# The learning mechanisms through public procurement for innovation: the case of government-funded basic research organizations

Castelnovo P.[a] and Dal Molin M.[b (*)]

**Abstract**

We investigate how the procurement activity of government-funded science organizations support the performance of the firms involved in their supply chain. Specifically, the aim of the paper is to identify the mechanisms and disentangle the channels driving this process.

Our testing ground is the Italian Institute for Nuclear Physics (INFN). We frame our study as a mixed-methods research project: three distinct but complementary methodologies are employed, which combine quantitative and qualitative evidence. Firstly, econometric and Bayesian Network analyses are performed, using the information collected through an online survey to suppliers as well as balance-sheet data extracted from online databases. Then, five case-studies are investigated in-depth, carrying out direct interviews with company staff.

Our findings suggest that four types of benefits stem from suppliers' cooperation with INFN: learning, innovation, market penetration, and networking. These gains represent "intermediate outputs" which in turn impact on suppliers' socio-economic performance. We provide evidence that suppliers involved in innovative procurement usually experience the greatest benefits. This is mainly explained by the new technical competencies acquired, which are exploited to develop new products that support company business development and sales. On the contrary, reputational gains, leading to the acquisition of new clients, are experienced also by companies involved in regular procurement.

**Keywords:** public procurement; innovation; basic research; technological spill-overs.

**JEL Codes:** C11; H57; O31, O32.

[a] Department of Economics, Management, Quantitative Methods, Università degli Studi di Milano, Italy.

[b] Gran Sasso Science Institute, Social Science

*correspondence to: martina.dalmolin@gssi.it

## 1. Introduction

Nowadays, there is a widespread recognition of the positive role played by large Research Infrastructures (RIs) in expanding the scientific and technological knowledge frontier (see Del Bo, 2014).

Nonetheless, it has become increasingly relevant to identify and quantify also the economic benefits generated to society by government-funded RIs. This is important to justify high public investments in huge capital-intensive scientific projects, especially in periods of financial crises and reduction of government budgets. For this reason, a growing strand of the economic literature has investigated the socio-economic benefits stemming from these facilities. Some studies performed Cost-Benefit analyses of government-funded RIs (e.g. Florio et al. 2016 for the case of CERN) while others focused on the impact that RIs procurement has on companies involved in their supply chain (e.g. Castelnovo et al. 2018; Florio et al. 2018; Vuola and Hameri, 2006). Indeed, these facilities are built, maintained and up-graded in collaboration with companies (OECD, 2014; Autio et al., 2004; Autio et al., 1996) and their procurement activity can be considered as a specific kind of Public Procurement for Innovation (PPI).

PPI occurs when public authorities place an order for a product or a service that still does not exist on the market, or is not commercially available on a large scale, but which could be developed within a reasonable timeframe (Edquist, Hommen and Tsipouri, 2000). By means of PPI, the public authorities, both directly or through firms, public agencies, and large research centers, act as a launch-customer stimulating the R&D and innovation activities of the firms which should fulfil their requests (Edquist et al., 2015; Edler and Georghiou, 2007). PPI has been shown to act as an effective demand-side policy which stimulates and promotes innovation (Ghisetti, 2017; Caloghirou et al., 2016; Georghiou et al., 2014; Edquist and Zabala-Iturriagagoitia, 2012, Aschoff and Sofka, 2009) by generating technological spill-overs. Its impact on firms' expenditure in innovative activities may be even stronger than R&D subsidies and tax credits (Guerzoni and Raiteri, 2015). Moreover, public organizations act as risk-takers in breakthrough technologies investments whose uncertain returns may discourage private companies from bearing innovation costs (see Mazzucato, 2016).

The procurement activity of RIs has specific features and produces relevant benefits to supplier companies, as highlighted by Castelnovo et al. (2018), Florio et al. (2018) and Dal Molin and Previtali (2019).

