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Is a firm's productivity level affected by its number and types of innovation cooperation partners?

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ABSTRACT

We first examine the effect of having innovation cooperation arrangements on the productivity level among firms with innovation activities. Then, we examine whether a firm's productivity level is affected by its number and types of innovation cooperation partners among those with innovation cooperation arrangements. Data on Norwegian firms with innovation activities is used. In the analysis, we differentiate between small and large firms. The estimation results show that unlike small firms, large firms can benefit from cooperation arrangements by achieving productivity improvements. Using the group of internal partners as the reference category, the results show that the productivity level is relatively higher in the short term among all and small firms that had cooperation arrangements with competitors or other enterprises in their sector, and relatively lower both in the short and medium term among all and small firms that had arrangements with partners in the academic sector. This level is relatively higher among large firms that had arrangements with consultants or consulting enterprises, and relatively lower among large firms that had arrangements with commercial labs or R&D-enterprises, in the medium term. We also find that most effects of the number of different types of cooperation partners are not significant.

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1. Introduction

The relationship between innovation and productivity in firms has been studied extensively. Several studies reveal that firm productivity is positively related to innovation activities (Crépon, Duguet, and Mairesse 1998; Cainelli, Evangelista, and Savona 2006; Hashi and Stojčić 2013; De Fuentes et al. 2015; Lopes and Godinho 2019; Gogokhia and Berulava 2021; Ugur and Vivarelli 2020). Other studies find that there is a positive impact of product innovation on productivity (Hall, Lotti, and Mairesse 2009; Hall 2011; Baumann and Kritikos 2016), while the impact of process innovation is more ambiguous or not significant (Hall 2011; Baumann and Kritikos 2016), or that process innovation has a larger effect via the associated investment (Hall, Lotti, and Mairesse 2009). In the study by Castellani et al. (2019), the results are claimed to support the view that productivity gains can be originated by different types of innovation, with more complex and radical product innovation generally relying on formal R&D, while process innovation more related to embodied technical change. Mohnen and Hall (2013) conclude that not only product and process innovations, but also organisational and marketing innovations, contribute to a better productivity performance. The findings in Damioli, Van

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Roy, and Vertesy (2021) reveal a positive and significant impact of artificial intelligence (AI) patent applications on labour productivity, but some studies emphasise that (among other things) productivity can become more difficult to measure and interpret as AI and its complements more rapidly add to our (intangible) capital stock (Brynjolfsson, Rock, and Syverson 2019), and that there is a growing need for quantitative analyses to measure the impacts of AI on economic outcomes such as growth, productivity and employment, but the requirement for high quality, firm-level data acts as an important barrier (Raj and Seamans 2019).

According to Mariev et al. (2021), firms acquire the knowledge needed for innovation based on technological diffusion mechanisms, which matters for firms' performance (Orlando 2004; Aldieri, Sena, and Vinci 2018; Urbig et al. 2021). Firms cannot only rely on in-house knowledge and internal processes to develop innovation, since knowledge and information are distributed across many different economic actors and new knowledge is constantly being generated, and thus collaboration with different types of partners (including external partners) is crucial for innovation (Haus-Reve, Fitjar, and Rodríguez-Pose 2019). As emphasised in de Faria, Lima, and Santos (2010), innovation cooperation activities are considered an efficient means for the industrial organisation of complex R&D and innovation processes, and cooperation has therefore gained an important role in the innovation process at the firm level. With focus on firms' motivations for cooperative R&D, Bayona, García-Marco, and Huerta (2001) conclude that their results suggests that such motivations are the complexity of technology and the fact that innovation is costly and uncertain. Furthermore, strong evidence has been found that the likelihood of innovation developed by the firm and in collaboration with other firms increases with external collaboration intensity (Audretsch and Belitski 2020).

It is therefore important to understand how innovation cooperation arrangements are related to a firm's productivity level. To our knowledge, very few studies have examined and estimated this relationship. Two exceptions are Goedhuys (2007) and Fernández Gual and Segarra-Blasco (2013). Goedhuys (2007) investigates the impact of innovation activities on total factor productivity (TFP) among Brazilian manufacturing firms, and finds that cooperation with clients (to acquire new technology), and product innovation, help firms to raise their productivity levels. The study by Fernández Gual and Segarra-Blasco (2013), where it seems that cooperation and productivity are linked through innovation, shows that Spanish firms which cooperate in innovative activities are more likely to invest in R&D in subsequent years, and that innovation output has a positive impact on firms' productivity (being greater in process innovations).

We examine the effects of having innovation cooperation arrangements on a firm's productivity level. The research questions are as follows: How is the productivity level affected by having innovation cooperation arrangements among firms with innovation activities? And how is the productivity level affected by the number and types of innovation cooperation partners among firms with innovation cooperation arrangements? These questions are examined using data of Norwegian firms. The data consists of firms with innovation activities, and is based on matched employer–employee register data, financial register data and innovation survey data. Although several studies have found a positive link between firm productivity and innovation activities, far fewer studies have examined how productivity is related to innovation cooperation arrangements (see above). As de Faria and Mendonça (2011) observe an impact of innovation activities in performance gains three years later, we examine the effects of cooperation arrangements on the productivity level both in the short and medium term.

When estimating the effects of the number and types of innovation cooperation partners on the productivity level among firms with innovation cooperation arrangements, three different types of regressions are used. In the first regression type, we estimate the effect of each type of external innovation cooperation partner on productivity, where the group of internal partners is used as the reference category (seven different types of partners in total). In the second type, we estimate the number of different types of cooperation partners on the productivity level using this number as a continuous variable. The number of different types of partners is used as a categorical variable in the third regression type, where the middle category (i.e. the category consisting of four different types of partners) is used as the reference category.

The relationship between firm productivity and innovation cooperation arrangements can be based on at least three theoretical frameworks. Two of these are the resource-based view (Mowery, Oxley, and Silverman 1998), and the 'open innovation' perspective (Perkmann and Walsh 2007; López et al. 2015). The third framework, which we consider as an analytical framework for this study, is a so-called knowledge-based view, where we refer to de Faria, Lima, and Santos (2010) and Haus-Reve, Fitjar, and Rodríguez-Pose (2019). According to de Faria, Lima, and Santos (2010), cooperation activities with other firms or institutions can be characterised by intensive knowledge exchange and learning processes, which tend to combine complementary assets and to build synergies. They find that firms place greater value on cooperation partners in the innovation process if they cooperate with certain partners, and thus the effect of each cooperation partner on the productivity level may vary for different types of partners. In our analysis, the effect of each type of external partner is measured in relation to the category of internal partners.

Haus-Reve, Fitjar, and Rodríguez-Pose (2019) emphasise that collaboration with various types of partners facilitates access to new knowledge and accelerates the propensity to innovate. They argue that using a variety of different partners provides a variety of knowledge that contributes to enhancing the innovation potential in a firm, and is thus considered desirable. Therefore, we expect that the productivity level is positively affected by the number of different types of innovation cooperation partners.

The rest of the article is organised as follows. Section 2 presents previous studies, while Section 3 describes the data and the variables. The econometric approach is presented in Section 4. Section 5 gives descriptive statistics, while the estimation results are presented in Section 6. In Section 7, robustness checks are conducted. Section 8 provides conclusions.

2. Previous studies

As emphasised in the introductory section, very few studies have, as far as we are aware, examined and estimated how innovation cooperation arrangements are related to the productivity level. However, several studies focus on firms' collaboration with other firms or institutions on R&D or innovation activities. Examples of such studies are presented in the following.

Kaiser (2002) focuses on innovation cooperation with customers and competitors (including suppliers) as possible cooperation partners. The results indicate that firms with multiple customer groups invest more in innovation than firms with more homogeneous customers, and firms that are faced with foreign competition invest more in innovation than firms without foreign competitors. In a study of firms engaged in R&D cooperation with research centres, Bayona Sáez, Marco, and Arribas (2002) find that such cooperation is initiated in order to carry out basic research. De Propris (2002) finds that firms benefit from engaging in cooperation over innovation with either buyers or suppliers, and that firms are more likely to be innovators if they cooperate with other firms (than if they do not).

As concluded by Capron and Cincera (2003), the most important sources of information on firms' innovative activities at the European level are within the enterprise or with other firms of the group and with clients or customers. Investigating cooperative innovative activity, Abramovsky et al. (2009) find that receipt of public support is positively related to undertaking collaborative innovation. Sánchez-González, González-Álvarez, and Nieto (2009) investigate the factors determining cooperation in developing innovations between firms and a specific group of agents, customers and users, and find that the existence of sticky information and the presence of heterogeneous needs in the market exert a positive influence on cooperative relationships with these agents. Tsai (2009) focuses on the relationships between different types of collaboration partners and product innovation performance, and his summary signifies that absorptive capacity is a contingency that influences the magnitude and direction of these relationships under different degree of product innovativeness, firm size and industrial sector.

The study by de Faria, Lima, and Santos (2010) shows that firms that cooperate with other firms within the firm group or with suppliers place greater value on cooperation partners in the innovation process. Piga and Vivarelli (2003) conclude that 'the estimates suggest that a firm with a concentrated ownership structure and with targets in the areas of both process and product R&D, exhibits a greater tendency to seek external R&D partners' (245–246). With focus on different motives for R&D cooperation, Arvanitis (2012) finds that technology-motivated collaborative activities show a weaker tendency to positive direct effects on productivity than cost-motivated cooperation. Edwards-Schachter et al. (2013) show that the dynamics of cooperation on R&D and innovation at firm level is determined by a complex interplay of motives, economic constraints, and practical opportunities.

Ritala and Hurmelinna-Laukkanen (2013) conclude that it is evident that some firms are better able to reap the benefits of collaborating with their competitors in innovation than others. Their study provides evidence of reasons for such differences, specifically on the firm's ability to acquire knowledge from external sources and to protect its innovations and core knowledge from imitation. Tomlinson and Fai (2013) find that small and medium-sized firms' cooperation with rivals (coopetition) has no significant impact upon innovation, while Hyll and Pippel (2016) show that R&D cooperation with competitors is positively correlated only to process innovation failures.

The relationship between coopetition (cooperation between competitors) and product innovation performance is examined in Wu (2014), and the results show an inverted U-shaped relationship. The analysis in Lewandowska, Szymura-Tyc, and Gołębiowski (2016) identifies foreign innovation cooperation partners as conducive to increased export intensity. Seo, Chung, and Yoon (2017) find that the relationship between partner types and the likelihood of unintended innovation performance in R&D cooperation varies with respect to technological intensity and appropriability conditions. As illustrated in Vanyushyn et al. (2018), firms that cooperate with competitors internationally are more likely to exhibit higher propensity to introduce more radical (new-to-market) innovations.

Haus-Reve, Fitjar, and Rodríguez-Pose (2019) find that firms benefit strongly from collaborating with scientific or supply-chain partners, but collaborating with both types of partners simultaneously does not yield multiplicative benefits. As found in Radicic et al. (2019), increasing the number of cooperation partnerships has a positive impact on innovation performance. Edwards, Ferrett, and Gravino (2020) focus on a firm's incentive to collaborate in cost-reducing R&D, and show that collaboration with a foreign rather than a local firm is more likely the bigger the foreign firm's home market size.

3. The data

The data consists of Norwegian firms, and is based on three data sources from Statistics Norway: matched employer–employee register data, financial register data, and innovation data. The matched employer–employee register data contains yearly information on all employees, and all plants and enterprises, in Norway in the period 2000–2016. In the employer–employee data, both plants and enterprises are identified by unique codes, where each enterprise consists of at least one plant. For each unique plant code, there is a corresponding unique enterprise code.

The financial register data contains information on total assets for all enterprises in Norway in 2014. Total assets are measured in 1000 NOK, and are the sum of current and long-term assets. A firm's capital stock is defined as its total assets, and the capital stock per employee is used as a measure of the capital intensity.

The innovation data is from the Norwegian Innovation Survey for 2014, which is part of Eurostat's Community Innovation Survey (CIS) (SSB 2014). This survey contains information on innovation activities in the Norwegian business enterprise sector for 2014, and measures the extent to which firms have introduced different forms of innovations during the period 2012–2014. The survey covers firms with at least 5 employees, except in NACE groups F and H (41–43, 49–53) and NACE 56 which only cover firms with at least 20 employees.

In the analysis, firms are defined at the enterprise level. The reasons are that the enterprise level is the unit in the innovation data, and that total assets are defined at this level in the financial data. Enterprises are identified by unique codes in the financial data and the innovation data, and these codes correspond to the enterprise codes in the employer–employee data. The financial data and the innovation data are linked to the employer–employee data at the enterprise level based on the enterprise codes.

Since the innovation data is cross-sectional data, we cannot conduct a panel data analysis. However, the employer–employee data for the period 2014–2016 is used to calculate a firm's productivity level for each year in this period. This study is therefore an analysis both in the short and medium term.

3.1. Labour productivity or TFP?

According to Tang (2017), labour productivity and TFP should be considered as different proxies for firm heterogeneity. Syverson (2011, Section 2.1) emphasises that labour productivity is the most common measure of Single-factor productivity levels, which reflect units of output produced per unit of a particular input. Such productivity levels are affected by the intensity of use of the excluded inputs. Therefore, TFP is often used as a productivity measure, which is invariant to the intensity of use of observable factor inputs.

