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# Arbeitspapiere/ Working Papers

Spyros Arvanitis, Nora Sydow and Martin Wörter

Is There Any Impact of  
University-Industry Knowledge Transfer  
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# **Is There Any Impact of University-Industry Knowledge Transfer on the Performance of Private Enterprises? – An Empirical Analysis Based on Swiss Firm Data\***

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## **Abstract**

This study investigates the impacts of a palette of Knowledge and Technology Transfer (KTT) activities (general information, educational and research activities, activities related with technical infrastructure, and consulting) (a) on several innovation indicators ( $a_1$ ) in the framework of an innovation equation with variables of endogenized KTT activities (overall activities, specific *forms* of activities) as additional determinants of innovation, and ( $a_2$ ) based on a matched-pairs analysis for several *forms* of KTT activities; (b) on labour productivity in the framework of a production function with endogenized KTT activities as an additional production factor. The data used in the study were collected by means of a survey of Swiss enterprises that took place at the beginning of 2005. We found that KTT activities improve the innovation performance of firms both in terms of R&D intensity and sales of innovative products. The positive effect of overall KTT activities can be traced back mainly to *research* and *educational* activities. This could be shown by several methods: the innovation equation approach with endogenized KTT variable as well as three matching methods. Further, KTT activities seem to exercise a positive influence on labour productivity both through a direct effect as well as through an indirect effect by raising the elasticity of R&D intensity with respect to labour productivity.

## 1. Introduction and plan of the study

The topic “knowledge and technology transfer” has spurred great interest among academic researchers and policy-makers since many years. The interaction of business sector and science institutions through the exchange of knowledge and technology has become a central concern not only for applied economics but also for economic policy in the last years.<sup>1</sup> In a knowledge economy, science is exerting an increasingly large influence on innovation, especially in fast-growing knowledge-intensive industries. Thus, the extent and intensity of industry-science relationships is considered to be a major factor contributing to high innovation performance, either at the firm-level, industry-level or country-level (see OECD 2002).

Experiences of the USA suggest that research excellence of publicly financed science institutions and commercialization of research results by private enterprises are compatible goals which reinforce each other, if both sides adopt a long-term perspective (as e.g. in aerospace, computers and telecommunication). However, there is accumulating evidence that many OECD countries are lagging behind in terms of KTT. The interface between business firms and science institutions, especially universities, has to be improved and as a consequence knowledge and technology transfer activities have to be intensified. Also in Switzerland it is asserted by many observers that the industry-science interface is far from being satisfactory (see e.g. Zinkl and Huber 2003).

Particularly in the view of policy-makers an intensive exchange of knowledge is not a goal by itself but a means to seizable economic benefits. Measuring the impacts of transferred knowledge and technology is a methodological challenge for economists because the impacts are usually numerous and they are almost always difficult to separate from other parts of firm activities. In many instances, determining the meaning of knowledge transfer “effectiveness” proves to be a difficult task.<sup>2</sup>

This study investigates the impacts of a palette of Knowledge and Technology Transfer (KTT) activities (general information, educational and research activities, activities related with technical infrastructure, and consulting) (a) on several innovation indicators ( $a_1$ ) in the framework of an innovation equation with variables for endogenized KTT activities (overall activities, specific *forms* of activities) as additional determinants of innovation, and ( $a_2$ ) based on a matched-pairs analysis for several *forms* of KTT activities; (b) on labour productivity in the framework of a production function with endogenized KTT activities as an additional

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<sup>1</sup> *Economics*: see e.g. volume 34, issue 3 of *Research Policy* of April 2005 (edited by A.N. Link and D.S. Siegel) dedicated to “University-based Technology Initiatives”; “Academic Science and Entrepreneurship” (edited by A. Jaff, J. Lerner, S. Stern and M. Thursby), forthcoming in the *Journal of Economic Behaviour and Organization*; volume 28, issue 3-4 of the *Journal of Technology Transfer* of August 2003 devoted to the “Symposium on the State of the Science and Practice of Technology Transfer”. *Policy*: see e.g. OECD (2003), OECD (2002) and OECD (1999).

<sup>2</sup> See e.g. Bozeman 2000; Georghiou and Roessner (2000) for recent reviews of the central issues related to this question; for reviews of the related econometric issues see e.g. Klette et al. (2000); Hall and Van Reenen (2000).

production factor. The data used in the study were collected by means of a survey of Swiss enterprises that took place at the beginning of 2005.

New elements of the analysis are: (a) the differentiated measurement of a wide spectrum of KTT activities covering 19 single forms of KTT activities (see table A.2 in the appendix); (b) the use of alternative methods for estimating the impact of KTT activities on innovation and economic performance (matched-pairs analysis, innovation and productivity equations); (c): the wide coverage of industries and firm size classes (manufacturing, selected service industries, construction; firms with at least 5 employees). This is the first study on this topic for Switzerland.

In section 2 we present a summary of empirical literature. Section 3 deals with the data used in this study. In section 4 we present the firms' assessment of the impact of KTT activities on their R&D activities as well as their innovation performance. In the next section we introduce a simple model of innovation performance and test the hypothesis of KTT activities correlating positively with innovation performance measured e.g. by the R&D intensity or the sales share of innovative products. In a further step we investigate in section 6 the same hypothesis in a different setting by comparing the innovation performance between firms with and firms without KTT activities with the help of matched-pairs analysis based on two different matching methods. Finally, in section 7 we construct a labour productivity model including KTT activities; we test (a) the hypothesis that this factor exercises a positive influence on productivity, and (b) that this positive effect is channelled mainly through R&D activities. Section 8 contains a summary and some conclusions.

## **2. Summary of empirical literature**

We distinguish three groups of empirical studies: (a) studies investigating the impact of KTT activities on the innovation performance at firm level based on direct measures of KTT activities emphasizing formal R&D co-operation and/or the intensive use of university knowledge as external knowledge source via publications, educational activities etc. (10 studies; table 1a); (b) studies investigating the impact of KTT activities through knowledge spillovers from universities and other public research institutions building a firm's "knowledge environment" but without information on explicit firm-university links (table 1b; 4 studies); (c): studies dealing with the impact of KTT activities on firm economic performance measured, e.g. by labour productivity, total factor productivity, sales growth and so on (table 1c; 4 studies). The main criterion for the choice of the studies reported in the tables 1a, 1b and 1c respectively was that the studies should be based on firm-level data.<sup>3</sup>

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<sup>3</sup> For recent studies on the impact of public R&D expenditure on business R&D at country or sector level see e.g. Guellec and van Pottelsberghe de la Potterie (2003) (17 OECD countries); Bönnte (2004) (West German manufacturing industries); for studies measuring the impact of public R&D expenditure on economic performance at sector or country level see e.g. Mamuneas (1999) (6 high-tech US manufacturing industries);

Most of the studies that are based on direct measures of KTT activities, primarily R&D cooperation and/or intensive use of university knowledge as an external knowledge source, found a positive effect of KTT activities on different measures of innovation performance such as the propensity of registering an innovation for patenting, the number of patents applications, the R&D intensity, the introduction of product and/or process innovations as well as the sales share of innovative products. This was particularly the case for R&D cooperation in European countries (Germany, France, Sweden). However, a study dealing with projects supported by the Advanced Technology Programme (ATP) in the USA could not find any significant effect of university participation in such projects on the generation of new technology applications. Moreover, university participation showed even a negative effect on the expectation of commercialization of new inventions.

All studies reported in table 1b are referring to the USA and are based on knowledge spillover variables. University R&D expenditures and some measure of geographic coincidence of industry and science are used to construct these spillover variables. The results demonstrated that university research exercises a significant positive influence on industry R&D. With respect to the relevance of the geographic coincidence of universities or government labs and firms the evidence from these studies is mixed.

Finally, most studies investigating the impact on economic performance found a positive effect either on labour productivity, sales productivity with respect to innovative products or sales growth. However, a study of Italian firms could not identify a positive contribution of research collaboration with universities to firm performance. A study on the technology programmes of the European Union found an improvement of economic performance of the participants of the EUREKA Framework but not of the 3<sup>rd</sup> and 4<sup>th</sup> Framework Programme for Science and Technology (FPST).

On the whole, the results are indicative but not completely comparable because some of the observed differences can be traced back to differences with respect to the sectors and industries covered in the studies, the specification of the variables of KTT activities and the nature of the investigations (cross-sectional versus longitudinal approach).

### **3. Data**

The data used in this study were collected in the course of a survey of Swiss firms that yielded data on the incidence of KTT activities, on forms, channels, motives and impediments of the KTT activities as well on some basic firm characteristics (innovation and R&D activities, investment, sales, exports, employment and employees' vocational education).<sup>4</sup> The survey was based on a (with respect to firm size) disproportionately stratified random sample of

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Guellec and van Pottelsberghe de la Potterie (2001) (16 OECD countries); Sorensen et al. (2003) (Danish manufacturing industries); Bönte (2003) (US manufacturing industries).

<sup>4</sup> Versions of the questionnaire in German, French and Italian are available in [www.kof.ethz.ch](http://www.kof.ethz.ch).



firms with at least 5 employees covering all relevant industries of the manufacturing sector, the construction sector and selected service industries (excluding industries with an expected very low propensity of KTT activities such hotels/catering, retail trade, real estate/leasing, personal services) as well as firm size classes (on the whole 25 industries and within each industry three industry-specific firm size classes with full coverage of the upper class of large firms). Valid answers were received from 2582 firms, i.e. 45.4% of the firms in the underlying sample. The response rates do not vary much across industries and size classes with a few exceptions (over-representation of wood processing, energy industry and machinery, under-representation of clothing/leather industry). The non-response analysis (based on a follow-up survey of a sample of the non-respondents) did not indicate any serious selectivity bias with respect to the incidence of KTT activities with science institutions (see table A.1 in the appendix for the structure of the used data set by industry and firm size class).. A careful examination of the data of these 2582 firms led to the exclusion of 49 cases with contradictory or non-plausible answers; there remained 2533 valid answers which were used for this analysis.

Further, we used the multiple imputations technique by Rubin (1987) to substitute for missing values in the variables due to item non-response (see Donzé 2001 for a detailed report on these imputations). The estimations were based on the mean of five imputed values for every missing value of a certain variable. To test the robustness of this procedure we estimated the innovation models (section 5) and the productivity model (section 7) also for the original data without imputed values and compared the results. This comparison showed relatively high robustness of the estimated parameters.

