ETLA Working Papers
No. 30
14 August 2015

Heli Koski

Commercial Success of Innovation

The Roles of R&D Cooperation and Firm Age

Suggested citation: Koski, Heli (14.8.2015). "Commercial Success of Innovation: The Roles of R&D Cooperation and Firm Age". ETLA Working Papers No 30. http://pub.etla.fi/ETLA-Working-Papers-30.pdf

ETLA ELINKEINOELÄMÄN TUTKIMUSLAITOS
THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY

ISSN-L 2323–2420
ISSN 2323–2420 (print)
ISSN 2323–2439 (online)

Commercial success of innovation:

the roles of R&D cooperation and firm age

Heli Koski*

Abstract:
Data comprising 1790 Finnish firms and covering the years 2006-2012 suggest that turnover from innovative sales per employee were higher for both young firms - particularly for young innovative companies (or YICs) - and older incumbents that had broad innovation collaboration involving vertical, horizontal and institutional partners. Younger firms with simultaneous horizontal and vertical innovation collaboration tend to also generate higher turnover due new products and services, while this type of collaboration did not appear statistically significant in innovation production function for older incumbents. Our data further indicate that not only the relationship between inventor age and patentable inventions at the inventor level is inversely u-shaped – as previous studies report - but also the relationship between employee age structure and the generation of commercially successful products and services at the firm level follows the same pattern. High education of employees distinguished particularly the top performers from others at the highest 0.9 quantile of turnover from innovative sales per employee. Furthermore, firms with relatively highly educated employees and broad innovation collaboration had clearly higher returns from innovative sales per employee than other firms, while none of the innovation collaboration types was statistically significantly related to the innovation output of firms with relatively low education of employees.

JEL Classification: L2, O31, O32
Keywords: Innovation performance, R&D cooperation, human capital

* The Research Institute of the Finnish Economy (ETLA). E-mail: heli.koski@etla.fi.

1. Background

Innovation collaboration with external partners provides a firm an access to new ideas and technologies. Firms tend to choose innovation partners with knowledge, experience and competences complementing their own innovation capabilities (see, e.g., Hagedoorn, 1993; Cassiman and Veugelers, 2002; Hagerdoorn, 2002). This empirically oriented study addresses the following questions: i) Whether and how a firm's innovation collaboration with different external parties (i.e., vertical, horizontal and institutional innovation collaboration) affects its innovation performance?, ii) Does the relationship between innovation performance and (the combinations of) different innovation collaboration strategies differ between young innovative companies (i.e. YICs) and other companies, and iii) Do (the combinations of) different R&D collaboration strategies and the quality of a firm's human capital affect differently to firms' innovation performance in different quantiles of innovation performance?

The existing mixed evidence on the relationship between R&D strategies and innovation (see, e.g., Klomp and van Leuuwen, 2001; Lööf and Heshmati, 2002; Belderbos et al. 2004b, 2006; Aschhoff and Schmidt 2008) does not provide clear conclusions or guidance on the relative order of magnitude of benefits arising from the different forms of external innovation collaboration. The role of the synergies or complementarities of firms' R&D cooperation strategies in firms' performance has not deserved much attention in the empirical literature (see Belderbos et al, 2006). We empirically explore the roles of different innovation collaboration strategies in the spirit of Belderbos et al. (2006) using exclusive dummy variable to capture the complementarities of different collaboration strategies but - unlike Belderbos et al. (2006) concerning productivity growth - our empirical study focuses on the firm's innovation performance measured by the turnover from innovative sales per employee.

We investigate the impacts of innovation collaboration on innovation performance using data from the three waves of the biannual Finnish Community Innovation Survey that is combined with other firm-level financial and background data. The years covered by the survey are 2006-2008, 2008-2010 and 2010-2012 providing a rather contemporary perspective on the roles of different collaboration strategies in a firm's innovation performance. Furthermore, our study contributes to the literature by shedding light on the question to what extent and in which forms YICs benefit from the adoption of (the combinations of) different R&D strategies. This question is not only academically intriguing but it's also of interest to policymakers as means to release the innovation potential of young, small firms are needed (see, e.g., European Commission, 2010). Also, we assess whether the drivers of innovation production of the top performers differs from that of those that are having relatively lower innovation performance to learn more about the mechanisms of successful innovation production.

The reported research links also to the more general literature on the openness of a firm's innovation strategy and its performance. The previous studies on this field of literature provide relatively vast empirical evidence that a firm's broader external knowledge search is positively related to its innovation performance (see, e.g., Garriga et al., 2013; Laursen and Salter, 2006; Leiponen and Helfat, 2010; Love et al., 2013).

Our empirical analysis employs data comprising 1790 Finnish firms and covering the years 2006-2012. Our data suggest that turnover from innovative sales per employee were higher for both young firms - particularly for YICs - and older incumbents that had broad innovation collaboration involving vertical, horizontal and institutional partners. There were some differences between old and young firms though. Younger firms with mere horizontal and vertical innovation collaboration tend to generate higher turnover due new products and services, while this type of collaboration did not appear statistically significant for older incumbents. Our data further suggest that the age and education structure of a firm matters. The relationship between the employee age and the generation of commercially successful products and services is U-shaped. High education of employees particularly distinguished the top performers from others at the highest 0.9 quantile of turnover from innovative sales per employee.

The rest of the paper is organized as follows. Section 2 provides conceptual discussion on the roles of different types of innovation collaboration in the firm's innovation production. Section 3 introduces data and the variables used in the estimations. Section 4 first provides a descriptive look on the data, and then introduces the estimation methodology and reports the results of the empirical analysis. Section 5 concludes.

2. R&D cooperation and innovation performance

Competitors, customers and suppliers and research organizations may contribute each in a different way to a firm's innovation process, to the launch of new products and services, and further to the value of innovation the firm produces. Their knowledge, experience and competences may be complementary to a firm's own innovation capabilities. The knowledge based view of the firm states that access to R&D partners' technology resources or knowledge base provides a major motivation for a firm to engage into innovation collaboration with external parties (Hagedoorn, 2002). However, a firm has to have a sufficient ability to absorb and utilize exchanged information, i.e. absorptive capacity, to be able to innovatively exploit the knowledge and technology outside of its boundaries (Cohen and Levinthal, 1990). Here, *technological proximity* of collaborators matters: R&D partners with related technology or knowledge bases are better able to integrate exchanged information from each other to their own innovation activities.

Horizontal innovation collaboration or *innovation coopetition* means that there is at least a certain overlapping technology base between collaborating firms enhancing the possibilities of a firm to understand and exploit knowledge absorbed from its innovation partners. Particularly in the industries in which product life cycles are short, technology development involves multiple converging technologies and R&D expenditures are high, it often is attractive for a firm to share costs, risks, expertise and other resources with its competitors (Gnyawali and Park, 2011). Therefore, innovation partnerships between competitors may be attractive despite of the apparent risk of unwanted knowledge leakages potentially improving the partner's competitive position in the markets for final goods (see, e.g., Ritala and Hurmerinta-Laukkanen, 2013).