Differences in TFP reflect shifts in output while holding inputs constant (Syverson 2011, Section 2.2). TFP is commonly identified with the level of technology, but it actually incorporates a wide variety of factors such as the internal organisation of firms and the level of worker effort (Sargent and Rodriguez 2000). This indicates that TFP may be more relevant to use than labour productivity when analysing long-term trends in the economy.

Sargent and Rodriguez (2000) argue that labour productivity may be a better choice than TFP for time periods of less than a decade, while TFP may be a better choice than labour productivity for longer periods. Furthermore, if there are important biases in the estimates of the capital stock used to construct measures of TFP growth,[1] then it may be better to rely on measures of labour productivity (Sargent and Rodriguez 2000). Based on these considerations, we prefer to use labour productivity instead of TFP, mainly due to the cross-sectional nature of the innovation data.

3.2. The final sample of firms

The sample consists of firms that are both included in the innovation data and in the matched employer–employee register data in 2014. There are 5977 firms in the innovation data. We exclude 12 enterprises in the innovation data from the sample, since they are not included in the matched employer–employee data in 2014. This reduces the number of firms in the sample to 5965.

In the innovation survey, firms were asked about whether they had any cooperation arrangements on innovation activities and R&D with other enterprises or institutions during the period 2012–2014. Of the 5965 firms in the sample, we find that there are 1404 firms with cooperation arrangements (which by definition are firms with innovation activities), 1503 firms without cooperation arrangements but with innovation activities, and 3058 firms without innovation activities. None of the 3058 firms without innovation activities have answered the question whether they had any cooperation arrangements. Only firms with innovation activities are included in the sample, which reduces the sample to 2907 firms (1404 firms with cooperation arrangements and 1503 firms without).

Firms with innovation activities are either product- and/or process-innovative firms, or firms that had innovation projects that were either abandoned or had not yet led to a product or process innovation by the end of the period 2012–2014. Product-innovative firms have introduced a good or service that is new or significantly improved with respect to its characteristics or intended uses, while process-innovative firms have implemented a new or significantly improved production or delivery method.

An explanatory variable used in the analysis is the (log of the) capital intensity. 133 firms with cooperation arrangements and 107 firms without cooperation arrangements but with innovation activities are found to have missing values for the capital stock, and these firms are excluded from the sample. This reduces the number of firms in the sample to 2667 (1271 with cooperation arrangements and 1396 without). We also find that 52 firms with cooperation arrangements and 29 firms without cooperation arrangements but with innovation activities have missing values for the productivity level in 2014. In addition, there is only one firm in each of the industrial sectors 'human health and social work activities' (Q) and 'arts, entertainment and recreation' (R) (alphabetical NACE codes in parenthesis) among those with cooperation arrangements. These 54 firms with cooperation arrangements and 29 firms without such arrangements are excluded from the sample. The final sample therefore consists of 2584 firms with innovation activities in total, of which there are 1217 firms with cooperation arrangements and 1367 firms without.

Based on the final sample, we define three year cohorts. These are the 2014 cohort, the 2015 cohort, and the 2016 cohort. All firms in the final sample are included in the 2014 cohort, while the 2015 (2016) cohort only includes firms in the final sample that are included in the matched employer–employee register data in 2015 (2016). Therefore, the number of firms in the 2015 (2016) cohort (which is used when estimating the effects of the regressors on a firm's productivity level in 2015 (2016)) will be lower than the number of firms in the 2014 cohort (used when estimating the corresponding effects in 2014).

In the empirical analysis, we use either all firms in the final sample (i.e. all firms in the final sample of firms with innovation activities) or only those with cooperation arrangements in this sample (i.e. all firms in the final sample of firms with innovation cooperation arrangements). In addition, we differentiate between the following two firm sizes: 'small' firms are defined as those with 1–99 employees, and 'large' firms are defined as those with at least 100 employees.

3.3. Sampling weights

The innovation survey is a census of all units within the population with at least 50 employees, while a random sample is drawn within each stratum among the other units with 5–49 employees (SSB 2014). There are no enterprises with less than 5 employees included in the innovation survey (see above). Therefore, linking the innovation data to the matched employer–employee register data introduces a bias in favour of larger-sized firms.

This bias is accounted for by weighting all the empirical results in Sections 5 and 6 using sampling weights from the innovation data. Based on the 2014 cohort and the final sample of firms with innovation cooperation arrangements, we find that the average value of the weights (in parenthesis) is higher among the 137 enterprises with 5–9 employees (6.2) than among the 507 enterprises with 10–49 employees (2.6), and lowest among the 573 enterprises with at least 50 employees (1.1). This average value is 2.3 among the 1217 enterprises in the final sample of firms with cooperation arrangements.

If we use the 2014 cohort and the final sample of firms without innovation cooperation arrangements but with innovation activities, we find that the average value of the weights is higher among the 200 enterprises with 5–9 employees (7.1) than among the 645 enterprises with 10–49 employees (3.6), and lowest among the 522 enterprises with at least 50 employees (1.2). This average value is 3.2 among the 1367 enterprises in the final sample of firms without cooperation arrangements (but with innovation activities).

3.4. The dependent variable and the explanatory variables

The dependent variable is the log of the productivity level, where this level is defined as a firm's turnover per employee. Turnover is given in 1000 NOK. The productivity level is measured by the labour productivity, since turnover is a measure of the firm's production value.

The explanatory variables consist of the key regressors and the control variables. There are four types of the key regressors. The first type is the dummy variable 'innovation cooperation arrangements', which is equal to 1 if a firm stated that it had cooperation arrangements on innovation activities and R&D with other enterprises or institutions (0 otherwise).

The second types of the key regressors are the explanatory variables that account for different types of innovation cooperation partners, which are based on information about cooperation arrangements on innovation activities and R&D (with other enterprises or institutions). These partners are: (1) other enterprises within their enterprise group, (2) suppliers of equipment, materials, components or software, (3) clients or customers in the private sector, (4) clients or customers in the public sector, (5) competitors or other enterprises in their sector, (6) consultants or consulting enterprises, (7) commercial labs or R&D-enterprises, (8) universities or university colleges, and (9) public or private research institutes. Many of the firms with innovation cooperation arrangements in the final sample had such arrangements with several of the types of partners (1) to (9) during the period 2012–2014 (see Section 5).

We find it difficult to explain why there should be potential productivity differences between the types (3) and (4), and between the types (8) and (9). Therefore, (3) and (4) are replaced by (10), and (8) and (9) are replaced by (11). The two new types of partners are: (10) clients or customers (firms that had cooperation arrangements with (3) and/or (4)), and (11) academic sector (cooperation arrangements with (8) and/or (9)). The seven different types (1), (2), (5), (6), (7), (10) and (11) are thus used in the analyses. Partners of type (1) are defined as internal partners, while partners of types (2), (5), (6), (7), (10) and (11) are defined as external partners.

The second types of the key regressors are all dummy variables. Each of these key regressors accounts for a particular type of innovation cooperation partner, and is equal to 1 if a firm stated that it had cooperation arrangements with this type of partner (0 otherwise). In the regressions, internal partners are used as the reference category.

The third type of the key regressor is the number of different types of innovation cooperation partners, which varies from 1 to 7. In the regressions, the number of different types of partners is used as a continuous variable.

The fourth types of the key regressors consist of seven dummy variables. Each key regressor is equal to 1 if a firm stated that it had cooperation arrangements with a particular number of different types of innovation cooperation partners (0 otherwise). This means that the number of different types of partners is used as a categorical variable in the regressions.

Explanatory variables other than the key regressors are the following control variables: the log of the capital intensity (measured as total assets per employee), the log of the number of employees, proportion of females of total employees, average age of employees, educational level (measured as proportions of employees at different highest attained educational levels: employees with primary, secondary or higher education, including a separate category of employees with unknown educational level), location of innovation cooperation partner, firm age, geographic markets (measured as the markets where the firms sell their products, either only in the Norwegian market, only abroad, or both in Norway and abroad), industrial sectors (alphabetical NACE codes, SIC2007), and a firm's location according to region.

The same control variables are used in the analysis in Børing (2019), with the exception of firm location (and location of innovation cooperation partner). Syverson (2011) surveys empirical literature on determinants of productivity, and his literature review and other studies presented in Børing (2019) relate each control variable to a firm's productivity. The studies by Martin, McHugh, and Johnson (1993) and Venables (2010) relate firm location to firm productivity.

We use the matched employer–employee data for the period 2000–2014 to calculate a firm's age. Firm age is calculated as the number of years from the founding year until 2014. Many firms in these data have a one-year period of deregistration, which means that they are not included in the data in this period. This may be related to statistical errors or temporary exit, rather than a permanent exit. Since we may underestimate a firm's age if we assume that it makes a permanent exit in a one-year deregistration period, we use a deregistration period of at least two years to define a firm's founding year. If a firm has one or more deregistration periods of at least two years, its founding year is defined as the first year it is included in the employer–employee data after the last deregistration period. If a firm does not have a deregistration period of at least two years, its founding year is defined as the first year it is included in the employer–employee data if the first year is 2002 or later, or the founding year will be 2001 or earlier if the first year is 2000 or 2001 (which means that the firm is 14 years or older).

The innovation data is the data source of the key regressors, and location of innovation cooperation partner and geographic markets used as control variables. All the other control variables are from the employer–employee data. Location of innovation cooperation partner, industrial sectors and firm location are represented by dummy variables, while all other control variables are continuous.

4. The econometric approach

4.1. The productivity model

The empirical model is based on the productivity models used in Børing (2014). Let Y_i be the monetary value of the production, L_i the number of employees, K_i the monetary value of the capital stock, and T_i the state of technology, in firm i, $i = 1, 2, \dots, n$. We then assume that each firm has the following production function:

$$Y_i = F_i(K_i, L_i, T_i) = A_i K_i^p L_i^q T_i, \tag{1}$$

which is of Cobb–Douglas form. A_i represents the Hicksian neutral efficiency level, which is not observable. The function in (1) has non-constant returns to scale in (K_i, L_i) if the sum of the parameters, $d = p + q$, is not equal to 1. We model the technology T_i in the following way:

$$T_i = \exp(\boldsymbol{X}_i\boldsymbol{b} + \boldsymbol{Z}_i\boldsymbol{c}), \tag{2}$$

where X_i is a row vector of the four types of the key regressors, and Z_i is a row vector of control variables other than $(\ln(K_i/L_i), \ \ln L_i)$. b and c are column vectors of coefficients. Let a measures the mean efficiency level across firms, and ε_i the firm-specific deviation from this mean. If we use (1) and (2), and set $\ln A_i = a + \varepsilon_i$, then we get the following expression for the log of the labour productivity:

$$\ln\left(\frac{Y_i}{L_i}\right) = a + p\ln\left(\frac{K_i}{L_i}\right) + (d-1)\ln L_i + X_i b + Z_i c + \varepsilon_i. \tag{3}$$

The short-term effects of the explanatory variables on the productivity level can be estimated by using (3), which refers to the base year (i.e. 2014). Denote t_0 as the base year, and t_T as the final year (i.e. 2016). As we will examine how each of the regressors affects the productivity level both in the short and medium term, we replace (3) by the following equation:

$$\ln\left(\frac{Y_{it}}{L_{it}}\right) = a + p\ln\left(\frac{K_{it_0}}{L_{it_0}}\right) + (d-1)\ln L_{it_0} + X_{it_0} b + Z_{it_0} c + \varepsilon_{it}, \tag{4}$$

which is the basic equation to be estimated for each of the four type(s) of the key regressor(s). The year t refers to the period from t_0 to t_T. In the estimations, the explanatory variables are $(\ln(K_{it_0}/L_{it_0}), \ \ln L_{it_0}, X_{it_0}, Z_{it_0})$.

4.2. The potential endogeneity problem

We suspect each of the component in X_{it_0} to be an endogenous variable. The reason is that a firm's productivity level may not only be affected by each of these components (which will be examined in this study), but also that the productivity level may affect each of the components, since a firm with aiming to increase its productivity may choose to cooperate with different types of innovation partners. Therefore, we cannot assume that each of the component in X_{it_0} is statistically independent of ε_{it}, but we assume that ε_{it} is statistically independent of $(\ln (K_{it_0}/L_{it_0}),\ \ln L_{it_0}, Z_{it_0})$.[2]

Instrumental variables (IV) techniques are commonly used to address the endogeneity problem. The instruments must be both relevant and exogenous (Chang and Kang 2019). We will probably be able to find an instrument that is associated with each of the variables that may be endogenous (i.e. the four types of the key regressors), but the problem is to find exogenous instruments. Based on the data set, we have no suggestions for such instruments. According to Haus-Reve, Fitjar, and Rodríguez-Pose (2019), there are also econometric challenges in using IV techniques based on CIS data, due to the lack of strong exogenous instruments.

Several studies highlight the problem of the lack of such instruments. Andrews, Stock, and Sun (2019) emphasise that conventional methods for IV estimation and inference become unreliable when instruments are weakly correlated with endogenous regressors. As concluded in Bound, Jaeger, and Baker (1995), even if only a weak relationship exists between the instruments and the error in the structural equation, instruments that explain little of the variation in the endogenous explanatory variables can lead to large inconsistencies in the IV estimates. Although the variation in an instrument is largely unrelated to the process under study, this is not sufficient to imply that IV estimates will be less biased than OLS estimates (Bound, Jaeger, and Baker 1995). Berkowitz, Caner, and Fang (2008) show that 2SLS t-statistic over- or under-rejects the null hypothesis that the endogenous regressor is insignificant when instruments are nearly exogenous.

