffe 1989) find a strong association. In his empirical study, Mansfield (1998) finds that industrial innovations that could not have been developed (without a delay of a year or more) in the absence of academic research accounted for over 5 percent of total sales in major firms in the U.S. in 1994. In addition, Mansfield (1998) estimates total cost savings by major firms due to new processes first commercialized between 1991 and 1994 to 2 percent of total 1994 costs. For the nine year period 1986-1994 he finds that 15 percent of the product innovations and 11 percent of the process innovations in seven U.S. industries [iii] could not have been developed, without substantial delay, without spillover from the academic research.

Interestingly, Mansfield (1998) also reports a significant decrease in the average time lag between the academic research results and the first commercial introduction of new products and processes based on these results. A plausible interpretation is that firms that are quick to utilize the findings of recent academic research could obtain considerable economic benefits. Mansfield (1997) discusses a quite different implication of the decreased time lag between academic research: the risk of a shift from patient and time consuming basic research toward more applied and short-term work.[iv]

A major problem with the assessment studies reviewed in this section, and most evaluation of the university-industry link in the literature as well, is that they suffer from *selectivity bias* problem. The analyses are based on selected groups and therefore we cannot use them for generalization. Those firms participating in university partnership are likely to be those with the largest innovation propensity, meaning that they will have more incentives to invest in R&D and more ability to produce innovation output, than those not collaborating.

To estimate the real effect of academic knowledge on firms' innovative performance it would be necessary to address questions such as: How much would the collaborating firms invest in R&D had they not participated in innovation projects with universities? What would the firms' innovation output have been without complementary knowledge from universities? In fact, only a few university-industry studies attempts to model this counterfactual situation.

3. THE DATA

The data used in this study is obtained from the Community Innovation Survey III for Sweden. The survey was collected in 2001 and it covers the period 1998 to 2000. It covers both the manufacturing sector and business services. The *original sample* contains 2,114 firm level observations. From this we have dropped firms belonging to industry classes with low R&D

activities. (See Table 1). They are Nace 36-41 (142 observations) and Nace 51-67 (468 observations). The elimination of low R&D sectors resulted in a *basic sample* consisting of 1, 504 observations.

Next, to create our *used sample*, we removed all firms with no R&D or other innovation expenditures in year 2002 (636 observations). In addition to this, all firms were dropped from the sample that had R&D and other innovation expenditures exceeding sales with 300% or more (78 observations). The sample used consists of 790 observed firms, divided into 205 firms (25%) that have innovation cooperation with universities, and a control group of 585 innovative firms where no collaboration can be observed.

In the last step we create a matching sample consisting of 196 firms collaborating with universities and a selected control group with two nearest neighbours (twin-firms) for each collaborated firms. The twin-firms are R&D firms not collaborating with universities.

Looking at different industry classes Table 2 shows the share of collaborating firms ranging from 8 percent to 40 percent among the 13 industry classes studied. The highest percentage can be found in basic and fabricated metal (40%), and an aggregate consisting of telecom, computers and precision instrument (38%) and business services (35%). The share of collaborators is lowest within textile, apparel and leather (8%) and publishing (10%).

Table 3 reports a size dimension of the pattern of industry-university links. Considering the smallest innovative firms in our sample (10-24 employees), it is shown that only one in 6 firms are utilizing universities as a cooperation partner. The proportion is about the same within size classes of 25-49 employees, and 50-99 employees respectively. In the size class of 100-199 employees one in four firms collaborate and the share increases to one in three firms in the size class of 200-499 employees. Among firms with 500 or more employees the cooperation share is over 60 percent.

The three performance variables investigated are R&D and other innovation input expenditures per employee, innovation sales (sales income in year 2000 from innovation launched on the market during the period 1998-2000) as a share of total sales, and the propensity to apply for innovation.

The hypothesis to be tested is whether academic research has an impact on both innovation input and innovation output ceteris paribus, or everything else equal. In order to do this we use 13 control variables. The control variables are: public R&D support, valid patents as an attempt to capture the R&D-history of the firms or their stock of knowledge, a demand-pull variable created from information on the firms' innovation strategy, two variables describing financial or skilled problem as obstacles to innovation, group membership, if the firm is a multinational, and if the firm is controlled by foreign owners, export activities, three variables capturing the firms most significant market (local, national or global) and number of employees. To account for industrial heterogeneity among the observed firms, 13 industry dummy variables are included.