While in most cases public purchasers do not take part directly in the innovation process carried out by companies, in the case of RIs a direct involvement of public institutions can often be observed. This is, for example, the case of the CERN, which makes available to supplier companies its infrastructures and know-how to carry out experiments, and often takes an active part in the design and development of the products demanded. This collaboration may boost the learning process by firms and foster the technological transfer (Nielsen and Anelli, 2016).

However, the available empirical evidence on the economic impact of the procurement placed by large RIs is still scarce. Studies like Schmied (1977), Bianchi-Streit et al. (1984), and Castelnovo et al. (2018) proved the existence of relevant innovation, productivity and market penetration benefits generated to the supplier companies. Yet, the mechanisms leading to such performance gains are still unclear. As reported by Autio et al. (2004), big-science centres are often treated as a "black-box": little effort has been put to understand the factors leading to spill-overs.

We contribute to the extant literature by identifying and disentangling the mechanisms through which the procurement placed by a large RI may generate enhancement in company economic performance, in terms of revenues, business development and employment. Specifically, we are interested in understanding the impact of the collaboration with a research center on firms' knowledge, innovation, reputational and relational assets[1], and the effect of these assets changes on firms' economic performance.

[1] As explained in the Conceptual framework below, we identify four categories of "*intermediate outcomes*" capturing changes in companies' knowledge, innovation, reputational and relational assets due to the collaboration with INFN.

Our testing ground is the Italian Institute for Nuclear Physics (INFN), a research agency that studies the fundamental constituents of matter and the laws that govern them, and conducts theoretical and experimental research in the fields of sub-nuclear, nuclear and astroparticle physics.
We frame our study as a mixed-methods research project (see e.g. Creswell and Clark, 2017; Starr, 2014) that involves the collection and analysis of both qualitative and quantitative data.
The mixed methods analysis allows examining the convergence of findings from the qualitative and quantitative phases of the study, while exploiting the strengths of each: depth and complexity from the qualitative stage vs. greater representativeness and statistical power from the quantitative one.
Quantitative analysis is based on online survey to INFN suppliers complemented by firm-level information retrieved from the AIDA and Orbis databases. These data are firstly analysed with econometric methods, to identify the main determinants of suppliers' performance enhancements derived from INFN collaboration. Then, a Bayesian Network analysis is performed to explore all the possible interlinkages among the set of variables considered: this method highlights the direct and indirect factors that affect suppliers' outcomes and thus the mechanisms of performance gains.
In the qualitative phase, we complement and enrich the quantitative evidence with an in-depth discussion of five case-studies from our sample of suppliers, based on direct interviews, which allows to grasp interesting insights on the features of the collaboration established and the benefits enjoyed by companies.
The paper proceeds as follows. Section 2 summarizes the relevant literature on the positive spill-overs from basic research to the industrial sector. Section 3 defines the conceptual framework and the hypothesis to be tested. Data and descriptive statistics of our sample are presented in section 4. Section 5 explains the research methodology, while results are presented and discussed in Section 6. Section 7 draws conclusions and policy implications. Lastly, in Section 8, we discuss the limitations of the study and suggest future research avenues.

## 2. Spill-overs from basic research: findings and methods

Basic research centers are considered a fertile learning environment for companies (Autio et al. 2004). Basic research[2], particularly in high energy physics, requires the development of highly complex, high technological and large-scale infrastructures (see e.g. the Large Hadron Collider at CERN), which are often developed in collaboration with firms. This collaboration favours the knowledge and technology transfer from the research center to supplier companies, generating benefits to the latter and, ultimately, to the society as a whole.

Public investment in basic research is able to trigger a variety of benefits, which Salter and Martin (2001) classified into six main categories:

1. Increase company know-how, in particular, the stock of useful knowledge which allows the exploitation of technological opportunities;
2. Improve the ability to develop new equipment and methodologies;
3. Enhance problem-solving ability;
4. Develop new networks and social relations;
5. Creation of new companies, start-ups, and spin-offs;
6. Build new human capital, including Ph.D. students and researchers.