In our analysis, we also have a challenge related to the second and third types of the key regressors. Each of these types consists of seven dummy variables (one is used as a reference category), which will probably involve the use of many valid instrumental variables. This has the potential to improve efficiency, but makes the usual inference procedures inaccurate (Hansen, Hausman, and Newey 2008). The study by Hansen and Kozbur (2014) concludes that many traditional IV techniques perform poorly when many instruments are used.

Since it is difficult to find suitable instruments, and that large inconsistencies in the IV estimates can occur if instruments explain little of the variation in the endogenous regressors, we will not use IV techniques in the analysis. Instead, we try to reduce the potential bias from endogeneity in the following way: As we examine the effects of the explanatory variables on the productivity level in the medium term, the potential endogeneity of the key regressors may be reduced since the year of the dependent variable is later than 2014. In principle, this means that the explanatory variables are lagged.[3] Furthermore, a firm's innovation cooperation arrangements refer to the period 2012–2014. Thus, even when estimating the effects of the key regressors on the productivity level in 2014, some firms may have been involved in cooperation arrangements before 2014.

5. Descriptive statistics

Table 1 shows that 72% of the firms in the final sample of firms with innovation cooperation arrangements have suppliers of equipment, materials, components or software as their cooperation partner, and 60% have clients or customers as their partner. We also find that under half of the firms have internal partners, and partners among consultants or consulting enterprises. 40% of the firms have partners in the academic sector, and a quarter cooperate with commercial labs or R&D-enterprises. About a third of the firms cooperate with competitors or other enterprises in their sector.

The table also shows that large firms have a higher proportion of a specific type of innovation cooperation partner than small firms among most types of partners. In particular, the difference is large among internal partners and partners in the academic sector. However, there are two exceptions: A relatively lower proportion of large firms cooperate with clients or customers, and with competitors or other enterprises in their sector.

These descriptive statistics indicate that most firms in the final sample of firms with cooperation arrangements have several cooperation partners. This can be seen from the table. We find that the

Table 1. Descriptive statistics, all firms in the final sample of firms with innovation activities by year cohort, weighted results.

	Without cooperation arrangements			With cooperation arrangements		
	2014	2015	2016	2014	2015	2016
Proportion of females of total employees	29%	29%	29%	28%	28%	27%
Average age of employees	41	41	41	42	42	42
Educational level (per cent)						
Employees with primary education	27%	28%	28%	22%	22%	23%
Employees with secondary education	37%	37%	37%	33%	33%	33%
Employees with higher education	31%	30%	30%	41%	41%	41%
Employees with unknown educational level	5%	5%	5%	4%	4%	4%
Number of employees (per cent)						
1–9 employees	33%	32%	32%	30%	29%	29%
10–24 employees	36%	36%	36%	32%	33%	33%
25–99 employees	25%	26%	26%	26%	26%	26%
100 employees or more	6%	6%	6%	12%	12%	12%
Average number of employees	38	39	39	81	82	84
Firm age						
1–5 years	16%	16%	15%	16%	15%	16%
6–9 years	14%	13%	13%	16%	15%	15%
10–13 years	16%	16%	16%	17%	17%	16%
14 years or older	54%	55%	56%	52%	53%	53%
Geographic markets						
Only sell products in the Norwegian market	58%	57%	57%	47%	46%	46%
Only sell products abroad	1%	1%	1%	2%	3%	3%
Sell products both in Norway and abroad	41%	42%	42%	50%	51%	51%
Type of innovation cooperation partner						
Internal partners (i.e. other enterprises within a firm's enterprise group)				47%	47%	47%
Suppliers of equipment, materials, components or software				72%	72%	72%
Clients or customers				60%	60%	60%
Competitors or other enterprises in a firm's sector				31%	30%	30%
Consultants or consulting enterprises				44%	45%	45%
Commercial labs or R&D-enterprises				25%	25%	25%
Academic sector				40%	40%	40%
Number of different types of innovation cooperation partners						
1 partner				21%	21%	21%
2 partners				21%	21%	21%
3 partners				19%	19%	20%
4 partners				16%	16%	16%
5 partners				10%	10%	10%
6 partners				5%	6%	5%
7 partners				8%	7%	7%
Average number of different types of innovation cooperation partners				3.2	3.2	3.2
Location of innovation cooperation partner						
Locally/regionally in Norway				73%	72%	72%
Other Norway				56%	56%	56%
Nordic countries				25%	26%	26%
Other Europe				36%	37%	37%
United States				12%	12%	12%
China or India				7%	6%	6%
Other countries				8%	8%	8%
Industrial sector						
Agriculture, forestry and fishing (A)	1%	1%	1%	2%	2%	2%
Mining and quarrying (B)	1%	1%	1%	2%	2%	2%
Manufacturing (C)	25%	26%	26%	28%	28%	28%
Electricity, gas, steam and air conditioning supply (D)	1%	0.47%	1%	2%	2%	2%
Water supply; sewerage, waste management and remediation activities (E)	1%	1%	1%	1%	1%	1%
Construction (F)	7%	7%	7%	3%	3%	3%
Wholesale and retail trade; repair of motor vehicles and motorcycles (G)	20%	21%	20%	15%	15%	15%
Transportation and storage (H)	3%	3%	3%	3%	3%	3%
Accommodation and food service activities (I)	7%	7%	7%	4%	3%	3%
Information and communication (J)	15%	16%	16%	16%	15%	16%
Professional, scientific and technical activities (M)	16%	15%	15%	20%	21%	20%

(*Continued*)

Table 1. Continued.

	Without cooperation arrangements			With cooperation arrangements		
	2014	2015	2016	2014	2015	2016
Administrative and support service activities (N)	3%	3%	2%	4%	4%	4%
Arts, entertainment and recreation (R)			0.09%			
Unknown industrial sector		0.02%	0.03%		0.32%	0.33%
Number of enterprises	1367	1326	1264	1217	1175	1137

Small firms (1–99 employees) in the final sample of firms with innovation activities

	Without cooperation arrangements			With cooperation arrangements		
	2014	2015	2016	2014	2015	2016
Proportion of females of total employees	29%	29%	29%	28%	28%	28%
Average age of employees	41	41	42	42	42	42
Educational level (per cent)						
Employees with primary education	28%	28%	28%	22%	22%	22%
Employees with secondary education	37%	37%	37%	32%	32%	32%
Employees with higher education	31%	31%	31%	41%	42%	42%
Employees with unknown educational level	5%	5%	5%	4%	4%	4%
Firm age						
1–5 years	17%	16%	16%	17%	17%	18%
6–9 years	14%	14%	14%	17%	16%	16%
10–13 years	16%	16%	16%	17%	17%	16%
14 years or older	53%	54%	54%	49%	50%	50%
Geographic markets						
Only sell products in the Norwegian market	59%	58%	58%	50%	49%	48%
Only sell products abroad	1%	1%	1%	2%	2%	2%
Sell products both in Norway and abroad	40%	41%	41%	48%	49%	49%
Type of innovation cooperation partner						
Internal partners (i.e. other enterprises within a firm's enterprise group)				43%	44%	43%
Suppliers of equipment, materials, components or software				71%	71%	71%
Clients or customers				60%	60%	60%
Competitors or other enterprises in a firm's sector				31%	30%	30%
Consultants or consulting enterprises				42%	43%	43%
Commercial labs or R&D-enterprises				22%	23%	22%
Academic sector				37%	37%	37%
Number of different types of innovation cooperation partners						
1 partner				23%	22%	23%
2 partners				22%	22%	22%
3 partners				19%	19%	20%
4 partners				16%	16%	16%
5 partners				9%	9%	9%
6 partners				4%	4%	4%
7 partners				7%	7%	7%
Average number of different types of innovation cooperation partners				3.1	3.1	3.1
Location of innovation cooperation partner						
Locally/regionally in Norway				73%	73%	73%
Other Norway				53%	54%	54%
Nordic countries				22%	23%	23%
Other Europe				33%	34%	35%
United States				10%	10%	10%
China or India				6%	5%	5%
Other countries				6%	6%	7%
Industrial sector						
Agriculture, forestry and fishing (A)	1%	1%	1%	2%	2%	3%
Mining and quarrying (B)	1%	1%	1%	1%	1%	1%
Manufacturing (C)	25%	26%	26%	26%	26%	26%
Electricity, gas, steam and air conditioning supply (D)	1%	0.48%	1%	2%	2%	2%
Water supply; sewerage, waste management and remediation activities (E)	1%	1%	1%	1%	1%	1%
Construction (F)	7%	7%	7%	3%	3%	3%
Wholesale and retail trade; repair of motor vehicles and motorcycles (G)	21%	21%	21%	16%	16%	16%
Transportation and storage (H)	2%	2%	2%	2%	2%	2%

(*Continued*)

Table 1. Continued.

	Without cooperation arrangements			With cooperation arrangements		
	2014	2015	2016	2014	2015	2016
Accommodation and food service activities (I)	7%	7%	7%	4%	4%	4%
Information and communication (J)	16%	16%	16%	16%	15%	16%
Professional, scientific and technical activities (M)	17%	16%	16%	21%	22%	22%
Administrative and support service activities (N)	3%	3%	2%	5%	5%	5%
Arts, entertainment and recreation (R)			0.09%			
Unknown industrial sector					0.32%	0.33%
Number of enterprises	1095	1060	1011	876	845	818

Large firms (at least 100 employees) in the final sample of firms with innovation activities

	Without cooperation arrangements			With cooperation arrangements		
	2014	2015	2016	2014	2015	2016
Proportion of females of total employees	27%	26%	26%	24%	24%	24%
Average age of employees	40	41	41	42	42	42
Educational level (per cent)						
Employees with primary education	27%	27%	27%	22%	23%	23%
Employees with secondary education	43%	43%	43%	39%	40%	40%
Employees with higher education	26%	27%	26%	35%	35%	35%
Employees with unknown educational level	4%	4%	4%	3%	3%	3%
Firm age						
1–5 years	8%	9%	7%	3%	3%	3%
6–9 years	7%	7%	6%	8%	8%	8%
10–13 years	12%	12%	12%	16%	15%	16%
14 years or older	73%	73%	75%	73%	73%	73%
Geographic markets						
Only sell products in the Norwegian market	47%	45%	46%	28%	28%	28%
Only sell products abroad	2%	2%	2%	5%	5%	5%
Sell products both in Norway and abroad	51%	53%	52%	67%	67%	67%
Type of innovation cooperation partner						
Internal partners (i.e. other enterprises within a firm's enterprise group)				71%	71%	71%
Suppliers of equipment, materials, components or software				78%	78%	78%
Clients or customers				56%	57%	58%
Competitors or other enterprises in a firm's sector				30%	28%	27%
Consultants or consulting enterprises				56%	57%	58%
Commercial labs or R&D-enterprises				44%	44%	45%
Academic sector				62%	62%	61%
Number of different types of innovation cooperation partners						
1 partner				9%	10%	9%
2 partners				16%	16%	15%
3 partners				19%	19%	19%
4 partners				16%	15%	16%
5 partners				15%	15%	14%
6 partners				15%	15%	15%
7 partners				10%	10%	10%
Average number of different types of innovation cooperation partners				4.0	4.0	4.0
Location of innovation cooperation partner						
Locally/regionally in Norway				67%	66%	66%
Other Norway				72%	71%	71%
Nordic countries				47%	47%	47%
Other Europe				54%	54%	55%
United States				25%	24%	24%
China or India				14%	14%	13%
Other countries				17%	17%	16%
Industrial sector						
Agriculture, forestry and fishing (A)	0.36%	0.37%		2%	2%	2%
Mining and quarrying (B)	4%	4%	4%	8%	6%	6%
Manufacturing (C)	28%	29%	29%	45%	46%	46%
Electricity, gas, steam and air conditioning supply (D)	1%	0.37%	0.39%	4%	3%	3%
Water supply; sewerage, waste management and remediation activities (E)				1%	2%	2%

(*Continued*)

Table 1. Continued.

	Without cooperation arrangements			With cooperation arrangements		
	2014	2015	2016	2014	2015	2016
Construction (F)	12%	12%	13%	6%	5%	6%
Wholesale and retail trade; repair of motor vehicles and motorcycles (G)	15%	15%	16%	6%	6%	6%
Transportation and storage (H)	11%	10%	11%	5%	5%	5%
Accommodation and food service activities (I)	7%	6%	6%	0.29%	0.30%	
Information and communication (J)	14%	13%	13%	13%	13%	13%
Professional, scientific and technical activities (M)	5%	6%	6%	9%	10%	9%
Administrative and support service activities (N)	3%	3%	3%	1%	1%	1%
Arts, entertainment and recreation (R)						
Unknown industrial sector		0.37%	0.39%		0.30%	0.31%
Number of enterprises	272	266	253	341	330	319

Notes: (1) Alphabetical NACE codes in parenthesis for industrial sector. (2) Firms with innovation activities consist of those with innovation cooperation arrangements and those without such arrangements but with innovation activities.

firms in this sample have just over three different types of cooperation partners, on average. The average number of different types of partners is higher among large firms than among small firms. About two-fifths of the firms in the sample have either at least four partners (up to seven partners) or they have two or three partners, while about one-fifth have only one partner. Large firms have a much higher proportion of firms with at least four partners, and a much lower proportion of firms with only one partner, than small firms. The proportion of firms with two or three partners is also relatively lower among large firms.

