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Abstract

This paper analyzes the relationship between competition and R&D cooperation with universities and competitors. Our simple model predicts that more competitors reduce the incentives for horizontal cooperation as it diminishes the gains from "collusion". Assuming that the value of synergies and spillovers created by cooperation depends on competition intensity reveals two distinct and opposing incentives for cooperation. While synergies foster R&D cooperation, spillovers may hinder cooperation. We mainly hypothesize that university cooperation corresponds to product innovation and hence quality competition, while horizontal cooperation lead to process innovations and therefore relates to price competition. We test these hypotheses based on Swiss firm-level panel data controlling for simultaneity of cooperation decisions and endogeneity of competition. Our empirical analysis supports the relevance of distinguishing between competition dimensions and cooperation partners, respectively. We find that price competition matters for both university and horizontal cooperation and it takes the form of an inverted U-shape. On the contrary, quality competition only matters for university cooperation and the relationship shows a U-form. Moreover we see that the number of principal competitors is significantly related only to cooperation between competitors and the relationship shows an inverted U-form. Hence, markets with a medium number of competitors are more receptive for horizontal cooperation. In sum these findings advance our understanding of the relationship between innovation and competition policy.

JEL Classification: O3

Key words: innovation cooperation, university cooperation, horizontal cooperation, number of competitors, price competition, quality competition, synergy, knowledge spillover, collusion

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1. Introduction

This paper provides a theoretical as well as empirical investigation about the relationship between competition and R&D cooperation partner choice. More concretely we look at the relationship between competition and R&D cooperation with competitors and/or R&D cooperation with universities. This is an interesting research question for several reasons. Firstly, Fehr and Fischbacher (2003) found that in the absence of any institutional restrictions individuals prefer to cooperate. Since competition can be seen as an institutional restriction to avoid cooperation among competitors, we should not observe cooperation among competitors in very competitive markets. Secondly, since Smith (1776) we know that the temptation to "collude" among competitors is considerable and hence it is not surprising that in economic practice we observe both, competitive behaviour on sales markets and cooperation in R&D (Research and Development). Even more, certain competitive constellations (e.g. few principal competitors) may facilitate and promote cooperation behaviour. Thirdly, when looking at the relationship between competition and R&D cooperation partner, existing literature does not distinguish between the type of cooperation partner, i.e. universities or competitors.

This paper adds to the literature by developing a simple theoretical framework that illustrates the relationship between competition and the type of R&D cooperation partner and by testing the predicted hypothesis in an empirical setting.

Our framework distinguishes between two partner types, namely university partners and horizontal partners (competitors). Based on the existing empirical evidence (see, e.g., Miotti and Sachwald, 2003, Belderbos et al., 2004 and Aschhoff and Schmidt, 2008), we assume that university cooperation[1] relates to product innovation while horizontal cooperation corresponds to process innovation. In order to account for these differences between the cooperation goals, we differentiate two dimensions of competition intensity, namely price and quality competition. Furthermore we measure the number of principal competitors, which is the third measure of competition.

Given this setup, the framework discusses three distinct channels by which competition effects cooperation partner choice. First, an increasing value of the synergies realized in cooperation suggests positive incentives for cooperation. Secondly, the knowledge spillovers created through cooperation create disincentives to cooperate. Given that cooperation increases the probability of innovation, the incentives for cooperation are related to the market value of innovation. A great market value of innovation increases the incentives for innovation and vice versa. Furthermore we know that the market value of innovation is

[1] When we are talking about cooperation we always refer to R&D cooperation.

related to competition. In the literature we find three stylized types of relationships. Arrow (1962) under the assumption of closed markets found a positive relationship between innovation and competition, i.e. innovation activities increase with competition intensity. Schumpeter (1942) proposed a negative relationship, and Aghion et al. (2005) found an inverted U-shape relationship between innovation and competition, i.e. the incentives for innovation increase until a certain point and decrease beyond that point. Assuming an inverted U-shape incentive structure suggests that the probability for cooperation increases with lower competition intensity and decreases with greater competition intensities if the synergy effect prevails. If the spillover effect prevails, we would see exactly the opposite, a U-shape relationship between competition and cooperation. This is due to the fact that knowledge spillovers gain in importance if the innovation market value increases and loose importance if the innovation market value decreases. Since spillovers cause negative incentives for cooperation, we would observe decreasing cooperation probabilities if competition increases until a certain point and we would see that the cooperation probability increases beyond that point. Remember we assume an inverted U-shape incentive structure. In sum we see that the relationship between cooperation and competition (in terms of price and quality competition) is ambiguous. Although we assumed a certain incentive structure of competition, the relationship depends on the dominance of "synergies" or "spillovers".

The third channel, the ability of a firm to collude with its competitors as well as the benefits from collusion depends on the market concentration, suggesting a negative relationship between the number of principal competitors and horizontal cooperation.

Our empirical findings are based on comprehensive firm-level panel data of Swiss firms (Swiss Innovation Survey). We focus on R&D active manufacturing firms. Against the background of our theoretical findings we can empirically confirm the presence of synergies, since our proxies for incoming spillovers, absorptive capacity, and technological potential are positively related to both types of cooperation partners. Furthermore we find evidence supporting the hypothesis that the presence of spillovers effects cooperation partner choice, as our proxy for appropriability is positively related to cooperation with universities but not to cooperation with competitors, though the estimate becomes insignificant once we instrument our proxies for competition.

Price competition intensity matters for both university and horizontal cooperation, though only after instrumentalisation. The relationship takes the form of an inverted U-shape supporting the hypothesis that the inverted U-shape of synergies dominates. The finding further indicates that university cooperation yields synergies in respect to process innovation.

Furthermore we find a U-shape relationship between quality competition and university cooperation, suggesting that the existence of knowledge spillovers are important in this case. In line with our predictions, we do not find a relationship between quality competition and horizontal cooperation.

We also find evidence that the value of collusion matters, as there is an inverted U-shape relationship between number of principal competitors and the probability of cooperation among competitors. This indicates that in markets with a medium number of principal competitors, horizontal cooperation are more likely compared to markets with very few competitors and markets with many competitors. This is plausible, since competition authorities are likely to prohibit cooperation in markets with very few competitors and in markets with many competitors the gains from horizontal collusion are diminishing.

In sum the results show that competition is significantly related to cooperation. However, the form of the relationship depends on the type of competition (price, quality, number of competitors) and on the type of partners. Synergies in cooperation activities and knowledge spillovers are important factors in order to understand how competition effects cooperation decisions.

The paper is organized as follows. The second chapter presents the existing literature. Chapter three introduces our theoretical framework and subsequent hypotheses. Chapter four discusses the data and the empirical setup. Chapter five presents the results and chapter six concludes.

2. Literature Review

There are mainly two strains of literature related to the investigation at hand. First, there is a great amount of literature analyzing the relationship between competition and innovation. Secondly, there exists a small but increasing literature investigating the driving forces for R&D partner choice. What is hardly investigated empirically as well as theoretically is the relationship between competition and R&D partner choice.