Table 4 introduces the analytical part of the paper. It gives the mean values and standard error for the performance variables (endogenous variables) and for the determinant variables. Exploiting this information we conduct a two-sample t test on equality. A significant value of the t-statistic suggests that the mean value is significantly different between collaborating and non-collaborating firms. Not surprisingly the evidence is unanimous on the collaborating firms as a selective group. In particular they have higher R&D expenditures as a share of sales (16% vs. 5%), higher innovation sales as a share of sales (24% vs. 15%) and a larger probability to apply for patent (67% vs. 27%). We also see that the collaborating firms are larger, they are more commonly foreign owned and have a stronger orientation on the global market. In addition a significantly larger share of the collaborating firms receive R&D support for innovation, possess valid patents and have subsidiaries in different countries.

The descriptive statistics and the t-tests indicate that an analysis of the importance of knowledge diffusion between universities and firms with non collaborators as a control group would lead to biased results due to the systematic differences between the groups. The next section will discuss methods to handle this problem.

4. METHODOLOGY

Our fundamental research issue is to measure the effect of academic research on firms' innovation performance. A methodological challenge is what is discussed in the statistics literature as the lack of *counterfactual evidence*; we do not know what would have happened with the firms' innovation performance in the absence of university collaboration. (For a detailed discussion on the *problem with counterfactual evidence in assessment analyses,* see Holland 1986). Following the literature for assessing the outcome of particular treatment effects, we will use the outcomes on noncollaborators to estimate what collaborators would have experienced had they not participated in joint research projects with universities. A first crossroad in this literature goes between non-experimental and experimental methods. In a non-experimental evaluation, as pointed out by Smith (2002): "statistical techniques are used to adjust the outcomes of persons who choose to participate to look like what the participant would have experienced, had they not participated. In contrast, an experiment directly produces the counterfactual of interest by forcing some potential participants not to participate."

The present study considers data on nonexperimental comparison groups of firms. The estimator we apply is a semi-parametric method of matching. More conventional methods in causality studies are parametric estimators such as instrumental variable estimators, the two-step estimator of Heckman (1979) or difference-in-difference. The particular estimator choice is motivated by the data as well as the research question.

Heckman *et al* (1998) notes that pioneering matching studies were made by Fecher (1860). Traditional matching estimators pair each collaborator with an observable similar non-collaborator and interpret the difference in their outcomes as the effect of collaboration. However, when there are many control variables, it is difficult to determine along which variables (or more correctly cells) to match a unit. Moreover, for some values of X among participants, close matches will perhaps not be found among comparison members. A solution to this problem is the "propensity score" matching developed by Rosenbaum and Rubin (1983). Smith (2002) notices that this problem is reduced, but not eliminated when matching on a scalar P(X) compare to a vector X. Propensity score matching, rather than using a vector of observed characteristics X, matches participants and nonparticipants based on their estimated probability of participation P(X). Rosenbaum and Rubin (1983) show that when matching on X produces consistent estimates, matching on P(X) has the same effect.

The propensity score matching estimation methods have become increasingly popular in medical trials and in the evaluation of economic policy interventions (Becker and Ichino, 2003). To our knowledge, this is one of the first attempts to evaluate public innovation policy through knowledge transmission between university and industry by matching methods.

Some important conditions apply to the use of matching estimators. We mention one highly relevant here. (Heckman, Ichimura and Todd, 1997, Heckman, Ichimura, Smith and Todd, 1998, Heckman, Ichimura and Todd, 1998, Smith and Todd, 2004, and Smith, 2000, provide critical discussions on strengths and weakness of matching estimators). Matching, whether on X or on P(X), relies on a conditional independence assumption. In our case, the assumption states that once we condition on P(X), participation in university collaboration is independent of the outcome in the non-collaboration state. This requires that all variables that affect both collaboration and outcomes in the absence of collaboration be included in the matching. As emphasised by Smith (2002), making this conditional independence assumption plausible in practice requires access to very rich data. It also requires careful thought, guided by economic theory, about what variables do and do not affect participation and outcomes. [v]However, in the present study, as well as in most other evaluation analyses, no robust theoretical guidance exists as to how to choose the conditioning X-variables. In addition, Smith and Tood (2004) suggest that evaluation estimators are only found to work well when they are applied to comparison group data satisfying the following criteria: (a) the same data sources are used for participants and non participants, (b) the data contain a rich set of variables relevant to modelling the participating decision, and (c) participants and nonparticipants reside in the same market.

Although the assessment estimators discussed by Smith and Todd concern labor-market programs, we assume that the criteria can be generalized to other markets. If so, we conclude that the

Community Innovation Survey information fulfil criteria (a) and at least partly (c)[1]. In addition we find support for (b) in Almus and Czarnitzki (2003), who argue that the CIS-data has comprehensive information on the firms for identifying a similar control observation for every treated firm.