Figure 1 shows the relative productivity level by type of innovation cooperation partner, where the relative productivity level is measured as the ratio of 'the average productivity level among firms with the specified type of partner in the year cohort' to 'the average productivity level among all firms with innovation cooperation arrangements in the year cohort'. For each year cohort, the relative productivity level is highest among firms with internal partners and lowest among those with partners in the academic sector. This level is also relatively high among firms that have suppliers of equipment, materials, components or software as their cooperation partner, and relatively low among those that cooperate with competitors or other enterprises in their sector, for each cohort.

In Figure 2, we show the relative productivity level by number of different types of innovation cooperation partners. The relative productivity level is measured as the ratio of 'the average productivity level among firms with the specified number of different types of partners in the year cohort' to 'the average productivity level among all firms with innovation cooperation arrangements in the year cohort'. We see that the relative productivity level is higher among firms with less than four cooperation partners than among those with at least four partners, on average, and this holds for each year cohort. This level is highest among firms with three partners for each year cohort, but there are marginal differences in the relative productivity level between those that had one or three partners for the 2014 cohort. The level is lowest among firms with four partners for the 2014 and 2015 cohorts, and among those with six partners for the 2016 cohort.

Figure 3 shows that the proportion of firms with innovation cooperation arrangements is much higher among firms with at least 100 employees than among those with 1–99 employees. We see that there are small differences in this proportion between the three smallest employee categories, while the proportion increases with increasing number of employees among firms with at least 50 employees. There are small differences in the proportion between the three cohorts.

We see from Figure 4 that the average number of different types of innovation cooperation partners is higher among firms with at least 100 employees than among those with 1–99 employees. This average number first decreases with increasing number of employees, and then increases. The differences between the three cohorts are small. Both the results in Figures 3 and 4 can provide a partial justification for our definition of 'small' and 'large' firms (see Section 3.2).

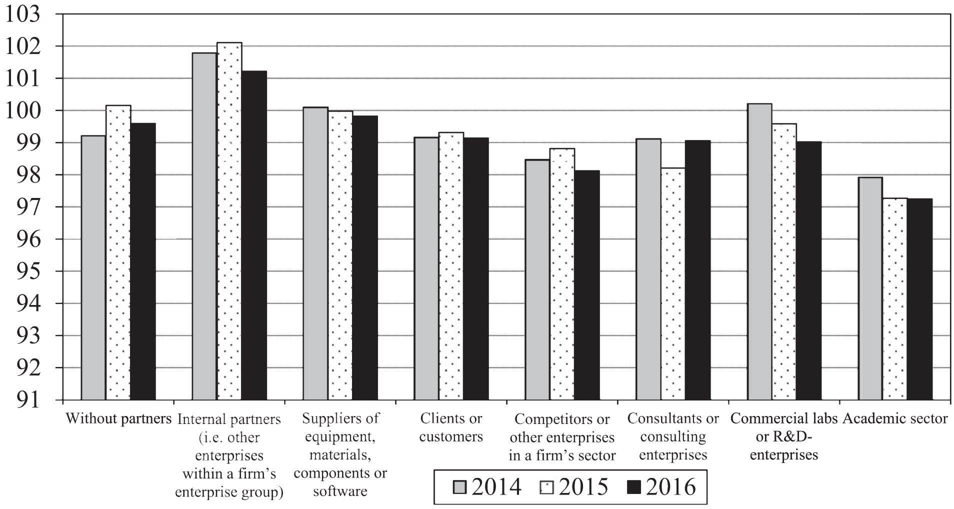

Figure 1. The relative productivity level by type of innovation cooperation partner and year cohort, final sample of firms with innovation activities, weighted results.

Notes: (1) The figure includes the 1217 firms with at least one type of innovation cooperation partner (i.e. those with innovation cooperation arrangements) and the 1367 firms without any innovation cooperation partners (i.e. those without innovation cooperation arrangements) but with innovation activities in the 2014 cohort, the 1175 firms with at least one type of partner and the 1326 firms without any partners in the 2015 cohort, and the 1137 firms with at least one type of partner and the 1264 firms without any partners in the 2016 cohort. (2) For a specific type of innovation cooperation partner in a year cohort among firms with innovation activities in the final sample, the relative productivity level is measured as the ratio of 'the average productivity level among firms with the specified type of partner in the year cohort' to 'the average productivity level among all firms with innovation cooperation arrangements in the year cohort'. (3) The relative productivity level is measured in per cent in the figure.

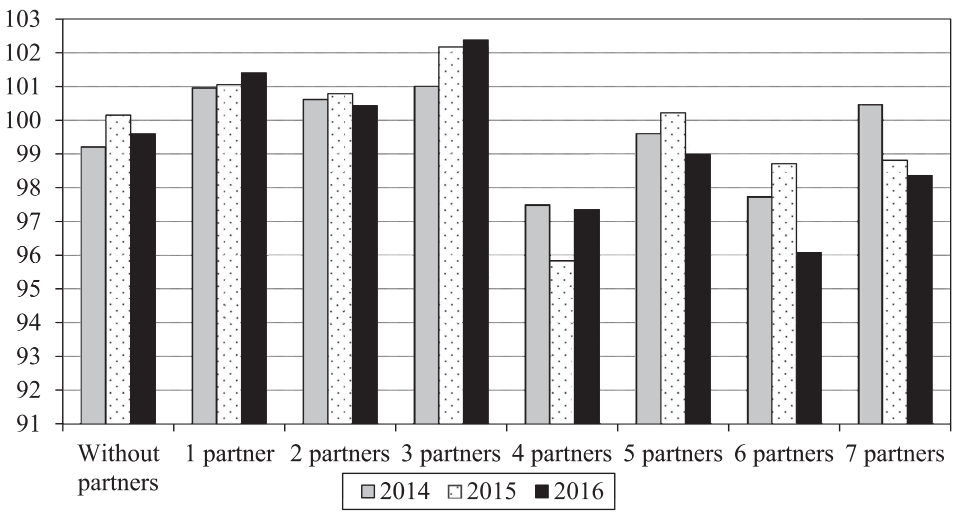

Figure 2. The relative productivity level by number of different types of innovation cooperation partners and year cohort, final sample of firms with innovation activities, weighted results.

Notes: (1) The figure includes the same firms with at least one type of innovation cooperation partner and those without any innovation cooperation partners but with innovation activities in the three year cohorts as described in Note (1) in Figure 1. (2) For each number of different types of innovation cooperation partners in a year cohort among firms with innovation activities in the final sample, the relative productivity level is measured as the ratio of 'the average productivity level among firms with the specified number of different types of partners in the year cohort' to 'the average productivity level among all firms with innovation cooperation arrangements in the year cohort'. (3) The relative productivity level is measured in per cent in the figure.

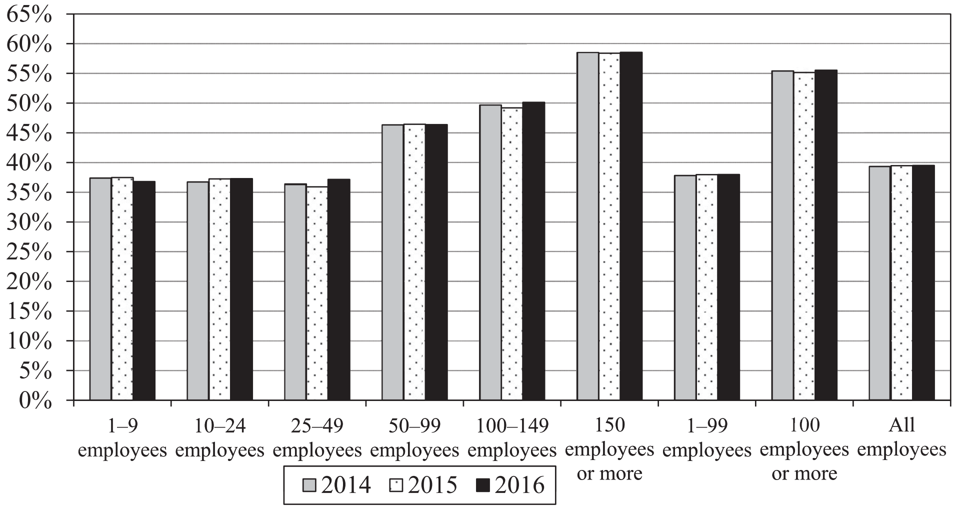

Figure 3. The proportion of firms with innovation cooperation arrangements by number of employees and year cohort, final sample of firms with innovation activities, weighted results.

Notes: The figure includes the same firms with at least one type of innovation cooperation partner and those without any innovation cooperation partners but with innovation activities in the three year cohorts as described in Note (1) in Figure 1.

For each type of innovation cooperation partner, the average number of different types of partners is higher among firms with at least 100 employees than among those with 1–99 employees in the 2014 cohort. This can be seen from Figure 5. This average number is highest for all firms that cooperate with commercial labs or R&D-enterprises and competitors or other enterprises in their sector, and lowest for all firms that cooperate with suppliers of equipment, materials, components or software.

Table 1 shows that the proportion of females of total employees is below 30% both among firms with and without innovation cooperation arrangements, on average, and this proportion is lower

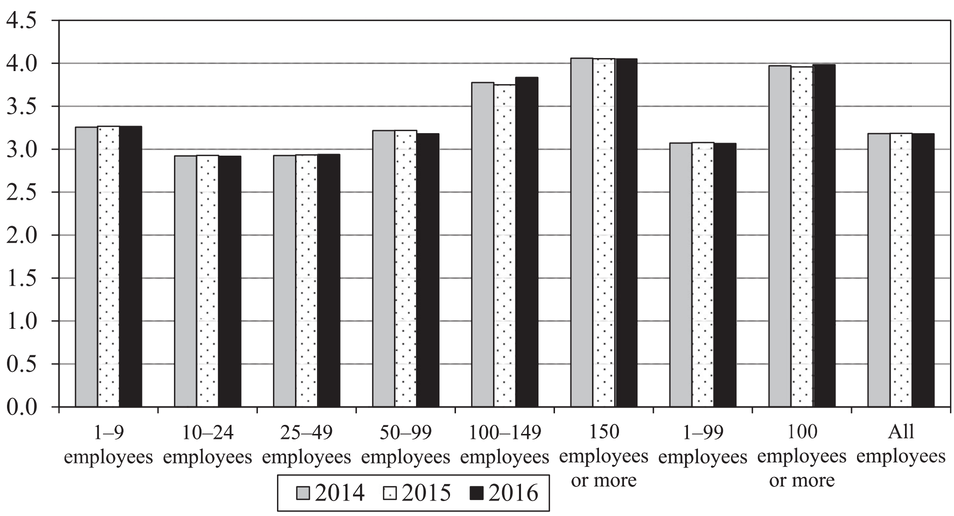

Figure 4. The average number of different types of innovation cooperation partners by number of employees and year cohort, final sample of firms with innovation cooperation arrangements, weighted results.

Notes: The figure includes the same firms with at least one type of innovation cooperation partner in the three year cohorts as described in Note (1) in Figure 1.

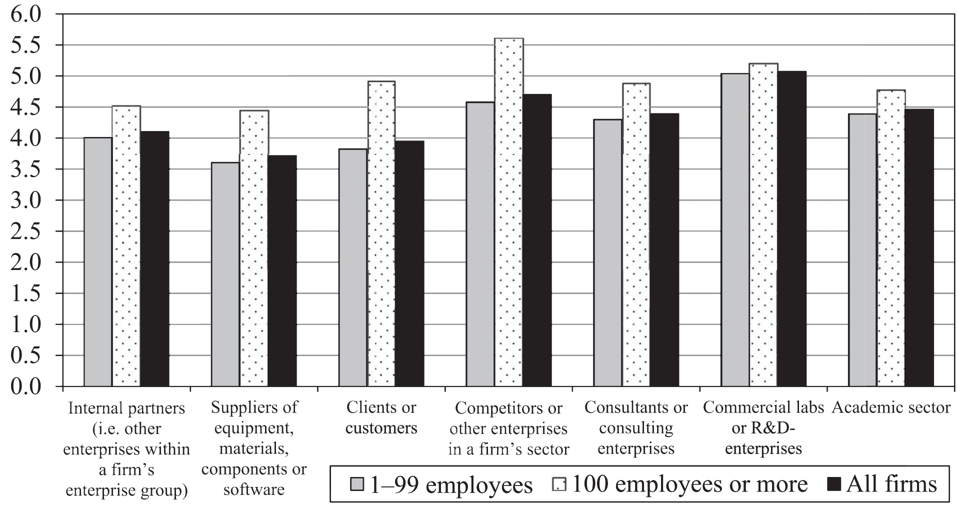

Figure 5. The average number of different types of innovation cooperation partners by type of partner and number of employees, final sample of firms with innovation cooperation arrangements, the 2014 cohort, weighted results.

Notes: The figure includes the same firms with at least one type of innovation cooperation partner in the 2014 cohort as described in Note (1) in Figure 1.

among large firms than among small firms. The average age of employees is 40–42 years. We also find that the educational level among employees is higher in firms with cooperation arrangements than in firms without, and higher in small firms than in large firms, on average. Only 3–5% of the firms in the final sample have employees with an unknown level of education.