#### **4. Firms' assessment of the impact of KTT activities on innovation performance**

The firms were asked to report their assessment of possible impacts of KTT activities on their R&D and innovation activities respectively. Particularly, they were asked if the undertaken KTT activities contributed, first, to the *adoption* of new technology either aiming at supplementing existing know-how or developing new products and/or new processes; second, to the *generation* of new technology for new products and/or new processes; third, to an increase of human capital either through employing in R&D university graduates or through training courses, sabbaticals etc. Fourth, firms were asked if KTT activities changed the direction of their R&D activities towards more basic or applied research; fifth, if technology transfer caused a reduction of internal R&D capacity substituting for university capacity; sixth, if KT activities influenced R&D costs. Table 1 contains the percentage of firms by sector and firm size with values 4 or 5 on a five-point Likert scale (1: 'is not true'; 5: 'is true to a high extent') for assessments of various types of impact effects of KTT activities. 28.1% of KTT-active firms reported that technology transfer increased and/or upgraded *considerably* their know-how. This means that considerably more firms than those involved in research co-

operations with a university (i.e. 17.8% of KTT-active firms, see table A.2 in the appendix) benefited significantly from KTT. Obviously these benefits were realized by focusing on forms of KTT activities other than research, e.g. to educational activities, consulting etc.. 19.9% of KTT-active firms stated that the *adoption* of new technology helped them significantly to develop new products, 17.0% to develop new processes. The *generation* of new technology was less frequently the outcome of technology transfer. However, 13.5% of KTT-active firms reported a significant increase of their know-how due to new knowledge generation with the help of KTT activities, 14.9% ascertained that transfer-induced generation of new knowledge led to the development of new products, 9.4% of new processes. The recruitment of R&D personnel (15.3% of firms) and/or university-based training courses and/or sabbaticals (7.2%) contributed considerably according to firms' assessment to the increase of firms' human capital. 12.0% of firms re-oriented their R&D activities towards more applied research as a result of co-operation with universities. For 7.9% of firms KTT activities resulted to a considerable increase of R&D expenditure (complementarity effect). For only 2.8% of firms a reduction of R&D expenditure or even a reduction of internal R&D capacity (0.7%) (substitution effect) took place as a consequence of KTT activities.

In general, the above-mentioned effects were stronger in manufacturing, particularly in the high-tech sector than in the economy as a whole. For firms in knowledge-based service industries the human capital effect was considerably higher than the average of the economy. There is a tendency for smaller firms to benefit more from KTT activities than large firms with respect to the acquisition of new knowledge and the development of product and process innovations; large enterprises seem to benefit more than small ones with respect to the recruitment of R&D personnel.

In sum, the development of new products and/or new processes as well as the augmentation of human capital were according to firms' assessment the most relevant impacts of KTT activities on R&D and innovation. Thus, there is some preliminary empirical evidence that KTT activities do have a discernible positive impact on innovation performance.

## **5. Impact of KTT activities on innovation performance I: a model of innovation and technology transfer**

### *Main hypotheses, model specification and estimation method*

Our main hypothesis is that KTT activities would improve the innovation performance of firms. This KTT effect could be traced back to an increase of technological opportunities anticipated by firms due to university-industry knowledge transfer. This would include effects from a wide palette of KTT activities such as exchanging scientific and technical information, various educational activities (e.g. recruitment of R&D personnel from the universities, joint PhDs, specialized training courses), consulting, use of technical infrastructure, and, of course,

co-operation in research. The prominent role of technological opportunities as a major supply-side determinant of innovation is often emphasized in literature (see e.g. Klevorick et al. 1995; for the empirical relevance of technological opportunities for Swiss firms see Arvanitis and Hollenstein 1996). We further hypothesize that R&D activities which are closely related to knowledge generation would be stronger enhanced by the interaction with universities than activities which are near to the market launching of a new product (e.g. construction of prototypes, test production, market tests for new products, etc.).

We estimated an equation for the logarithm of R&D intensity (LRSDS; R&D expenditure divided by sales), the logarithm of the sales share of new products (LNEWS) and the logarithm of the sales share of significantly modified already existing products (LIMPRS).<sup>5</sup> The resource endowment of the firm is besides firm size the most important determinant of innovation performance taken into consideration in our model. We used as independent variables proxies for the intensity of human capital (LQUAL; logarithm of the share of employees with tertiary-level education), the intensity of physical capital (LCI: gross investment per employee), the affiliation of the firm (FOREIGN; foreign firm yes/no), and control variables for firm size (6 dummy variables) and 2-digit industry (12 dummy variables). According to standard empirical evidence from earlier studies we expected positive effects for LQUAL, LCI and the firm size. The effect of the variable FOREIGN is not a priori clear.

Finally, we included alternatively three dichotomous variables for the KTT activities: overall KTT activities yes/no (variable KTT); (b) focus to *educational* activities (variable EDUC1: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities (see table A.2 in the appendix); 0: all other KTT-active firms); (c) focus to *research* activities (variable REAS: (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities (see table A.2 in the appendix); 0: all other KTT-active firms).

However, being involved in KTT activities is not exogenous to innovation activities. Innovative firms have a tendency to acquire external knowledge, particularly science-based knowledge, to complement the in-house generated know-how. We accounted for this endogeneity effect by estimating a second version of each innovation equation, in which the variables for KTT activities (KTT; EDUC2; REAS) were instrumented. As instruments were used a series of firm characteristics which are relevant for KTT activities but do not correlate strongly with the innovation variables. These were the export intensity (logarithm of exports

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<sup>5</sup> In order to be able to calculate the logarithms of R&D intensity for firms without R&D expenditures, thus LRDS=0, we put these firms at the minimum value of R&D intensity of the firms with R&D expenditure which was 0.00001. We then calculated the logarithms of RDS and subtracted  $\log(0.0001)=-11.513$  to get 0 values for the firms without R&D expenditures. The minimum value for the sales share of new products was 0.4, thus LNEWS=-0.916, for the sales share of considerably modified already existing products 0.6, thus LIMPRS=-0.511; also in this case we performed a linear transformation of the data in order to get zero values for the firms without sales of innovative products.

as a share of sales; LEXP), the firm age (logarithm of firm age; LAGE), variables for five groups of obstacles of KTT activities constructed through a principal component factor analysis of 26 single obstacles (OBSTACLE1 to OBSTACLE5; see Arvanitis et al. 2005 for details), and dummy variables for the geographical location. In a first step we estimated probit models for KTT, EDUC1 and REAS respectively (see table A.4 in the appendix). Based on the parameters of this model we calculated values for KTT; EDUC1 and REAS respectively that were then inserted as independent variables in the innovation equations. In a second step we estimated a tobit model for each of the three innovation variables that were downward censored at 0.

### *Results*

Table 2 contains the tobit estimates for the three dependent variables (LRDS, LNEWS, LIMPRS), one estimate with KTT as independent variable and a second one with the (presumably endogenous) variable KTT instrumented.

The two variables reflecting the firms' resource endowment LQUAL and LCI respectively have the expected positive signs and are highly significant in all equations presented in table 2. The estimated coefficient of the human capital intensity in the estimates for LRDS is considerably larger than that of capital intensity. Seemingly, it does not make a difference if the firm is domestic or foreign. The variable KTT has also the expected positive sign and is highly significant in both estimates with and without endogenization (column 1 and 2 respectively); however, the coefficient becomes smaller if KTT is instrumented. This is an important result emphasizing the relevance of KTT activities for a firm's innovation performance. Finally, firm size is positively correlated with the innovation variables quite in accordance with standard empirical results of earlier studies.<sup>6</sup>

Positive effects of LQUAL and LCI respectively were found also for the variables LNEWS and LIMPRS which showed quite similar results (column 3 to 6 respectively). In the case of these two dependent variables the coefficients of both independent variables LQUAL and LCI are considerably smaller than for the variable LRDS (0.34 to 0.44 and 0.22 to 0.24 respectively). Also the coefficient of the variable KTT, which is significantly positive in all equations, is smaller than in the case of the R&D intensity (0.91 to 1.54). It seems quite reasonable that the effects of the variables LQUAL, LCI and KTT would be larger in case of R&D activities, which are directly related to the innovation process, than for sales, for which e.g. marketing activities are necessary too. There is no significant effect for the variable FOREIGN also in the case of the two sales share variables. Finally, there is a discernible positive size effect. Since the results are only cross-section estimates, it is not possible to test directly the existence of causal relations between the independent variables, particularly KTT,

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<sup>6</sup> Estimates based on an alternative specification of firm size with a linear and a quadratic term with respect to the number of employees showed a relationship of an inverse U-shape. This is in accordance with earlier findings; see e.g. Arvanitis (1997).

and the dependent variables. Nevertheless, some robust regularities come out, which if interpreted in view of our main hypothesis could possibly indicate the direction of causal links.

In sum, KTT activities seem to improve considerably the innovation performance of firms both in terms of R&D intensity and sales of innovative products.

Table 3 contains the tobit estimates for the three dependent variables (LRDS, LNEWS, LIMPRS), one estimate with EDUC1 as independent variable and a second one with the (presumably endogenous) variable EDUC1 instrumented. The coefficient of the instrumented variable EDUC1 is positive and statistically significant in the estimates for all three innovation variables.

Table 4 contains the tobit estimates for the three dependent variables (LRDS, LNEWS, LIMPRS), one estimate with REAS as independent variable and a second one with the (presumably endogenous) variable REAS instrumented. Also in this case the coefficient of the instrumented variable EDUC1 is positive and statistically significant in the estimates for all three innovation variables.

The coefficients of the instrumented variable REAS are considerably larger than those of the variable EDUC1 in the estimates for LRDS, reflecting a more direct link of research-oriented KTT to in-house R&D activities than KTT that is primarily oriented to educational activities. This is not the case for the market-oriented variables LNEWS and LIMPS.

Further estimates with the variables INFO, INFR and CONS as independent variable that are not presented here showed only for INFR a rather weak positive effect on the innovation variables LRDS and LNEWS.

The positive effect of overall KTT activities on all three innovation measures can be obviously traced back mainly to research and educational activities in co-operation with universities and other research organizations.

## **6. Impact of KTT activities on innovation performance II: a matched-pairs analysis**

### **6.1 Main hypotheses, model specification and estimation method**

Our main hypothesis is that KTT activities, particularly research projects and/or educational activities in co-operation with universities, would show on average a significantly higher innovation performance, measured both through input (e.g. R&D expenditure as a percentage of sales) and output innovation measures (e.g. sales share of innovative products), than “structural similar” firms without such activities. To show this, we also used matched-pairs analysis which can be viewed as an alternative approach to the innovation model presented in the previous section.