The first studies attempting to empirically assess the spill-overs from publicly funded basic research to industry date back to the '80s and focused on academic research.

[2] Basic research is defined as experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view (OECD, 2014).

The seminal paper by Jaffe (1989) empirically assessed the existence of spill-overs from academic research to business innovation, measured by corporate patents. This evidence is supported by the subsequent studies of Mansfield, who showed that a consistent share (from 9 to 15%) of firms' product and process in the U.S. could not have been developed without a substantial delay in the absence of university research (Mansfield et al. 1991, Mansfield, 1995 and 1998).
These seminal results were later confirmed by more recent studies, like Toole (2012), who focused on the pharmaceutical industry, and Tijssen (2002), who carried out a nation-wide mail survey amongst inventors working in the corporate and public research sectors in The Netherlands.
The beneficial side-effects of academic research are also found in business start-ups (Bania et al., 1993) and high-technology innovations (Anselin et al., 1997). Studies showing a significant contribution of academic research to economic and productivity growth include Griliches (1986), Bergman (1990), Martin (1998) and Browns et al. (2003).

Existing research on the economic spill-overs from the basic research carried out in large RIs drew mainly on case-studies and surveys of suppliers, which suggest that the impact on supplier companies is multi-dimensional and not limited to the financial dimension. This evidence is available mainly for basic physics and aero-space RIs, like the European Centre for Nuclear Research (CERN), the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA).
Analyses based on case-studies provide an interesting qualitative insight into how the RIs-industry collaboration support firms' innovative activities and economic performance. Among the research taking this approach, Aberg and Bengston (2015), Autio et al. (1996) and CSIL (2019) focused specifically on the CERN experience, while Martin and Tang (2007) and Edquist et al. (2000) collected the experiences of a large number of companies, belonging to different European countries, which took advantage from the collaboration established with different kinds of public institutions.
Studies relying on surveys of suppliers make it possible investigating the experience of a larger sample of companies, even if with a less in-depth detail level but allowing a superior generalization of the results.
Schmied (1977) is one of the first studies to have assessed the economic impact of a large RI on its supply chain. Exploiting interviews to the management of 134 CERN suppliers over the period 1955-1973, his findings suggest an average economic utility ratio of 3, meaning that each Swiss Franc (CHF) spent in a high-tech contract generated 3 CHF in the form of increased turnover or cost savings. The idea was that these economic utilities would reveal the extra benefit of working for CERN, which in turn should capture the spill-over effect. In a subsequent analysis, Bianchi-Streit et al. (1984), using a sample of 160 European high-tech CERN suppliers, confirmed the average utility-sales ratio was in the range of 3:1.
More recent studies point to the existence of significant technological externalities and increased innovation from CERN. The work by Autio et al. (2003), based on a survey to 154 companies over the period 1997-2001, reported that 38% of the respondents developed new products, 44% and 36% recognized respectively technological or market learning and 13% created new R&D teams. Similar conclusions are drawn by Autio (2014).
Florio et al. (2018) updated the survey methodology with a Bayesian Network Analysis of the outcomes of being a CERN supplier for over 600 firms. The determinants of suppliers' sales, profits and development activities are investigated, finding that collaborative relations between CERN and its suppliers improve the economic performance of the latter and increase positive spill-overs along the supply chain.
A survey methodology, based on direct interviews with contracting firms, has been adopted also by studies focusing on the space industry. A comprehensive evaluation of the indirect industrial effects generated by the European space programs was conducted by B.E.T.A.[3] (1980, 1988, 1996) and then analyzed and discussed by Cohendet (1997) and Bach et al. (2003). Findings suggest that, on average, every euro paid by the European Space Agency (ESA) to the industry resulted in a three-times higher indirect economic benefit

[3] Bureau d'Économie Théorique et Appliquée of the University of Strasbourg (B.E.T.A.)