The matching estimation procedure we are using can be described as follows: Initially a probit model is applied in order to estimate the propensity score. The dependent variable is the decision whether to collaborate. The vector of determinant variables contains the set of characteristics (13 explanatory variables and 13 dummies for industry classifications) that potentially influence the probability of university-firm cooperation. After the probit equation and determinants to collaborating is estimated, a mono-dimensional propensity score is calculated for every observation. This measure is used to find counterparts for every collaborating firm. In the next step we are conducting a nonparametric matching approach based on the propensity score. Here the procedure is as follows: First the observations are separated with respect to their status of university partnering. Second, a firm *i* that is cooperating is selected. Third, we utilize the propensity score and calculate a proper measure of distance to find the nearest two neighbors or *matched* firms for every collaborating firm. The matching procedure is regarded successful if the means of the probability to collaborate with universities and the determinants of partnering in both groups do not differ significantly. Finally the impact of research cooperation for innovation purposes is evaluated by comparing the average of our three performance measures between the groups of collaborating and non-collaborating firms.

We now proceed to the more formal notation of the estimation approach applied in this study. Following Heckman, Ichimura, Smith and Todd (1998)[vi], we denote by Y_1 the outcome conditional on collaboration on innovation with universities and Y_0 the outcome on non-collaboration. (See also Fisher (1935), Roy (1951) and Quandt (1972) Further, let U=1 signify participation in cooperation research with universities, U=0 otherwise. Since we only observe Y_0 or Y_1 for each firm,

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but never both, without statistical techniques we cannot compute the causal effect of university collaboration Y_1-Y_0 for any firm.

The method of matching applied is aimed at identifying non-collaborating firms with the same probability to partner with universities as the actual collaborators. That is, conditional on some X, Y_0 is independent of U:

$$Y_0 \perp U \mid X \qquad (1)$$

where "⊥" denotes independence and the variables to the right of "|" are the conditioning variables. This assumption generate a control group with the following characterisations: conditional on X, the distribution of Y_0 given U=1 is the same as the distribution of Y_0 given U=0. Hence, considering mean value, the implication of (1) is

$$E(Y_0 \mid X, U=1) = E(Y_0 \mid X, U=0) \qquad (2)$$

Rosenbaum and Rubin (1983) prove that given that the Y_0 outcomes are independent of collaboration participation conditional on X, they are also independent of participation conditional on the propensity score, Pr(U=1|X). The important implication is the following: provided that we can apply a probit model and parametrically estimate the conditional probability of participating in a joint research program, the multi-dimensionality of the matching problem is reduced by matching on a mono-dimensional (scalar) propensity score. The formal notion for the applied probit model is

$$\Pr\{U_i=1 \mid X_i\} = F(h(X_i)) \qquad (3)$$

where F(.) is the normal or logistic cumulative distribution and $h(X_i)$ is a function of covariates with linear and higher terms.

Traditional propensity score matching methods pair each participant, with a single non- participant (a "twin"). Nearest neighbours may be far apart. For that reason a metric criterion is imposed to ensure that the match is close enough:

$$C(X_i) = \min_j |X_i - X_j|,\ i \in \{U=1\}\ j \in \{U=0\}. \qquad (4)$$

Smith (2000) points out that nearest neighbour matching can be operationalized with more than one nearest neighbour and with and without replacement, where "with replacement" means that a given nonparticipant observation can form the counterfactual for more than one participant. In this paper we use the two nearest neighbours. The main advantage of a larger number of neighbours, compared to pairwise matching, is a reduction in the variance of the estimators (Smith and Todd, 2004). Moreover, this method admits to drop observations with not enough close neighbours. In the present study, 4 per cent (9 firms) of observed collaborating firms are dropped from the matching procedure.

A successful matching process is defined by a large extent of overlapping of the propensity scores for collaborators and non-collaborators. This is illustrated by figure 1 and figure 2 in the paper. The average of the difference in innovation performance between university collaborators and the control group of non-collaborating twin firms will provide an unbiased estimator of the importance of the university/firm link. Formally this can be expressed as:

$$\hat{\theta} = \frac{1}{N^1}\left(\sum_{i=1}^{N^1} Y_1 - \sum_{j=1}^{N^1} Y_0\right), \ i \in \{U=1\}, \ j \in \{U=0\} \qquad (5)$$

5. THE RESULTS

The first phase of the assessment approach is to choose the determinants of firms' R&D collaboration with universities. In order to facilitate the interpretation of the probit estimate, the marginal effects are given in the right part of Table 5. The point estimates are the marginal effect of marginal changes of the determinant variables. Note that the marginal for a dummy variable is the discrete change from 0 to 1.