In order to measure appropriately the influence of KTT activities (“treatment effect”)<sup>7</sup> on a firm’s innovation performance we should be able to measure the performance difference of the two “states” (involved / not involved in KTT activities) of a firm, keeping all other things equal. Mostly is only one of these two possible states observable: either is a firm involved *or* not involved in KTT activities. Thus, the proper comparison of these states is in most cases not possible. Heckman et al. 1998 developed a methodology to approximate this non-observable (“counterfactual”) state of a certain firm with the observable same state of another firm which is “structurally similar” to the first one according to a series of firm characteristics formally defined by a vector X. Thus, besides the group of firms which are KTT-active we need a pool of firms which are not KTT-active (control group) out of which “structurally similar” firms are selected according to a “proximity” criterion. The comparison of the two states for KTT-active firms and firms which are not KTT-active is performed by comparing the means of the innovation performance variables for the “treated” firms and the “twin” “non-treated” firms matched to the “treated” ones according to the used proximity criterion. The multi-dimensionality of the matching problem (matching with respect to each single element of vector X) can under certain conditions (see Rosenbaum and Rubin 1983) reduced to a mono-dimensional (scalar) propensity score which comprehends the entire information of all relevant characteristics. If  $Y_{1i}$  is a vector of innovation measures for the treated firm  $i$  [ $i \in (d=1)$ ] and  $Y_{0i}$  the corresponding vector for a firm  $j$  belonging to the control group [ $j \in (d=0)$ ], which is the twin firm to firm  $i$ , then the performance difference between the two firms is defined as:

$$\Delta Y = Y_{1i} - Y_{0i} \tag{1}$$

In a first step we estimated the propensity scores  $P(X)$  by applying a probit model of the probability of a firm to get involved in KTT activities (dichotomous variable KTT). As independent variables X we used variables for a firm’s endowment (LQUAL; LCI; RD), for the degree of exposition to international competition (LEXP), for firms’ affiliation (FOREIGN), a series of impediments of KTT activities (OBSTACLE1 to OBSTACLE5) and a series of dummy variables controlling for industry, firm size and geographical location (see table A.3 in the appendix for more details and Arvanitis et al. 2005 for a discussion of the model specification used).

Further, we estimated propensity scores for the dichotomous variables REAS (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities; 0: all other KTT-active firms), EDUC2 (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities *and* taking the value 0 for the variable REAS; 0: all other KTT-active firms); CONS (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two

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<sup>7</sup> The expression “treatment effect” comes from the labour market research, where individuals are “treated” via a concrete policy measure. It is used here analogously for firms involved in KTT activities, even if this is not the result of any policy measure.

single forms of consulting activities; 0: all other KTT-active firms), and INFR (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of activities related to technical infrastructure; 0: all other KTT-active firms); see table A.2 in the appendix for more information on the single forms of KTT activities.<sup>8</sup> As independent variables in addition to the variables in the estimates for KTT also variables for the motives for KTT activities (MOTIVE1 to MOTIVE4; see table A.3 in the appendix).

In a second step all firms were distributed to adjustment cells according to the quintiles of the estimated propensity scores. The search for a “twin” firm is then restricted only to the firms of the same adjustment cell, i.e. quintile of propensity scores.

In a third step the “structurally similar” firm inside an adjustment cell was identified for each treated firm. We used three different matching methods to identify the structurally similar firms out of the pool of the non-treated firms.<sup>9</sup> According to the first method used in this study, nearest neighbour matching, the “twin” firm  $j$  to firm  $i$  is one fulfilling the condition:

$$\min_j |P_i - P_j| \quad (2)$$

whereas  $P_i$ ,  $P_j$  are propensity scores for the firms  $i$  and  $j$  respectively. The treated firm can have a higher or a lower propensity score than the non-treated one, therefore the absolute value of the difference of the two propensity scores has to be considered. The second method used in this study, caliper matching, is based on the same proximity measure as the nearest neighbour method which in this case is restricted up to a certain value  $\varepsilon$  (maximum admissible difference of the propensity scores):

$$|P_i - P_j| < \varepsilon \quad (3)$$

Different adjustment cells can have different  $\varepsilon$  values; the  $\varepsilon$  values are dependent on the distribution of the propensity scores inside an adjustment cell.

According to the third method, kernel matching, a weighted sum of all available control group firms inside an adjustment cell, not a single “twin” firm as in the other two methods, is ascribed to every treated firm. The performance difference between the treated and the non-treated firms is now defined as:

$$\Delta = Y_{1i} - \sum_{j \in \{d=0\}} W_{N_0, N_1}(i, j) Y_{0j} \quad (4)$$

with:

- $N_0$  : number of observations in the control group;
- $N_1$  : number of observations in the group of the KTT-active firms;

<sup>8</sup> Firms with a focus in educational activities *without* the additional restriction “taking the value 0 for the variable REAS” (as in variable EDUC1 in section 5) could not be compared with other firms because the number of available control firms is in this case considerably lower than the number of treated firms; 414 firms out of 635 KTT-active firms assessed educational activities as very important (values 4 or 5).

<sup>9</sup> We used the kernel method in addition to the other two methods in the case of the KTT variable (KTT-active firms vs. firms without KTT activities); see table 6c.

$W_{N_0N_1}(i, j)$ : weighting factor ( $\sum_{j \in \{d=0\}} W_{N_0N_1}(i, j) = 1 \quad \forall i$ ).

The weighting factor in equation (4) is defined as:

$$W_{N_0N_1}(i, j) = \frac{G_{ij}}{\sum_{k \in \{d=0\}} G_{ik}} \quad (5)$$

with:

$$G_{ik} = G\left(\frac{(P_i - P_k)}{a_{N_0}}\right) : \text{kernel}^{10} \text{ at the point } \left(\frac{(P_i - P_k)}{a_{N_0}}\right)$$

$a_{N_0}$  : bandwidth of the kernel

The band-width was set specifically for every adjustment cell. Also in this case the choice of the band-width was dependent on the distribution of the propensity scores in the adjustment cells.

In a fourth and last step the means of the variables measuring innovation performance of the group of the treated firms and the group of the “twin” non-treated firms were compared. We used five innovation variables: (1) R&D expenditure as a percentage of sales; (2) percentage reduction of average variable production costs due to process innovation; (3): sales of new products as a percentage of total sales; (4): sales of significantly improved or modified (already existing) products as a percentage of total sales; (3): the sum of sales of new products *and* significantly improved or modified (already existing) products as a percentage of total sales.

## 6.2 Results

### *Treatment effect: KTT activities*

Tables 5a, 5b and 5c contain the results of the nearest neighbour, the caliper and the kernel matching method respectively for the comparison of active and non-active firms with respect to overall KTT activities. The differences of the R&D expenditure as a percentage of sales, the cost reduction due to process innovation and the sales share of new products are all significant at the test level of 5% for all three methods (column 4 in the tables 5a, 5b and 5c). Thus, treated firms have a significantly higher innovation performance than non-treated firms. It is quite remarkable that KTT-active firms are better than non-active ones with respect to *new* products. This is not the case for significantly improved or modified products; for them the difference of the sales shares is statistically insignificant. The results are quite robust with respect to the three matching methods used.

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<sup>10</sup> We used for the function  $G(\cdot)$  a „biweight kernel“ (quartic kernel) which is defined as follows:  $15/16 \left(1 - \left((P_i - P_k)/a_{N_0}\right)^2\right)^2$ . The results are sensitive not to the kernel function used but to the choice of the bandwidth.



Treated firms show on average an R&D intensity, which is about 75% to 100% higher than that of the non-treated firms (see row 1 in all three tables). The cost reduction due to process innovation is about 30%, the share of new products about 13% to 21% higher than in the case of non-treated firms (see row 2 and row 4 respectively in all three tables).

#### *Treatment effect: focus to specific KTT activities*

We compared also the innovation performance of firms assessing besides other activities research co-operations with universities as a highly important part of their KTT activities. In this case the treated firms are those for which the dichotomous variable REAS takes the value 1, non-treated firms are those with the value 0. According to the results reported in the tables 6a and 6b firms with a focus in research co-operation are not significantly more R&D intensive than firms without such a focus, but they are more innovative in terms of sales shares of new products (row 4 in the tables 6a and 6b respectively). On the contrary, research-oriented firms are significantly less effective than other firms with respect to sales shares of improved products (row 5) and cost reduction due to process innovation (row 2).

Also firms focusing to educational activities (without significant research co-operation; the variable EDUC2 takes the value 1) are not more R&D intensive than other firms (row 1 in the tables 7a and 7b respectively). Contrary to research-oriented firms, these firms are better than the rest of the firms in terms of significantly improved or modified products (row 5) and innovation-driven cost reduction (row 2). A stronger research orientation seems to contribute to a higher performance with respect to product innovation.

The results for the rather few firms concentrating to consulting activities (value 1 of the variable CONS) or to activities related to technical infrastructure (value 1 of the variable INFR) show that no discernible differences of innovation performance in comparison to other KTT-active firms could be found (tables 8a to 8b).<sup>11</sup>

The findings are quite robust with respect to the two matching methods used.

## **7. Impact of KTT activities on economic performance: a model of labour productivity**

### *Main hypotheses, model specification, and method*

Our main hypothesis is that KTT activities would contribute as an additional production factor to an improvement of labour productivity of KTT-active firms compared to firms that are not involved in such activities. The overall positive KTT effect could be traced back, first, to a direct link to productivity. Thus, we expect a significantly positive coefficient for the KTT variable. This direct effect would include effects from a wide palette of KTT activities such as

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<sup>11</sup> There is an exception: the results for CONSULT according to the caliper method showed that firms with a focus in consulting are less R&D intensive than other firms and achieve a smaller innovation-driven cost reduction (row 1 and 2 in table 5b).

exchanging information, various educational activities (e.g. recruitment of R&D personnel, joint PhDs, specific training courses), consulting, use of technical infrastructure, and, of course, co-operation in research. Second, we further hypothesize that the main effect of research co-operation with universities would be channelled through the firms' R&D activities. This means that we expect firms with KTT activities to have a significantly higher elasticity of R&D with respect to labour productivity than firms without such activities. Behind this hypothesis is the idea that university knowledge would enhance the effectiveness of R&D with respect to economic performance by complementing, not substituting, in-house knowledge.

We estimated an equation for the logarithm of value added (sales minus intermediate inputs) per employee ( $Q/S$ ) (see table 11). The productivity equation contained proxies of the intensity of human capital (LQUAL; logarithm of the share of employees with tertiary-level education), physical capital (LCI; logarithm of gross investment per employee) and knowledge capital (R&D expenditure divided by sales), further a dummy variable for firm affiliation (FOREIGN; foreign firm yes/no) and dummy variables for firm size and 2-digit industries. We expected positive effects for the resource endowment variables LCI, LQUAL and LRDS. The signs for the variable FOREIGN as well as for the firm size dummies are not a priori clear. Finally and most important, model 1 contained the variable KTT (KTT activities yes/no), model 2 the variable KTT and instead of LRDI the "switch" variables LRDS(KTT=1) and LRDS(KTT=0) respectively. The former variable takes the value of LRDS, if KTT=1, otherwise the value 0; the latter variable takes the value of LRDS, if KTT=0, otherwise the value 0. In this way we are able to estimate the elasticity of R&D intensity with respect to labour productivity separately for the firms with KTT activities and those without KTT activities.