through ESA contracting firms. More recently, the Danish Agency for Science (2008) has surveyed Danish companies involved in the ESA supply chain over the years 2000-2007, finding that every million euros of Danish contributions to ESA generated a total benefit of 4.5 million euros, through the direct turnover for ESA contractors and the indirect effects resulting from the development of new technologies and competencies.
The first and, to our knowledge, unique research that applied econometric techniques to firms' balance-sheet data to quantify the benefits to CERN suppliers is Castelnovo et al. (2018). Their findings show that companies involved in a collaboration with CERN experienced a positive impact on R&D investment and probability to patent new products, which in turn led to enhanced productivity and economic performance. These results are driven by suppliers operating in high-tech sectors, while the impact on low-tech companies is smaller and often not statistically significant.

## 3. Conceptual framework

Technological procurement may trigger learning and innovation processes for supplier companies. In particular, Big-science centers are often seen as a technological learning environment for firms involved in their supply chain. However, they are often treated as a "black-box" (see Autio et al. 2004): little research has been carried out to understand the mechanisms leading to enhancements of suppliers' performance.
The analytical framework proposed by the seminal work of Schumpeter (1934) to analyze economic development suggests that new economic configurations have an impact on products, production and sales techniques, market and company organization and methods. Within this theoretical context, Cohendet (1987) distinguished four categories of spill-over effects: i) technological; ii) commercial; iii) managerial and iv) work-factor effects.
The classification provided by Salter and Martin (2001), already presented in the previous section, largely traces this taxonomy but goes into more details in defining the array of positive side-effects, beyond the direct financial impact of the contract, that may stem from publicly-funded basic research. Technological spill-overs encompass benefits to company technical know-how, problem-solving capabilities and ability to develop new equipment and methodologies. Commercial spill-overs include enhancements in marketing reference value associated with being a big-science center supplier (see Schmied, 1982). Managerial side-effects may involve improvement of quality control, production techniques, and project management. Lastly, work factor effects include the building of new human capital, like Ph.D. students and researchers.
In addition, Salter and Martin (2001) recognize possible impacts on the development of new networks and social relations and in the creation of new companies, start-ups, and spin-offs.

Referring to this theoretical background and following Schmied (1982), Autio et al. (2004) and Florio et al. (2018), we identify four categories of *cooperation* (or *intermediate*) outcomes capturing changes in companies' knowledge, innovation, reputational and relational assets due to the collaboration with INFN:

- *Learning outcomes* refer to the acquisition of new technical and managerial competencies and to the improvement of market knowledge.
- *Innovation outcomes* include the development of new products, services, and technologies, as well as changes in the technological status of suppliers (e.g. the acquisition of new patents);
- *Market penetration outcomes* include the acquisition of new clients and improved reputation due to the RIs marketing reference for the company
- *Network outcomes* encompass new partnerships, new international collaborations, and co-patenting.

We claim that the collaboration with INFN first affects the achievement of these intermediate outcomes that, in turn, may have an impact on firms' economic performance and employment.

According to the extant literature, some features of the procurement relationship may, in fact, foster the improvement of companies' knowledge, innovation, and relational assets. For example, the development of learning and innovation outcomes depends on the technological content of the order placed (see e.g. Castelnovo et al. 2018, Hameri and Vuola, 1996, and Edquist and Hommen, 2000) and by the type of interaction established between the supplier and the research centre, like the continuity and involvement of the collaboration (see Åberg and Bengtson, 2015; Florio et al., 2018).
While innovation outcomes are more likely to stem from PPI-like relationships requiring the development of products at the technological frontier, market-related outcomes such as reputational benefits may accrue also to companies which deliver off-the-shelf products. Autio et al. (2004) and Bianchi-Streit et al. (1984) documented that reputational benefits may accrue simply from being the supplier of a world-renowned research center like CERN, which is used as a signal for other potential customers.