Using the model formulated in equation (4) in Section 4, we find a strong association between the likelihood of receiving governmental R&D subsidies and university collaboration. Our interpretation is as follows: The most innovative are those who have the largest possibility to get their funding application awarded, and a broad innovation network including universities is a prerequisite for a high level of innovativeness. A complementary interpretation is that collaboration between industry and university can be a requirement for some funding programs.

In the probit estimation the possession of patents has a significant and positive influence on the probability to cooperate with universities. In line with Romer's model of knowledge-driven growth we assume that the holding of patent indicate the prior stock of knowledge accumulated by the firm and that the firm has a history of being engaged in R&D with successful results.

A highly significant and positive association is found between the demand-pull variable and the probability of cooperating on innovation with universities. We are using this composite variable as an indicator of whether or not the firms' innovation strategy is a result of market demand.

Not surprisingly membership of a multinational group is closely associated with the probability of cooperating with universities. In particular Swedish owned multinational firms have both a higher R&D intensity than other firms and a more frequent cooperation with universities. Unlike membership of a multinational company, the membership of a group *per se* has no positive influence on the industry-university link.

Seemingly contradictory, "financial constraints" as an obstacle to innovation is found to be positively associated with university collaboration. The plausible interpretation is that most innovative firms also are those who have many good ideas, and due to financial constraints only the very promising ones survive in the internal competition for funding. Some of the survivors might end up in a joint project with universities. It turns out that three industries (telecom- only at the 10% level of significance-, instruments and business service) have ceteris paribus a higher possibility to collaborate on innovation with universities.

The next phase in the estimation procedure is to calculate the unbounded propensity scores for pairwise matching. Starting with the prematch situation, Figure 1 shows the average frequency distribution of the propensity scores for 205 firms collaborating with universities and the potential control group of 585 non-collaborating firms. The two graphs do not overlap and the divergence between the groups is obvious. The situation after the matching process is depicted in Figure 2.

Here 9 observations on collaborators have been removed since no acceptable match has been made with these firms. For the remaining 196 collaborators and the nearest two neighbours Figure 2 presents the average frequency distributions. We see that the both graphs overlap to a great extent. Hence, the similarity of distributions of the X-variables in both groups fulfils the condition on a successful matching process.

The causal effect of university/industry collaboration is investigated by the average innovation performance between the groups of collaborating and non-collaborating twin-firms, that is $Y_1 - Y_{0.}$ The unbiased estimator of the causal effect is the difference between the means of the groups. The results presented in Table 6 shows that university collaboration has on average a positive impact on the firm specific innovation performance if the causal effect is significantly greater than 0. The evaluation is carried out by means of a two-tailed t-test. The first column displays the mean values for the collaborators, and the second column shows the mean values for the counterfactual sub-sample of non-collaborating firms. Starting with the determinant variables we first observe that there is no significant difference in the probability of collaborating with universities on innovation between the two groups of firms when the 13 control variables and the 13 industry dummies are considered. The only exception is one industry class (wood and wood products, pulp, paper, and paper products); however, it is significantly different from 0 only at the 10% level of significance. More essentially, the estimated probability of collaborating on innovation is exactly the same for the actual collaborators and the firms in the selected control group.

However, all three performance-variables: R&D intensity, innovation sales and the propensity to apply for patents differ significantly between the two groups. Given the results, the interpretation is as follows. After the matching process, controlling for the differences between collaborating and non-collaborating firms, knowledge diffusion from academic research contribute to an increase in the total R&D efforts of private firms as well as their R&D productivity in terms of innovation sales and patent application.

6. SUMMARY

The scientific innovation system is supposed to be a key element in the national innovation system and perhaps the most forceful public policy instrument for stimulating innovation in modern economies: In Sweden, for instance, approximately 70% of the governmental R&D support goes to universities, and university research corresponds to 20% of total research. See Appendix A.

The fundamental research problem in this paper was to measure the effect of academic research on firms' innovation performance. We addressed this issue by exploiting the internationally harmonized Community Innovation Survey (CIS) data and matching estimators for average treatment effects. The CIS-survey provided information about the industry/university link reported by 790 R&D investing firms with 10 employees or more. Within the group of innovative firms approximately 25 percent were conducting R&D collaboration with universities.

The specific research question was the effect of academic knowledge on three different categories of innovation performance: R&D intensity, patent application and innovation sales. Empirically the study attempted to assess how much innovation input and how much innovation output the university collaborating firms would have had without working with universities. The methodological challenge was that the firms participating in university partnership were likely to be those with the largest propensity for high innovation performance, meaning that they will have greater incentives to invest in R&D, and have a greater ability to produce innovation output, than those not collaborating.