The literature referring to innovation and competition goes (at least) back to Schumpeter (1912, 1942). Schumpeter (1942) argued that competition reduces the expected profit reaped from innovating and hence reduces the incentives to invest in R&D. However, in the case of concentrated markets, firms may refrain from introducing new innovative products since part of the revenues of older products would be challenged (see Arrow 1962; replacement effect). Thus, firms in concentrated markets have low incentives to invest in R&D and commercialize new products. Geroski (1990) argues in a similar way. He stated that a monopolist whose position is based on previous innovation will have a lower net return on innovation than new market entrants, since a new innovation from a monopolist would displace part of its revenues from the older products. Furthermore, the opportunity cost for monopolists in order to develop a new technology are greater compared to new entrants, if the capital stock of incumbents is locked into an older technology. Hence expected returns and hence incentives to innovate are greater in competitive markets.

Gilbert (2006) combines the findings of Schumpeter and Arrow into an intuitive argument that moderate levels of competition should promote innovation. In highly competitive markets, the incentive to innovation may be small because small scale units might benefit less from new technologies, while the Arrow replacement effect dominates in monopolistic markets. Thus, intermediate levels of competition should prepare the most fertile environment for innovation. Empirical tests confirm the inverted U-relationship between innovation and competition (see Levin et al. 1985, Aghion et al. 2005). However the inclusion of proxies for technical opportunity and appropriability into innovation equations weakens the proposed relationship, while technological opportunity and appropriability remained significant (see Gilbert 2006). Furthermore, it remains unclear how to measure competition (see e.g. Boone 2008a, 2008b and Vives 2008).

The second strain of literature relevant to our research at hand refers to the driving forces for R&D partner choice. Here, it is well understood that incoming spillovers, appropriability, and absorptive capacity (see Cohen and Levinthal 1989, 1990 and Cassiman and Veugelers 2002) are positively related with R&D collaboration. We also know that differences between partner types exist. Higher incoming spillovers are positively related with the probability to cooperate with public research institutions, while better appropriability results in a higher propensity to cooperate with customers or suppliers (see Cassiman and Veugelers 2005). Also R&D contracts (buy) and in-house activities (make) have been subject to several empirical investigations (see, e.g., Beneito 2006, Veugelers and Cassiman 1999 and Veugelers 1997).

Finally, the literature contains a small number of papers studying the relationship between innovation cooperation and competition, reporting rather mixed results. Hernán et al. (2003), Röller et al. (2007) and Negassi (2004) find a positive relationship between market concentration and cooperation, i.e. a negative relationship between competition and cooperation. Similarly, Beneito (2003) reports an increasing probability of in-house R&D as the number of principal competitors increases. However, Eisenhardt and Schonhofen (1996) find a positive impact of the number of competitors on cooperation and Hayton et al. (2010) find a negative relationship between market concentration and cooperation.

Colombo et al. (2006) do not find a significant relationship between a direct measure of price competition intensity and technological cooperation. However, using a similar measure, Woerter (2010) finds a positive impact of price competition on cooperation. Furthermore, he does not find a significant relationship between the number of principal competitors or quality competition and cooperation.

The literature review shows that the relationship between innovation and competition is well investigated and that we have also some knowledge about the driving forces for R&D collaborations. However, the literature does not tell us how competition is related to R&D partner choice. Hence in the next chapter we try to develop our hypotheses based on the just mentioned two strains of related literature.

3. Theoretical Framework

In our simple framework, firm i maximizes the expected return to innovation input, $E[r_i]$, the ratio of innovation profit, π, and innovation input, x.[2] Multiplying both the nominator and the denominator of the expected return to innovation input by innovation output, y, allows to decompose the expected return to innovation input into two components, namely innovation productivity, λ, and return to innovation output, pcm. Since profit is the product of the price-cost margin and output, the return to innovation output collapses to what is commonly referred to as price-cost margin. Hence, we denote the return to innovation output as pcm. Assuming ex-ante symmetry of firms and perfect foresight, we write $E[r_i]$ as:

$$E[r_i] = \mathrm{r} = \frac{\pi}{\mathrm{x}} = \frac{\mathrm{y}}{\mathrm{x}} * \frac{\pi}{\mathrm{y}} = \lambda * \mathrm{pcm} \quad (1)$$

The decomposition into innovation productivity and price-cost margin frames two distinct channels through which innovation cooperation, C={0,1}, effects the return to innovation input. We label the impact of cooperation on innovation productivity the *synergy effect*, S. It increases innovation productivity from λ to Sλ and hence r to Sr. The *competition effect*, G, refers to the impact of cooperation on the competitive environment and hence the price-cost margin, which increases from pcm to Gpcm and hence r to Gr.

Before discussing these effects in detail, we introduce the distinction between two types of innovation cooperation analyzed in this paper, namely cooperation with universities, C_u, and horizontal cooperation with competitors, C_h. The probability to cooperate with partner type j={u,h} refers to the probability that the return under cooperation exceeds the return without. Since cooperation partner choices are interrelated, we write the probability to cooperate with partner type j conditional on other collaborations C_{-j}:

$$\mathrm{prob}[C_j=1|C_{-j}] = \mathrm{prob}[S_j\lambda*G_j\mathrm{pcm})\geq\lambda*\mathrm{pcm}|C_{-j}]=\mathrm{prob}[S_jG_j \geq 1|C_{-j}] \quad (2)$$

[2] Since this paper focuses on the cooperation decision, we treat innovation input as predetermined.

where λ_j and pcm_j denote innovation productivity and price-cost margin under cooperation. The last equality of equation (2) reveals that the cooperation decision depends on the relationship between the *synergy* and *competition effect*, rather than on the level of innovation productivity or price-cost margin, i.e. cooperation takes place if S times G exceeds one.

In order to understand cooperation decisions, we further need to distinguish between product and process innovations, suggesting that the return to innovation input is a weighted function of these two innovation types.

Miotti and Sachwald (2003) find a significant positive impact of university cooperation on patenting activities but not on the sales share of innovative products. Horizontal cooperation effects neither patenting activities nor sales share of innovative products. Belderbos et al. (2004) show that university cooperation increases growth in innovative sales productivity but not in labor productivity. Conversely, horizontal cooperation mainly increases labor productivity. Aschhoff and Schmidt (2008) find that university cooperation enhances the sales share generated by market novelties but they do not have an impact on cost reductions, while the opposite holds for horizontal cooperation. Based on these empirical findings, the key assumptions of our model are that

a) only university cooperation increases product innovation productivity
b) only horizontal cooperation enhances process innovation productivity.

This theoretical framework allows us to discuss the *synergy effect* and *competition effect* and deduce hypothesis in respect to the relationship between competition and cooperation:

Kamien et al. (1992) argue that the *synergy effect*, i.e. the improvement in innovation productivity from λ to $S\lambda$, arises because innovation cooperation eliminates wasteful duplication and hence increases research productivity. Similarly, Glaister and Buckley (1996) argue that economies of scale and the transfer of complementary resources create synergies. The *synergy effect* increases in incoming spillovers (Cassiman and Veugelers, 2002), absorptive capacity of the firm (Cohen and Levinthal 1989, 1990), and technological opportunity.