Over half of all firms in the final sample are 14 years or older. The proportion of firms in the oldest category is lower among firms with cooperation arrangements than among those without, and this holds for each year cohort when using all firms or only small firms. Large firms are much older than small firms, which is not surprising since in most cases larger firms are older firms (Heyman 2007).

About half of all and small firms with cooperation arrangements sell their products both in Norway and abroad, but this proportion is much lower among firms without such arrangements. The proportion is much higher among large firms with and without cooperation arrangements than among small firms. It follows that large firms have a much lower proportion of those that only sell their products in the Norwegian market than small firms. Very few firms only sell their products abroad, and this proportion is somewhat higher among large firms than among small firms.

Nearly three quarters of all firms with innovation cooperation arrangements have a cooperation partner locally/regionally in Norway, while 56% have a partner from Other Norway. A significant proportion of all firms with such arrangements also have a cooperation partner from the category 'Other Europe' (36–37%) or from a Nordic country (25–26%), while far fewer have a partner from United States (12%), China or India (6–7%) or from a country in the category 'Other countries' (8%). The proportion of those with a partner locally/regionally in Norway is higher among small firms than among large firms, while the proportion of those with a partner from one of the other locations is relatively lower among small firms.

We see from the table that 28% of all firms with cooperation arrangements in the final sample are manufacturing firms. The corresponding proportion is somewhat lower among all firms without such arrangements. The proportion of manufacturing firms is much higher among large firms than among small firms for those with cooperation arrangements, and also somewhat higher for those without such arrangements. There are also relatively many firms included in 'professional, scientific and technical activities', 'wholesale and retail trade; repair of motor vehicles and motorcycles', and 'information and communication'. Few firms are included in each of the other sectors.

The average number of employees in each firm is much higher among firms with innovation cooperation arrangements than among those without such arrangements but with innovation activities.[4] One third of the firms with cooperation arrangements have 10–24 employees, while the corresponding proportion among those without cooperation arrangements is somewhat higher. The proportion of those with less than 10 employees is somewhat lower among those with cooperation than among those without. A quarter of the firms with and without cooperation arrangements have 25–99 employees, while the proportion of firms with at least 100 employees is twice as high among those with cooperation than among those without.

Furthermore, we see that the average number of employees in each firm is somewhat higher for the 2016 cohort than for the other two cohorts among all firms with innovation cooperation arrangements in the final sample. We also find that the proportion of competitors or other enterprises in a firm's sector is somewhat higher for the 2014 cohort than for the other two cohorts among firms with at least 100 employees in the final sample. The absolute differences in the other proportions and averages in the table are smaller, and almost all of them are about the same, when comparing the three year cohorts for firms with and without innovation cooperation arrangements. Therefore, the descriptive statistics indicate that no large sample selection biases arise by the fact that some firms with and without cooperation in the 2014 cohort are not included in the other year cohorts.

6. The estimation results

We have estimated the effects of the four types of key regressors and control variables on the log of a firm's productivity level based on the 2014, 2015 and 2016 cohorts.[5] Table 2 presents the estimated results when using the first type of the key regressor for each of the three year cohorts (denoted regression type R1), where we use the final sample of firms with innovation activities. The first type is the dummy variable 'innovation cooperation arrangements'. This variable is equal to 1 if a firm stated that it had cooperation arrangements on innovation activities and R&D with other enterprises or institutions (0 otherwise). The final sample of firms with innovation cooperation arrangements is used in Tables 3 and 4. In Table 3, we present the estimated results when using the second types of the key regressors (denoted R2), and Table 4 presents the corresponding results when using the third types of the key regressors (denoted R3). The second types of the key regressors are the explanatory variables that account for different types of innovation cooperation partners. The third types consist of the seven dummy variables, where the number of different types of partners is used as a categorical variable. In Tables 2–4, we first use all firms in the final sample, and then only firms with 1–99 employees (defined as 'small' firms) and at least 100 employees (defined as 'large' firms) in the final sample.

We have also estimated the effect of the fourth type of the key regressor for each of the three cohorts (denoted R4), where the fourth type is the number of different types of innovation cooperation partners used as a continuous variable. As this effect is not significant for any of the year cohorts when using all firms or only those with 1–99 employees or at least 100 employees in the final sample, the estimated results when using the fourth type are not shown.

All control variables described in Section 3.4 are used in Tables 3 and 4. With the exception of location of innovation cooperation partner, the same control variables are used in Table 2. Due to space limitations, the results from the effects of the dummies for industrial sectors and a firm's location are not shown in any of the three tables. Calculations of the Variance Inflation Factor (VIF) indicate that we have no serious multicollinearity problem in any of the regressions R1–R4.[6]

6.1. The effects of the first three types of the key regressors

Table 2 shows that the productivity level is lower among firms that had cooperation arrangements on innovation activities and R&D with other enterprises or institutions than among those that did not have such arrangements for the 2015 cohort when using all firms in the final sample. As shown in the

Table 2. Effects of explanatory variables on the log of the productivity level, all firms in the final sample of firms with innovation activities by year cohort, weighted results.

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	4.450	***	0.337	4.911	***	0.297	4.934	***	0.316
Log of the capital intensity	0.488	***	0.035	0.476	***	0.031	0.462	***	0.035
Log of the number of employees	−0.112	***	0.022	−0.131	***	0.023	−0.138	***	0.025
Proportion of females of total employees	−0.077		0.148	0.116		0.155	−0.115		0.170
Average age of employees	0.009	**	0.005	0.004		0.005	0.005		0.005
Educational level									
Employees with primary education	−0.291	*	0.160	−0.328	*	0.193	−0.134		0.197
Employees with higher education	−0.301	**	0.138	−0.231	*	0.133	−0.049		0.152
Employees with unknown educational level	0.001		0.256	−0.366		0.314	−0.191		0.326
Innovation cooperation arrangements	−0.043		0.046	−0.111	**	0.051	−0.065		0.052
Firm age									
1–5 years	−0.243	***	0.082	−0.136		0.085	−0.160	*	0.093
6–9 years	−0.018		0.066	0.111		0.073	0.108		0.068
10–13 years	0.023		0.053	0.042		0.056	−0.009		0.070
Geographic markets									
Only sell products abroad	−0.103		0.171	−0.708		0.587	−0.159		0.314
Sell products both in Norway and abroad	−0.085		0.054	−0.073		0.050	−0.098	*	0.055
F value			30.500			27.270			28.880
Prob > *F*			0.000			0.000			0.000
R-squared			0.374			0.337			0.324
Root MSE			0.836			0.873			0.898
Number of enterprises			2584			2501			2402

Small firms (1–99 employees) in the final sample of firms with innovation activities

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	3.902	***	0.364	4.480	***	0.324	4.381	***	0.341
Log of the capital intensity	0.476	***	0.038	0.461	***	0.034	0.447	***	0.039
Log of the number of employees	0.043		0.031	0.004		0.033	0.031		0.036
Proportion of females of total employees	−0.115		0.152	0.074		0.159	−0.174		0.173
Average age of employees	0.014	***	0.005	0.008		0.005	0.009	*	0.005
Educational level									
Employees with primary education	−0.268	*	0.162	−0.301		0.195	−0.100		0.199
Employees with higher education	−0.319	**	0.140	−0.240	*	0.137	−0.052		0.153
Employees with unknown educational level	−0.065		0.259	−0.472		0.320	−0.268		0.331
Innovation cooperation arrangements	−0.043		0.049	−0.144	***	0.054	−0.086		0.055
Firm age									
1–5 years	−0.193	**	0.083	−0.092		0.085	−0.101		0.092
6–9 years	0.014		0.068	0.135	*	0.076	0.129	*	0.072
10–13 years	0.053		0.056	0.063		0.060	0.024		0.075
Geographic markets									
Only sell products abroad	−0.294		0.208	−1.014		0.675	−0.364		0.354
Sell products both in Norway and abroad	−0.116	**	0.056	−0.093	*	0.052	−0.130	**	0.057
F value			28.130			47.160			40.150
Prob > *F*			0.000			0.000			0.000
R-squared			0.421			0.373			0.365
Root MSE			0.764			0.806			0.817
Number of enterprises			1971			1905			1830

Large firms (at least 100 employees) in the final sample of firms with innovation activities

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	7.574	***	0.727	6.977	***	0.770	7.909	***	0.833
Log of the capital intensity	0.526	***	0.059	0.545	***	0.057	0.469	***	0.072
Log of the number of employees	−0.497	***	0.063	−0.535	***	0.067	−0.583	***	0.069
Proportion of females of total employees	−0.750	**	0.382	−0.353		0.415	−0.206		0.502
Average age of employees	−0.013		0.013	0.000		0.014	−0.001		0.016
Educational level									
Employees with primary education	−1.401	**	0.681	−1.593	**	0.693	−1.872	***	0.688

(*Continued*)

Table 2. Continued.

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Employees with higher education	−0.094		0.491	−0.074		0.448	−0.358		0.535
Employees with unknown educational level	0.977		0.705	1.642	**	0.651	0.714		0.834
Innovation cooperation arrangements	0.009		0.099	0.284	**	0.116	0.157		0.114
Firm age									
1–5 years	−0.120		0.178	0.006		0.209	−0.373		0.446
6–9 years	−0.183		0.212	0.107		0.230	0.250	*	0.146
10–13 years	−0.064		0.135	−0.029		0.141	−0.133		0.150
Geographic markets									
Only sell products abroad	0.332		0.222	0.392	**	0.177	0.554	***	0.212
Sell products both in Norway and abroad	0.067		0.129	0.026		0.121	0.100		0.143
F value			12.530			13.720			13.850
Prob > *F*			0.000			0.000			0.000
R-squared			0.396			0.416			0.405
Root MSE			1.186			1.182			1.268
Number of enterprises			613			596			572

Notes: (1) Estimated coefficients and standard errors from model (4) based on OLS. (2) Firms with innovation activities consist of those with innovation cooperation arrangements and those without such arrangements but with innovation activities. (3) *** Significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level. (4) The dummy variable 'innovation cooperation arrangements' is equal to 1 if a firm stated that it had cooperation arrangements with other enterprises or institutions (0 otherwise). (5) In the regressions, we have also controlled for dummies for industrial sectors and a firm's location according to region, where we use alphabetical NACE codes for industrial sector. These results are not shown in the table. (6) The reference firm is: employees with secondary education, no innovation cooperation arrangements, 14 years or older (firm age), only sell products in the Norwegian market, and included in the manufacturing sector (NACE code C).

table, this is also the result for small firms (1–99 employees), while having innovation cooperation arrangements has a positive effect on the productivity level for large firms (at least 100 employees), for the same cohort. There is a non-significant effect of having innovation cooperation arrangements on productivity for the other two year cohorts for all firms and for small and large firms.

If we use all firms in the final sample, we find from Table 3 that the productivity level is higher in the short term among firms that had any cooperation arrangements on innovation activities and R&D with competitors or other enterprises in a firm's sector than among those that cooperated with internal partners (i.e. the reference category). The productivity level is relatively lower both in the short and medium term among firms that had any cooperation arrangements with partners in the academic sector. We also find that the productivity level is relatively lower among those that cooperated with consultants or consulting enterprises for the 2015 cohort, or with suppliers of equipment, materials, components or software, where the latter result is a medium-term effect that is only significant at the 10 per cent level. There are no significant differences in productivity between firms that cooperated with internal partners and those that cooperated with clients or customers, or with commercial labs or R&D-enterprises.

The results for small firms are the same as for all firms in Table 3, except that there are no significant differences in productivity between firms that cooperated with suppliers of equipment, materials, components or software and those that cooperated with internal partners among small firms, even at the 10 per cent level. We find that the productivity level is relatively higher both in the short and medium term among large firms that cooperated with consultants or consulting enterprises, but the effect is only significant at the 10 per cent level for the 2014 cohort and not significant for the 2015 cohort. The productivity level is relatively lower in the medium term among large firms that cooperated with commercial labs or R&D-enterprises. There are no significant differences in the productivity level between firms that cooperated with one of the other types of partners and those that cooperated with internal partners among large firms.

In Table 4, we use the number of different types of innovation cooperation partners as a categorical variable. The table shows that firms with less than four (different types of) cooperation partners have a higher productivity level than those with four partners (i.e. the reference category) for the

Table 3. Effects of explanatory variables on the log of the productivity level, all firms in the final sample of firms with innovation cooperation arrangements by year cohort, R1, weighted results.