However, being involved in KTT activities is not exogenous to other firms' activities. Innovative firms have a tendency to acquire external knowledge, particularly science-based knowledge, to complement their in-house generated know-how (see also section 5). We accounted for this endogeneity effect by estimating a second version of each productivity equation (model 1 and model 2 respectively), in which KTT was instrumented. As instruments were used a series of firm characteristics which are relevant for KTT activities but do not correlate with the innovation variables. In a first step we estimated a probit model for KTT (see table A.4 in the appendix). Based on the parameters of this model we calculated values for KTT, which were then inserted as independent variables in the productivity equations. In a second step we estimated an OLS model for each of the two productivity equations.

### *Results*

As expected, the coefficients of the variables for resource endowment (LCI; LQUAL, LRDS) are positive and highly statistically significant (see table 11). The elasticity of gross

investment per employee is 0.045, meaning that an increase of 1% of this variable is correlated with an increase of 0.045% of labour productivity (column 1); the elasticity of the share of employees with tertiary-level education is of the same magnitude (0.043). These elasticities are quite stable across the model versions presented in table 9. In accordance to earlier studies (see e.g. Arvanitis and Hollenstein 2002), the elasticity of R&D intensity is considerably lower than that of physical capital and human capital respectively (0.11; column 1). It becomes smaller and statistically insignificant in model B with instrumented KTT due to the high multicollinearity between these variables (see also the correlation matrix in table A.5). The coefficient of the variable FOREIGN is also positive and highly significant, which can be interpreted as a hint that foreign firms are, after controlling for all other factors, more productive than domestic ones.

Now we turn to the technology transfer variable KTT. In the first version (without instrumentation of KTT) of both models 1 and 2 the coefficient of the variable KTT is unstable and statistically insignificant (column 1 and 2). It becomes positive and highly significant in the second version (instrumented KTT) of both models 1 and 2 (0.072 and 0.076 respectively; column 3 and 4). An economic interpretation of these coefficients is that on average a switch from a firm without KTT activities to a firm that is involved in such activities, is correlated to an increase of 6.9% and 7.3% of labour productivity.<sup>12</sup> It seems that a direct link of KTT activities to productivity does exist. The estimates of both versions of model 2 that an important indirect channel of KTT activities is related to R&D activities. In both estimates only the coefficient of the variable LRDS for the group of KTT-active firms is positive and statistical significant (0.011 and 0.017 respectively); the coefficient of the same variable for the group of firms without KTT activities is considerably smaller and insignificant (0.008 and 0.05 respectively). This result shows clearly that KTT activities, particularly research activities in co-operation with universities, enhance the performance effectiveness of a firm's R&D as measured by the elasticity of R&D intensity with respect to labour productivity. In this case an increase of 1% of R&D intensity is correlated with an increase of labour productivity of 0.017% and 0.011% respectively (column 2 and 3 in table 11). Also in this case the warning with respect to causal conclusions based on cross-section investigations already mentioned in section 5 has to be kept in mind.

In sum, KTT activities seem to exercise a positive influence on labour productivity both through a direct effect as well as through an indirect effect by raising the elasticity of R&D intensity with respect to labour productivity.

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<sup>12</sup> We calculated the relative increase of LRDS by the formulas:  $100 \cdot \ln(1+0.072) = 6.9$  and  $100 \cdot \ln(1+0.076) = 7.3$  respectively; see Halvorsen and Palmquist 1980, p. 475.

## 8. Summary and Conclusions

This study investigated the impacts of a palette of Knowledge and Technology Transfer (KTT) activities (general information, educational and research activities, activities related with technical infrastructure, and consulting) (a) on several innovation indicators ( $a_1$ ) in the framework of an innovation equation with variables for endogenized KTT activities (overall activities, specific *forms* of activities) as additional determinants of innovation, and ( $a_2$ ) based on a matched-pairs analysis for several *forms* of KTT activities; (b) on labour productivity in the framework of a production function with endogenized KTT activities as an additional production factor.

In sum, KTT activities with research institution and/or institutions of higher education seem to improve considerably the innovation performance of firms both in terms of R&D intensity and sales of innovative products. Moreover, the positive effect of overall KTT activities on all three innovation measures can be traced back mainly to research and educational activities in co-operation with universities and other research organizations. This could be shown by several methods: the innovation equation approach with endogenized KTT variable as well as three matching methods.

The matched-pairs analysis yielded further interesting results. Firms with a focus to research activities showed a significantly higher sales share than structural similar firms with a different focus of KTT activities for both categories of innovative products (new products; considerably modified already existing products). Firms concentrating to educational activities without a focus in research co-operation showed a better performance with respect to innovation-induced cost reduction as well as the sales share of significantly improved products than structural similar KTT-active firms without such a focus. Firms with a focus either on consulting or technical infrastructure did not differ from structural similar firms with other forms of KTT activities in any type of innovation activities.

Finally, KTT activities seem to exercise a positive influence on labour productivity both through a direct effect as well as through an indirect effect by raising the elasticity of R&D intensity with respect to labour productivity.

New elements of the analysis are: (a) the differentiated measurement of (the range of) KTT activities covering 19 single forms of KTT activities; (b) the use of alternative methods for estimating the impact of KTT activities on innovation and economic performance (matched-pairs analysis, innovation and productivity equations); (c): the wide coverage of industries and firm size classes (manufacturing, selected service industries, construction; firms with at least 5 employees). The main drawback of the study is the lack of data for more than one points of time which does not allow the confirmation as well elaboration of the cross-sectional findings in a longitudinal framework. We hope to be able to offer some remedy for this problem in the near future.

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**Table 1a: Impact on KTT activities on innovation performance; studies based on *direct* measures of KTT activities**

Study	Impact variable	Data/KTT activities	Impact
Nelson (1986)	R&D intensity	Data from the Yale Survey for enterprises in 130 US industries 1984; assessment of the relevance of various fields of university research for a firm's own R&D activities	University research contributes positively and significantly to R&D intensity of the industry in question
Mansfield (1991, 1998)	Percentages of new products and processes that could have not been developed (without substantial delay) in the absence of recent academic research; percentages of new products and processes that were developed with very substantial aid from recent academic research	Sample of 76 major US firms in seven industries for 1975-1985; sample of 77 major firms in seven industries) for 1986-1994.	Similar results for both periods: about 10% of the new products and processes introduced in these industries could not have been developed (without substantial delay) in the absence of recent academic research. Time-lag between academic research results and first commercial introduction of new products/processes was smaller in the second period.
Beise and Stahl (1999)	Firms were asked whether any of the innovations could not have been developed or only with a delay of at least 1 year in the absent of recent research at universities and other public research institutions; share of sales of new products which could not have been developed without university research	Data from Mannheim Innovation Panel for 2500 German manufacturing firms	Public research has an considerable effect on industrial innovations. A considerable share of companies has identified product and process innovations which would not have been developed without recent research of public research institutions. Geographical proximity is not important for Germany.
Kaufmann, and Tödting (2001)	Products new to the market/products new for the firm only	Data from the REGIS survey 1996 for firms from several European regions; assessment of the relevance of several types of external innovation partners (customers, suppliers, consultants, technology transfer offices, contract research organisations and universities) for a firm's innovation activities	Firms cooperating with science increase their ability to realise more radical innovations and to introduce products which are new to the market. Universities are not important for incremental innovations.
Adams, Chiang and Jensen (2003)	Patents, laboratory R&D budget, company financed laboratory R&D budget, federally funded laboratory R&D budget, expenditures on federal laboratory R&D.	Data from (a) survey of industrial laboratories (200 US companies from chemicals, machinery, electrical equipment, and motor vehicle industries; 1996-1997); (b) survey collecting data on intramural R&D carried out in federally funded laboratories – the same that are cited by the industrial laboratories in the 1996-1997 survey. KTT activities: government contractor (yes/no); collaborative	Co-operative research and development agreements (CRADAs) have stimulated industrial patents and company-financed R&D. No other channel of technology transfer yielded a comparable effect.



		R&D (yes/no)	
Becker (2003)	Innovation input indicators: R&D expenditures intensity, R&D labour intensity; innovation output indicators: introduction of product innovations, introduction of process innovation	Data from the Mannheim Innovation Panel Survey for 1584 German manufacturing firms; assessment of the importance of several external knowledge sources	Input indicators: university research as a knowledge source and/or R&D co-operation with universities show a stimulating effect on the level of in-house R&D. Output: university knowledge as an external knowledge source has no stimulating effect on product innovations. In contrast, joint R&D with universities do have a stimulating effect. Process innovations are positively influenced by university knowledge and R&D co-operation with universities.
Hall, Link and Scott (2003)	Development and Commercialization of new technology applications	Data for 352 projects founded by the Advanced Technology Programme (ATP) in the period 1991-1997; three types of university involvement	University participation showed no effect on the generation of new technology applications and a negative effect on the expectation of early commercialization.
Monjon and Waelbroeck (2003)	Introduction of product innovations; introduction of process innovations; degrees of novelty of product innovations (incremental, radical product innovations)	Data from the Community Innovation Survey, the ' <i>Enquête Annuelle d'Entreprises</i> ', and the ' <i>Enquête Annuelle d'Entreprises par fractions</i> ' for about 3200 French enterprises; formal R&D co-operations; universities and public research institutions as important knowledge sources	Firms benefit from formal international collaboration with universities and public research institutions. There is little evidence for direct spillovers from universities.
Fritsch and Franke (2004)	Propensity to register innovations for patenting; number of innovations registered for patenting	Data from a survey in three German regions (Baden, Hanover-Brunswick-Goettingen, Saxony) comprising all enterprises with ten or more employees (1800 firms); co-operation with public research institutions (yes/no); external funds attracted by public research institutions	The indicator for R&D co-operations with public research institutions as well as the logarithm of external funds attracted by public research institutions impact positively the propensity to register at least one innovation for patenting but not the number of innovations registered for patenting.
Lööf and Broström (2005)	Expenditures on R&D, patents applications, sales share of new products	Data from the Community Innovation Survey for Sweden for the period 1998-2000 for 790 firms (after the elimination of low R&D sectors and all firms without R&D or other innovation expenditures)	A comparison of R&D collaborating with non-collaborating firms based on a matched-pairs analysis showed that in the case of collaborating firms knowledge diffusion from academic research contributed to an increase in total R&D expenditures. Furthermore collaborating firms showed a greater R&D productivity in terms of sales of innovative products and patent applications.