In the first phase of the assessment approach, the paper found six variables that had a significant influence on the likelihood of firms' innovation collaboration with universities. They were receiving governmental R&D subsidies, the possession of patents as a proxy for firms' R&D history, demand pull variable aimed at capturing some of the characteristics of the innovations, membership of a multinational group, an indicator variable - financial constraints - on main obstacles to innovation and finally, membership of a domestically owned non-multinational group (negative influence for the latter variable and positive influence for the five former variables). It turned out that three industries (telecom, instruments and business services) have a higher possibility to collaborate on innovation with universities than other industries.

After having parametrically estimated the likelihood of participating in joint research projects with universities, a propensity score method was introduced in order to account for potential selection bias problems. The study then matched each collaborating firm with a pair of nearest non-collaborating firms that have the same probability to partner with universities. Finally the impact of research cooperation for innovation purposes was evaluated by comparing the average of three performance measures between the groups of collaborating and non-collaborating twin-firms. The average of these differences provided an unbiased estimator of the importance of knowledge transmission between university and industry.

The study was able to establish that university/industry collaboration had a significant and positive influence on three measures of innovative activity. First, it was found that the average R&D firm that cooperated on innovation with universities spend more money on R&D compared to an almost identical R&D firm (nearest neighbours) witch had no collaboration with academic researchers. Second, the results showed that the collaborating firms have a larger propensity to apply for patents than other R&D firms. Finally, it was shown that income from new product sales is considerable greater for a firm that have joint research projects with universities than for a non-collaborating twin firm.

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TABLES AND FIGURES

Table 1:

Data treatment

Original sample	
Observed firms in the original sample	**2,114**
Firms belonging to Industry classes Nace 36- Nace 41	-142
Firms belonging Industry classes Nace 51-Nace 67	-468
Basic sample	**1, 504**
Firms with no R&D or other innovation expenditures	-636
Firms with R&D and other innovation expenditures more than three larger than sales	- 78
Used sample	
Firms with positive innovation expenditures; used sample	**790**
Of which	
Group 1: Innovative firms collaborating with universities	205
Group2: Non collaborating innovative firms in potential control group	585
Matching sample	
Group1: Innovative firms collaborating with universities	196
Group2: Non collaborating innovative firms in selected control group	392

Table 2.

Panel A: Distribution of firms by industrial sector and cooperation on innovation with universities. Only firms with report R&D and other innovation expenditures.

Nace 2	Industrial sector	Observations	Collaborating with universities	Collaborating Share %
15-16	Food, beverages and tobacco	40	6	15.0
17-19	Textile, apparel and leather	36	3	8.3
20-21	Wood and wood products, pulp, paper and paper products	69	19	27.5
22	Publishing	38	4	10.5
23-25	Chemical industry, rubber and plastic products	98	24	24.5
26	Other non-metallic mineral products	26	6	23.
27	Basic metal and fabricated metal	30	12	40.0
28	Fabricated metal products except machinery and equipment	44	7	15.9
29	Machinery and equipment	81	24	29.6
31	Electrical machinery and apparatus	39	7	17.9
30, 32-33	Office machinery and computers, tele products, precision instruments etc.	87	33	37.9
34-35	Motor vehicles and trailers, and other transport equipment	56	9	16.1
72-74	Computers and related activities, R&D, Other business activities	146	51	34.9
Total	**Number of firms**	**790**	**205**	**25.9**

Note: Nace is a system for classification of industries.

Table 3:
Distribution of firms collaborating on innovation with universities by size-classes.

Firm size, Employment	Total	Collaborate with universities	Collaborating share %
10-24	228	36	15.8
25-49	143	19	13.3
50-99	103	19	18.4
100-199	81	19	23.5
200-499	132	48	36.4
500-	103	64	62.1
Total	**790**	**205**	**25.9**

Table 4.

Descriptive statistics of the characteristics of the firms and two sample test on unequality of mean. Firms collaborating in innovation with universities and a potential control group.