It is unclear whether the economic benefits derived from horizontal innovation collaboration or innovation coopetition are larger or smaller than other types of R&D cooperation. Innovation coopetition comprises both factors enhancing the development of commercially successful innovation as well as factors hindering the knowledge spill-overs between the collaborating companies. Direct competition in the markets for end products is likely to generate a strong incentive for innovation partners to protect their proprietary knowledge base and prevent unwanted leakages of information to their collaborators (Oxley and Sampson, 2004). This may mean – as compared to the innovation collaboration between parties that do not compete in the markets for final goods – less exchange of information and knowledge and thus weaker innovation performance of firms participating into coopetitive R&D activities. Yet, another possibility is that competitors collaborate in innovation activities to avoid costly patent races and cross-licensing negotiations, or due to network effects and standard setting and monopoly power that are expected to arise from coopetitive innovation activities[1]. In these cases, firms may have a greater incentive to share their knowledge with their innovation partners, and higher value of innovation output can be expected.

Vertical innovation collaboration with customers may be helpful in the development and creation of value from new products and services both for targeting a mass market and for more specialized user needs. Customers may benefit a firm's innovation process by providing information on the end users' needs and preferences, assist the firm to identify emerging markets trends and reduce uncertainties or risks related to the launch of new products (see, e.g., Tether, 2002). The importance of a firm's customers further indicates the importance of market demand or demand pull in the generation of new products and services.

Innovation collaboration with a firm's suppliers, instead, is likely to affect mostly the firm's process innovation (see, e.g., Un and Asakawa, 2015). Suppliers working closely with a firm in new product development may provide knowledge generating process innovation that reduce costs and increases efficiency of production, reduces project development lead times as well as improves quality. Suppliers working with various companies may further spread knowledge on best practices used by the firms in the industry and facilitate a firm's process innovation. Thus, vertical collaboration with suppliers is likely to relate positively to a firm's turnover from innovation per employee as it tends to make the production of new products and services more efficient rather than increase the value of final innovation output.

Institutional innovation collaboration with universities and research institutes is likely to be a channel for the leading edge technological and scientific knowledge (see, e.g., Dooley and Kirk,

[1] Particularly for large firms with market power, horizontal innovation collaboration or innovation coopetition may provide possibility to set industry standards making collaboration with competitors a potentially lucrative option.

2007). This type of innovation collaboration may be particularly fruitful for firms working on complex ideas and doing R&D at the technological frontier, and generate radical innovations new to the market (see, e.g., Miotti and Sachwald, 2003; Monjon and Walbroeek, 2003; Belderdos et al., 2004a). Consequently, innovation collaboration with institutional partners is assumed to be positively related particularly to a firm's turnover from products and/or services new to the market. The importance of a firm's innovation collaboration with institutional research partners in the innovation performance equation also reflects the role of technology push in the generation and launch of new products and services.

In practice, firms often have collaborative partnerships and joint R&D projects simultaneously with multiple different types of organizations (see, e.g., Belderbos et al., 2004b). The empirical literature provides mixed evidence on the relationship between R&D cooperation and a firm's innovation performance (Klomp and van Leuuwen, 2001; Lööf and Heshmati, 2002; Belderbos et al. 2004b; Aschhoff and Schmidt 2008). Studies distinguishing various types of innovation collaboration partners indicate that firms' innovation performance varies with the types of collaboration partners. For instance, the empirical study of Miotti and Sachwarld (2003) using French firm-level data indicates that international R&D cooperation contributes to firms' innovation performance, while R&D cooperation with national partners do not provide similar benefits.

The previous studies do not shed much light on the role of synergies or complementarities of firms' R&D cooperation strategies in firm's innovation performance. Belderbos et al. (2004b) use Dutch Community Innovation Survey data from the years 1996 and 1998 to explore the complementarity of different R&D strategies and their impact on the firm's productivity growth. Their empirical findings indicate that R&D cooperation is generally positively related to labor productivity growth but the magnitude of the impacts varies by the (combinations of) R&D cooperation types. The relationship between (the combinations of) different innovation collaboration types and firm innovation performance remains as an empirical question.

Various policy-oriented documents address that supporting the innovation activities of young and small companies is crucial as young SMEs are an important source of innovative ideas (see, e.g., European Commission, 2010). Financial and liquidity constraints may limit particularly the materialization of young firms' innovation potential as they affect directly a firm's R&D decisions (see, e.g., Czarnitzki and Hottenrott, 2011; Audretsch et al., 2014). There is a relatively vast empirical literature of which findings on the age-innovation relationship are, overall, inconclusive (see, e.g., Huergo and Jaumandreu, 2004a,b). Schneider and Veugelers (2010) report that though young, small innovation-intensive companies are relatively rare among their sample of innovative firms, their share of sales from innovative new products – and particularly sales of products that are new to the market - is significantly higher than that of other innovative firms.

Contemporary literature provides, however, little research-based knowledge on the drivers of innovation performance of young innovative companies and whether and how these drivers differ from those of other companies. Pellegrino et al. (2012) and Garcia-Quevedo et al. (2014) find that the R&D expenditures of YICs are more sensitive to certain 'demand-pull' factors such as functioning in the expanding markets and the amount of exports. To what extent innovation collaboration with external partners contributes to the innovation performance of young firms or YICs (e.g., via mitigating access to finance as the barrier of innovation) is an empirical question that the previous literature does not provide answer to.

For newly established firms, external sources of knowledge and collaboration are highly important for developing capabilities essential to succeed in R&D activities and new product development (see, e.g., Häussler et al., 2012). Research organizations may be particularly useful partners for companies that have innovation ideas but do not yet have accumulated sufficient resources for undertaking required R&D. Furthermore, as innovation collaboration with external partners enables the sharing of costs and reduces the risks of R&D projects (see, e.g., Sakakibara, 1997), R&D cooperation may particularly contribute to the generation and commercialization of innovation among resource-constrained young companies.

Start-ups and older incumbents may obtain different benefits from innovation collaboration with external parties. Newly established companies have less experience than older incumbents, and they are in the early stages of the learning process that builds up innovative capability and absorptive capacity essential for innovation (Pellegrino et al., 2012). Young firms may not have yet established inter-organizational collaboration practices enabling efficient adoption and use of knowledge (with lower transaction costs) available from their innovation collaboration partners. For incumbents companies, innovation collaboration may particularly provide access to new technologies and possibility to enter new product or markets areas (see, e.g., Mitchell and Singh, 1983) enhancing their sales from innovative products.

A firm's own R&D investments and human capital are also factors that are critically important inputs in the firm's innovation production function. The role of the quality of human capital has deserved less attention in the prior empirical studies though it seems obvious that the qualities of a firm's employees are likely to affect the firm's innovation performance (McGuirk et al., 2015). Prior empirical evidence on the role of the qualities of human capital - such as age and education -

in innovation performance is relatively scarce and primarily based on the inventor-specific data concerning the generation of patentable ideas.