**Table 1b: Impact of KTT activities on innovation performance; studies based on indirect measures of KTT activities (knowledge spillover variables)**

Study	Impact variable	Data/spillover measures	Impact
Jaffe (1989)	Corporate patents, industrial R&D	States are unit of observation. Data on patents and industry R&D, industrial R&D laboratories (totals on labs and employees); spillover variable: university R&D expenditures; index of geographic coincidence of industry R&D and university research for each state.	Patents: <ul style="list-style-type: none"> <li>- evidence of geographically mediated commercial spillovers from university research</li> <li>- weak evidence that spillovers are facilitated through geographic coincidence of universities and research labs within the state</li> <li>- spillovers are focused on specific areas (e.g. electronics)</li> </ul> Industrial R&D: <ul style="list-style-type: none"> <li>- it appears that university research causes industry R&amp;D and not vice versa</li> </ul>
Acs et al. (1992)	Number of innovations	Data from the census of innovation citations conducted by the U.S. Small Business Administration in 1982; spillover variables: research expenditures undertaken at universities, measure of geographical coincidence of university and corporate research	Spillovers are facilitated by the geographic coincidence of universities and research labs within the state. Results are influenced by “technological regime”, i.e. university spillovers are relatively more important than private-company R&D spending in the electronics sector
Jaffe, Trajtenberg and Henderson (1993)	Comparison of location of patent citations with that of the cited patents as evidence of geographically localised knowledge spillovers.	Two cohorts of US patents: the 1975 originating cohort contains about 950 patents with a total of about 4750 citations by the end of 1989; the 1980 originating cohort contains 1450 patents with about 5200 citations; spillover variable: patent citations to science	Little evidence of differences in localisation between the citations of university and corporate patents (more often self-cited, more often localised). Knowledge spillovers are geographically localised. Geographic localisation fades over time. Citations in the same class (technological area) are no more likely to be localised.
Feldman (1994)	Number of innovations for a specific industry in a specific state	Data from the census of innovation citations conducted by the U.S. Small Business Administration in 1982; also from the National Science Foundation’s survey of sciences Resources; spillover variable: university research expenditures measured at the level of academic department and allocated to the relevant industry group	Innovation input from university has a significant positive impact on the number of innovations. This effect is stronger for small firms than for large firms.

**Table 1c: Impact of KTT activities on economic performance**

Study	Impact variable	Data/KTT activities	Impact
Benfratello and Sembenelli (2002)	Labour productivity; total factor productivity; price cost margins	EU Data on 1031 and 3874 research joint ventures (RJV) under the EUREKA Framework and the 3 <sup>rd</sup> and 4 <sup>th</sup> Framework Programme for Science and Technology (FPST) respectively; AMADEUS database for balance sheet information of participating firms (750 and 1339 manufacturing firms in EUREKA and FPST respectively)	EUREKA: Participants experienced an significant improvement of their economic performance measured as a difference of “pre” and “post” period; FPST: Did not show any clear pattern.
Belderbos, Carree and Lokshin (2004)	Growth of value-added per employee (labour productivity); growth of sales per employee from products new to the market (innovative sales productivity)	Community Innovation Survey data for about 2000 Dutch enterprises; different types of (formal) R&D co-operation (with competitors, suppliers, customers, and research institutes and universities)	R&D co-operation with universities is more focused on radical innovation and the creation of new products, thus enhancing innovative sales productivity. Co-operation with suppliers are more focused on reducing input costs and improving assembly processes, thus improving labour productivity. Co-operation with competitors increase both labour productivity and innovative sales productivity.
Medda, Piga and Siegel (2005)	Growth in total factor productivity	Data from the <i>Mediocredito Centrale</i> survey (1998) for 2222 Italian firms with more than 500 employees; R&D collaboration with universities and research centres	External (collaborative) R&D seems to generate higher returns than internal R&D The positive external R&D contribution is caused by research collaboration with other companies and research centres and <b>not</b> by collaborative research with universities.
Brandstetter and Ogura (2005)	Deflated sales; introduction of new products based on bioscience-related inventions	Firm-level data from the NBER Patent Citation Database (mostly large US firms) supplemented with data from smaller firms in technology-intensive industries, including biotechnology, semiconductors, and information technology; patent citations to science.	Deflated sales: impact is positive and statistically significant. Coefficient implies that a 100% increase in citations generates 2%-3% increase in productivity. New product introduction (bio nexus): impact is positive and significant. Coefficient implies that a 100% increase in science citations yields 70% more approved products.

**Table 2: Firms' assessment of the impact of KTT activities on innovation performance by sector and firm size**

Effects	Sectors				Firm size			Total
	High-tech manufacturing	Low-tech manufacturing	Knowledge-based services	Traditional services	Small 5-49 employees	Medium 50-249 employees	Large 250 employees and more	
Technology adoption to supplement our know-how	31.2	33.5	29.1	18.3	29.2	25.3	21.5	28.1
Technology adoption to develop new products	33.7	32.5	16.4	10.6	21.1	17.6	10.2	19.9
Technology adoption to develop new processes	15.0	22.2	16.9	14.3	18.0	14.2	13.1	17.0
Technology generation to supplement our know-how	20.0	19.3	17.5	8.0	13.3	14.6	11.1	13.5
Technology generation to develop new products	25.6	27.8	14.4	8.4	14.8	17.0	6.0	14.9
Technology generation to develop new processes	7.5	8.6	10.4	13.7	9.1	10.7	9.3	9.4
Orientation towards: more applied research	14.8	15.9	12.1	5.3	10.3	17.1	17.4	12.0
more basic research	2.4	0.1	3.9	5.3	3.7	0.4	0.5	2.9
Reduction of internal R&D capacity	4.1	0.9	0.1	0.0	0.5	1.4	1.4	0.7
Decrease of R&D costs	4.4	1.8	4.1	2.6	3.2	1.4	3.0	2.8
Increase of R&D costs	20.0	13.7	3.8	6.4	7.0	11.2	7.6	7.9
Human capital increase through the recruitment of graduates in R&D	25.4	15.6	25.5	5.9	14.5	16.6	24.3	15.3

Human capital increase through training courses, sabbaticals, etc.	5.8	3.6	13.8	5.3	8.4	3.0	6.0	7.2
N	275	170	136	56	182	288	199	669

Percentage of KTT-active firms with values 4 or 5 on a five-point Likert scale (1: 'is not true'; 5: 'is true to a high extent'); high-tech manufacturing: chemicals, plastics, machinery, electrical machinery, vehicles, and electronics/instruments; low-tech manufacturing: all other manufacturing industries (see table A.1 in the appendix); knowledge-based industries: banking, insurance, computer services, other business services, telecommunication; traditional services: wholesale trade, transportation.

**Table 3: Innovation performance and KTT activities (KTT variable); tobit estimates**

Explanatory variables	LRDS <sup>(1)</sup>	LRDS/KTT instrumented	LNEWS <sup>(2)</sup>	LNEWS/KTT instrumented	LIMPRS <sup>(3)</sup>	LIMPS/KTT instrumented
LQUAL <sup>(4)</sup>	1.024*** (0.176)	1.378*** (0.187)	0.337*** (0.068)	0.397*** (0.070)	0.380*** (0.077)	0.439*** (0.079)
LCI <sup>(5)</sup>	0.403*** (0.111)	0.339** (0.117)	0.244*** (0.044)	0.232*** (0.045)	0.221*** (0.048)	0.217*** (0.050)
FOREIGN <sup>(6)</sup>	-0.427 (0.431)	-0.659 (0.458)	0.085 (0.177)	0.025 (0.180)	-0.107 (0.202)	-0.131 (0.207)
KTT <sup>(7)</sup>	5.874*** (0.352)	4.479*** (0.379)	1.355*** (0.148)	1.034*** (0.141)	1.537*** (0.166)	0.911*** (0.158)
<i>Firm size:</i>						
20 to 49 employees	1.685*** (0.502)	1.259** (0.531)	0.650*** (0.186)	0.637*** (0.190)	0.722*** (0.210)	0.687*** (0.215)
50 to 99 employees	3.044*** (0.518)	3.217*** (0.542)	0.670*** (0.202)	0.730*** (0.230)	0.883*** (0.227)	1.012*** (0.215)
100 to 199 employees	4.211*** (0.526)	4.296*** (0.555)	0.981*** (0.207)	0.942*** (0.211)	1.145*** (0.234)	1.170*** (0.240)
200 to 499 employees	4.329*** (0.561)	5.105*** (0.588)	1.145*** (0.225)	1.297*** (0.226)	1.271*** (0.254)	1.511*** (0.257)
500 to 999 employees	4.819*** (0.815)	5.629*** (0.861)	1.263*** (0.346)	1.472*** (0.349)	1.587*** (0.388)	1.937*** (0.396)
1000 employees and more	5.036*** (0.948)	6.085*** (0.995)	1.688*** (0.411)	1.936*** (0.411)	2.098*** (0.463)	2.481*** (0.464)
Constant	-17.605*** (1.336)	-12.261*** (1.473)	-5.702*** (0.484)	-4.436*** (0.536)	-5.844*** (0.532)	-4.780*** (0.601)
N	2404	2404	2213	2213	2213	2213
N(left-censored)	1638	1638	1349	1349	1370	1370
Pseudo R <sup>2</sup>	0.169	0.153	0.109	0.104	0.103	0.093
LR statistics ( $\chi^2$ )	1285***	1112***	677***	623***	647***	567***

Note: (1) LRDS: logarithm of the R&D expenditure divided by sales (R&D intensity); (2): LNEWS: logarithm of the sales share of new products; (3): LIMPRS: logarithm of the sales share of significantly modified already existing products; (4): LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); (5): LCI: logarithm of gross investment per employee 2004; (6): FOREIGN: dummy variable for foreign firms; (7): KTT: dummy variable for knowledge and technology transfer activities in the period 2002-2004 and/or in the period before 2002; instrumented KTT: see table A.2 for the instrument equation for KTT; 12 dummy variables for 2-digit industries and 6 dummy variables for firm size; reference industry: construction; reference firm size class: 5-19 employees; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level.