Hypothesis 1: Incoming spillovers, absorptive capacity and technological potential increase the probability of R&D cooperation.

The *synergy effect* as defined so far creates no relationship of cooperation to the competitive environment. However, assuming that the value of enhancing innovation productivity depends on competition suggests a relationship between competition and cooperation. The existing literature discusses three potential forms of the relationship between innovation value and competition, namely an increasing (see, e.g., Arrow, 1962), decreasing (see, e.g., Schumpeter, 1942) or inverted U (see, e.g., Aghion et al.m 2005) shape. Hence we remain agnostic in respect to the functional form of the *synergy effect*.

The *competition effect* captures the relationship between cooperation and the competitive environment. It moves the price-cost margin from pcm to Gpcm. The *competition effect* consists of two distinct effects: the *collusion effect* and the *spill+ effect*.

The *spill+ effect* arises because cooperation increases outgoing spillovers and thereby enhances competition. These effects can be indirect, e.g. in the case of universities, where the knowledge acquired by the university in the course of the cooperation is spread to the wider economy through technology transfer activities with other cooperation partners. The *spill+ effect* decreases in appropriability, which denotes the ability of a firm to protect its knowledge and to control outgoing spillovers. The *spill+ effect* resembles the *synergy effect* in a way that the relationship between competition and cooperation depends on the relationship between the value of innovation and competition[3], i.e. whether it increases, decreases or follows an inverted U-shape. While the synergy effect increases profits, spillovers reduce profits.

Hence, the predicted form of the relationship between cooperation and competition depends upon whether the *spill+ effect* or the *synergy effect* prevails. If we assume an inverted U-shape relationship between innovation value and competition (see Aghion et al. 2005), we would expect that the incentive for cooperation increases with competition for lower levels of competition intensity and it decreases with higher levels of competition. In case the spill+ effect prevails, we would think that the negative value of spillovers increases with the market value of innovation. Hence, the greater the market value of innovation the greater spillovers and the lower the probability for cooperation. If the market value of innovation decreases also the importance of spillovers decreases and hence the probability of cooperation increases. In sum we see that in assuming an inverted U-shape relationship between innovation value and competition, we see a U-shape relationship between competition and cooperation if the spillover effect prevails. However, if we would assume a Schumpeterian relationship where innovation value decreases with competition, the probability of cooperation would increases with competition, if the spill+ effect prevails.

Now it should be obvious that *synergy* and *spill+ effect* predict the opposite relationship between competition and cooperation. A potential reconciliation between these opposing forces is to assume that firms protect their intellectual property better when competition intensifies and hence the *spill+ effect* becomes weaker. Assuming no parallel effect for the value of synergies suggests that the *spill+ effect* described dominates for low levels of

[3] Like mentioned above, we assume that cooperation increase the probability for innovation.

competition while the *synergy effect* dominates for high levels of competition. Nevertheless, the uncertainty concerning the underlying relationship between the value of innovation and competition remains.

Given the theoretical uncertainty, we remain agnostic in respect to the functional form of the relationship between competition and cooperation. The theoretical uncertainty could only be solved if we make a strong assumption about the relationship between innovation value and competition and if we would know (ex ante) whether the spill+ effect or the synergy effect prevails. Taking into account our two key assumptions (only horizontal cooperation enhances process innovation productivity and only university cooperation increases product innovation productivity) implies

Hypothesis *2a) Price competition has no relation to university.*
2b) Price competition and horizontal cooperation have a significant relationship of ambiguous form.

3a) Quality competition and university cooperation have a significant relationship of ambiguous form.
3b) Quality competition has no relation to horizontal cooperation.

Finally, the *collusion effect* increases the price-cost margin by reducing the number of effective competitors and hence competitive pressure. It only occurs in horizontal cooperation. The *collusion effect* is strongest for a duopoly and decreases as competition intensifies, as shown empirically by Oxley et al. (2009) and Tong and Reuer (2010). Clougherty and Duso (2009) on the other hand find evidence of the *collusion effect* but not of differences in market concentration.

Hypothesis 4: a) The number of principal competitors decreases horizontal cooperation
b) The number of principal competitors has no impact on university cooperation

Hernán et al. (2003), Röller et al. (2007), Negassi (2004) and Beneito (2003) support the hypothesis that cooperation decreases as markets become less concentrated, though only Hernán et al. (2003) focus on horizontal cooperation. Eisenhardt and Schonhofen (1996) on the other hand argue that the value of cost and risk sharing increases in competition and show empirically a positive relationship between the number of competitors and cooperation. Similarly, Hayton et al. (2010) find a negative relationship between market concentration and cooperation. Woerter (2010) does not find a significant relationship between the number of principal competitors and cooperation.

4. Data and Methodology

4.1. Data

We use a panel of Swiss firms observed across five periods (1996, 1999, 2002, 2005, and 2008). The Swiss Economic Institute (KOF) at the ETH Zurich collected the data in the course of five postal surveys using a questionnaire similar to the "Community Innovation Survey" (available from www.kof.ethz.ch[4]). The data includes information on firm characteristics, innovation activities, and R&D activities, among other things. The surveys are based on a stratified random sample of firms having at least five employees covering all relevant industries in the manufacturing, construction, and service sectors. Stratification depends on 28 industries and, within each industry, three firm size classes (with full coverage of the upper class of firms). The number of observations (response rates) are 1748 (32.5%), 2172 firms (33.8%), 2583 firms (39.6%), 2555 firms (38.7%), and 2141 (36.1%) for the years 1996, 1999, 2002, 2005 and 2008 respectively. The employed sample entails only R&D active manufacturing firms, thereby ensuring sample homogeneity and hence internal validity, but questioning external validity. Dropping observations with missing values yields a highly unbalanced firm-panel with 3296 observations.