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	5.075	***	0.491	5.554	***	0.503	5.246	***	0.485
Log of the capital intensity	0.459	***	0.042	0.419	***	0.044	0.422	***	0.048
Log of the number of employees	−0.093	***	0.033	−0.063	*	0.034	−0.104	***	0.034
Proportion of females of total employees	0.072		0.262	0.362		0.259	0.305		0.302
Average age of employees	0.006		0.009	0.006		0.010	0.013		0.009
Educational level									
Employees with primary education	−0.493	*	0.300	−0.819	**	0.354	−0.500		0.309
Employees with higher education	−0.414	**	0.195	−0.431	**	0.201	−0.374	*	0.209
Employees with unknown educational level	0.022		0.468	−0.599		0.555	−0.613		0.592
Type of external innovation cooperation partner									
Suppliers of equipment, materials, components or software	−0.065		0.078	−0.106		0.088	−0.130	*	0.078
Clients or customers	0.016		0.077	0.065		0.097	0.002		0.080
Competitors or other enterprises in a firm's sector	0.194	**	0.084	0.267	**	0.108	0.136		0.092
Consultants or consulting enterprises	−0.054		0.080	−0.179	**	0.089	−0.026		0.077
Commercial labs or R&D-enterprises	−0.058		0.103	−0.001		0.117	−0.077		0.109
Academic sector	−0.224	***	0.080	−0.257	***	0.089	−0.298	***	0.083
Location of innovation cooperation partner									
Other Norway	−0.012		0.091	−0.018		0.096	0.061		0.110
Nordic countries	0.068		0.080	0.148	*	0.087	0.101		0.093
Other Europe	−0.203	**	0.081	−0.175	*	0.095	−0.228	***	0.085
United States	−0.203		0.165	−0.192		0.180	0.017		0.205
China or India	0.135		0.142	0.265		0.174	0.127		0.178
Other countries	0.125		0.131	0.052		0.138	−0.054		0.164
Firm age									
1–5 years	−0.461	***	0.134	−0.454	***	0.151	−0.400	***	0.148
6–9 years	−0.039		0.113	0.108		0.122	0.156		0.127
10–13 years	−0.036		0.096	0.030		0.101	−0.016		0.096
Geographic markets									
Only sell products abroad	−0.019		0.230	−1.036		0.728	−0.094		0.350
Sell products both in Norway and abroad	−0.078		0.082	−0.175	**	0.088	−0.141		0.089
F value		11.480			12.470			11.360	
Prob > *F*			0.000			0.000			0.000
R-squared			0.378			0.369			0.364
Root MSE			0.905			0.971			0.933
Number of enterprises			1217			1175			1137

Small firms (1–99 employees) in the final sample of firms with innovation cooperation arrangements

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	4.189	***	0.524	4.969	***	0.557	4.573	***	0.520
Log of the capital intensity	0.453	***	0.047	0.398	***	0.049	0.392	***	0.053
Log of the number of employees	0.092	*	0.051	0.085		0.059	0.058		0.056
Proportion of females of total employees	−0.004		0.270	0.274		0.270	0.162		0.315
Average age of employees	0.012		0.009	0.010		0.010	0.018	*	0.010
Educational level									
Employees with primary education	−0.415		0.305	−0.725	*	0.371	−0.343		0.326
Employees with higher education	−0.307		0.195	−0.311		0.211	−0.219		0.225
Employees with unknown educational level	0.108		0.481	−0.578		0.565	−0.521		0.612
Type of external innovation cooperation partner									
Suppliers of equipment, materials, components or software	−0.083		0.083	−0.107		0.091	−0.138		0.084
Clients or customers	0.058		0.084	0.099		0.107	0.040		0.088
Competitors or other enterprises in a firm's sector	0.259	***	0.092	0.291	**	0.122	0.141		0.101
Consultants or consulting enterprises	−0.097		0.090	−0.216	**	0.100	−0.076		0.088
Commercial labs or R&D-enterprises	−0.002		0.117	0.062		0.133	0.038		0.124
Academic sector	−0.265	***	0.087	−0.271	***	0.100	−0.339	***	0.092
Location of innovation cooperation partner									
Other Norway	−0.045		0.099	−0.075		0.103	0.021		0.120
Nordic countries	0.159	*	0.092	0.193	*	0.099	0.149		0.106
Other Europe	−0.154	*	0.089	−0.134		0.103	−0.192	**	0.094

(*Continued*)

Table 3. Continued.

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
United States	−0.290		0.192	−0.235		0.208	−0.043		0.237
China or India	0.191		0.158	0.278		0.204	0.154		0.211
Other countries	−0.045		0.151	−0.058		0.165	−0.152		0.186
Firm age									
1–5 years	−0.371	***	0.136	−0.404	***	0.154	−0.309	**	0.146
6–9 years	0.007		0.123	0.099		0.130	0.158		0.144
10–13 years	0.022		0.106	0.061		0.113	0.043		0.107
Geographic markets									
Only sell products abroad	−0.193		0.299	−1.392		0.874	−0.247		0.426
Sell products both in Norway and abroad	−0.116		0.089	−0.194	**	0.096	−0.174	*	0.097
F value			10.060			17.360			15.980
Prob > *F*			0.000			0.000			0.000
R-squared			0.450			0.419			0.416
Root MSE			0.824			0.921			0.867
Number of enterprises			876			845			818

Large firms (at least 100 employees) in the final sample of firms with innovation cooperation arrangements

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	8.979	***	1.210	8.253	***	1.181	8.892	***	1.347
Log of the capital intensity	0.438	***	0.074	0.472	***	0.075	0.460	***	0.072
Log of the number of employees	−0.460	***	0.079	−0.418	***	0.078	−0.518	***	0.080
Proportion of females of total employees	−1.666	***	0.602	−1.012	*	0.606	−0.271		0.583
Average age of employees	−0.022		0.018	−0.016		0.018	−0.016		0.019
Educational level									
Employees with primary education	−1.219		1.021	−1.102		0.949	−1.610	*	0.950
Employees with higher education	−0.224		0.719	0.148		0.655	−0.821		0.749
Employees with unknown educational level	0.112		1.212	0.888		0.784	−0.068		0.851
Type of external innovation cooperation partner									
Suppliers of equipment, materials, components or software	−0.001		0.186	−0.117		0.172	−0.123		0.172
Clients or customers	−0.247		0.173	−0.203		0.160	−0.123		0.146
Competitors or other enterprises in a firm's sector	−0.063		0.178	0.132		0.140	0.171		0.147
Consultants or consulting enterprises	0.271	*	0.158	0.137		0.130	0.303	**	0.140
Commercial labs or R&D-enterprises	−0.189		0.166	−0.230		0.160	−0.438	***	0.157
Academic sector	0.147		0.193	−0.068		0.171	0.053		0.173
Location of innovation cooperation partner									
Other Norway	0.211		0.158	0.234		0.166	0.133		0.152
Nordic countries	−0.114		0.151	0.020		0.146	0.049		0.137
Other Europe	−0.175		0.152	0.109		0.151	−0.013		0.143
United States	−0.048		0.186	−0.146		0.180	0.240		0.211
China or India	−0.045		0.234	0.083		0.286	−0.104		0.263
Other countries	0.582	***	0.189	0.299		0.195	0.057		0.257
Firm age									
1–5 years	−0.397		0.244	−0.370		0.228	−0.821		0.674
6–9 years	−0.459		0.339	0.152		0.334	0.373	**	0.170
10–13 years	−0.119		0.177	−0.124		0.181	−0.278		0.200
Geographic markets									
Only sell products abroad	0.328		0.331	0.082		0.258	0.257		0.286
Sell products both in Norway and abroad	−0.101		0.216	−0.181		0.174	−0.069		0.192
F value			6.950			7.940			8.070
Prob > *F*			0.000			0.000			0.000
R-squared			0.378			0.425			0.465
Root MSE			1.170			1.093			1.106
Number of enterprises			340			328			318

Notes: (1) Estimated coefficients and standard errors from model (4) based on OLS. (2) *** Significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level. (3) In the regressions, we have also controlled for dummies for industrial sectors and a firm's location according to region, where we use alphabetical NACE codes for industrial sector. These results are not shown in the table. (4) The reference firm is: employees with secondary education, internal innovation cooperation partners (i.e. other enterprises within a firm's enterprise group), innovation cooperation partner located locally/regionally in Norway, 14 years or older (firm age), only sell products in the Norwegian market, and included in the manufacturing sector (NACE code C).

Table 4. Effects of explanatory variables on the log of the productivity level, all firms in the final sample of firms with innovation cooperation arrangements by year cohort, R3, weighted results.

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	4.965	***	0.512	5.425	***	0.568	5.054	***	0.501
Log of the capital intensity	0.446	***	0.041	0.395	***	0.042	0.412	***	0.046
Log of the number of employees	−0.110	***	0.034	−0.094	***	0.034	−0.119	***	0.040
Proportion of females of total employees	0.133		0.269	0.428		0.274	0.350		0.308
Average age of employees	0.007		0.009	0.007		0.010	0.013		0.009
Educational level									
Employees with primary education	−0.538	*	0.318	−0.879	**	0.360	−0.582	*	0.314
Employees with higher education	−0.468	**	0.201	−0.500	***	0.192	−0.467	**	0.202
Employees with unknown educational level	0.004		0.461	−0.600		0.541	−0.578		0.570
Number of different types of innovation cooperation partners									
1 partner	0.165		0.131	0.333	**	0.161	0.261	**	0.125
2 partners	0.162		0.121	0.308	*	0.159	0.232	*	0.121
3 partners	0.096		0.124	0.327	**	0.155	0.244	**	0.116
5 partners	0.075		0.143	0.253		0.158	0.059		0.132
6 partners	−0.090		0.280	0.112		0.279	−0.149		0.392
7 partners	0.236		0.150	0.429	**	0.212	0.196		0.167
Location of innovation cooperation partner									
Other Norway	−0.013		0.091	−0.011		0.098	0.045		0.106
Nordic countries	0.081		0.083	0.176	*	0.093	0.112		0.096
Other Europe	−0.185	**	0.083	−0.157		0.097	−0.222	**	0.088
United States	−0.205		0.160	−0.203		0.180	0.010		0.195
China or India	0.108		0.149	0.212		0.180	0.108		0.184
Other countries	0.139		0.134	0.081		0.138	0.006		0.169
Firm age									
1–5 years	−0.477	***	0.133	−0.458	***	0.147	−0.404	***	0.145
6–9 years	−0.043		0.114	0.110		0.122	0.169		0.126
10–13 years	−0.030		0.099	0.049		0.103	0.012		0.095
Geographic markets									
Only sell products abroad	−0.122		0.227	−1.157		0.772	−0.240		0.367
Sell products both in Norway and abroad	−0.125		0.085	−0.217	**	0.092	−0.199	**	0.092
F value		11.420			12.740			11.260	
Prob > *F*			0.000			0.000			0.000
R-squared			0.370			0.359			0.356
Root MSE			0.911			0.978			0.940
Number of enterprises			1217			1175			1137

Small firms (1–99 employees) in the final sample of firms with innovation cooperation arrangements

	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	4.241	***	0.552	4.918	***	0.628	4.452	***	0.548
Log of the capital intensity	0.434	***	0.047	0.372	***	0.046	0.384	***	0.050
Log of the number of employees	0.061		0.052	0.037		0.056	0.033		0.060
Proportion of females of total employees	0.074		0.277	0.367		0.287	0.213		0.315
Average age of employees	0.013		0.010	0.011		0.010	0.018	*	0.010
Educational level									
Employees with primary education	−0.500		0.326	−0.816	**	0.375	−0.468		0.331
Employees with higher education	−0.397	**	0.199	−0.396	**	0.200	−0.340		0.216
Employees with unknown educational level	0.017		0.474	−0.599		0.551	−0.515		0.581
Number of different types of innovation cooperation partners									
1 partner	0.116		0.145	0.328	*	0.174	0.229	*	0.137
2 partners	0.115		0.134	0.315	*	0.169	0.224	*	0.132
3 partners	0.047		0.136	0.322	*	0.166	0.222	*	0.125
5 partners	−0.013		0.158	0.213		0.173	−0.014		0.148
6 partners	−0.114		0.377	0.100		0.376	−0.187		0.546
7 partners	0.224		0.174	0.530	**	0.245	0.230		0.190
Location of innovation cooperation partner									
Other Norway	−0.046		0.098	−0.061		0.104	0.009		0.113
Nordic countries	0.169	*	0.095	0.227	**	0.105	0.155		0.109

(*Continued*)

Table 4. Continued.