Highly educated employees tend to have a greater capacity to search for useful knowledge and to recognize the relevant state of the art scientific advancements than employees with relatively low education (see, e.g., Giuri and Mariani, 2013). Education further enhances employees' ability to absorb and use relevant external knowledge for innovation purposes. Mariani and Romanelli (2007) found that inventors with higher levels of education are likely to produce more patented inventions. The empirical inventor-level study of Toivanen and Väänänen (2011) further concluded that particularly engineering education promotes generation of technological inventions. Given this reasoning and prior empirical findings, we expect that higher education of employees relates positively to innovation performance at the firm level.

The literature also addresses that the age of an individual relates to his/her capacity to innovate and to produce economically relevant innovation. The literature review of Frosch (2009) concerning workforce age and innovation suggests that the relationship between age and inventions is inversely u-shaped, and that the performance of inventors tends to peak between the ages of 30 and 50. The prior empirical studies, by and large, focus on patentable inventions, however. The literature lacks empirical evidence whether the age-innovation relationship is similar in the generation of new products and services more generally.

3. Data

The data used in the estimations comprise 2353 observations from 1790 firms. It is gathered by Statistics Finland via the CIS (Community Innovation Survey) questionnaires concerning firms' innovation activities for the years 2006-2008, 2008-2010 and 2010-2012. The CIS data are further combined with other databases of Statistics Finland concerning firm-level financial information and data on the characteristics of firms' employees. The majority of the sample firms replied only one of the three waves of innovation survey so the nature of the data is rather cross-sectional than panel data. Table 1 provides details of the variables used in the estimations.

The dependent variable, the value of a firm's innovation output is measured by the (log) revenues per employee (deflated by producer price indices for manufacturing and services) generated at year t due to new or significantly improved products introduced during the past three years (the variable VALUE_INNO). This variable is calculated using the reported percentages of a firm's total turnover at year t from new or significantly improved products introduced during the past three years. The prior evidence on the use of innovation surveys indicates that firms can report relatively accurately the share of sales due to new products as many of them track their sales by type of product (Mairesse and Mohnen, 2010). Turnover from innovative sales per employee provides a better measure for the value of innovation than the share of innovative sales that is often used in the empirical analysis. The share of innovative sales is likely to be strongly affected by the degree of product variety: specialized or single product firms are likely to have higher shares of innovative sales than multi-product firms. Thus, the share of innovative sales may not necessarily capture the economic value of innovation.

We measure a firm's innovation collaboration with the following eight exclusive dummy variables: i) NO_COLLAB that gets value 1 a firm had no innovation collaboration, ii) HORIZONTAL that gets value 1 if a firm had innovation collaboration only with competitors, iii) VERTICAL that gets value 1 if a firm had innovation collaboration only with vertical partners (i.e. customers and/or suppliers), iv) INSTIT that gets value 1 if a firm had innovation collaboration only with research organizations and/or universities, v) HOR_VER that gets value 1 if a firm had horizontal and vertical innovation collaboration exclusively, vi) HOR_INST that gets value 1 if a firm had horizontal and institutional innovation collaboration exclusive, vii) VER_INST that gets value 1 if a firm had vertical and institutional innovation collaboration exclusively, and viii) HOR_VER_INST that gets value 1 a firm had all three types of innovation collaboration exclusively, and 0 otherwise.

The variable RD measures a firm's R&D intensity, or the firm's R&D expenditures divided by its turnover. The variables EDUC_COLLEGE and EDUC_ACADEMIC capture, respectively, the shares of college and academically educated persons of the total number of a firm's employees. The age structure of a firm's employees is measured by the shares of employees in different age groups (i.e., the groups of 16-24, 25-34, 35-44, 45-54 and 55-70 years old employees).

- TABLE 1 HERE -

We further control for a set of factors that the literature identifies as the drivers of a firm's innovation performance. Various studies find that larger firms tend to have a higher propensity to innovate but that the firm size is not so strongly linked to the share of total sales due to new or improved products (Mairesse and Mohnen, 2010). We control for firm size by the dummy variables for small (i.e, firms with 10-49 employees, medium-sized (i.e,. firms with 50-250 employees) and large (i.e., firms with over 250 employees) firms. The literature identifies firm age as one of the factors affecting innovation but provides mixed evidence on whether it affects positively or negatively on the firm's innovation performance (Coad et al, 2013). The AGE variable controls for (log) firm's age, or the years elapsed since the establishment of the firm. We further use dummy variables for 21 industrial sectors to control for variation in technological opportunities in different industries (see also, e.g., Klevorick et al.,1995). Dummy variables for the observation years control for time-varying changes affecting firms' innovation performance.

4. Empirical results

4.1 Descriptive findings

Our data show that the collaboration patterns of firms are quite bipolar distributed (see Figure 1): the majority of firms either did not have external innovation collaboration at all (i.e. 45 percent of sample firms) or they innovation collaboration was broad involving vertical, horizontal and institutional partners simultaneously (i.e. 43 percent of sample firms). About 8 percent of firms had innovation collaboration with both their customers/suppliers and institutional research partners, but not with their competitors. Only vertical, horizontal or institutional innovation collaboration was relatively rare. Strikingly few firms (only 4) had collaboration merely with their competitors or firms in the same industry. In other words, almost all firms that had innovation collaboration with their competitors also collaborated with other external parties. Also, the majority of firms that had vertical innovation collaboration with their customers and/or suppliers also had institutional innovation collaboration.

- FIGURE 1 HERE -

Figure 2 shows that the turnover generated from innovative sales differs between firms with different innovation collaboration patterns. The average value of turnover per employee due to new products and services generated during the past three years exceeded 46 000 euros among companies that had vertical and institutional collaboration partners and was close to 42 000 euros for companies that had all three types of innovation collaboration. Those firms that had no innovation collaboration had close to 33 000 euros turnover per employee from innovative sales. Our data indicate that turnover from innovative sales were relatively high for young firms up to 6 years old with vertical and institutional innovation collaboration: they obtained, on average, more than 74 000 euros turnover from innovative sales per employee. Also, YICs that were collaborating broadly with all three types of external partners generated close to 72 000 turnover euros per employee from the sales of new products and services.

- FIGURE 2 HERE -

These numbers show interesting variation but as they do not take into account variation in relevant firm characteristics (such as a firm's R&D investments) affecting the value of innovation output, they are not conclusive but require a more careful empirical analysis of data.

4.2 Estimation methodology and results

The following innovation production function was used for estimating the relationship between a firm's innovation collaboration patterns, human capital and innovation performance:

$$INNO\_VALUE_{it} = \alpha_0 + \alpha_1 RD_{it} + \sum_{h=0}^{1}\sum_{v=0}^{1}\sum_{u=0}^{1}\beta_{hvu} I_{(h,v,u)} + \beta_H H_{it} + \alpha_j \sum_j C_{ijt} + \varepsilon_{it} \quad (1)$$

, where RD captures a firm's R&D intensity, indicators h, v, and u represent horizontal, vertical and institutional innovation collaboration, respectively, H denotes a firm's human capital, and C is a vector of control variables.