4.2. Empirical setting

The empirical estimation consists of two equations with binary dependent variables (COOP UNI and COOP HOR) which indicate whether a firm has conducted innovation cooperation with a particular partner type within the previous three years. Hence we estimate both equations defined by (5) using probit estimators:

$$\text{prob}[\text{COOP UNI}_{i,t}=1|\text{COOP HOR}_{i,t}]=\text{prob}[\beta_{u,0}+\beta_{u,1}\text{SPILLINC}_{i,t}+\beta_{u,2}\text{ABSCAP}_{i,t}+\beta_{u,3}\text{TECHPOT}_{i,t}+\beta_{u,4}\text{ APPROP}_{i,t} +\Sigma_j\beta^j_{u,5}\text{QUALCOMP}^j_{i,t} +\Sigma_j\beta^j_{u,6}\text{PRICECOMP}^j_{i,t} +\Sigma_j\beta^j_{u,7}\text{COMPETITORS}^j_{i,t}+\beta_{u,8}\text{Control}_{i,t}+\varepsilon_{u,i,t}\geq 0] \quad (5a)$$

$$\text{prob}[\text{COOP HOR}_{i,t}=1|\text{COOP UNI}_{i,t}]=\text{prob}[\beta_{h,0}+\beta_{h,1}\text{SPILLINC}_{i,t}+\beta_{h,2}\text{ABSCAP}_{i,t}+\beta_{h,3}\text{TECHPOT}_{i,t}+\beta_{h,4}\text{ APPROP}_{i,t} +\Sigma_j\beta^j_{h,5}\text{QUALCOMP}^j_{i,t} +\Sigma_j\beta^j_{h,6}\text{PRICECOMP}^j_{i,t} +\Sigma_j\beta^j_{h,7}\text{COMPETITORS}^j_{i,t}+\beta_{u,8}\text{Control}_{i,t} +\varepsilon_{h,i,t}\geq 0] \quad (5b)$$

where i refers to firm and t to time. j={1,2} describes the quadratic polynomial of competition variables. Subscripts u and h denote coefficients of the estimation with university and horizontal cooperation as dependent variable, respectively.

In order to account for interdependence between cooperation choices, we also estimate the equation system using a multivariate probit model, i.e. a SUR model with binary dependent variables. Assuming multivariate normal distribution of the robust error terms ε_u and ε_h, we

[4] Questionnaires are available in German, Italian, and French language.

estimate the system by simulated maximum likelihood with 400 draws (see, e.g., Greene 2003, p. 710). In order to account for the potential interdependence of university and horizontal cooperation with other forms of knowledge acquisition, we also estimate a specification with two additional equations for vertical and group internal cooperation, respectively. Finally, we address the problem of endogeneity and simultaneity (see, e.g., Gilbert, 2006) by instrumenting competition using an IV estimator.[5]

The vector of independent variables follows our theoretical framework and the empirical model specification of Cassiman and Veugelers (2002). Table 1 provides details about the construction of variables. Tables A1 and A2 in the appendix display summary statistics and pair-wise correlations of the employed variables.

We measure the relevance of atmospheric spillovers (SPILLINC) as the average importance of several information sources, including universities, horizontal, vertical and group internal information sources. The share of employees holding a tertiary education degree captures absorptive capacity (ABSCAP). The data further allows us to control for technological potential outside of the firm (TECHPOT).[6] The inverse of the innovation obstacle "easiness to copy" approximates appropriability (APPROP), since we assume that appropriability is low if competitors can easily copy innovation results and the other way round.

Following Belderbos et al. (2004), we include the relevance of the innovation obstacle "high costs" in the control vector. This cost variable (COST) refers to the costs of innovation activities. Hence, COST captures the Schumpeterian idea (Schumpeter, 1942) that innovation activities require financial resources. Finally, we control for firm size measured in number of full-time employees (SIZE) and its square (SIZE^2), whether a firm is foreign owned (FOREIGN), whether the firm is an exporter (EXPORT) as well as time and industry dummies.

We include linear and quadratic terms of two types of competition measures, namely the intensity of price and quality competition (PRICECOMP, PRICECOMP_SQU, QUALCOMP, QUALCOMP_SQU) on a five point likert scale (1 very weak … 5 very strong). Furthermore, we can identify the number of principal competitors according to five categories, namely 0-5, 6-10, 11-15, 16-50 and more than 50 principal competitors (NCOMP, NCOMP_SQU). In our base specification, we include the competition variables assuming

[5] Due to multicollinearity between competition measures and the corresponding squared terms, we manually implement the IV estimator, i.e. estimate the first stage using OLS and include the predicted values for both linear and quadratic terms in the second stage probit estimations. Bootstrapping with 400 repetitions corrects for non-simultaneity of the estimation strategy.

[6] Technological potential is defined as the basically available knowledge useful for innovation. Firms have been asked in a questionnaire to evaluate the technological potential on a five point likert scale (1 very low … 5 very high).

linearity, but also report a variation that allows for potential non-linearity by including four distinct dummy variables for each competition dimension. Furthermore we control for industry fixed effects (two-digit level) and time fixed effects.

Table 1 about here

Table 1 summarizes our hypotheses. Incoming spillovers, absorptive capacity, technological potential and appropriability should be positively related to both types of cooperation (COOP UNI and COOP HOR). Quality competition relates to university cooperation, but has no impact on horizontal cooperation. Conversely, price competition is expected to effect horizontal cooperation only. The number of principal competitors should be negatively related to horizontal cooperation.

5. Results

The first two columns of Table 2 display probit models for university cooperation and horizontal cooperation, respectively. Columns 3 and 4 instrument competition measures in the corresponding estimations. Table A3 in the appendix demonstrates the validity of instruments by showing a significant predictive power in the first stage and no direct impact on cooperation in second stage. Marginal effects corresponding to the first four columns of Table 2 appear in Table A4 in the appendix. The last two columns of Table 2 entail the results of a multivariate probit with university cooperation and horizontal cooperation as dependent variables. Finally, Table A5 in the appendix displays a multivariate probit model that entails vertical and group internal cooperation as dependent variables besides university and horizontal cooperation. Table A5 further checks our assumption, that the variable capturing the number of principal competitors can be treated as continuous by including four dummies for the categories 0-5, 6-10, 16-50 and more than 50 principal competitors, respectively. Hence, a medium number of principal competitors, i.e. 11-15, serves as the reference category.

Table 2 shows that SPILLINC, ABSCAP, and TECHPOT are positively related to both COOP UNI and COOP HOR, suggesting the presence of synergies and hence supporting hypothesis 1.

Table 2 about here

We see a positive effect of appropriability (APPROP) for university cooperation but find an insignificant effect for horizontal cooperation. These results indicate that appropriability mechanisms and the fear of spillovers are more important for university cooperation than for horizontal cooperation. A potential explanation for this finding is that university cooperation implies sharing of sensitive information that is closer to firms' core activities than it is the case in horizontal cooperation. This suggests that university cooperation are more technology and innovation oriented while horizontal cooperation focuses more on commercial aspects. However, instrumenting competition variables results in an insignificant impact of appropriability on university cooperation, though the sign of the coefficient estimate remains the same.

Hypothesis 2a predicts that price competition and university cooperation are unrelated, while hypothesis 2b predicts a significant relationship between price competition and horizontal cooperation. Rather surprisingly, simple correlations only support hypothesis 2a as price competition intensity effects neither university nor horizontal cooperation significantly in the base estimation. However, instrumenting price competition yields an inverse U-shaped relationship between price competition and both university cooperation and horizontal cooperation.

This finding rules out a strictly positive or negative relationship between innovation value and competition. Instead, this finding suggests an inverted U-shape relationship between price competition and cooperation in which the synergy effect dominates the spill+ effect. Hence the gains from cooperation in terms of synergies outpace the costs from resulting spillovers if we look at price competition. Moreover, the finding that price competition matters for both types of cooperation partners further suggests that university cooperation leads to synergies in respect to both process and product innovation.