At the light of these considerations, the hypothesis we aim to test is the following:

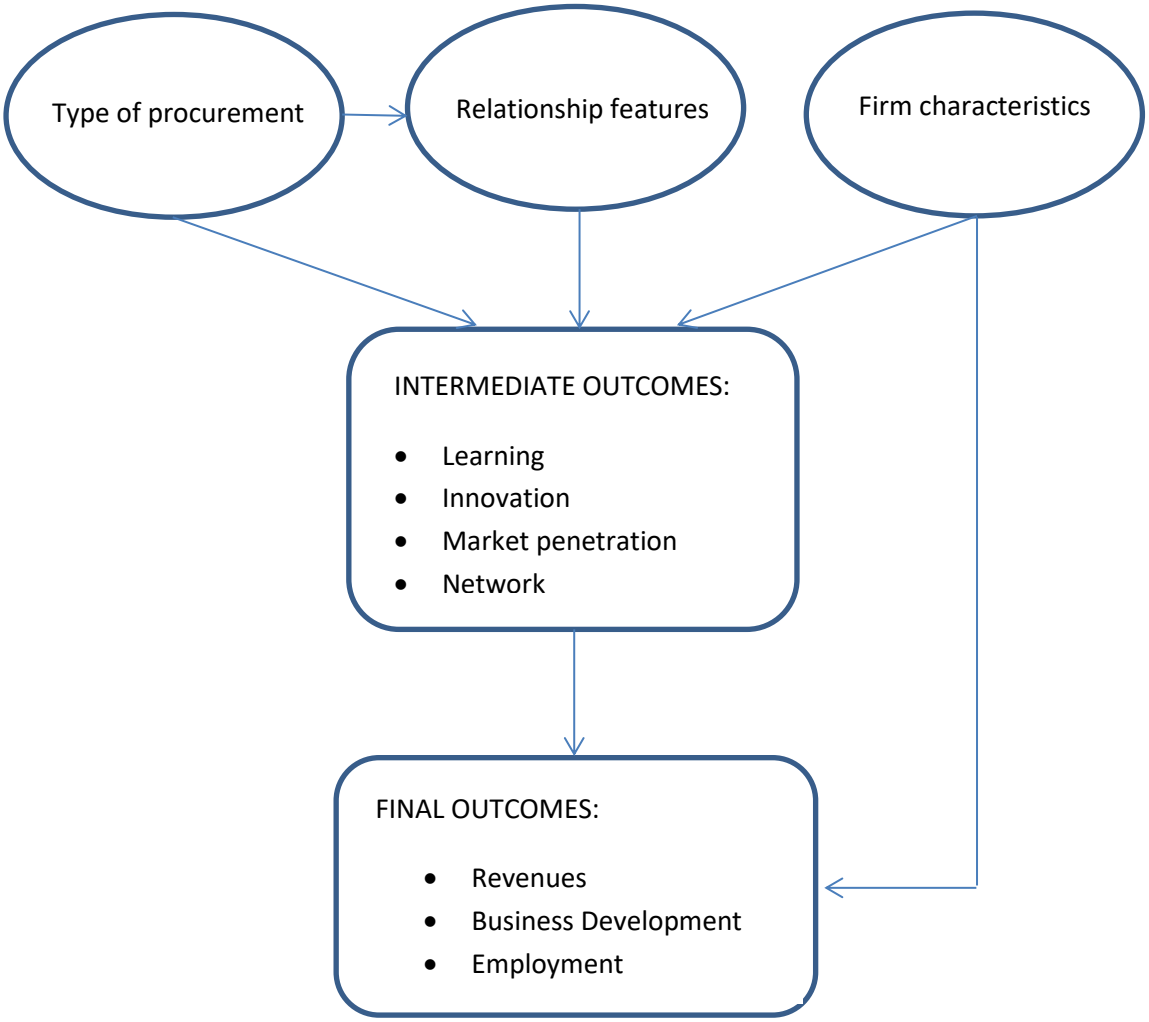
*HP: The features of the procurement relationship (such as the technological novelty embedded in the order and the intensity/strength of the collaboration established) affect the suppliers' intermediate outcomes: learning, innovation, and market penetration outcomes, as well as the networking benefits from new alliances and collaborations. In turn, intermediate outcomes positively affect suppliers' socio-economic performance.*