Equation (1) was estimated for the three different years (i.e., for the years 2008, 2010 and 2012) but as the data are pooled with strongly cross-sectional characteristics (i.e., the majority of the sample firms appears only once in the data set), the cross-sectional estimation approach suits better for the task than the panel data estimation methods. The sample used in the estimations was restricted to the firms that had produced new products and/or services during the sample years. In other words, the dependent variable was censored based on whether a firm was innovative or not. The dependent variable didn't comprise significant fraction of zero values as only about 5 percent of the sample firms hadn't generated any income due to their new products and/or services. Since the dependent variable was, by and large, continuous with relatively few zero observations (i.e., corner solution outcomes), the OLS model was in this respect suitable (i.e., there was no need to employ type I Tobit model).

Though the mass of zero observations for the dependent variable was relatively small, we acknowledged that the use of non-randomly formed sample may generate biased OLS estimates. We therefore assessed the magnitude of selectivity bias to provide further guidance for the choice of the estimation method. We estimated Heckman's (1979) two-stage model (or type II Tobit model) for the dependent variable using in the first stage the equation for a firm's probability to produce product innovation as the selection equation.[2] In the second stage, equation (1) was used as the regression equation in which the inverse Mill's ratio was used as an additional independent variable. The estimated coefficient of the inverse Mill's ratio was not statistically significant

[2] The estimation results are available from the author.

meaning that the data provide no evidence on the sample selection bias. Thus the OLS model was concluded to be adequate, and the baseline model was estimated using the OLS with White-heteroscedasticity robust standard errors. Column 1 of Table 2 reports the estimation results of the baseline model.

- TABLE 2 HERE -

There were two few observations of firms that had adopted only horizontal collaboration strategy or both horizontal and institutional innovation collaboration so the variables HORIZONTAL and HOR_INST were dropped from the estimated equation. Our estimation results show that turnover from the total innovative sales per employee was clearly higher in those companies that had simultaneously innovation collaboration with horizontal, vertical and institutional partners. The adoption of a strategy involving both vertical and institutional collaboration was also positively and statistically significantly related to a firm's turnover from innovative sales per employee. The orders of magnitude of the coefficients for the variable HOR_VER_INST and VER_INST suggest that those companies with all three types of innovative partners and those with simultaneous vertical and institutional collaboration had, on average, about 36 and 50 percent – respectively - higher innovative sales per employee than firms that had no innovation collaboration. The estimated coefficient for the variable VER_HOR capturing a firm's joint vertical and horizontal innovation collaboration was also positive but only moderately statistically significant (at p=0.10).

The firm's R&D intensity was also positively related to a firm's innovative sales per employee emphasizing the role of the firm's own innovation capabilities. The estimation results suggested that the variables capturing the shares of youngest (i.e. 16-24 years old) and the oldest (i.e. 55-70 years old) employee groups were negatively related to the firm's innovation performance. Firm's education structure didn't appear statistically significant in our baseline estimation.

We further generated separate innovation collaboration dummy variables for young firms and for other companies. The idea here was to estimate modified models that provide information of the relationship between the different innovation collaboration patterns and innovation performance among young and older firms. The definition of "young firm" used in the literature usually means companies that are either maximum six or ten years old. Furthermore, various recent empirical studies have focused on the "young innovative companies" or YICs that are, according to commonly accepted definition, maximum six years old, employ less than 250 persons and invest more than 15 % of their operating expenses on R&D (see, e.g., Schneider and Veugelers, 2010). We estimated three models with different definitions for "young" companies to explore whether there are differences in how: i) YICs, ii) firms that were maximum 6 years old, and iii) firms that were maximum 10 years old benefit from innovation collaboration. Columns 2-4 of Table 2 summarize the results.

The comparison of the estimated coefficients for young and older companies revealed interesting differences. Positive and statistically significant coefficient of the variable VER_HOR*YOUNG suggests that young firms tend to gain larger benefits from the combination on vertical and horizontal collaboration. Both young and old firms collaborating simultaneously with their competitors and vertical and institutional partners had higher turnover from innovative sales per employee than other companies. The estimated coefficient of the variables VER_HOR*YOUNG and HOR_VER_INST*YOUNG were only moderately (i.e., p=0.10) significant for the group of all young firms up to 6 six years old though. When the definition of “young” was stretched to comprise firms up to 10 years old, the coefficients appear positive and statistically significant.

As a next step, we used quantile regressions to evaluate the impacts of the explanatory variables across conditional distribution of turnover per employee due to innovative sales. The advantage of the quantile regression, as compared to the OLS estimation technique, is that it takes into account not only the average firm behaviour but explores behavioural patterns across the complete conditional distribution of the dependent variable. The estimated coefficients for the explanatory variables tell the magnitude of (percent) change in innovative sales per employee at the □th conditional quantile due to marginal change in each explanatory variable. We were particularly interested in whether and how the relationship between innovation collaboration variables and innovation performance varies between the top performers and those with relatively lower innovation performance.

- TABLE 3 HERE -

Table 3 shows that the estimated coefficients for the dummy variables VER_INST and HOR_VER_INST were positive and statistically significant at all other quantiles, except for the variable VER_INST at the highest quantile. Also, there was a clear decreasing pattern in the estimated values of the coefficients for these variables across the quantiles. Change in the firm’s R&D intensity also seemed to generate the largest increase in innovative sales per employee at the lowest quantile. Furthermore, the estimated coefficient for the variable R&D decreased with the higher quantiles of innovation performance. The estimation results further indicate that for the top 25 percent of firms in terms of innovation performance, marginal increase in a firm's R&D expenditures was not statistically significantly contributing to the firm's innovation output.

The negative and statistically significant coefficients of the dummy variables AGE_16-24 and AGE_55-70 in all but the lowest quantile further emphasizes the role of a firm's personnel age structure. Those firms employing relatively high share of under 25 years old and over 55 years old people seem to generate lower turnover from the sales of innovative products than others. These findings hint that not only the relationship between inventor age and patentable inventions is inversely u-shaped but also the relationship between the employee age and generation of commercially successful products and services follows the same pattern.

Also, firm age was statistically significantly and negatively related to the firm's innovation performance only at the top two quantiles (i.e, □ = 0.75 and □ = 0.90). It thus seems that it is relatively younger firms rather than older ones that tend to generate greater turnover from innovative sales among the top 25 percent of firms measured by their innovation performance. Another interesting finding is that though the variables capturing the education structure of a firm's employees were not statistically significant in the estimations concerning the average patterns, the estimated coefficients of the variables EDUC_COLLEGE and EDUC_ACADEMIC were highly statistically significant at the top 90 % quantile. This hints that relatively high education of a firm's personnel contributes particularly to the turnover from innovative sales per employee of top performers.

We further explored the potential mediating effect of the employees' education by estimating a model in which the collaboration variables were multiplied separately by the dummy variables for those firms that had higher and lower share of employees with university degree than the sample median. Table 4 provides the estimation results that give rather interesting further insights into the relationship between firms' innovation collaboration patterns and innovation performance. Those firms with relatively highly educated employees that collaborated simultaneously with vertical and institutional partners or with all three types of partners had clearly higher turnover from innovative sales per employee than other firms. Instead, firms with employees that had lower than median share of employees with university degree didn't gain significantly higher returns from any type of innovation collaboration than other firms.