Hypothesis 3a suggests that quality competition (QUALCOMP, QUALCOMP_SQU) and university cooperation have a significant relationship of ambiguous form. Hypothesis 3b claims that quality competition has no impact on horizontal cooperation. Table 2 supports these hypotheses, as we find a U-shaped relationship between quality competition and university cooperation and no correlation between quality competition and horizontal cooperation. However, while the U-shaped relationship holds for the multivariate (MV) estimation and the probit estimation, the significance of the increasing portion of quality competition becomes marginally insignificant when employing the instrumental variable approach. Hence, assuming an inverse U-shaped relationship between the return to innovation and competition as indicated by Aghion et al. (2005), we see that in the case of quality competition the spill+ effect outpaces the synergy effect. This means that cooperation gets less attractive if the market value of innovation increases, since the costs of spillovers outpace the gains from synergies. However if the market values of innovation due to competition decreases the cost of spillovers decrease as well and cooperation with university becomes more attractive.

Quality competition shows a U-shaped relationship with university cooperation, while the functional form follows an inverted U-shape in the case of price competition. This difference between the two competition types suggests that appropriability and hence the *spill+ effect* matters more for product innovation than for process innovation, which is consistent with the differences in the significances of appropriability in the non-instrumented university and horizontal cooperation equations.

Confirming both hypotheses 4a and 4b, Table 2 further reveals that the number of competitors (NCOMP, NCOMP_SQU) effects horizontal cooperation but not university cooperation. However, the impact on horizontal cooperation is nonlinear, i.e. follows an inverted U-shape instead of decreasing linearly in the number of principal competitors. Legal restrictions by competition authorities might explain the increasing part of the relationship, while the decreasing part might be due to the diminishing "collusion gains" of cooperation among competitors if the number of competitors increases. These patterns remain robust after instrumenting competition and accounting for interdependence between university and horizontal cooperation.

Furthermore, our results show that financial constraints, measured by OCOST, increase the probability of university cooperation, but OCOST is not significantly related with horizontal cooperation. This finding implies that the cost-sharing motive applies to university cooperation only, while alternative reasons motivate horizontal cooperation.

We further control for firm size (SIZE, SIZE^2), exporter status (EXPORTER), foreign ownership (FOREIGN), time fixed effects and industry fixed effects. Firm size relation to both types of cooperation follows a U-shape. Exporter status relates positively to university cooperation and negatively to horizontal cooperation. Foreign ownership is negatively related to cooperation with both partner types. However the significance of the coefficients for exporter status and foreign ownership disappears if we employ an instrumental variable approach.

Table A5 checks the robustness of the above results in respect to simultaneity of cooperation decisions with vertical and group internal partners. Furthermore, it allows the number of competitors to effect cooperation non-linearly by including four dummy variables. The bottom panel of Table A5 reports the pair-wise hypotheses that the coefficients are equal.

The results for PRICECOMP, QUALCOMP, OCOST, SPILLINC, ABSCAP, TECHPOT and APPROP remain robust, suggesting that simultaneity represents a minor estimation problem despite significant correlation coefficients, atrho. As above, the estimation suggests no relationship between university cooperation and the number of principal competitors. The functional form for horizontal cooperation, i.e. an inverted U-shape, remains robust as well, though the dummy for very low number of principal competitors becomes marginally insignificant.

Besides providing a robustness check, Table A5 further allows us to asses the nature of vertical and group internal cooperation. Vertical cooperation behaves similarly as university cooperation in respect to competition. Concretely, it remains unaffected by the number of competitors, but follows a U-shaped pattern for quality competition. Furthermore, the relevance of spillovers, absorptive capacity and technological potential all increase vertical cooperation. However, appropriability does not effect cooperation with vertical partners. Furthermore, financial constraints (OCOST) do not matter, suggesting that the ability of universities to overcome financial constraints does not extend to vertical cooperation partners.

Group internal cooperation is unaffected by our competition measures. Furthermore, we do not find evidence for a *spill+ effect* as appropriability remains insignificant. However, since the significance of the relevance of spillovers, absorptive capacity and technological potential suggests the presence of a *synergy effect*.

6. Conclusions

The investigation at hand looks at the meaning of competition for the choice of cooperation partners distinguishing between two types of cooperation partner, i.e. universities and horizontal partners. Our simple theoretical framework distinguishes three channels how competition effects innovation cooperation. First, the *synergy effect* arises due to the increasing value of innovation as competition intensifies, thereby fostering cooperation. Secondly, the increasing value of spillovers *(spill+ effect)* discourages cooperation. Thirdly, the value of collusion *(collusion effect)* increases in market concentration.

Using Swiss firm level data, we confirm our assumptions that university cooperation but not horizontal cooperation corresponds to quality competition and hence product innovation. In addition, both university and horizontal cooperation respond to price competition after instrumentalisation, suggesting that both cooperation partners provide synergies in respect to process innovation. Furthermore, our results support the hypothesis of a collusion effect. Concretely, the relationship between the number of principal competitors and horizontal cooperation follows an inverted U-shape, in which the increasing portion might be due to regulatory restrictions.

An interpretation of our results in terms of competition emphasises two points.
First, competition plays a different role for horizontal and university cooperation, respectively. We do not see any effect of appropriability or quality competition for horizontal

cooperation, indicating that other factors drive firms to collaborate with competitors. Actually, it is the number of principal competitors that provides incentives for horizontal cooperation. Thus, market overview seems to be more important than synergies in innovation activities. In contrast, the number of principal competitors is much less important for cooperation with universities. Here, appropriability and quality competition are important driving forces. Firms try to realize synergies in innovation activities and they take care about outgoing spillovers that might increase product market competition.

Secondly, our results suggest that innovation policy and competition policy are related (see Teece 1992). R&D cooperation are intended to improve the innovation performance of firms. However, in markets with many principal competitors we hardly observe R&D collaborations independently of the type of partner. Furthermore we found that intensive non-price competition (quality competition) is positively related with university collaborations and unrelated with horizontal cooperation. Based on these results one can suggest that in case of competition policy emphasising the number of principal competitors as an important criteria for competition, innovation policy and competition policy go into different policy directions, i.e. innovation policy fostering R&D cooperation goes for markets with few principal competitors and competition policy fostering competition go for markets with many competitors. In case competition policy takes into account non-price competitive factors then innovation and competition policy go into the same direction. Competition policy would (indirectly) also promote firm-university collaborations.