**Table 4: Innovation performance and educational activities (variable EDUC); tobit estimates**

Explanatory variables	LRDS <sup>(1)</sup>	LRDS/KTT instrumented	LNEWS <sup>(2)</sup>	LNEWS/KTT instrumented	LIMPRS <sup>(3)</sup>	LIMPS/KTT instrumented
LQUAL <sup>(4)</sup>	1.027*** (0.229)	0.975*** (0.232)	0.221** (0.106)	0.200* (0.106)	0.133 (0.119)	0.062 (0.120)
LCI <sup>(5)</sup>	0.269** (0.131)	0.247* (0.134)	0.127** (0.059)	0.135** (0.062)	0.055 (0.068)	0.052 (0.071)
FOREIGN <sup>(6)</sup>	0.151 (0.422)	0.219 (0.422)	-0.005 (0.188)	-0.080 (0.190)	0.026 (0.215)	0.026 (0.218)
EDUC1 <sup>(7)</sup>	0.729** (0.359)	0.441*** (0.128)	0.365** (0.162)	0.213*** (0.058)	0.096 (0.185)	0.244*** (0.067)
<i>Firm size:</i>						
20 to 49 employees	0.557 (0.661)	0.411 (0.656)	0.661** (0.299)	0.675** (0.300)	0.450 (0.342)	0.408 (0.343)
50 to 99 employees	1.519** (0.627)	1.310** (0.617)	0.429 (0.286)	0.464* (0.284)	0.803** (0.324)	0.789** (0.322)
100 to 199 employees	2.155*** (0.632)	1.998*** (0.631)	0.954*** (0.289)	0.928*** (0.291)	1.065*** (0.329)	0.954*** (0.331)
200 to 499 employees	1.766*** (0.616)	1.471** (0.615)	0.807*** (0.283)	0.750*** (0.285)	0.924*** (0.322)	0.821** (0.324)
500 to 999 employees	1.585** (0.778)	1.230 (0.772)	0.917*** (0.352)	0.843** (0.355)	0.918** (0.400)	0.743* (0.403)
1000 employees and more	1.562* (0.841)	0.884 (0.841)	0.970** (0.389)	0.831** (0.389)	1.246*** (0.440)	1.037** (0.440)
High-tech manufacturing <sup>(8)</sup>	5.324*** (0.783)	5.327*** (0.796)	1.490*** (0.367)	1.376*** (0.375)	1.585*** (0.409)	1.409*** (0.419)
Low-tech manufacturing <sup>(9)</sup>	2.378*** (0.808)	2.503*** (0.817)	0.935** (0.379)	0.903** (0.384)	0.390 (0.424)	0.332 (0.430)
Knowledge-based services <sup>(10)</sup>	1.246 (0.849)	1.451* (0.863)	-0.007 (0.404)	-0.088 (0.416)	0.253 (0.451)	0.169 (0.458)
Traditional services <sup>(11)</sup>	-1.505 (0.979)	-0.960 (0.981)	0.716* (0.432)	0.922** (0.433)	0.054 (0.490)	0.279 (0.496)
Constant	-5.898*** (1.608)	-5.257*** (1.646)	-2.224*** (0.743)	-2.080*** (0.767)	-0.994 (0.828)	-0.718*** (0.863)
N	660	660	588	588	588	588
N(left-censored)	196	196	178	178	188	188
Pseudo R <sup>2</sup>	0.075	0.079	0.046	0.046	0.041	0.046
LR statistics ( $\chi^2$ )	242***	243***	93***	93***	86***	95***

Note: (1) LRDS: logarithm of the R&D expenditure divided by sales (R&D intensity); (2) LNEWS: logarithm of the sales share of new products; (3) LIMPRS: logarithm of the sales share of significantly modified already existing products; (4) LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); (5) LCI: logarithm of gross investment per employee 2004; (6) FOREIGN: dummy variable for foreign firms; (7) EDUC1: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities (see table A.2 in the appendix); 0: all other KTT-active firms); instrumented EDUC: see table A.4 for the instrument equation for EDUC; (8): dummy variable for high-tech manufacturing: chemicals, plastics, machinery, electrical machinery, electronics, instruments and vehicles; (9): dummy variable for low-tech manufacturing: all other manufacturing industries; (10): dummy variable for knowledge-based services: banks, computer services, business services; (11): dummy variable for traditional services: wholesale trade, transportation; reference sector: construction; 6 dummy variables for firm size; reference firm size class: 5-19 employees; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level.

**Table 5: Innovation performance and educational activities (variable REAS); tobit estimates**

Explanatory variables	LRDS <sup>(1)</sup>	LRDS/KTT instrumented	LNEWS <sup>(2)</sup>	LNEWS/KTT instrumented	LIMPRS <sup>(3)</sup>	LIMPS/KTT instrumented
LQUAL <sup>(4)</sup>	0.940*** (0.225)	0.702*** (0.216)	0.229** (0.106)	0.186* (0.106)	0.133 (0.119)	0.053 (0.120)
LCI <sup>(5)</sup>	0.257** (0.129)	0.226* (0.125)	0.127** (0.059)	0.138** (0.061)	0.056 (0.068)	0.056 (0.071)
FOREIGN <sup>(6)</sup>	0.027 (0.415)	-0.033 (0.393)	-0.048 (0.188)	-0.141 (0.189)	0.015 (0.215)	-0.044 (0.217)
REAS <sup>(7)</sup>	1.748*** (0.390)	1.088*** (0.111)	0.343* (0.180)	0.226*** (0.053)	0.126 (0.205)	0.245*** (0.061)
<i>Firm size:</i>						
20 to 49 employees	0.598 (0.650)	0.207 (0.614)	0.697** (0.299)	0.660** (0.299)	0.456 (0.341)	0.380 (0.343)
50 to 99 employees	1.647*** (0.615)	1.178** (0.576)	0.499* (0.285)	0.467* (0.283)	0.820** (0.323)	0.784** (0.322)
100 to 199 employees	2.298*** (0.620)	1.573*** (0.588)	1.026*** (0.288)	0.935*** (0.289)	1.082** (0.327)	0.965*** (0.330)
200 to 499 employees	1.767*** (0.604)	1.160** (0.571)	0.857*** (0.282)	0.795*** (0.282)	0.933*** (0.320)	0.868*** (0.321)
500 to 999 employees	1.329* (0.767)	0.700 (0.716)	0.934*** (0.352)	0.892** (0.350)	0.912** (0.401)	0.794** (0.399)
1000 employees and more	1.420* (0.828)	0.382 (0.781)	0.968** (0.390)	0.849** (0.386)	1.239*** (0.441)	1.066** (0.437)
High-tech manufacturing <sup>(8)</sup>	5.173*** (0.772)	4.240*** (0.751)	1.467*** (0.367)	1.216*** (0.377)	1.574*** (0.409)	1.245*** (0.423)
Low-tech manufacturing <sup>(9)</sup>	2.246*** (0.796)	1.972*** (0.766)	0.895** (0.379)	0.803** (0.384)	0.376 (0.424)	0.229 (0.432)
Knowledge-based services <sup>(10)</sup>	1.259 (0.837)	1.783** (0.808)	-0.006 (0.404)	0.027 (0.409)	0.252 (0.451)	0.294 (0.459)
Traditional services <sup>(11)</sup>	-1.507 (0.964)	-0.555 (0.922)	0.657 (0.431)	0.933** (0.437)	0.041 (0.488)	0.290 (0.496)
Constant	-5.369*** (1.585)	-1.208*** (1.582)	-2.105*** (0.742)	-1.444* (0.787)	-0.957 (0.828)	-0.042 (0.889)
N	660	660	588	588	588	588
N(left-censored)	196	196	178	178	188	188
Pseudo R <sup>2</sup>	0.080	0.106	0.045	0.053	0.041	0.048
LR statistics ( $\chi^2$ )	258***	325***	91***	105***	86***	97***

Note: (1) LRDS: logarithm of the R&D expenditure divided by sales (R&D intensity); (2) LNEWS: logarithm of the sales share of new products; (3) LIMPRS: logarithm of the sales share of significantly modified already existing products; (4) LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); (5) LCI: logarithm of gross investment per employee 2004; (6) FOREIGN: dummy variable for foreign firms; (7) REAS: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities (see table A.2 in the appendix); 0: all other KTT-active firms); instrumented REAS: see table A.4 for the instrument equation for REAS; (8) dummy variable for high-tech manufacturing: chemicals, plastics, machinery, electrical machinery, electronics, instruments and vehicles; (9) dummy variable for low-tech manufacturing: all other manufacturing industries; (10) dummy variable for knowledge-based services: banks, computer services, business services; (11) dummy variable for traditional services: wholesale trade, transportation; reference sector: construction; 6 dummy variables for firm size; reference firm size class: 5-19 employees; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level.



**Table 6a: Comparison of active/non-active firms (KTT overall yes/no); matching by the „Nearest Neighbour“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	2.90 (0.47)	3.24 (0.39)	6.49 (1.35)	3.25 (1.37)	yes
Percentage reduction of average variable production costs due to process innovation	3.63 (0.25)	4.00 (0.29)	5.19 (0.36)	1.19 (0.45)	yes
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	20.82 (0.78)	28.58 (1.16)	32.14 (1.18)	3.56 (1.62)	yes
Sales of new products as a percentage of total sales	9.37 (0.48)	11.39 (0.62)	13.78 (0.73)	2.39 (0.98)	yes
Sales of significantly improved or modified (already existing) products as a percentage of total sales	11.45 (0.53)	17.20 (0.86)	18.36 (0.86)	1.16 (1.18)	no

N(non-active firms)=241; 600; 1226; 1226; 1226; N(active firms)=377; 404; 549; 549; 549; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 6b: Comparison of active/non-active firms (KTT overall yes/no); matching by the „Caliper“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	2.90 (0.47)	3.71 (0.11)	5.99 (1.37)	2.28 (1.37)	yes <sup>(1)</sup>
Percentage reduction of average variable production costs due to process innovation	3.63 (0.25)	4.06 (0.71)	5.19 (0.36)	1.13 (0.36)	yes
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	20.82 (0.78)	30.58 (1.16)	32.14 (1.18)	1.56 (1.14)	no
Sales of new products as a percentage of total sales	9.37 (0.48)	12.21 (0.15)	13.78 (0.73)	1.57 (0.74)	yes
Sales of significantly improved or modified (already existing) products as a percentage of total sales	11.45 (0.53)	18.36 (0.28)	18.36 (0.86)	0.00 (0.84)	no

(1): significant only at the 10% test level; N(non-active firms)=241; 600; 1226; 1226; 1226; N(active firms)=346; 404; 549; 549; 549; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 6c: Comparison of active/non-active firms (KTT overall yes/no); matching by the „Kernel” Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	2.90 (0.47)	3.56 (0.12)	5.99 (1.37)	2.43 (1.37)	yes <sup>(1)</sup>
Percentage reduction of average variable production costs due to process innovation	3.63 (0.25)	4.06 (0.08)	5.19 (0.36)	1.13 (0.36)	yes
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	20.82 (0.78)	30.43 (0.36)	32.14 (1.18)	1.71 (1.14)	no
Sales of new products as a percentage of total sales	9.37 (0.48)	12.18 (0.17)	13.78 (0.73)	1.60 (0.74)	yes
Sales of significantly improved or modified (already existing) products as a percentage of total sales	11.45 (0.53)	18.25 (0.28)	18.36 (0.86)	0.11 (0.84)	no

(1): significant only at the 10% test level; N(non-active firms)=241; 600; 1226; 1226; 1226; N(active firms)=346; 404; 549; 549; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 7a: Comparison of active/non-active firms (REAS yes/no); matching by the „Nearest Neighbour“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	5.70 (1.72)	6.86 (1.53)	8.26 (1.98)	1.40 (2.40)	no
Percentage reduction of average variable production costs due to process innovation	5.14 (0.42)	7.24 (0.75)	5.57 (0.72)	-1.67 (1.06)	no
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	30.80 (1.36)	44.57 (2.36)	36.92 (2.40)	-7.65 (3.43)	yes
Sales of new products as a percentage of total sales	12.57 (0.82)	13.46 (1.27)	18.12 (1.62)	4.66 (2.19)	yes
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.23 (1.01)	31.11 (2.26)	18.80 (1.57)	-12.31 (2.88)	yes