5. Conclusions

This study used data comprising 1790 Finnish firms' innovation and economic activities and covering the years 2006-2008, 2008-2010 and 2010-2012 to explore the relationship between a firm's innovation collaboration patterns and innovation performance. The data show that the collaboration patterns of firms are quite bipolar distributed: the majority of firms either did not have external innovation collaboration at all or they innovation collaboration was broad involving vertical, horizontal and institutional partners simultaneously. The empirical estimations results indicate that the simultaneous collaboration with horizontal, vertical and institutional partners related positively to a firm's innovation performance. The data provided particularly strong support for this finding in case of YICs investing heavily in R&D in the early stages of the company life. For young firms up to six years old, generally, the data provided only moderate support for the statistical significance of this relationship.

Our empirical findings further indicate that firms that had a relatively high share of employees that were under 25 years old or over 54 years old tend to have clearly lower revenues from innovative sales per employee than other firms. This hints that not only the relationship between inventor age and patentable inventions at the inventor level is inversely u-shaped - as previous studies report - but also the relationship between employee age structure and generation of commercially successful products and services at the firm level follows the same pattern. In other words, it seems that both the performance of inventors generating patentable ideas and innovators generating new products and service hits the peak after about the age of 25-30 and decreases dramatically after the age of 50.

The data further implies that the higher education level of a firm’s employees contributes particularly to the innovation performance of firms at the highest 0.9 quantile of turnover from innovative sales per employee. In other words, relatively high education of employees distinguishes particularly the top performers from others among the top 10 percent of firms in terms of their innovation performance. Another interesting finding is that high education had also a mediating effect on the relationship between firms’ innovation collaboration and innovation performance. Those firms with relatively highly educated employees and broad innovation collaboration had clearly higher returns from innovative sales per employee than other firms, while none of the innovation collaboration types was statistically significantly related to the innovation output of firms with relatively low education of employees.

Though the top performers at the highest quantile of turnover due to innovative sales per employee are distinguished from other firms by relatively more highly educated employees, it seems that their R&D investments do not deviate significantly from those of other firms at the top quantile. Instead, it seems that the order of magnitude of R&D rather explains the differences in the firms’ innovation performance at the lowest quantiles. In other words, a marginal increase in a firm’s R&D expenditures clearly enhances the firm’s chances to increase its returns from innovation when its new products and services have not yet generated any returns or have generated relatively low returns.

Our empirical findings, overall, suggest that that when a firm matures it tends to accumulate capacity useful in gaining economic benefits from broad innovation collaboration with different types of external partners. However, heavy investments in R&D combined with highly educated workforce may alleviate the adverse effects of inexperience in innovation collaboration for young companies. Our data indicate that YICs have already accumulated knowledge and developed innovative and absorptive capacity enabling successful innovation partnerships simultaneously with various types of complementarity parties. Furthermore, our data suggest that younger firms tend to have higher revenues due to innovative sales than the older ones at the highest performance quantiles.

References

Aschhoff, B. and Schmidt, T. (2008): Empirical evidence on the success of R&D cooperation – happy together? *Review of Industrial Organization* 33, 41-62.

Audretsch, D.B., Segarra, A. and Teruel, M. (2014). Why don't all young firms invest in R&D? *Small Business Economics* 43, 751-766.

Belderbos, R., Carree, M., Diederen, B., and Lokshin, B. (2004a). Heterogeneity in R&D cooperation strategies. *International Journal of Industrial Organization* 22, 1237–1263.

Belderbos, R., Carree, M., and Lokshin, B. (2004b). Cooperative R&D and firm performance. *Research Policy* 33, 1477–1492.

Belderbos, R., Carree, M., and Lokshin, B. (2006). Complementarity in R&D cooperation strategies. *Review of Industrial Organization* 28, 401-426.

Cassiman, B. and Veugelers, R. (2002). R&D cooperation and spillovers: some empirical evidence from Belgium. *The American Economic Review* 92, 1169-1184.

Coad, A., Blasco, A.S., and Teruel, M. (2013). Innovation and firm growth: Does firm age plays a role? (June 8, 2013). Available at SRN: http://ssrn.com/abstract=2276414 or http://dx.doi.org/10.2139/ssrn.2276414

Cohen, W. and Levinthal, D. (1990). Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly* 35, 128–152.

Czarnitzki D. and Hottenrott, H. (2011). R&D investment and financing constraints of small and medium-sized firms. *Small Business Economics* 36, 65-83.

Dooley, L. and Kirk, D. (2007). University-industry collaboration. Grafting the entrepreneurial paradigm onto academic structures. *European Journal of Innovation Management* 10, 316-332.

European commission (2010). Europe 2020 Flagship Intitiative Innovation Union, Research & Innovation Policy SEC(2010) 1161. European Commission.

Frosch, K. (2009). Do only new brooms sweep clean? A review on workforce age and innovation. *MPIDR Working Paper,* WP 2009-005. February 2009.

Garcia-Quevedo, J., Pellegrino, G. and Vivarelli, M. (2014). R&D drivers and age: Are young firms different? *Research Policy* 43, 1544-1556.

Garriga, H., von Krogh, G. and Spaeth, S. (2013). How constraints and knowledge impact open innovation. *Strategic Management Journal* 34, 1134–1144.

Giuri, P. and Mariani, M. (2013). When distance disappears: Inventors, education, and the locus of knowledge spillovers. *The Review of Economics and Statistics* 95, 449-463.

Gnyawali, D.R and Park, B-J. (2011). Co-opetition between giant: Collaboration with competitors for technological innovation. *Research Policy* 40, 650-663.

Hagedoorn, J. (1993). Understanding the rational of strategic technology partnering: Interorganizational modes of cooperation and sectors differences. *Strategic Management Journal* 14, 371-385.

Hagedoorn, J. (2002). Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. *Research Policy* 31, 477-492.

Heckman, J. J. (1979). Sample Selection Bias as a Specification Error. *Econometrica*, 47, 153-162.

Huergo, E. and Jaumandreu, J. (2004a). Firms' age, process innovation and productivity growth. *International Journal of Industrial Organization* 22, 541-559.

Huergo, E. and Jaumandreu, J. (2004b). How does probability of innovation change with firm age? *Small Business Economics* 22, 193–207.

Häussler, C., Patzelt, H. and Zahra, S.A. (2012). Strategic alliances and product development in high technology new firms: The moderating effect of technological capabilities. *Journal of Business Venturing*, 27, 217-233.

Klevorick, A.K., Levin, R.C., Nelson, R.R., and Winter, S.G. (1995). On the sources and significance of interindustry differences in technological opportunities. *Research Policy* 24, 185-205.

Klomp, L. and van Leeuwen, G. (2001). Linking innovation and firm performance: A new approach. *International Journal of the Economics of Business* 8, 343-365.

Laursen, K. and Salter, A. 2006. Open for innovation: The role of openness in explaining innovation performance among U.K. manufacturing firms. *Strategic Management Journal* 27, 131-150.

Leiponen; A. and Helfat C.E. 2010. Innovation objectives, knowledge sources, and the benefits of breadth. *Strategic Management Journal* 31, 224-236.