Table 1: Variable Definitions

Name	Definition	Expected Effect	
		COOP UNI	COOP HOR
Dependent Variables			
COOP UNI	Binary variable whether a firm had R&D cooperation with universities or other research institutions in the previous 3 years (yes/no)		
COOP HOR	Binary variable whether a firm had R&D cooperation with competitors in the previous 3 years (yes/no)		
COOP VERT	Binary variable whether a firm had R&D cooperation with suppliers or customers in the previous 3 years (yes/no)		
COOP GROUP	Binary variable whether a firm had R&D cooperation with firms of the same group in the previous 3 years (yes/no)		
Explanatory Variables			
PRICECOMP	Category of price competition intensity on a five point likert scale (1 very weak … 5 very strong)	0	?
QUALCOMP	Category of non-price, or quality competition intensity on a five point likert scale (1 very weak … 5 very strong)	?	0
NCOMP	Category of number of principal competitors between 1 and 5 (0-5,6-10,11-15, 16-50, 50+ competitors)	0	-
SPILLINC	Incoming spillovers, calculated as the average relevance of universities, other research institutions, competitors, suppliers, customers and firm group as a source of information for the R&D activity on a five point likert scale (1 none … 5 very important)	+	+
ABSCAP	Absorptive capacity, measured by the share of workers holding a tertiary education degree	+	+
TECHPOT	Technological potential outside the firm on a five point likert scale (1 very low … 5 very high)	+	+
APPROP	Appropriability, measured by six minus the relevance of the innovation obstacle “easiness to copy” on a five point likert scale (1 none … 5 crucial)	+	+
OCOST	Binary variable that is 1 if the relevance of the innovation obstacle “high costs” scores 4 or 5 on a five point likert scale (1 none … 5 crucial), and 0 otherwise		
FOREIGN	Binary variable that is 1 if the majority of the firm is foreign-owned, and 0 otherwise		
SIZE	Log of the number of full time employees		
TDUM99 …TDUM08	Time dummies for the years 1999, 2002, 2005, 2008		
IND2 … IND18	Industry dummies (two digit level)		
Instrumental Variables			
INST1	Industry average of PRICECOMP (two digit level)		
INST2	Industry average of QUALCOMP (two digit level)		
INST3	Relevance of consulting agencies as a source of information for the R&D activity on a five point likert scale (1 none … 5 crucial)		
INST4	Relevance of innovation obstacle “environmental legislation” on a five point likert scale (1 none … 5 crucial)		
INST5	Relevance of innovation obstacle “building legislation” on a five point likert scale (1 none … 5 crucial)		
INST6	Industry average of the relevance of innovation obstacle “lack of R&D personnel” on a five point likert scale (1 none … 5 crucial)		

Note: ? means significant relationship of ambiguous form; 0 means no relationship; + and – means significant positive and significant negative relationship, respectively.

Table 2: Main Table

	Prob Uni	Prob Hor	IV Uni	IV Hor	MV Uni	MV Hor
NCOMP	-0.054	0.264**	-0.068	2.141**	-0.045	0.277**
	(0.098)	(0.110)	(0.897)	(1.047)	(0.098)	(0.109)
NCOMP^2	0.008	-0.048**	-0.115	-0.312*	0.007	-0.050***
	(0.017)	(0.019)	(0.174)	(0.187)	(0.017)	(0.019)
PRICECOMP	0.022	0.064	3.966**	3.348*	0.011	0.080
	(0.179)	(0.200)	(1.806)	(1.992)	(0.177)	(0.202)
PRICECOMP^2	0.003	-0.004	-0.512**	-0.402	0.004	-0.006
	(0.024)	(0.027)	(0.227)	(0.249)	(0.024)	(0.027)
QUALCOMP	-0.304**	-0.137	-6.003*	-0.862	-0.317**	-0.140
	(0.152)	(0.175)	(3.335)	(1.975)	(0.149)	(0.177)
QUALCOMP^2	0.048**	0.027	0.701	0.082	0.049**	0.026
	(0.023)	(0.026)	(0.467)	(0.288)	(0.023)	(0.026)
SPILLINC	0.323***	0.177***	0.551***	0.194***	0.321***	0.169***
	(0.048)	(0.052)	(0.141)	(0.065)	(0.047)	(0.052)
ABSCAP	0.010***	0.007***	0.010***	0.010***	0.011***	0.007***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
TECHPOT	0.167***	0.088***	0.256***	0.085**	0.166***	0.080**
	(0.028)	(0.032)	(0.055)	(0.036)	(0.028)	(0.032)
APPROP	0.059**	-0.006	0.025	0.018	0.060**	-0.010
	(0.024)	(0.026)	(0.030)	(0.030)	(0.024)	(0.026)
OCOST	0.151***	0.026	0.189***	0.035	0.150***	0.023
	(0.056)	(0.062)	(0.070)	(0.078)	(0.055)	(0.061)
SIZE	-0.047	-0.164*	-0.295*	-0.143	-0.066	-0.147
	(0.090)	(0.089)	(0.159)	(0.111)	(0.090)	(0.090)
SIZE^2	0.024**	0.028***	0.053***	0.026**	0.026***	0.027***
	(0.009)	(0.009)	(0.018)	(0.011)	(0.010)	(0.009)
EXPORTER	0.005***	-0.002**	0.003	0.002	0.005***	-0.002**
	(0.001)	(0.001)	(0.002)	(0.003)	(0.001)	(0.001)
FOREIGN	-0.149**	-0.177**	-0.200*	0.035	-0.144**	-0.180**
	(0.070)	(0.085)	(0.117)	(0.149)	(0.070)	(0.084)
CONSTANT	-2.485***	-2.104***	2.531	-10.357*	-2.405***	-2.110***
	(0.455)	(0.524)	(6.883)	(5.494)	(0.449)	(0.532)
N	3272	3272	3272	3272	3272.000	
Wald chi2	603.403	184.885	610.392	165.787	747.195	
Prob > chi2	0.000	0.000	0.000	0.000	0.000	
atrho					0.679***	
					(0.046)	

The table displays coefficients and robust standard errors in parentheses. *, ** and *** denote significance levels of 10%, 5% and 1%, respectively. Columns 2 and 3 show the results of probit models for universities and horizontal partners, respectively. Columns 4 and 5 display the second stage results of a manual IV estimator for universities and horizontal partners, respectively. Standard errors are bootstrapped with 400 repetitions. Columns 6 and 7 each capture an equation for universities and horizontal partners of a multivariate probit model with 400 draws. "atrho" denotes correlations between equations. In addition to the displayed coefficients, all estimations entail year and industry dummies.