N(non-active firms)=264; 297; 418; 418; 418; N(active firms)=114; 108; 132; 132; 132; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 7b: Comparison of active/non-active firms (REAS yes/no); matching by the „Caliper“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	5.70 (1.72)	8.26 (1.29)	8.23 (2.00)	-0.03 (2.43)	no
Percentage reduction of average variable production costs due to process innovation	5.14 (0.42)	6.58 (0.35)	5.49 (0.73)	-1.09 (0.80)	no
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	30.80 (1.36)	42.93 (1.18)	36.95 (2.42)	-5.98 (2.67)	yes
Sales of new products as a percentage of total sales	12.57 (0.82)	13.20 (0.49)	18.15 (1.63)	4.95 (1.76)	yes
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.23 (1.01)	29.73 (1.35)	18.80 (1.59)	-10.93 (2.14)	yes

N(non-active firms)=264; 297; 418; 418; 418; N(active firms)=113; 107; 131; 131; 131; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 8a: Comparison of active/non-active firms (EDUC2 yes/no); matching by the „Nearest Neighbour“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	5.74 (1.09)	5.95 (1.44)	7.44 (2.73)	1.49 (3.12)	no
Percentage reduction of average variable production costs due to process innovation	4.75 (0.47)	4.10 (0.51)	5.76 (0.57)	1.66 (0.77)	yes
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	31.54 (1.50)	27.80 (1.59)	32.89 (1.89)	5.09 (2.47)	yes
Sales of new products as a percentage of total sales	13.66 (0.92)	13.23 (1.01)	13.93 (1.18)	0.70 (1.58)	no
Sales of significantly improved or modified (already existing) products as a percentage of total sales	17.88 (1.06)	14.57 (0.97)	18.96 (1.40)	4.39 (1.67)	yes

N(non-active firms)=211; 227; 303; 303; 303; N(active firms)=166; 177; 246; 246; 246; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 8b: Comparison of active/non-active firms (EDUC2 yes/no); matching by the „Caliper“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 10%)
R&D expenditure as a percentage of sales	5.74 (1.09)	6.29 (0.46)	7.47 (2.74)	1.18 (2.70)	no
Percentage reduction of average variable production costs due to process innovation	4.75 (0.47)	4.37 (0.12)	5.80 (0.57)	1.43 (0.57)	yes
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	31.54 (1.50)	29.12 (0.42)	33.03 (1.89)	3.91 (1.93)	yes
Sales of new products as a percentage of total sales	13.66 (0.92)	12.60 (0.23)	13.99 (1.19)	1.39 (1.23)	no
Sales of significantly improved or modified (already existing) products as a percentage of total sales	17.88 (1.06)	16.52 (0.21)	19.04 (1.40)	2.52 (1.40)	yes

N(non-active firms)=211; 227; 303; 303; 303; N(active firms)=165; 174; 245; 245; 245; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 9a: Comparison of active/non-active firms (CONS yes/no); matching by the „Nearest Neighbour“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	7.33 (1.66)	3.04 (0.40)	2.93 (0.38)	-0.11 (0.51)	no
Percentage reduction of average variable production costs due to process innovation	5.33 (0.42)	6.85 (0.75)	4.63 (0.62)	-2.22 (1.29)	no
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	31.27 (1.30)	35.07 (2.73)	35.53 (2.82)	0.46 (3.99)	no
Sales of new products as a percentage of total sales	13.15 (0.76)	15.25 (1.43)	16.35 (2.06)	1.10 (2.61)	no
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.12 (0.95)	19.82 (2.00)	19.19 (2.04)	-0.63 (2.97)	no

N(non-active firms)=305; 323; 443; 443; 443; N(active firms)=72; 81; 107; 107; 107; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 9b: Comparison of active/non-active firms (CONS yes/no); matching by the “Caliper” Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	7.33 (1.66)	6.21 (0.43)	2.93 (0.38)	-3.28 (0.63)	yes
Percentage reduction of average variable production costs due to process innovation	5.33 (0.42)	5.97 (0.22)	4.69 (0.63)	-1.28 (0.62)	yes
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	31.27 (1.30)	33.54 (0.71)	35.53 (2.82)	1.99 (2.84)	no
Sales of new products as a percentage of total sales	13.15 (0.76)	13.32 (0.27)	16.35 (2.06)	3.03 (2.05)	no
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.12 (0.95)	20.22 (0.68)	19.19 (2.04)	-1.03 (2.13)	no

N(non-active firms)=305; 323; 443; 443; 443; N(active firms)=72; 80; 107; 107; 107; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 10a: Comparison of active/non-active firms (INFR yes/no); matching by the „Nearest Neighbour“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	5.33 (0.78)	16.65 (3.65)	10.30 (5.18)	-6.35 (6.55)	no
Percentage reduction of average variable production costs due to process innovation	5.17 (0.41)	4.69 (0.74)	5.27 (0.72)	0.58 (0.95)	no
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	31.06 (1.33)	38.34 (2.72)	36.22 (2.55)	-2.12 (3.92)	no
Sales of new products as a percentage of total sales	12.96 (0.80)	14.74 (1.65)	16.89 (1.76)	2.15 (2.51)	no
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.10 (0.98)	23.60 (2.30)	19.34 (1.78)	-4.26 (2.94)	no

N(non-active firms)=289; 323; 434; 434; 434; N(active firms)=88; 81; 115; 115; 115; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 10b: Comparison of active/non-active firms (INFR yes/no); matching by the „Caliper“ Method**

<i>Measures of Innovation Performance</i>	<i>All non-active firms before matching</i>	<i>Non-active firms after matching (control group)</i>	<i>Active firms</i>	<i>Difference of means of active firms/non-active firms (column 3 – column 2)</i>	
	Means				Statistical significance (test level 5%)
R&D expenditure as a percentage of sales	5.33 (0.78)	7.72 (1.53)	10.90 (5.55)	3.19 (5.75)	no
Percentage reduction of average variable production costs due to process innovation	5.17 (0.41)	5.28 (0.20)	5.16 (0.72)	-0.12 (0.78)	no
Sum of sales of new <i>and</i> significantly improved or modified (already existing) products as a percentage of total sales	31.06 (1.33)	34.53 (0.59)	36.08 (2.65)	1.55 (2.70)	no
Sales of new products as a percentage of total sales	12.96 (0.80)	14.17 (0.26)	17.02 (1.85)	2.85 (1.86)	no
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.10 (0.98)	20.36 (0.40)	19.07 (1.84)	-1.29 (1.85)	no

N(non-active firms)=289; 323; 434; 434; 434; N(active firms)=82; 76; 107; 107; 107; the number of firms is not in every case the same a) dependent on the type of innovation activities (e.g. not all firms have process innovations) and b) due to missing values. The standard errors are found in brackets under the means.

**Table 11: Labour productivity and KTT activities; dependent variable: log(value added per employee); OLS estimates**

Explanatory variables	Model 1	Model 2	Model 1	Model 2
			KKT instrumented	KKT instrumented
LCI <sup>(1)</sup>	0.045*** (0.008)	0.045*** (0.008)	0.045*** (0.008)	0.045*** (0.008)
LQUAL <sup>(2)</sup>	0.043*** (0.014)	0.043*** (0.014)	0.041*** (0.015)	0.043*** (0.015)
LRDS <sup>(3)</sup>	0.011*** (0.004)	//	0.005 (0.004)	//
LRDS (KTT=1) <sup>(4)</sup>	//	0.017*** (0.005)	//	0.011** (0.005)
LRDS(KTT=0) <sup>(5)</sup>	//	0.008 (0.005)	//	0.005 (0.004)
KTT <sup>(6)</sup>	-0.031 (0.026)	0.039 (0.056)	0.072*** (0.024)	0.076*** (0.024)
FOREIGN <sup>(7)</sup>	0.238*** (0.026)	0.238*** (0.042)	0.236*** (0.024)	0.236*** (0.044)
<i>Firm size:</i>				
20 to 49 employees	0.069** (0.034)	0.071** (0.034)	0.070** (0.034)	0.072** (0.034)
50 to 99 employees	0.106*** (0.036)	0.107*** (0.036)	0.102*** (0.035)	0.107*** (0.036)
100 to 199 employees	0.064* (0.035)	0.066* (0.035)	0.070** (0.035)	0.074** (0.035)
200 to 499 employees	0.106*** (0.040)	0.107*** (0.040)	0.100*** (0.040)	0.108*** (0.041)
500 to 999 employees	0.069 (0.061)	0.070 (0.061)	0.047 (0.061)	0.060 (0.061)
1000 employees and more	0.163 (0.110)	0.165 (0.110)	0.145 (0.112)	0.161 (0.111)
Constant	11.201*** (0.084)	11.164*** (0.090)	11.199*** (0.092)	11.205*** (0.091)
N	2533	2533	2533	2533
R2 adj.	0.202	0.202	0.216	0.217
SER	0.558	0.558	0.546	0.546
F	20.4***	19.8***	21.1***	20.6***

Note: (1): LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); (2): LCI: logarithm of gross investment per employee 2004; (3) LRDS: logarithm of the R&D expenditure divided by sales (R&D intensity); (4): this variable takes the value of LRDS, if KTT=1, otherwise the value 0; (5): this variable takes the value of LRDS, if KTT=0, otherwise the value 0; (6): KTT: dummy variable for knowledge and technology transfer activities in the period 2002-2004 and/or in the period before 2002; (7): FOREIGN: dummy variable for foreign firms; dummy variables for 2-digit industries and firm size; reference industry: construction; reference firm size class: 5-19 employees; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level, respectively; heteroscedasticity-robust standard errors (White procedure).