Small firms (1–99 employees) in the final sample of firms with innovation cooperation arrangements									
Other Europe	−0.129		0.092	−0.109		0.105	−0.183	*	0.096
United States	−0.271		0.183	−0.224		0.207	−0.027		0.218
China or India	0.169		0.167	0.220		0.210	0.143		0.215
Other countries	−0.028		0.152	−0.020		0.158	−0.074		0.186
Firm age									
1–5 years	−0.389	***	0.135	−0.407	***	0.150	−0.318	**	0.144
6–9 years	0.007		0.123	0.115		0.129	0.190		0.140
10–13 years	0.016		0.110	0.077		0.116	0.066		0.108
Geographic markets									
Only sell products abroad	−0.305		0.298	−1.555	*	0.924	−0.402		0.443
Sell products both in Norway and abroad	−0.169	*	0.092	−0.235	**	0.100	−0.231	**	0.100
F value			9.730			19.420			14.290
Prob > *F*			0.000			0.000			0.000
R-squared			0.435			0.407			0.406
Root MSE			0.836			0.930			0.875
Number of enterprises			876			845			818
Large firms (at least 100 employees) in the final sample of firms with innovation cooperation arrangements									
	2014			2015			2016		
Explanatory variables	Coeff.		SE	Coeff.		SE	Coeff.		SE
Constant	8.791	***	1.185	8.068	***	1.129	8.943	***	1.376
Log of the capital intensity	0.443	***	0.073	0.466	***	0.075	0.450	***	0.075
Log of the number of employees	−0.428	***	0.076	−0.389	***	0.073	−0.473	***	0.076
Proportion of females of total employees	−1.605	***	0.576	−0.904		0.593	−0.187		0.591
Average age of employees	−0.025		0.017	−0.020		0.017	−0.025		0.020
Educational level									
Employees with primary education	−1.492		1.040	−1.185		0.937	−1.733	*	0.976
Employees with higher education	−0.419		0.704	0.087		0.652	−0.877		0.763
Employees with unknown educational level	−0.117		1.110	0.644		0.804	−0.345		0.943
Number of different types of innovation cooperation partners									
1 partner	0.401		0.257	0.267		0.260	0.351		0.258
2 partners	0.301		0.205	−0.029		0.224	−0.012		0.243
3 partners	0.257		0.247	0.184		0.215	0.263		0.208
5 partners	0.418		0.277	0.186		0.251	0.170		0.240
6 partners	0.184		0.242	0.003		0.233	0.022		0.218
7 partners	0.509	**	0.250	−0.143		0.262	0.133		0.251
Location of innovation cooperation partner									
Other Norway	0.184		0.173	0.176		0.176	0.114		0.157
Nordic countries	−0.105		0.148	0.035		0.145	0.074		0.144
Other Europe	−0.240		0.153	0.033		0.144	−0.103		0.146
United States	−0.019		0.192	−0.144		0.182	0.255		0.222
China or India	−0.097		0.240	0.126		0.284	−0.122		0.286
Other countries	0.518	***	0.176	0.241		0.190	0.012		0.267
Firm age									
1–5 years	−0.308		0.290	−0.361		0.239	−0.725		0.669
6–9 years	−0.401		0.336	0.127		0.349	0.428	**	0.179
10–13 years	−0.132		0.174	−0.127		0.178	−0.293		0.198
Geographic markets									
Only sell products abroad	0.220		0.313	0.103		0.252	0.155		0.273
Sell products both in Norway and abroad	−0.111		0.210	−0.181		0.176	−0.087		0.197
F value			6.150			7.400			6.630
Prob > *F*			0.000			0.000			0.000
R-squared			0.374			0.420			0.447
Root MSE			1.174			1.098			1.124
Number of enterprises			340			328			318

Notes: (1) Estimated coefficients and standard errors from model (4) based on OLS. (2) *** Significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level. (3) In the regressions, we have also controlled for dummies for industrial sectors and a firm's location according to region, where we use alphabetical NACE codes for industrial sector. These results are not shown in the table. (4) The reference firm is: employees with secondary education, four different types of innovation cooperation partners, innovation cooperation partner located locally/regionally in Norway, 14 years or older (firm age), only sell products in the Norwegian market, and included in the manufacturing sector (NACE code C).

2015 and 2016 cohorts among all firms in the final sample, but the effect of having two partners is only significant at the 10 per cent level for both cohorts. The productivity level is also relatively higher among small firms with less than four cooperation partners for the same cohorts, but all these effects are only significant at the 10 per cent level. Firms with seven partners have a relatively higher productivity for the 2015 cohort among all and small firms. There are no significant differences in productivity between the reference category and those with five or six partners for the 2015 cohort, or between the reference category and those with more than four partners for the 2016 cohort, among all and small firms. If we use all or only small firms in the final sample, none of the effects of having a certain number of different types of partners for the 2014 cohort are significant at the 10 per cent level. For large firms, there is a positive effect of having seven partners for the 2014 cohort, while all other effects are not significant (10 per cent level). These results can explain the non-significant effect for each year cohort for small and large firms, and the non-significant effect for the 2014 cohort for all firms, when the number of different types of partners is used as a continuous variable (the results when using this continuous variable were presented at the beginning of this section).

It is difficult to see a clear pattern when comparing the estimated effects of the different types of external innovation cooperation partners for all firms with, for example, the studies by Goedhuys (2007), Capron and Cincera (2003), de Faria, Lima, and Santos (2010), and Tomlinson and Fai (2013). Goedhuys (2007) finds that innovation activities leading to higher productivity levels include cooperation with clients, while we find no significant differences in productivity between firms that cooperated with internal partners and those that cooperated with clients or customers. However, the productivity level in her analysis is not measured by the labour productivity (as in our analysis), but by the TFP. Capron and Cincera (2003) conclude that the most important source of information on firms' innovative activities are within the enterprise or with other firms of the group and with clients or customers, but it is difficult to see to what extent this conclusion supports our results. The analysis in de Faria, Lima, and Santos (2010) shows that firms establishing innovation cooperation links with other firms within the same group or suppliers attribute more importance to innovation linkages than those that do not establish links with these types of cooperation partners, while other enterprises within a firm's enterprise group (i.e. internal partners) is used as the reference category in our study. Tomlinson and Fai (2013) find that cooperation with rivals (coopetition) has no significant impact upon innovation, while we find that the productivity level is relatively higher in the short term among firms that had any cooperation arrangements with competitors (or other enterprises in a firm's sector).

In order to try to explain the estimated effects of the different types of external innovation cooperation partners for all firms, and in particular the (possibly unexpected) effect of firms having innovation cooperation arrangements with partners in the academic sector, we will highlight the studies by Cassiman and Veugelers (2002), and Veugelers and Cassiman (2005). Cassiman and Veugelers (2002) explore the effects of knowledge flows or 'spillovers' between firms on R&D cooperation. They find that higher incoming spillovers positively affect the probability of cooperating with research institutes, such as universities and public or private research labs, but have no effect on cooperation with customers or suppliers. Based on their results, it is somewhat surprising that we find that there is a lower productivity among firms that had any innovation cooperation arrangements with partners in the academic sector than among those that cooperated with internal partners, while there are no significant differences in productivity between firms that had any cooperation arrangements with internal partners and those that cooperated with clients or customers, or with suppliers of equipment, materials, components or software (at the 5 per cent level). Although several studies have found a positive relationship between productivity and innovation activities (see the introductory section), it is not obvious from this how productivity performance is related to cooperation arrangements with partners in the academic sector. It might be the case that cooperation arrangements with such partners are more science-based and thus more risky and more characterised by a long-term impact in terms of possible productivity gains than cooperation arrangements with internal partners.

The results in Veugelers and Cassiman (2005) indicate that innovation cooperation arrangements with partners in the academic sector might be risky. They find that 'firms for which risk is an important barrier to innovate are actually less likely to cooperate with universities' (370). Therefore, the importance of high risks as an obstacle to innovation is most likely negatively related to cooperation arrangements with partners in the academic sector, which can explain the negative relationship between productivity and cooperation arrangements with such partners.

We offer a resource argument in order to explain the different results between small and large firms in terms of the effect of innovation cooperation arrangements with partners in the academic sector. According to Eden, Levitas, and Martinez (1997), small firms face certain constraints due to small size and inadequate financing that raise their costs of technology production and transfer relative to the costs for large firms. Welsh and White (1981) also highlight the resource argument against small firms, and argue that a special condition is created by the size of small firms, which they refer to as 'resource poverty'. The resource argument implies that there is likely to be a higher risk of cooperating with partners in the academic sector for small firms compared with large firms. This can explain why the relationship between productivity and cooperation arrangements with partners in the academic sector is negative for small firms, and non-significant for large firms, for all three year cohorts.

As commented at the beginning of this section, a firm's productivity level is not significantly affected by the number of different types of innovation cooperation partners used as a continuous variable for any of the year cohorts when using all firms, small firms or large firms in the final sample. These results are surprising, since we have expected a positive relationship between the productivity level and the number of different types of partners (see Section 1). A positive relationship could be an indication that different types of innovation cooperation partners are primarily complements, while a negative relationship could be an indication that they are primarily substitutes. If different types of partners are substitutes, firms are allowed to switch between them although they provide access to different types of knowledge. In the case of complementarity, cooperation with different types of partners simultaneously is important for expected increases in productivity. Haus-Reve, Fitjar, and Rodríguez-Pose (2019) find that different types of collaboration may be substitutes rather than complements. They conclude that scientific and supply-chain collaboration appear to be substitutes.[7]

The estimation results for the academic sector (as type of external innovation cooperation partner) in Table 3 are in line with the results in Figure 1 for each year cohort when using all firms in the final sample.[8] We also see that the corresponding results for consultants or consulting enterprises are partly in line (since the effect is negative for the 2015 cohort and non-significant for the other two cohorts), while the results for competitors or other enterprises in a firm's sector are not in line, with the results in the figure.

In Table 4, the estimation results for the 2015 and 2016 cohorts are partly in line with the results in Figure 2 when using all firms. We found from this figure that the relative productivity level was higher among firms with less than four cooperation partners than among those with at least four partners for each year cohort, on average, but the difference in the relative level between those with two and seven partners is about the same for the 2014 cohort. The figure also shows that the relative productivity level is lower among firms with at least five partners for the 2016 cohort compared with the other two cohorts, which can explain why there are no significant differences in the productivity level (in Table 4) between firms with four partners and those with more than four partners for the 2016 cohort.

6.2. The effects of control variables

We see from Tables 2–4 that the productivity level is not significantly related to the proportion of females of total employees for all and small firms, even at the 10 per cent level. For large firms, this relationship is also non-significant in the medium term (at the 5 per cent level), but negative in the short term. The relationship between the productivity level and the average age among the employees is not significant (5 per cent level), except that we find a positive relationship in the short term among all and small firms with innovation activities.

Based on the final sample of firms with innovation activities, we find that the proportion of employees with higher education is negatively related to the productivity level in the short term for all and small firms, while this level is negatively related to the proportion of employees with primary education both in the short and medium term for large firms. None of the other relationships are significant (at the 5 per cent level), except that the productivity level is positively related to the proportion of employees with unknown educational level for the 2015 cohort for large firms.

If we use the final sample of firms with innovation cooperation arrangements, we find that the proportion of employees with higher education is negatively related to the productivity level both in the short and medium term for all firms, but the effect is only significant at the 10 per cent level for the 2016 cohort in Table 3. There is also a negative relationship between the proportion of employees with primary education and the productivity level for the 2015 cohort for all firms. Further, we find that this level is negatively related to the proportion of employees with higher education for the 2014 and 2015 cohorts, and the proportion of employees with primary education for the 2015 cohort, for small firms in Table 4. The proportions of employees by educational level are not significantly related to the productivity level for small firms in Table 3 and large firms (5 per cent level).

For all and small firms, those that are 1–5 years old are found to have a lower productivity level in the short term than the reference category (i.e. those that are 14 years or older) among firms with innovation activities, while the youngest firms have a relatively lower productivity level both in the short and medium term among those with innovation cooperation arrangements. There are no significant differences in this level between the reference category and each of the other three firm age groups for large firms (at the 5 per cent level), except that firms that are 6–9 years old have a relatively higher level for the 2016 cohort among those with innovation cooperation arrangements.

We find that firms that sell their products both in Norway and abroad have a lower productivity level in the medium term than those that only sell their products in the Norwegian market for all and small firms in Table 4, while this difference in productivity between the two groups of firms is not significant at the 5 per cent level for the 2016 cohort for all and small firms in Table 3. Small firms that sell their products both in Norway and abroad have a relatively lower productivity for the 2014 and 2016 cohorts among those with innovation activities. No significant differences in productivity are found between those that only sell their products in Norway and those that only sell abroad or both in Norway and abroad among all firms with innovation activities (5 per cent level) and among large firms with innovation cooperation arrangements. Large firms that only sell their products abroad have a relatively higher productivity in the medium term among those with innovation activities.

The capital intensity is positively related to the productivity level for all, small and large firms, while the number of employees is negatively related to this level for all and large firms.[9] The relationship between the number of employees and productivity is not significant for small firms at the 5 per cent level. It follows that the estimate of the parameter d is significantly different from 1 for all and large firms, and thus the production function has non-constant returns to scale with respect to capital and labour for these two groups of firms. For small firms, we cannot reject the hypothesis that the production function has non-constant returns to scale (with respect to capital and labour).

Furthermore, few of the effects of the dummy variables that represent location of innovation cooperation partner are significant at the 5 per cent level. We find that having a partner from the category 'Other Europe' is negatively related to the productivity level for the 2014 and 2016 cohorts for all firms, while having a partner from a country in the category 'Other countries' is positively related to this level in the short term for large firms, among those with innovation cooperation arrangements. For small firms, the productivity level is negatively related to having a partner from

'Other Europe' for the 2016 cohort in Table 3, and positively related to having a partner from a Nordic country for the 2015 cohort in Table 4.

7. Robustness checks

This section conducts robustness checks to determine how sensitive the estimation results are relative to the chosen regression technique (OLS) and control variables. In Section 7.1, a 'robustness check' is carried out by examining how the regression coefficient estimates of the key regressors are affected by removing control variables (Lu and White 2014), where the estimates are based on OLS. Section 7.2 examines how the coefficient estimates of the first type of the key regressor are affected by using the Heckman selection model instead of OLS. We only choose to perform robustness checks when all firms in the final sample are used.

7.1. Re-estimated models with omitted control variables

Eight regressions, denoted (R1)–(R8), are carried out for each of the four type(s) of the key regressor (s) and for each of the three year cohorts with smaller sets of control variables, except that (R1) is not relevant for the first type of the key regressor. Thus, we carry out a total of 95 regressions ($8 \times 4 \times 3 - 1 = 95$). The results from the re-estimated models (R1)–(R8) are then compared with the estimation results in Tables 2–4 and the results when using the fourth type of the key regressor. The control variables that are omitted from the eight regressions are: (R1) location of innovation cooperation partner, (R2) log of the capital intensity, (R3) log of the number of employees, (R4) proportion of females of total employees, average age of employees and educational level variables, (R5) firm age variables, (R6) geographic markets variables, (R7) industrial sectors, and (R8) a firm's location according to region.