Love, J.H., Roper, S. and Vahter, P. 2013. Learning from openness: The dynamics of breadth in external innovation linkages. Strategic Management Journal. Article first published online: 29 AUG 2013.

Lööf, H. and Heshmati, A. (2002): Knowledge capital and performance heterogeneity: A firm-level innovation study. *International Journal of Production Economics* 76, 61-85.

Mairesse, J. and Mohnen, P. (2010). Using innovation surveys for econometric analysis. in Hall, B.H. and Rosenberg, N. (eds.), *Handbook of the Economics of Innovation*, 1129-1155.

Mariani, M. and Romanelli, M. (2007) Stacking" and "picking" inventions: the patenting behavior of European inventors. *Research Policy* 36, 1128-1142.

McGuirk, H., Lenihan, H. and Hart, M. (2015). Measuring the impact of innovative human capital on small firms' propensity to innovate. *Research Policy* 44, 965-976.

Miotti, L. and Sachwald, F. (2003). Cooperative R&D: why and with whom? An integrated framework for analysis. *Research Policy* 32, 1481-1499.

Mitchell, W. and Singh, K. (1983). Incumbents' use of pre-entry alliances before expansion into new technical subfields of an industry. *Organization Science* 4, 152-180.

Monson, S. and Waelbroeek, P. (2003). Assessing spillovers from universities to firms: Evidence from French firm-level data. *International Journal of Industrial Organizat*ion 21, 1255-1270.

Oxley, J.E. and Sampson, R.C. (2004). The scope and governance of international R&D alliances. *Strategic Management Journal* 25, 723-749.

Pellegrino, G., Piva, M., and Vivarelli, M. (2012). Young firms and innovation: A microeconometric analysis. *Structural Change and Economic Dynamics* 23, 329-340.

Ritala, P. and Hurmelinna-Laukkanen, P. (2013). Incremental and radical innovation in coopetition – The role of absorptive capacity and appropriability. *Journal of Product Innovation Management* 30, 154-169.

Sakakibara, M. (1997). Heterogeneity of firm capabilities and cooperative research and development: An empirical examination of motives. *Strategic Management Journal* 18, 143-165.

Schneider, C. and Veugelers, R. (2010). On young highly innovative companies: why they matter and how (not) to policy support them. *Industrial and corporate change* 19, 1–39.

Tether, B.S. (2002). Who co-operate for innovations, and why: an empirical analysis. *Research Policy* 57, 294-308.

Toivanen, O. and Väänänen, L. (2014). Education and inventions. Forthcoming in *The Review of Economics and Statistics.*

Un, C.A. and Asakawa, K. (2015). Types of R&D collaborations and process innovation: The benefit of collaborating upstream in the knowledge chain. *Journal of Product Innovation Management* 32, 138-153.

Figure 1. Firms innovation collaboration patterns

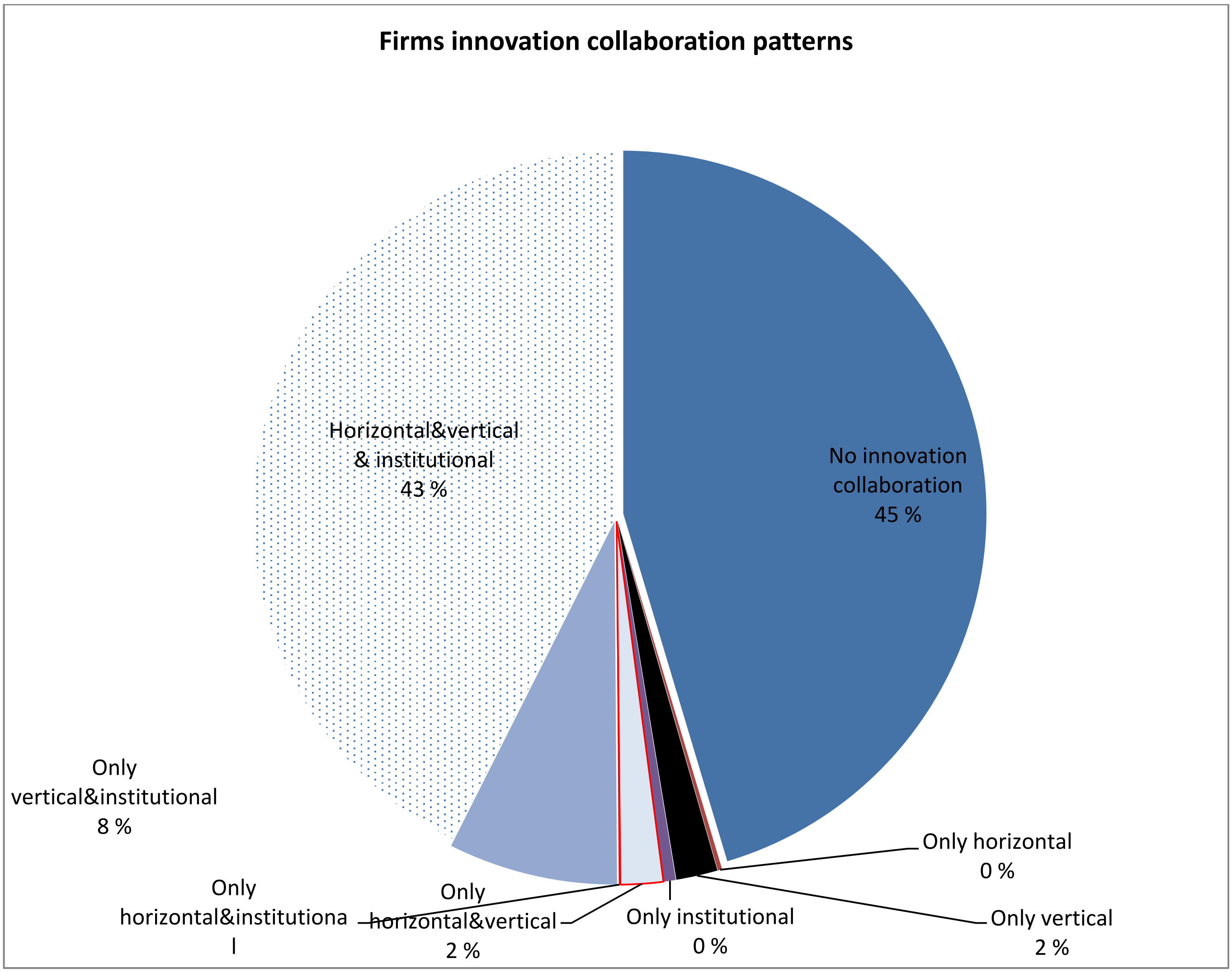
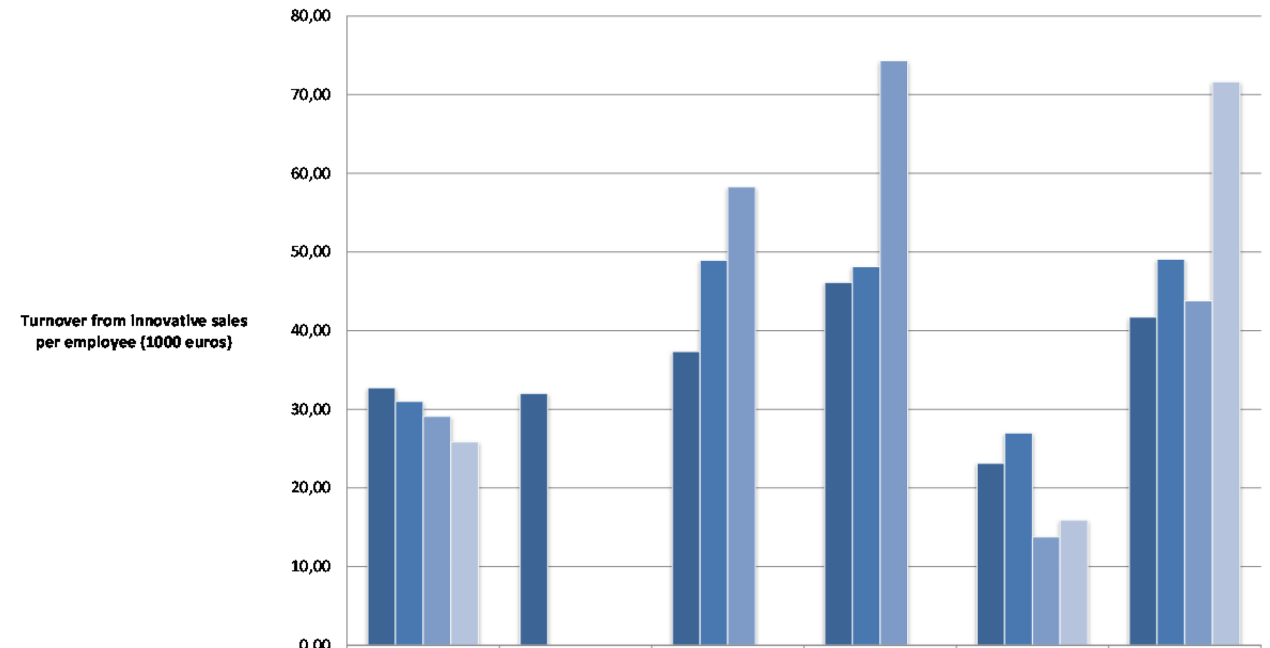