More specifically, we speculate that PPI is positively correlated with both learning and innovation outcomes, while regular procurement (RP) is likely to improve market penetration only. Moreover, relationships characterized by a higher degree of intensity are likely to exert a stronger impact on suppliers' intermediate outcomes.
The development of *intermediate* outcomes can be mediated by firm-level characteristics, like e.g. company size and the number of employees involved in R&D activities, which may influence firms' absorptive capacity (see e.g. Fernández-Olmos and Ramírez-Alesón, 2017; Cohen and Levinthal, 1990; Lane and Lubatkin, 1998).
In our model, the firms' socio-economic performance dimensions that can be affected by intermediate outcomes are:

- *Revenues*
- *Business development*, which encompasses several dimensions of firms' activities like new types of business undertaken thanks to the collaboration of INFN, creation of start-ups or spin-offs, entry in new markets, increase in market shares and reduction of the time to market.
- *Employment*, which is used a proxy for human capital, includes both new permanent and temporary new hiring.

Figure 1 summarizes our conceptual framework and the logical chain of implications we aim to test.

**Figure 1 – Conceptual Framework**




## 4. Data and summary statistics

Once outlined our conceptual framework and having clear in mind our two main research questions, we set up a multi-dimensional survey addressed to INFN suppliers.

The survey was carried out online in two waves, the first one from September-December 2016 and the second one from March-June 2017.

The organization of INFN is a network-like structure, made up by four national laboratories and 26 divisions spread into the national territory. Experiments take place in the four national laboratories, while in the divisions work researchers monitoring at distance the results of the experiments. Each experiment generally involves different divisions, therefore the INFN research groups are typically inter-regional.

In order to build a sample of supplier companies, five INFN divisions (three in Lombardy – Milano, Milano Bicocca and Pavia, two in Apulia – Bari and Lecce) and the INFN National South Laboratory in Catania (Sicily) were involved. The list of the companies that collaborated or still collaborate with the INFN was

obtained from the administrative databases compiled by each of the five divisions, which contain information on the orders assigned, the name of the company and their email contact. Following this procedure, we collected the name of 308 firms.

The questionnaire sent to these companies is divided into two sections. The first one includes queries about the features of the procurement relationship with the INFN, such as the characteristics of the order delivered (type of product, technological content, specificity with respect to the products/services provided to other clients, etc.) and its duration and "intensity" (i.e. occasional vs continuative collaboration). The second section contains questions on the perceived impact that such collaboration generated along several outcome dimensions. Companies are required to fill this part of the questionnaire selecting a binary choice, either "Yes" or "No"[4]. Such information is then coded using a dichotomous dummy variable taking value 1 if the selected answer is "Yes" and 0 otherwise[5]. Table A in the Appendix shows in detail the structure of the questionnaire and the specific items companies are required to answer.

Firm-level data are complemented by extracting additional information from the online databases AIDA and ORBIS. Specifically, we obtained information on firm size, sector of activity (based on NACE codes) and intangible assets. We opted for collecting most of the firms' information through secondary balance sheet data in order to keep the online questionnaire as light as possible: this allows to minimize the respondents' time devoted to filling the items and hence maximize the response rate.

This was a successful strategy since 159 firms took part to the survey, corresponding to a response rate of 51.6%, which is a very high rate with respect to comparable studies (see Schmied 1975; Bianchi-Streit et al. 1984, Autio et al. 2003 and Florio, 2018)[6]. Because 9 out of the 159 questionnaires contained several missing information/not answered items, we decided to drop them from the analysis. Hence the final sample includes 150 companies[7].

Among these, 35 (23.3%) are classified in AIDA/ORBIS as small firms[8], 66 (44%) as medium and 49 (32.7%) as large or very large. Most companies are located in Italy (141) while only a minority (9) outside of it. Among Italian firms, 83 are located in northern Italy, 38 in regions of the Centre and 20 in the South.