	Collaborating Firms N=205		Potential control group Non-Collaborating Firms N=585		Two- sample t test on unequal variances
	Mean	Std Err	Mean	Std Err	
Endogenous variables					
Research exp/sales[1]	0.164	0.019	0.051	0.004	-5.49***
Innovation sales/sales[1]	0.240	0.019	0.148	0.008	-4.29***
Patent applications	0.673	0.032	0.271	0.018	-10.66***
Determinat variables					
Univ.collaboration, *predicted*	0.474	0.017	0.183	0.007	-15.08***
Public R&D subsidies	0.375	0.033	0.133	0.014	-6.60***
R&D stock; Valid patents	0.697	0.032	0.341	0.019	-9.44***
Demand pull	0.541	0.034	0.441	0.020	-2.48**
Financial constraints	0.185	0.027	0.111	0.013	-2.46**
Skill constraints	0.160	0.025	0.148	0.014	-0.41
Multinational firm	0.497	0.035	0.249	0.017	-6.30***
Group membership	0.721	0.031	0.632	0.019	-2.40**
Export activities	0.917	0.019	0.853	0.014	-2.37**
Employment, log	5.237	0.119	4.056	0.055	-8.95***
Mainly national markets	0.302	0.032	0.429	0.020	3.32***
Mainly global. markets	0.629	0.033	0.418	0.020	-5.32***
IC2	0.014	0.008	0.056	0.009	3.28**
IC3	0.092	0.020	0.085	0.011	-0.30
IC4	0.019	0.009	0.058	0.009	2.81**
IC5	0.117	0.022	0.126	0.013	0.35
IC6	0.029	0.011	0.034	0.007	0.35
IC7	0.058	0.016	0.030	0.007	-1.54
IC8	0.034	0.012	0.063	0.010	1.79*
IC9	0.116	0.022	0.097	0.012	-0.76
IC10	0.034	0.012	0.054	0.009	1.29
IC11	0.160	0.025	0.092	0.011	-2.41**
IC12	0.043	0.014	0.080	0.011	1.99**
IC13	0.248	0.030	0.162	0.015	-2.54**

Notes: (1) As a share of sales. Significant at the <1% (***), <5%(**) and <10% level of significance.
IC1: Food, beverages and tobacco, IC2 : Food, beverages and tobacco, IC 3: Wood and wood products, pulp, paper and paper products, IC 4: Publishing, IC 5: Chemical industry, rubber and plastic products, IC 6: Other non-metallic mineral products, IC 7: Basic metal and fabricated metal, IC 8: Fabricated metal products except machinery and equipment, IC 9: Machinery and equipment, IC 10: Electrical machinery and apparatus, IC 11: Office machinery and computers, telecom products, precision instruments etc , IC 12: Motor vehicles and trailers, and other transport equipment, IC 13: Computers and related activities, R&D, Other business activities

Table 5:
Probit model. Probability of collaborating on innovation with universities.
Number of observations: 790

			Marginal effect	
Variable	Coefficient	t-statistic	dy/dx	t-statistic
Public R&D subsidies	0.776***	5.67	0.253***	5.17
R&D stock (Valid patents.)	0.580***	4.35	0.166***	4.29
Demand pull	0.283**	2.11	0.067**	2.11
Obstacles to innovation: Financial constraints	0.404**	2.46	0.124**	2.25
Obstacles to innovation: Skill constraints	-0.048	-0.31	-0.013	-0.31
Multinational firm	0.440***	3.10	0.131***	2.95
Group membership	-0.411***	-2.69	-0.120	-2.59
Export activities	-0.180	-0.91	-0.053	-0.86
Employment, log	0.151	0.66	0.042	0.67
$Employment^2$, log	0.013	0.62	0.003	0.62
Mainly national markets	0.198	0.93	0.056	0.91
Mainly global. markets	0.346	1.53	0.097	0.063
IC2	-0.311	-0.66	-0.076	-0.77
IC3	0.316	0.91	0.097	0.84
IC4	0.546	1.28	0.180	1.14
IC5	0.381	1.12	0.118	1.02
IC6	0.455	1.10	0.148	0.98
IC7	0.518	1.27	0.171	1.13
IC8	0.222	0.57	0.067	0.53
IC9	0.233	0.67	0.070	0.63
IC10	0.116	0.30	0.034	0.29
IC11	0.769**	2.25	0.260**	2.01
IC12	-0.235	-0.61	-0.060	-0.68
IC13	0.936***	2.94	0.313***	2.69

Notes: IC1: Food, beverages and tobacco, IC2 : Food, beverages and tobacco, IC 3: Wood and wood products, pulp, paper and paper products, IC 4: Publishing, IC 5: Chemical industry, rubber and plastic products, IC 6: Other non-metallic mineral products, IC 7: Basic metal and fabricated metal, IC 8: Fabricated metal products except machinery and equipment, IC 9: Machinery and equipment, IC 10: Electrical machinery and apparatus, IC 11: Office machinery and computers, telecom products, precision instruments etc , IC 12: Motor vehicles and trailers, and other transport equipment, IC 13: Computers and related activities, R&D, Other business activities

Fig 1

Estimated propensity score, firm collaborating with universities and a potential control group of non-collaborating innovative firms.