Appendix:

Table A1: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
COOP UNI	3272	0.26	0.44	0	1
COOP HOR	3272	0.13	0.33	0	1
COOP VERT	3272	0.35	0.48	0	1
COOP GROUP	3272	0.17	0.37	0	1
PRICECOMP	3272	4.01	0.97	1	5
QUALCOMP	3272	3.35	0.92	1	5
NCOMP	3272	2.36	1.30	1	5
SPILLINC	3272	2.76	0.64	1	5
ABSCAP	3272	20.11	17.21	0	100
TECHPOT	3272	3.11	1.05	1	5
APPROP	3272	3.43	1.19	1	5
OCOST	3272	0.43	0.49	0	1
SIZE	3272	4.47	1.40	0	9.95
EXPORTER	3272	45.19	37.09	0	100
FOREIGN	3272	0.18	0.38	0	1
INST1	3272	4.01	0.24	2.83	4.61
INST2	3272	3.35	0.20	2.57	4.33
INST3	3272	1.97	1.02	1	5
INST4	3272	2.01	1.16	1	5
INST5	3272	2.00	1.22	1	5
INST6	3272	3.05	0.30	2.05	4

Table A2: Crosscorrelations

	COOP UNI	COOP HOR	COOP VERT	COOP GROUP	PRICECOMP	QUALCOMP	NCOMP
COOP UNI	1.0000						
COOP HOR	0.3407*	1.0000					
COOP VERT	0.6667*	0.4210*	1.0000				
COOP GROUP	0.4771*	0.2860*	0.5055*	1.0000			
PRICECOMP	0.0561*	0.0353*	0.0627*	0.0524*	1.0000		
QUALCOMP	0.0670*	0.0440*	0.0362*	0.0399*	-0.0084	1.0000	
NCOMP	-0.0412*	0.0114	-0.0318	-0.0575*	0.1432*	0.0622*	1.0000
SPILLINC	0.2227*	0.1038*	0.1497*	0.2258*	0.1129*	0.1422*	-0.0028
ABSCAP	0.1917*	0.0808*	0.1240*	0.1068*	-0.0929*	0.0551*	-0.1033*
TECHPOT	0.2339*	0.0968*	0.1897*	0.1468*	0.0420*	0.1128*	-0.0189
APPROP	0.0315	-0.0232	-0.0164	0.0234	-0.0778*	-0.0186	-0.0744*
OCOST	0.0930*	0.0409*	0.0745*	0.0312	0.1019*	0.0378*	0.0141
SIZE	0.2323*	0.1018*	0.1780*	0.2851*	0.1107*	0.0672*	-0.0722*
EXPORTER	0.2344*	-0.0014	0.1923*	0.1974*	-0.0100	0.0874*	-0.2028*
FOREIGN	0.0357*	-0.0350*	0.0119	0.1732*	-0.0177	0.0575*	-0.1256*
INST1	0.0570*	0.0304	0.0704*	0.0438*	0.2434*	0.0263	0.0949*
INST2	0.0544*	-0.0133	0.0218	0.0522*	0.0287	0.2225*	0.0374*
INST3	0.1256*	0.0642*	0.0865*	0.0866*	0.0006	0.0476*	0.0201
INST4	-0.0093	0.0642*	0.0055	-0.0019	0.0755*	-0.0273	0.1055*
INST5	0.0005	0.0585*	0.0097	-0.0079	0.0653*	-0.0097	0.1091*
INST6	0.1688*	0.0577*	0.1345*	0.1114*	0.0879*	0.0468*	0.0158
	SPILLINC	ABSCAP	TECHPOT	APPROP	OCOST	SIZE	EXPORTER
SPILLINC	1.0000						
ABSCAP	0.0531*	1.0000					
TECHPOT	0.3107*	0.2160*	1.0000				
APPROP	-0.1503*	0.0374*	0.0216	1.0000			

OCOST	0.1251*	0.0979*	0.1276*	-0.2107*	1.0000		
SIZE	0.2980*	-0.0634*	0.1523*	0.0504*	-0.0370*	1.0000	
EXPORTER	0.1277*	0.2675*	0.2201*	0.0935*	-0.0197	0.2544*	1.0000
FOREIGN	0.1441*	0.1388*	0.0634*	0.0499*	-0.0343*	0.1074*	0.2192*
INST1	0.0571*	-0.1668*	-0.0028	-0.1155*	0.0810*	-0.0028	-0.0998*
INST2	0.0511*	0.0318	0.0726*	-0.0044	0.0434*	-0.0185	0.1110*
INST3	0.3714*	0.0188	0.1498*	-0.0553*	0.0985*	0.2287*	0.0280
INST4	0.1166*	-0.1029*	-0.0192	-0.2448*	0.1160*	-0.0248	-0.1477*
INST5	0.1196*	-0.1050*	-0.0150	-0.2268*	0.1286*	-0.0176	-0.1723*
INST6	0.0942*	-0.0044	0.0725*	-0.0899*	0.2101*	0.0368*	0.0329
	FOREIGN	INST1	INST2	INST3	INST4	INST5	INST6
FOREIGN	1.0000						
INST1	-0.0610*	1.0000					
INST2	0.0357*	0.1181*	1.0000				
INST3	-0.0007	0.0118	-0.0138	1.0000			
INST4	-0.0673*	0.0996*	-0.0087	0.1000*	1.0000		
INST5	-0.0787*	0.1305*	-0.0108	0.1043*	0.7017*	1.0000	
INST6	-0.0580*	0.3613*	0.2102*	0.0564*	0.0705*	0.1053*	1.0000

Notes: The table shows pairwise correlation coefficients. * denotes significance on the 5% level

Table A3: Instrument Validity

	First Uni NCOMP	First Uni PRICECOMP	First Uni QUALCOMP	Second stage Uni	First Hor NCOMP	First Hor PRICECOMP	First Hor QUALCOMP	Second stage Hor
SPILLINC	0.025	0.117***	0.148***	0.309***	0.034	0.087***	0.146***	0.170***
	(0.041)	(0.031)	(0.030)	(0.051)	(0.039)	(0.030)	(0.029)	(0.053)
ABSCAP	-0.002	-0.003***	0.001	0.010***	-0.002	-0.003***	0.001	0.007***
	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)
TECHPOT	0.031	0.013	0.050***	0.166***	0.030	0.011	0.049***	0.087***
	(0.024)	(0.018)	(0.018)	(0.028)	(0.024)	(0.018)	(0.018)	(0.032)
APPROP	-0.030	-0.020	-0.009	0.057**	-0.030	-0.024	-0.007	-0.001
	(0.020)	(0.015)	(0.015)	(0.024)	(0.020)	(0.015)	(0.014)	(0.026)
OCOST	-0.027	0.161***	0.023	0.145***	-0.029	0.156***	0.018	0.022
	(0.047)	(0.034)	(0.033)	(0.056)	(0.047)	(0.034)	(0.033)	(0.062)
SIZE	-0.141*	0.140**	-0.123**	-0.053	-0.141*	0.128**	-0.117**	-0.161*
	(0.080)	(0.056)	(0.056)	(0.090)	(0.079)	(0.056)	(0.056)	(0.088)
SIZE^2	0.014*	-0.007	0.015***	0.024***	0.014*	-0.006	0.015**	0.028***
	(0.008)	(0.006)	(0.006)	(0.009)	(0.008)	(0.006)	(0.006)	(0.009)
EXPORTER	-0.005***	-0.000	0.001**	0.005***	-0.005***	-0.000	0.001**	-0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
FOREIGN	-0.234***	-0.045	0.072*	-0.146**	-0.238***	-0.037	0.067	-0.174**
	(0.053)	(0.045)	(0.041)	(0.070)	(0.053)	(0.045)	(0.041)	(0.085)
NCOMP				-0.052				0.254**
				(0.098)				(0.110)
NCOMP^2				0.008				-0.046**
				(0.017)				(0.019)
PRICECOMP				0.021				0.069
				(0.179)				(0.201)
PRICECOMP^2				0.003				-0.005
				(0.024)				(0.027)
QUALCOMP				-0.307**				-0.137
				(0.151)				(0.174)
QUALCOMP^2				0.048**				0.028
				(0.023)				(0.026)
INST1	-0.022	0.975***	-0.075	0.094	0.013	0.974***	0.006	0.127
	(0.185)	(0.136)	(0.130)	(0.218)	(0.185)	(0.135)	(0.128)	(0.231)
INST3	0.021	-0.066***	-0.000	0.027				
	(0.024)	(0.018)	(0.017)	(0.027)				
INST4	0.055**	0.033**	-0.028*	-0.013				
	(0.022)	(0.016)	(0.016)	(0.026)				
INST6	-0.230*	-0.039	-0.081	0.207				
	(0.118)	(0.074)	(0.084)	(0.126)				
INST2					0.280*	-0.002	1.004***	-0.188
					(0.165)	(0.119)	(0.116)	(0.206)
INST5					0.053***	0.010	-0.013	0.033
					(0.020)	(0.015)	(0.015)	(0.025)
CONSTANT	3.331***	-0.609	3.692***	-3.302***	1.699*	-0.615	-0.390	-2.068
	(0.862)	(0.634)	(0.617)	(1.065)	(1.023)	(0.727)	(0.693)	(1.378)
N	3272	3272	3272	3272	3272	3272	3272	3272
Wald chi2				609.163				186.209
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The table displays coefficients and robust standard errors in parentheses. *, ** and *** denote significance levels of 10%, 5% and 1%, respectively. Columns 2 to 4 and 6 to 8 show first stage results of a manual IV estimator for the number of competitors (NCOMP), price competition (PRICECOMP) and quality competition (QUALCOMP) applying instruments for innovation cooperations with universities (columns 2 to 4) and competitors (columns 6 to 8), respectively. Columns 5 and 9 contain reduced form estimates for the probability of cooperation with universities and competitors, respectively. In addition to the displayed coefficients, all estimations entail year and industry dummies.