As it can be noticed in Figure 2, most companies operate in the wholesale and retail trade sector (46,8%) and in the manufacturing sector (33.8%), followed at a distance by companies active in the information/telecommunication sector (7.2%) and by those involved in professional, scientific and technical activities (5.8%). As far as the delivered products are concerned, the Technology Transfer Office of INFN identified the following main categories: specialized instrumentation, customized electronic products, logistic support to research, materials, mechanic components, and low temperature and space. One-fourth of the orders is classified as "generic procurement", including e.g. generic infrastructures, office supplies, furniture, cleaning services and catering.

[4] As suggested by the Oslo Manual (OECD, 2005), the use of binary questions is a simple and reliable strategy for collecting and interpreting technological innovation data.

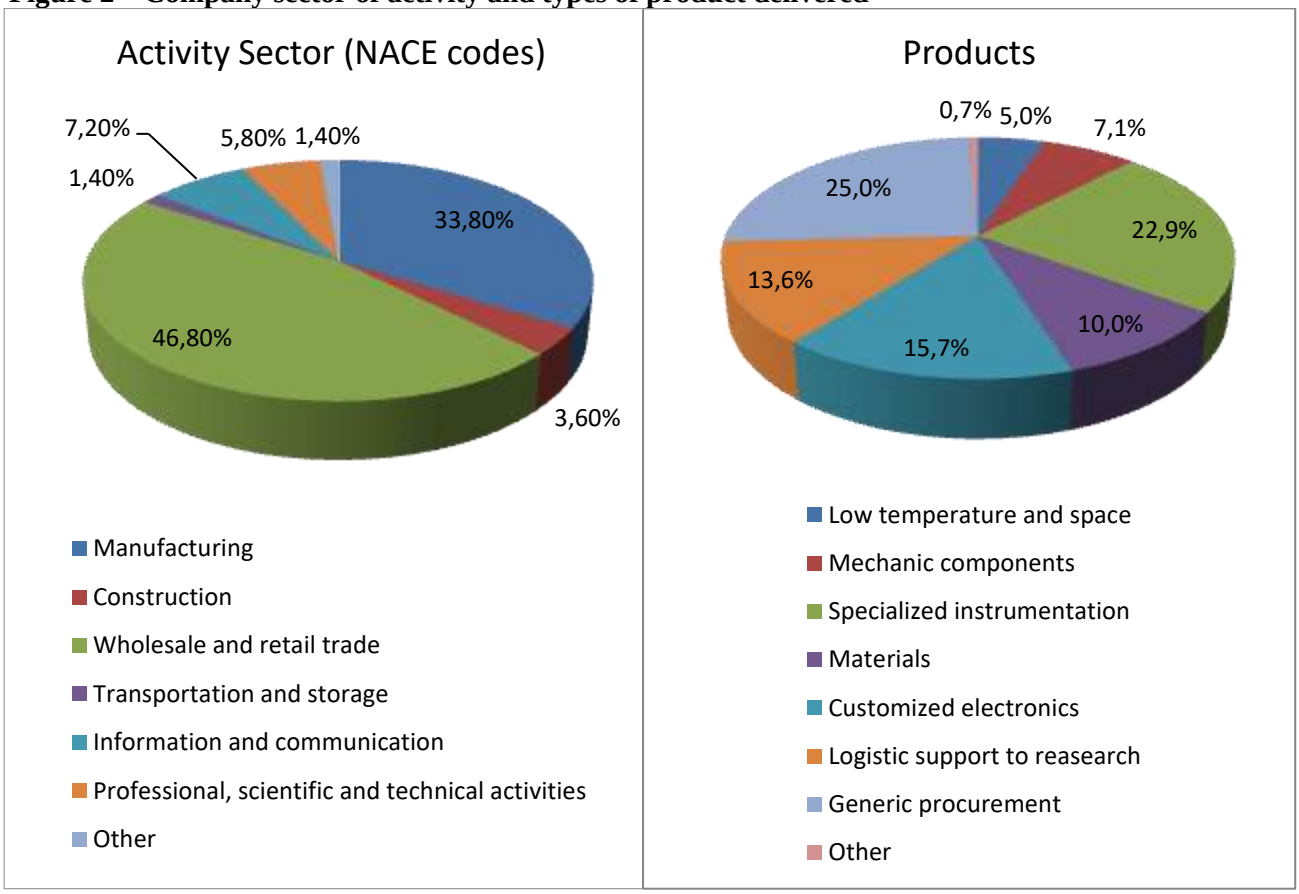
[5] Specifically, companies are asked to compare their post-procurement outcomes with those of the pre-procurement period and select "Yes" when the former outperformed the latter.