**APPENDIX:**

**Table A.1: Composition of the dataset; incidence of KTT activities by sectors, industries, and firm size**

	N	Percentage of the total	Percentage with KTT activities
<i>Industry:</i>			
Food, beverage	127	4.9	33.0
Textiles	30	1.2	30.1
Clothing, leather	11	0.4	0.0
Wood processing	56	2.2	25.5
Paper	31	1.2	31.2
Printing	91	3.5	26.7
Chemicals	93	3.6	41.9
Plastics, rubber	58	2.2	29.7
Glass, stone, clay	47	1.8	31.8
Metal	39	1.5	26.7
Metal working	173	6.7	28.4
Machinery	269	10.4	35.8
Electrical machinery	87	3.4	33.9
Electronics, instruments	152	5.9	40.1
Watches	54	2.1	26.2
Vehicles	29	1.1	32.4
Other manufacturing	54	2.1	25.4
Energy, water	49	1.9	30.5
Construction	271	10.5	14.2
Wholesale trade	215	8.3	31.6
Transport	154	6.0	28.4
Banks, insurances	179	6.9	26.5
Computer services	79	3.1	26.4
Business services	216	8.4	37.9
Telecommunication	18	0.7	32.9
<i>Firm Size:</i>			
5-19 employees	689	26.7	11.5
20-49 employees	596	23.1	17.2
50-99 employees	439	17.0	28.4
100-199 employees	395	15.3	32.3
200-499 employees	305	11.8	47.3
500-999 employees	93	3.6	56.5
> 1000 employees	65	2.5	61.5
Total	2582	100.0	27.6



**Table A.2: Forms of KTT activities**

<i>KTT main forms / single forms</i>	Percentage of KTT-active firms reporting 4 or 5 on a five-point Likert scale (1: 'not important'; 5: 'very important')
<i>INFORMAL (variable INFO)<sup>(1)</sup></i>	56.6
Informal contacts	30.4
Attending conferences	30.4
Reading of, referring to publications	33.1
<i>TECHNICAL INFRASTRUCTURE (variable INFR)<sup>(1)</sup></i>	11.9
Common laboratory	3.9
Use of university technical infrastructure	10.7
<i>EDUCATION (variable EDUC1)<sup>(1)</sup></i>	52.3
Employing graduates in R&D	18.4
Contacts with university of graduates employed in R&D	10.1
Students' participation in firm R&D	10.9
Joint diploma theses	15.7
Joint PhDs	7.0
University researchers' participation in firm R&D	10.1
Common courses	3.8
Teaching of firm researchers at the university	7.7
Attending university training courses	22.1
<i>RESEARCH (variable REAS)<sup>(1)</sup></i>	17.8
Joint R&D projects	16.3
Long-term research contracts	5.0
Research consortium	4.1
<i>CONSULTING (variable CONS)<sup>(1)</sup></i>	15.3
Expertise	11.1
Consulting	13.8
N	669

*Note:* (1): percentage of firms reporting a value 4 or 5 on a five-point Likert scale (1: 'not important'; 5: 'very important') at least in one of the single forms belonging to the corresponding main category of forms of KTT activities.

**Table A.3: Propensity to Knowledge and Technology Transfer Activities (KTT); research activities (REAS); educational activities EDUC2; consulting activities (CONS); activities related to joint technical structure (INFR)**

Firm characteristics	KTT <sup>(1)</sup>	EDUC2 <sup>(1)</sup>	REAS <sup>(1)</sup>	CONS <sup>(1)</sup>	INFR <sup>(1)</sup>
	(probit)	(probit)	(probit)	(probit)	(probit)
LQUAL <sup>(2)</sup>	0.308 (0.036)		0.262 (0.086)		
LCI <sup>(3)</sup>					
LEXP <sup>(4)</sup>			0.135 (0.044)		0.125 (0.038)
LAGE <sup>(5)</sup>	0.089 (0.039)				
R&D <sup>(6)</sup>	1.172 (0.067)	//	//	//	//
FOREIGN <sup>(7)</sup>		-0.301 (0.135)			
<i>Impediments:</i> <sup>(8)</sup>					
OBSTACLE	0.080 (0.033)				
Lack of information					
OBSTACLE2	-0.108 (0.034)	-0.142 (0.057)			
Firm deficiencies					
OBSTACLE3	-0.108 (0.034)				
Deficiencies of science institutions					
OBSTACLE4			0.161 (0.074)	-0.164 (0.070)	
Costs, risks					
OBSTACLE5				-0.162 (0.068)	
Organizational/institutional obstacles					
<i>Motives:</i> <sup>(9)</sup>					
MOTIV1	//	0.404 (0.055)		0.245 (0.063)	
Access to human capital („tacit knowledge“)					
MOTIV2	//	0.217 (0.054)	0.700 (0.075)	0.251 (0.063)	0.342 (0.064)
Access to research outcomes („codified knowledge“)					
MOTIV3	//		0.260 (0.066)	0.173 (0.062)	0.405 (0.062)
Financial motives					
MOTIV4	//		0.313 (0.062)	0.299 (0.060)	
Organizational/institutional motives					
IND_1 <sup>(10)</sup>					
IND_2 <sup>(11)</sup>				0.454 (0.180)	
IND_3 <sup>(12)</sup>			-0.562 (0.171)	0.295 (0.145)	

IND_4 <sup>(13)</sup>			-0.539 (0.211)		
IND_5 <sup>(14)</sup>				0.623 (0.298)	
DL_1 <sup>(15)</sup>					
DL_2 <sup>(16)</sup>					
<i>Firm size:</i>					
20-49 employees	0.204 (0.102)				
50-99 employees	0.447 (0.104)				
100-199 employees	0.464 (0.105)	-0.298 (0.131)	-0.652 (0.180)	-0.365 (0.163)	-0.355 (0.161)
200-499 employees	0.685 (0.112)				
500-999 employees	1.003 (0.181)				
1000 and more employees	1.418 (0.225)				
<i>Region:</i>					
Lake of Geneva	-0.356 (0.107)				
Espace-midland				-0.311 (0.155)	
Northwestern Switzerland					
Eastern Switzerland					
Central Switzerland	-0.222 (0.111)				
Ticino	-1.034 (0.242)				
Const.	-2.609 (0.202)		-1.846 (0.299)	-0.968 (0.096)	-1.292 (0.132)
N	2428	635	635	635	635
N (KTT-active)	635	283	149	120	122
Adjusted McFadden R <sup>2</sup>	0.284	0.087	0.287	0.084	0.153
LR statistic ( $\chi^2$ )	823	86	217	74	103
% concordant	85	71	86	74	77

*Note:* (1): KTT: knowledge and technology transfer activities in the period 2002-2004 and/or in the period before 2002; EDUC2 (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities *and* taking the value 0 for the variable REAS; 0: all other KTT-active firms); REAS: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities (see table A.2 in the appendix); 0: all other KTT-active firms); INFR: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of activities related to technical infrastructure (see table A.2 in the appendix); 0: all other KTT-active firms); CONS: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of consulting activities (see

table A.2 in the appendix); 0: all other KTT-active firms); (2): LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); (3): LCI: logarithm of gross investment per employee 2004; (4): LEXP: logarithm of exports as a share of sales; (5): LAGE: logarithm of firm age; (6): dummy variable for R&D activities; (7): FOREIGN: dummy variable for foreign firms; (8): impediments: factor values of a five-factor solution of a principal component factor analysis of the original 26 variables for single impediments of KTT, which were measured at a five-point Likert scale (1: "not important"; 5: "very important") (see table A.2 for details); (9): motives: factor values of a four-factor solution of a principal component factor analysis of the original 20 variables for single motives for KTT, which were measured on a five-point Likert scale (1: "not important"; 5: "very important"); (10): food and beverage, textiles, clothing and leather, wood processing; (11): paper, printing, chemicals, plastics and rubber, glass, stone and clay; (12): metal, metal working, machinery, electrical machinery; (13): electronics and instruments, watches, vehicles; (14): other manufacturing, energy and water; (15): wholesale trade, transportation, banking and insurance; (16): computer services, business services, telecommunication; reference industry: construction; 6 dummy variables for firm size; 6 dummy variables for geographical region; reference firm size class: 5-19 employees; reference region: Ticino. Only the coefficients are shown which were statistically significant at the 5% test level after a backward elimination of other variables.

**Table A.4: Probit estimates of the instrument equations for KTT, EDUC1 and REAS**

Explanatory variables	KTT <sup>(1)</sup>	EDUC1 <sup>(1)</sup>	REAS <sup>(1)</sup>
LEXP <sup>(2)</sup>	0.188*** (0.016)	-0.025 (0.057)	0.177** (0.071)
LAGE <sup>(3)</sup>	0.132*** (0.034)	-0.066 (0.108)	-0.154 (0.124)
<i>Motives:</i> <sup>(4)</sup>			
MOTIVE1 Access to human capital ("tacit knowledge")	//	0.155 (0.107)	0.372*** (0.117)
MOTIVE2 Access to research outcomes ("codified knowledge")	//	0.531*** (0.119)	1.188*** (0.136)
MOTIVE3 Financial motives	//	0.390*** (0.116)	0.595*** (0.116)
MOTIVE4 Institutional, organizational motives	//	1.028*** (0.111)	0.155 (0.115)
<i>Obstacles:</i> <sup>(5)</sup>			
OBSTACLE1 Lack of information	0.122*** (0.029)	0.137 (0.109)	-0.144 (0.118)
OBSTACLE2 Firm deficiencies	-0.191*** (0.031)	0.192* (0.116)	0.115 (0.127)
OBSTACLE3 Deficiencies of science institutions	-0.063** (0.030)	0.054 (0.104)	-0.248** (0.126)
OBSTACLE4 Costs, risks	0.139*** (0.029)	0.007 (0.108)	0.166 (0.131)
OBSTACLE5 Organizational/institutional obstacles	0.052* (0.029)	-0.344*** (0.109)	-0.069 (0.126)
<i>Region:</i>			
Lake of Geneva	0.783*** (0.216)	0.462 (0.890)	0.217 (0.900)
Espace-midland	0.939*** (0.205)	0.213 (0.844)	-0.074 (0.845)
Northwestern Switzerland	0.930*** (0.209)	0.541 (0.858)	-0.070 (0.857)
Zurich	1.090*** (0.206)	0.324 (0.848)	0.120 (0.852)
Eastern Switzerland	0.978*** (0.207)	0.287 (0.843)	-0.474 (0.845)
Central Switzerland	0.778*** (0.217)	0.204 (0.887)	-0.437 (0.919)
Constant	-2.437*** (0.239)	0.689 (0.934)	-1.420 (0.970)
N	2533	644	644
McFadden R <sup>2</sup>	0.186	0.339	0.393
LR statistic ( $\chi^2$ )	332***	182	194***
% concordant	73	81	84

Note: (1): KTT: knowledge and technology transfer activities in the period 2002-2004 and/or in the period before 2002; EDUC1: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities (see table A.2 in the appendix); 0: all other KTT-active firms); REAS: 1:

firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities (see table A.2 in the appendix); 0: all other KTT-active firms); (2): LEXP: logarithm of exports as a share of sales; (3): LAGE: logarithm of firm age; (4): motives: factor values of a four-factor solution of a principal component factor analysis of the original 20 variables for single motives for KTT, which were measured on a five-point Likert scale (1: “not important”; 5: “very important”); (5): impediments: factor values of a five-factor solution of a principal component factor analysis of the original 26 variables for single impediments of KTT, which were measured at a five-point Likert scale (1: "not important"; 5: "very important"); dummies for the geographical region; reference region: Ticino; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level.

**Table A.5 Correlation matrix; innovation models; labour productivity model**

	LQUAL	LCI	LRD	FOREIGN
LCI	0.060			
LRD	0.228	0.111		
FOREIGN	0.155	-0.004	0.124	
KTT	0.233	0.095	0.507	0.104