The comparisons between the results from the re-estimated models (R1)–(R8) and the estimation results in Tables 2–4 (and the results when using the fourth type of the key regressor) are based on a 5 per cent significance level. In the same way as in Table 2, we find a negative effect of having innovation cooperation arrangements on productivity for the 2015 cohort and a non-significant effect for the other (two) year cohorts for the re-estimated models (R2)–(R8) ((R1) is not relevant in this case). The only exception is that there is a non-significant effect for the 2015 cohort for the re-estimated model (R2).

The negative effect of having innovation cooperation arrangements with partners in the academic sector, as seen in Table 3, is found for all year cohorts for all the re-estimated models (R1)–(R8). We also find the same positive effect of having cooperation arrangements with competitors or other enterprises in a firm's sector for the 2014 and 2015 cohorts (as in the table) for most of the re-estimated models, except that there is a non-significant effect of this type of external cooperation partner for the 2014 cohort for (R2), (R5) and (R7), and for the 2015 cohort for (R2) and (R7). The negative effect of having cooperation arrangements with consultants or consulting enterprises for the 2015 cohort is found for most of the models, except that there is a non-significant effect for (R1), (R2) and (R6).

We found from Table 4 that there is a positive effect of having 1, 3 or 7 different types of innovation cooperation partners for the 2015 cohort. Based on the same cohort, the effect of having 1 partner is not significant for the re-estimated models (R2) and (R8), the effect of having 2 different partners is positive and significant for (R1) and (R7), the effect of having 3 different partners is not significant for (R7) and (R8), and the effect of having 7 different partners is not significant for (R3), (R5), (R6), (R7) and (R8).

There is also a positive effect of having 1 or 3 different partners for the 2016 cohort in Table 4, but the effect of having 1 partner is not significant for (R2) and (R3), the effect of having 2 different partners is positive and significant for (R1) and (R7), and the effect of having 3 different partners is not significant for (R7) and (R8) (based on the same cohort). For all the models (R1)–(R8), there is no significant effect of having different types of innovation cooperation partners for the 2014 cohort, in the same way as in the table.

Furthermore, as mentioned at the beginning of Section 6, the number of different types of innovation cooperation partners used as a continuous variable is not significant for any of the year cohorts. The same result is found for all the re-estimated models, except that this number is negative and significant for (R1) and (R7) for the 2016 cohort.

To summarise, the results from the re-estimated models (R1)–(R8) show that the effects of the key regressor in Table 2 and the fourth type of the key regressor are to a small extent affected by whether control variables are removed or not. We also find that the effects of the key regressors in Tables 3 and 4 are not greatly affected by such removals. These results show that the estimation results are not very sensitive relative to the chosen control variables.[10]

7.2. Heckman selection model

There is at least one type of potential bias related to the final sample of firms: potential sample selection bias due to missing values for the dependent variable. We have tried to account for this potential bias by using the Heckman selection model (the 'heckman' command in Stata) for each year cohort, where at least the first type of the key regressor (i.e. the dummy variable 'innovation cooperation arrangements') is included as variable in the selection equation (this variable is not in the outcome equation). In order to assess whether certain control variables may be relevant to include in the selection equation, we have compared the same descriptive statistics as in Table 1 (with the exception of key regressors and location of innovation cooperation partner) for the following two groups of firms: (i) the final sample of all firms with innovation activities given that the dependent variable is observed (selected), and (ii) the same sample given that the dependent variable is either observed or unobserved (not selected). The number of enterprises in each group for each year cohort is: 2584 in Group (i) and 2664 in Group (ii) (80 non-selected) for the 2014 cohort, 2501 in Group (i) and 2601 in Group (ii) (100 non-selected) for the 2015 cohort, and 2402 in Group (i) and 2495 in Group (ii) (93 non-selected) for the 2016 cohort.

We find that the average number of employees is higher in Group (ii) than in Group (i) for each year cohort: the average number for each cohort varies from 55 to 56 in Group (i) and from 59 to 61 in Group (ii). This indicates that the proportion of small firms with missing values for the dependent variable is higher than the corresponding proportion of large firms, where firm size is measured by the number of employees. Furthermore, some enterprises in Group (ii) are included in some industrial sectors that are not included in Group (i). These industries are (alphabetical NACE codes in parenthesis): financial and insurance activities (K), human health and social work activities (Q), and other service activities (S). As a result of all this, we also include the log of the number of employees and industrial sectors as variables in the selection equation.

Based on the Heckman selection model, the estimation results show that there is a negative effect of having innovation cooperation arrangements on the productivity level for the 2014 and 2015 cohorts, but these effects are only significant at the 10 per cent level. There is a non-significant effect for the 2016 cohort. In Table 2, there is a negative effect for the 2015 cohort, and a non-significant effect for each of the other cohorts. Therefore, the effects of the first type of the key regressor for the 2014 and 2016 cohorts are to a small extent affected by whether the Heckman selection model or OLS is used, in the sense that the effect of this key regressor is non-significant for both regression techniques for each of the two cohorts (5 per cent level). For the 2015 cohort, we find that the corresponding effect is sensitive to the technique used.

8. Conclusions

We have first examined the effect on a firm's productivity level of having innovation cooperation arrangements among those with innovation activities, and then we have examined whether the productivity level is affected by the number and types of innovation cooperation partners among firms with innovation cooperation arrangements. As far as we are aware, very few studies have examined and estimated how innovation cooperation arrangements are related to productivity. A firm's productivity level is measured by labour productivity, and not TFP. We use data of Norwegian firms, which is based on matched employer–employee register data, financial register data, and innovation survey data. The final sample of firms consists of firms with innovation activities. The effects of the four types of key regressors and the control variables on the productivity level are examined both in the short and medium term. All firms in the final sample are used, but we also differentiate between small and large firms.

The estimation results show that the effect of having innovation cooperation arrangements on a firm's productivity level is only significant for the 2015 cohort. The effect is negative for all and small firms, and positive for large firms, in the final sample. Thus, in contrast to small firms, large firms can achieve productivity improvements by having innovation cooperation arrangements.

Using firms that had innovation cooperation arrangements with internal partners (i.e. other enterprises within a firm's enterprise group) as the reference category, we find that the productivity level is relatively higher in the short term among all and small firms that had such arrangements with competitors or other enterprises in a firm's sector. The productivity level is relatively lower both in the short and medium term among all and small firms that had innovation cooperation arrangements with partners in the academic sector, and relatively lower among all and small firms that had arrangements with consultants or consulting enterprises for the 2015 cohort. In the medium term, we also find that the productivity level is relatively higher among large firms that had arrangements with consultants or consulting enterprises, and relatively lower among large firms that had arrangements with commercial labs or R&D-enterprises.

In Section 6.1, we have tried to explain why we find a negative relationship between the productivity level and innovation cooperation arrangements with partners in the academic sector (for each year cohort) for all firms in the final sample. One explanation might be that cooperation arrangements with such partners are more science-based and thus more risky, and that these arrangements are to a greater extent characterised by a long-term impact in terms of possible productivity gains, than cooperation arrangements with internal partners. Another explanation might be that the importance of high risks as an obstacle to innovation is negatively related to cooperation arrangements with partners in the academic sector.

Further in Section 6.1, we offer a resource argument in order to explain why there is a negative relationship between productivity and innovation cooperation arrangements with partners in the academic sector for small firms, and a non-significant relationship for large firms, for all three year cohorts. Due to small size and inadequate financing, small firms might face certain constraints that raise their costs of technology production and transfer compared with the costs for large firms. A policy recommendation might therefore be to increase public support for cooperation arrangements on innovation activities and R&D with partners in the academic sector for small firms with the aim of reducing their risk of cooperating with such partners. Public support can be provided via Innovation Norway, which is a state-owned statutory corporation. Innovation Norway is the Norwegian Government's most important instrument for innovation and development of Norwegian enterprises and industry, where enterprises have access to a broad business support system as well as financial means. This statutory corporation provides competence, advisory services, promotional services and network services.

The estimation results also show that the productivity level is not significantly affected by the number of different types of innovation cooperation partners used as a continuous variable. This holds for each year cohort when using all firms or only small or large firms. Furthermore, if we use firms with four (different types of) cooperation partners as the reference category, we find that the productivity level is relatively higher among all firms with one or three partners for the 2015 and 2016 cohorts, among all and small firms with seven partners for the 2015 cohort, and among large firms with seven partners for the 2014 cohort. The estimated effects when using the number of different types of innovation cooperation partners as a categorical variable can explain the non-significant effects of the number of different types of cooperation partners used as a continuous variable.

Based on all firms in the final sample, these results show that firms with the strategy of having a higher productivity level than the corresponding level for the reference category (i.e. four different types of partners) in the medium term should try to have one or three (different types of) innovation cooperation partners, *ceteris paribus*. An alternative strategy is to try to have seven cooperation partners, which holds for the 2015 cohort when using all or only small firms and for the 2014 cohort when using large firms. For all and small firms, the productivity level in the short term is not significantly affected by the number of different types of innovation cooperation partners used as a categorical variable.

The non-significant effects of the number of different types of innovation cooperation partners (used as a continuous variable) on productivity means that we cannot claim that each of these relationships could be an indication that (different types of) cooperation partners are primarily complements or substitutes. The term 'primarily complements' is used in the sense that the effect of cooperating with some partners on firms' productivity level is larger for firms that also cooperate with other partners, while we use the term 'primarily substitutes' when the effect of cooperating with some partners is smaller for those that also cooperate with other partners.

From these results we cannot claim that having many different types of innovation cooperation partners contributes positively or negatively to firm performance measured by firm productivity. In the analysis, we have considered a (so-called) knowledge-based view as the analytical framework (see Section 1). Based on this framework, we cannot conclude that the results indicate that knowledge and information generated from innovation cooperation arrangements contribute positively or negatively to productivity if a firm cooperate with many different types of partners. The reason for a negative contribution to productivity may be transaction costs of cooperating with many (different types of) partners. Such costs may include, for example, search and information costs or bargaining and decision costs (or both). Although firms with many cooperation partners can have access to different types of knowledge, this can also involve large transaction costs since coordination can be costly (Vivona, Demircioglu, and Audretsch 2022), which can have an impact on a firm's productivity level.

Finally, there are some limitations to this study. First, Cardoso, Guimarães, and Varejão (2011) claim that total output (or valued added) would be a more accurate measure of productivity than total sales per labour unit. This indicates that the use of turnover, due to data availability, instead of total production as a measure of productivity can be a limitation in our analysis. Second, we do not have panel data, which could improve the efficiency of econometric estimates. However, we have examined the effects of the explanatory variables on a firm's productivity level for each year in the period 2014–2016. Most of the explanatory variables refer to 2014, while the four types of key regressors refer to the period 2012–2014. This study therefore also includes analyses where there is a time gap between each of the explanatory variables and firm productivity.

Notes

1. Baily, Bosworth, and Doshi (2020) argue that the growth rate of TFP is a measure of technological change (either from innovative processes or products), and that measurement errors can have a big impact on estimated TFP growth since TFP is calculated as a residual. Syverson (2011) also emphasises that TFP is a residual: 'it is the variation in output that cannot be explained based on observable inputs' (330).
2. This is not obvious as information about location of innovation cooperation partner is based on the same question that provides information about an enterprise's different types of innovation cooperation partners. We assume, however, that an enterprise that aims to increase its productivity will primarily be concerned with the choice of different types of partners, and to a lesser extent be concerned with where they are located.
3. Reed (2015) demonstrates that the practice of replacing a suspected simultaneously determined explanatory variable with its lagged value does not enable one to avoid simultaneity bias. The study by Bellemare,

Masaki, and Pepinsky (2017) specifies the conditions under which lagged explanatory variables are appropriate responses to endogeneity concerns.

4. This is to some extent in line with Fritsch and Lukas (2001), but they focus on firms that are engaged in R&D cooperation. They find that such firms tend to be relatively large. In their estimations, the effect of the size of the enterprise (number of employees) on the propensity to cooperate is positive and statistically significant. This is in contrast to the study by Kleinknecht and Reijnen (1992), which finds that firm size has little impact on R&D cooperation between firms.
5. We do not use the average age of employees squared as one of the control variables due to the multicollinearity problem.
6. Based on each year cohort in all the regressions R1–R4, we find that VIF < 4 for each of the explanatory variables if we use all firms or only firms with 1–99 employees in the final sample and VIF < 7 for each of the explanatory variables if we only use firms with at least 100 employees in the final sample (weighted results), where we use the 'vif' command in Stata.
7. Haus-Reve, Fitjar, and Rodríguez-Pose (2019) use three innovation measures as dependent variables: product innovation, new-to-market product innovation, and share of turnover from new products.
8. The productivity levels for each year cohort in Figures 1 and 2 among firms with innovation cooperation arrangements are measured in relation to the average productivity level among all firms in the year cohort (see Note (2) in the figures).
9. The negative effect of the number of employees is only significant at the 10 per cent level for the 2015 cohort for all firms in Table 3.
10. For each of the four type(s) of the key regressor(s) and for each of the three year cohorts, calculations of the VIF indicate that we have no serious multicollinearity problem in any of the re-estimated models (R1)–(R8) ((R1) is not relevant for the first type of the key regressor). In all re-estimated models, we find that VIF < 4.

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