Figure 2. Revenues from innovative sales per employee by collaboration types



	No innovation collaboration	Vertical	Institutional	Vertical&institutional	Horizontal&vertical	Horizontal&vertical&institutional
Turnover per employee: all	32,74	32,02	37,35	46,13	23,15	41,74
Turnover per employee: max 10 years old	30,98		48,94	48,13	27	49,08
Turnover per employee: max 6 years old	29,09		58,27	74,32	13,78	43,79
Turnover per employee: YIC	25,87				15,9	71,66

*Missing information means that there are less than 3 observations.

Table 1. Descriptive statistics

Description of variable	**Variable name**	**Mean (S.D.)**
Dependent variables (for the years 2008, 2010 and 2012):		
(Log) total revenue (deflated by producer price indices for manufacturing and services, 2005=100) per employee generated at year t due to new or significantly improved products introduced during the past three years.	VALUE_INNO	2.54 (2.15)
Explanatory variables (past three years for the three sample time periods t: years 2006-2008, 2008-2010, and 2010-2012):		
Exclusive dummy variables that get value 1, and 0 otherwise if firm had i) no innovation collaboration, ii) innovation collaboration only with competitors iii) innovation collaboration only with vertical partners (i.e. customers and/or suppliers) iv) innovation collaboration with research organizations and/or universities v) horizontal and vertical innovation collaboration vi) horizontal and institutional innovation collaboration vii) vertical and institutional innovation collaboration, and viii) horizontal, vertical and institutional innovation collaboration.	i)NO_COLLAB ii) HORIZONTAL iii) VERTICAL iv) INSTITUTIONAL v) HOR_VER vi) HOR_INST vii) VER_INST viii) HOR_VER_INST	0.45 (0.50) 0.00 (0.04) 0.02 (0.13) 0.01 (0.07) 0.02 (0.14) 0.00 (0.02) 0.08 (0.26) 0.43 (0.49)
R&D intensity: R&D expenses/turnover at year t.	RD	0.04 (0.09)
Share of a firm's 16-24 years old employees.	AGE 16-24	0.07 (0.07)
Share of a firm's 25-34 years old employees.	AGE_25-34	0.27 (0.13)
Share of a firm's 35-44 years old employees.	AGE 35-44	0.27 (0.10)
Share of a firm's 45-54 years old employees.	AGE 45-54	0.25 (0.10)
Share of a firm's 54-70 years old employees.	AGE 55-70	0.15 (0.10)
Share of a firm's employees with upper secondary level education.	EDUC_COLLEGE	0.73 (0.14)
Share of a firm's employees with university degree.	EDUC_ACADEMIC	0.13 (0.15)
Dummy variable that gets value 1 if a firm has 10-49 employees, and 0 otherwise.	SMALL	0.42 (0.49)
Dummy variable that gets value 1 if a firm has 50-249 employees, and 0 otherwise.	MEDIUM	0.34 (0.47)
Dummy variable that gets value 1 if a firm has at least 250 employees, and 0 otherwise.	LARGE	0.20 (0.40)
Firm's age (log)	AGE	2.91 (0.75)
+ 21 industry dummies + locational dummies for 6 geographical areas		

Table 2. The estimation results of the OLS model for revenues from innovative sales per employee