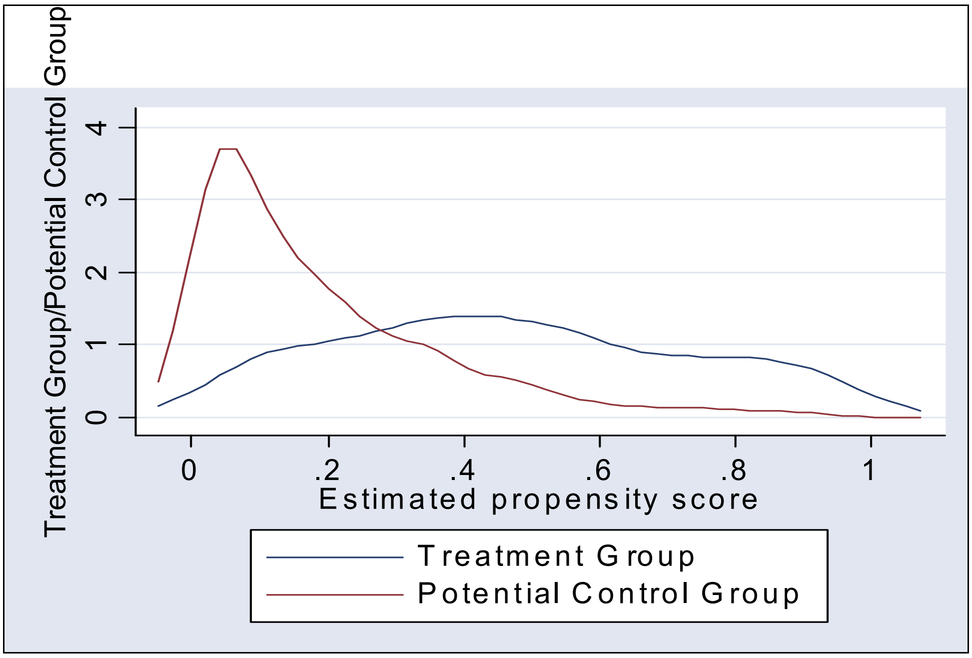
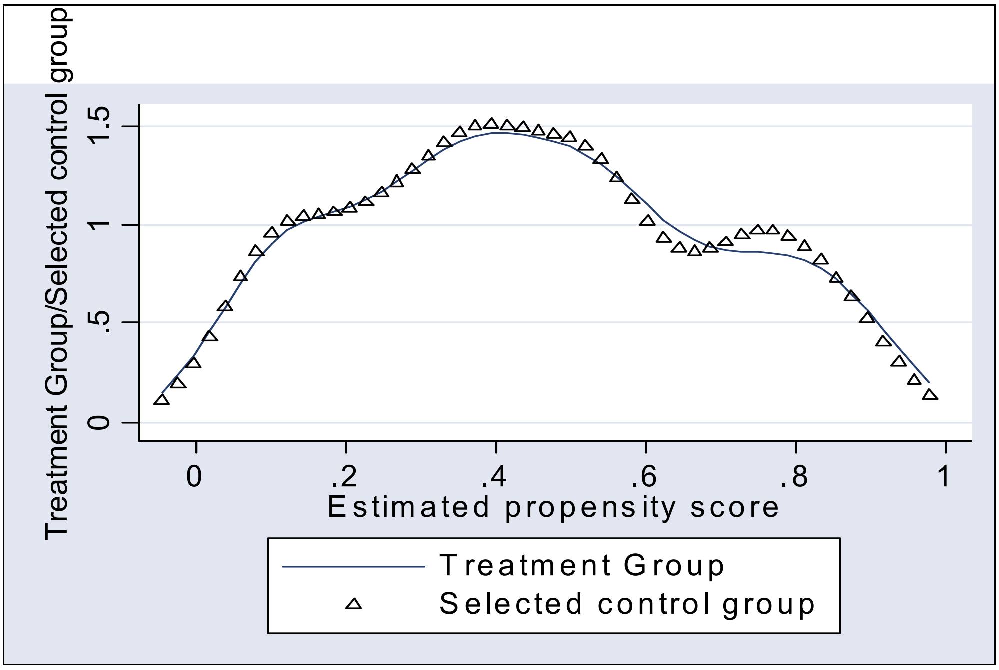


Fig 2

Estimated propensity score, firm collaborating with universities and the selected control group of non-collaborating innovative firms.



The propensity score is the conditional probability of collaborating with universities (U) given the determinant (X) variables:

$$P(X) \equiv \Pr\{U=1 \mid X\} = E\{U \mid X\}$$

Table 6.

The estimates of the two-sample test on unequality of mean after the nearest neighbour matching process. Firms collaborating on innovation with universities and the selected control group.