Table A4: Marginal Effects of Main Table Probit Estimations

	Prob Uni	Prob Hor	IV Uni	IV Hor
NCOMP	-0.01403	0.05093	-0.29169	0.41356
NCOMP^2	0.00219	-0.00929	-0.03858	-0.06034
PRICECOMP	0.00567	0.01242	0.74301	0.64690
PRICECOMP^2	0.00068	-0.00080	-0.12578	-0.07768
QUALCOMP	-0.07926	-0.02643	-2.50347	-0.16655
QUALCOMP^2	0.01247	0.00519	0.18606	0.01575
SPILLINC	0.08436	0.03418	0.30728	0.03740
ABSCAP	0.00271	0.00134	0.00188	0.00188
TECHPOT	0.04370	0.01695	0.12560	0.01636
APPROP	0.01538	-0.00123	-0.01517	0.00353
OCOST	0.03930	0.00511	0.09538	0.00683
SIZE	-0.01216	-0.03157	-0.20417	-0.02756
SIZE^2	0.00631	0.00539	0.03043	0.00507
EXPORTER	0.00125	-0.00046	0.00007	0.00035
FOREIGN	-0.03899	-0.03424	-0.06604	0.00668

Notes: The table displays marginal effects of the probit estimations in table 2, i.e. of the first four columns.

Table A5: Multivariate probit including alternative cooperation partners

	University	Horizontal	Vertical	Internal
NCOMP1	0.089	-0.129	0.020	0.007
	(0.084)	(0.094)	(0.078)	(0.094)
NCOMP2	0.036	-0.067	0.033	0.113
	(0.082)	(0.091)	(0.075)	(0.090)
NCOMP4	0.083	-0.030	0.018	-0.118
	(0.103)	(0.111)	(0.093)	(0.118)
NCOMP5	-0.025	-0.293**	-0.082	-0.004
	(0.108)	(0.123)	(0.100)	(0.121)
PRICECOMP	0.042	0.126	-0.057	0.172
	(0.173)	(0.199)	(0.162)	(0.187)
PRICECOMP^2	0.000	-0.013	0.014	-0.018
	(0.023)	(0.027)	(0.022)	(0.026)
QUALCOMP	-0.289**	-0.100	-0.192	-0.059
	(0.147)	(0.174)	(0.135)	(0.173)
QUALCOMP^2	0.046**	0.020	0.028	0.002
	(0.022)	(0.026)	(0.021)	(0.026)
SPILLINC	0.299***	0.150***	0.129***	0.317***
	(0.046)	(0.051)	(0.042)	(0.050)
ABSCAP	0.010***	0.007***	0.006***	0.007***
	(0.002)	(0.002)	(0.002)	(0.002)
TECHPOT	0.152***	0.083***	0.138***	0.048*
	(0.027)	(0.031)	(0.025)	(0.029)
APPROP	0.049**	-0.012	-0.009	0.032
	(0.023)	(0.025)	(0.021)	(0.026)
OCOST	0.136**	0.052	0.086*	0.034
	(0.054)	(0.060)	(0.050)	(0.059)
SIZE	-0.078	-0.142	-0.038	0.218**
	(0.083)	(0.087)	(0.085)	(0.103)
SIZE^2	0.026***	0.026***	0.017*	0.004
	(0.009)	(0.009)	(0.009)	(0.010)
EXPORTER	0.005***	-0.002**	0.004***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
FOREIGN	-0.147**	-0.199**	-0.162**	0.401***
	(0.069)	(0.083)	(0.066)	(0.071)
CONSTANT	-2.464***	-1.829***	-1.336***	-3.627***
	(0.433)	(0.520)	(0.411)	(0.498)
N	3272.000			
Wald chi2	1175.822			
Prob > chi2	0.000			
atrho	0.748***			
	(0.042)			
	1.305***	0.921***		
	(0.049)	(0.045)		
	0.849***	0.682***	1.036***	
	(0.043)	(0.044)	(0.047)	
p(NCOMP1>NCOMP2)	0.4073	0.3904	0.8377	0.1292
p(NCOMP1>NCOMP4)	0.9527	0.3123	0.9783	0.2286
p(NCOMP1>NCOMP5)	0.2424	0.1485	0.2614	0.9175
p(NCOMP2>NCOMP4)	0.5875	0.699	0.8585	0.0216**
p(NCOMP2>NCOMP5)	0.521	0.0396**	0.1985	0.265
p(NCOMP4>NCOMP5)	0.3316	0.0359**	0.3324	0.3701

The table displays coefficients and robust standard errors in parentheses. *, ** and *** denote significance levels of 10%, 5% and 1%, respectively. Each column captures an equation of a multivariate probit model with 400 draws for universities, horizontal, vertical and group internal cooperation partners, respectively. "atrho" denotes correlations between equations and p(var1>var2) reflects p-values of t-tests whether two variables are the same. In addition to the displayed coefficients, all estimations entail year and industry dummies.

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