	Dependent variable = INNO_VALUE			
	I. Baseline model	IV. YOUNG = YIC	III. YOUNG = max 6 years old	II. YOUNG = max 10 years old
	Coef./S.E	Coef./S.E	Coef./S.E	Coef./S.E
Constant	-2.65 (0.57)***	-2.68 (0.57)***	-2.67 (0.58)***	-2.74 (0.58)***
VERTICAL	-0.19 (0.41)			
INSTITUTIONAL	-0.45 (0.90)			
VER_INST	0.50 (0.17)***			
VER_HOR	0.36 (0.22)*			
HOR_VER_INST	0.36 (0.11)***			
VERTICAL*YOUNG		omitted*	0.57 (1.58)	0.34 (0.67)
INSTITUTIONAL*YOUNG	0	omitted*	omitted*	-1.19 (1.32)
VER_INST*YOUNG		omitted*	0.71 (0.31)**	0.17 (0.32)
VER_HOR*YOUNG		0.54 (0.26)**	0.63 (0.36)*	0.92 (0.31)***
HOR_VER_INST*YOUNG		0.93 (0.38)***	0.39 (0.21)*	0.53 (0.16)***
VERTICAL*OLD		-0.19 (0.41)	-0.15 (0.40)	-0.47 (0.49))
INSTITUTIONAL*OLD		-0.44 (0.91)	-0.45 (0.90)	-0.29 (1.05)
VER_INST*OLD		0.50 (0.17)***	0.47 (0.18)***	0.63 (0.18)***
VER_HOR*OLD		0.35 (0.22)	0.33 (0.23)	0.23 (0.25)
HOR_VER_INST*OLD		0.36 (0.11)***	0.36 (0.11)***	0.30 (0.12)***
RD	1.17 (0.60)**	1.04 (0.64)*	1.16 (0.61)*	1.16 (0.60)**
AGE 16-24	-1.72 (0.85)**	-1.70 (0.85)**	-1.72 (0.85)**	-1.72 (0.85)**
AGE_35-44	0.06 (0.55)	0.07 (0.55)	0.07 (0.55)	0.07 (0.56)
AGE 45-54	-0.54 (0.51)	-0.53 (0.52)	-0.53 (0.51)	-0.56 (0.51)
AGE 55-70	-1.56 (0.55)***	-1.57 (0.55)***	-1.57 (0.55)***	-1.56 (0.55)***
EDUC_COLLEGE	-0.27 (0.48)	-0.28 (0.48)	-0.27 (0.48)	-0.29 (0.48)
EDUC_ACADEMIC	0.06 (0.54)	0.05 (0.54)	0.06 (0.54)	0.06 (0.54)
SMALL	-0.54 (0.28)*	-0.52 (0.28)*	-0.54 (0.28)*	-0.39 (0.32)
MEDIUM	-0.60 (0.29)**	-0.58 (0.29)**	-0.61 (0.29)**	-0.55 (0.28)*
LARGE	-0.36 (0.30)	-0.34 (0.30)	-0.37 (0.30)	-0.60 (0.29)**
AGE	-0.05 (0.05)	-0.05 (0.05)	-0.05 (0.06)	-0.02 (0.06)
Industries	Yes	Yes	Yes	Yes
Years	Yes	Yes	Yes	Yes
Observations	2353	2353	2353	2353
Firms	1790	1790	1790	1790
R2	0.10	0.10	0.10	0.11

The robust firm cluster-specific standard errors are reported in parentheses. Significance levels are reported in superscript, where *** denotes a significance level of 1% and ** denotes a significance level of 5%

*Omitted means that the variables were dropped from the estimations due to insufficient variation.

.

Table 3. The estimation results of the quantile regressions for revenues from innovative sales per employee

	Dependent variable = INNO_VALUE				
	□ = 0.10	□ = 0.25	□ = 0.50	□ = 0.75	□ = 0.90
	Coef./S.E	Coef./S.E	Coef./S.E	Coef./S.E	Coef./S.E
Constant	-0.66 (4.22)	-3.13 (1.27)***	-3.45 (0.75)***	-3.61 (0.80)***	-3.93 (0.73)***
VERTICAL	-0.63 (1.49)	0.05 (0.64)	-0.05 (0.20)	-0.00 (0.62)	0.52 (0.14)***
INSTITUTIONAL	-0.63 (11.98)	-2.21 (2.59)	0.15 (0.26)	0.12 (0.27)	-0.27 (1.47)
VER_INST	0.90 (0.41)**	0.40 (0.16)***	0.25 (0.11)**	0.31 (0.14)**	0.11 (0.13)
VER_HOR	1.40 (0.85)*	0.24 (0.16)	0.05 (0.17)	-0.41 (0.07)***	-0.37 (0.54)
HOR_VER_INST	0.79 (0.30)***	0.34 (0.10)***	0.25 (0.08)***	0.13 (0.07)*	0.18 (0.06)***
RD	3.44 (1.82)*	1.38 (0.41)***	0.68 (0.36)*	0.22 (0.42)	0.09 (0.26)
AGE 16-24	-3.50 (2.27)	-2.13 (0.94)**	-1.29 (0.65)**	-1.51 (0.49)***	-1.95 (0.43)***
AGE_35-44	-1.28 (1.79)	0.29 (0.54)	-0.31 (0.40)	0.41 (0.38)	0.53 (0.35)
AGE 45-54	0.17 (1.60)	-0.68 (0.50	-0.54 (0.36)	-0.35 (0.32)	-0.19 (0.32)
AGE 55-70	-2.00 (1.65)	-1.25 (0.57)**	-1.65 (0.37)***	-2.14 (0.36)***	-1.51 (0.34)***
EDUC_COLLEGE	-2.28 (0.89)***	-0.43 (0.50)	0.09 (0.35)	0.15 (0.33)	0.63 (0.25)***
EDUC_ACADEMIC	-1.92 (0.89)**	-0.12 (0.51)	0.61 (0.38)*	0.48 (0.39)	0.99 (0.25)***
SMALL	-2.07 (0.83)***	-0.55 (0.18)***	-0.16 (0.21)	0.00 (0.12)	-0.13 (0.26)
MEDIUM	-1.72 (0.80)**	-0.52 (0.18)***	-0.29 (0.21)	-0.14 (0.13)	-0.38 (0.26)
LARGE	-1.35 (0.82)*	-0.34 (0.19)*	-0.02 (0.21)	0.23 (0.14)*	-0.06 (0.26)
AGE	-0.01 (0.09)	0.03 (0.05)	-0.04 (0.03)	-0.08 (0.03)***	-0.08 (0.02)***
Industries	Yes	Yes	Yes	Yes	Yes
Years	Yes	Yes	Yes	Yes	Yes
Observations	2353	2353	2353	2353	2353
R2	0.09	0.07	0.07	0.07	0.07

The robust standard errors are reported in parentheses. Significance levels are reported in superscript, where *** denotes a significance level of 1% and ** denotes a significance level of 5%.

Table 4. Mediating effect of education: The estimation results of the OLS model for revenues from innovative sales per employee

Dependent variable = INNO_VALUE	
Variable	Coef./S.E
Constant	-2.85 (0.43)***
VERTICAL*HIGH_EDUC	-0.48 (1.17)
INSTITUTIONAL* HIGH_EDUC	-0.59 (0.69)
VER_INST* HIGH_EDUC	0.64 (0.19)***
VER_HOR* HIGH_EDUC	0.19 (0.31)
HOR_VER_INST* HIGH_EDUC	0.48 (0.12)***
VERTICAL*OLD*LOW_EDUC	-0.26 (1.17)
INSTITUTIONAL*LOW_EDUC	0.06 (0.48)
VER_INST**LOW_EDUC	0.36 (0.23)
VER_HOR**LOW_EDUC	0.45 (0.28)
HOR_VER_INST**LOW_EDUC	0.20 (0.13)
RD	1.16 (0.59)**
AGE 16-24	-1.57 (0.84)*
AGE_35-44	0.09 (0.55)
AGE 45-54	-0.55 (0.51)
AGE 55-70	-1.50 (0.54)***
SMALL	-0.55 (0.28)**
MEDIUM	-0.62 (0.28)**
LARGE	-0.39 (0.30)
AGE	-0.06 (0.05)
Industries	Yes
Years	Yes
Observations	2353
Firms	1790
R2	0.10

The robust firm cluster-specific standard errors are reported in parentheses. Significance levels are reported in superscript, where *** denotes a significance level of 1% and ** denotes a significance level of 5%.

HIGH_EDUC = Dummy variable that gets value 1 if a firm has a higher than (sample) median share of employees with university degree.

LOW_EDUC = Dummy variable that gets value 1 if a firm has a lower than (sample) median share of employees with university degree.