	Collaborating Firms N=196		Selected control group Non-Collaborating Firms N=392		Two- sample t test on unequal variances
	Mean	Std Err	Mean	Std Err	
Endogenous variables					
Research exp/sales[1]	0.168	0.020	0.063	0.008	-4.44***
Innovation sales/sales[1]	0.232	0.019	0.125	0.009	-4.96***
Patent applications	0.658	0.033	0.502	0.025	-3.67***
Determinat variables					
Univ.collaboration, *predicted*	0.452	0.017	0.449	0.011	-0.11
Public R&D subsidies	0.352	0.034	0.390	0.024	0.90
R&D stock; Valid patents	0.683	0.033	0.630	0.024	-1.29
Demand pull	0.530	0.035	0.459	0.025	-1.63
Financial constraints	0.183	0.027	0.150	0.018	-1.00
Skill constraints	0.163	0.026	0.140	0.017	-0.72
Multinational firm	0.479	0.035	0.489	0.025	0.232
Group membership	0.709	0.032	0.709	0.022	0.00
Export activities	0.912	0.020	0.931	0.012	0.074
Employment, log	5.102	0.115	5.137	0.082	0.25
Mainly national markets	0.316	0.033	0.323	0.0230	0.18
Mainly global. markets	0.612	0.034	0.602	0.024	-0.23
IC2	0.015	0.008	0.002	0.002	-1.39
IC3	0.140	0.017	0.091	0.020	1.78*
IC4	0.020	0.010	0.012	0.005	-0.65
IC5	0.122	0.023	0.127	0.016	0.17
IC6	0.030	0.012	0.033	0.009	0.16
IC7	0.056	0.016	0.056	0.011	0.00
IC8	0.035	0.013	0.038	0.009	0.15
IC9	0.117	0.023	0.094	0.014	-0.83
IC10	0.035	0.013	0.022	0.007	-0.83
IC11	0.147	0.025	0.150	0.018	0.08
IC12	0.040	0.014	0.030	0.008	-0.61
IC13	0.255	0.031	0.250	0.021	-0.13

Notes: (1) As a share of sales. Significant at the <1% (***), <5%(**) and <10% level of significance.
IC1: Food, beverages and tobacco, IC2 : Food, beverages and tobacco, IC 3: Wood and wood products, pulp, paper and paper products, IC 4: Publishing, IC 5: Chemical industry, rubber and plastic products, IC 6: Other non-metallic mineral products, IC 7: Basic metal and fabricated metal, IC 8: Fabricated metal products except machinery and equipment, IC 9: Machinery and equipment, IC 10: Electrical machinery and apparatus, IC 11: Office machinery and computers, telecom products, precision instruments etc , IC 12: Motor vehicles and trailers, and other transport equipment, IC 13: Computers and related activities, R&D, Other business activities

Appendix. A

Financing R&D and R&D investors in Sweden in 2001

	R&D investors ⇓	⇓	⇓	⇓	
Financing R&D	Business Sector	Universities	Government	Private non profit R&D	Total R&D financing
National sources					
Business sector	70.8	1.1	0.1	-	**71.9**
Universities	-	0.3	-	-	**0.3**
Government	4.6	14.9	2.6	0.1	**22.2**
Private non profit R&D	-	2.2	-	-	**2.2**
Foreign sources	-	-	-	-	-
Business sector	2.0	0.3	-	-	**2.3**
EU	0.3	0.5	-	-	**0.8**
Other	-	0.2	0.1	-	**0.3**
Total R&D investing	**77,6**	**19,4**	**2,8**	**0,1**	**100,0**

Source: Statistics Sweden

NOTES

[i] Contrary to the 'linear model' where 'fundamental research by university scientist leads to a discovery, the practical importance of which is recognised by business firm, which collaborate with the university scientist in order to exploit it' (Pavitt 2003), the works by Pavitt and others explore issues such as the importance of increasing specialization and complexity, organizational behaviour, and difficulties of matching technological opportunities with market needs.

[ii] Cohen, Nelson and Walch (2003) stress that the Klevorick et al finding is not necessarily inconsistent with other studies reporting the impact from university research to be substantial.

[iii] The industries are Drugs and medical products (31% of the product innovations and 11% of the process innovations were based on recent academic research), Instruments (19 % of products and 20% of processes), Information processing (19% and 16% respectively), Chemical (9 % and 8% respectively), Metals (8% and 15% respectively), Machinery (8% and 5% respectively) and Electrical (5% and 3% respectively).

[iv] Salter et al (2000) are discussing the potential for increased commercial exploitation of university knowledge, but they are questioning the importance of various kinds of "technology transfer" programs since the underlying assumption often is the much discredited linear model of innovation

[v] Partly at variance with Deheija and Wahba (1999), Heckman, *et al.*(1998), Heckman, Ichimura and Todd (1999), Lechner (2002) and Smith and Todd (2004) find that the matching estimates can be quite sensitive to the variables needed to construct P(X).

[vi] See also Fisher (1935), Roy (1951) and Quandt (1972)

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