[6] These studies got a response rate respectively of: 37.3%, 30.8%, 24.4% and 25%.

[7] Some missing/not-answered items can be found also in the questionnaires used to carry out the econometric analysis. This is why the number of observations can vary according to the specification/outcome considered.

[8] This classification exploits information on the amount of total assets, operating revenues and the number of employees.

**Figure 2 – Company sector of activity and types of product delivered**




Source: authors' elaboration on the AIDA/Orbis and online-survey data

Companies' assessment of INFN procurement impact on the outcome dimensions under analysis is summarized in Table 1, which distinguishes between intermediate outcomes and performance achievements.
As it can be noticed, a consistent share of suppliers acknowledged that the procurement collaboration established with INFN generated positive benefits to the four intermediate outcomes considered. However, the recognized impact is heterogeneous across the different items included in each category.
Concerning learning outcomes, the greater impact is recognized on technical competencies acquisition (almost 40% of positive answers[9]), followed by improved market knowledge (22%) and acquisition of new managerial competencies (12%). Focusing on innovation outcomes, the magnitude of the impact seems smaller: 19% of the interviewed companies affirm to have developed new products or services. However, only 3.3% of such innovation resulted in new patent applications. The most relevant impact is on market penetration: more than half (50.3%) of the firms in our sample declared that the collaboration with the INFN improved their image and reputation, and more than a quarter (25.8%) acquired new clients.
Lastly, looking at possible new alliances and network improvement, 23.3% of the firms reported having been involved in new partnerships, while only 8.8% and 0.7% respectively were engaged in new international collaborations or in co-patenting activities.
As far as firms' performance is concerned, the relationship with INFN generated positive economic returns: around 40% of respondent companies declared an increase in their sales volume thanks to such collaboration. Heterogeneous impacts can be observed on business development. The stronger impact can be detected on

[9] In the present discussion we refer to the number of positive answers over the total number of questionnaires used in the empirical analysis (150). Since, as previously explained, some questionnaires may contain some not-filled items, such percentage would be obviously higher if computed as the share of positive answers over filled items (see the last column of table 1).

two market dimensions, i.e. entrance in new markets (22.7%) and increase in market shares (19.3%), followed by the development of new types of activities (15.3%). A limited impact can instead be ascertained on the creation of new start-ups or spin-offs (6.3%) and in the reduction of the time to market (6%).
The impact on employment is higher for permanent hiring (13.3% of positive answers) while it is quite low for temporary hiring (only 5%).
In the following sections, we will shed light on these statistics, investigating more in-depth the determinants of the benefits accrued to suppliers, the mechanisms underlying the effects triggered by INFN procurement, as well as the relationships linking the different types of outcome considered.

**Table 1. Survey results: the impact of INFN public procurement on supplier companies**

| Dimension | Asked Questions | % of positive answers | % of positive answers excluding missing answers |
|---|---|---|---|
| ***Intermediate outcomes*** | | | |
| ***Learning*** | Acquisition of new technical competencies | 39.6% | 48.1% |
| | Acquisition of new managerial competencies | 12% | 15.8% |
| | Improvement of market knowledge | 22% | 28% |
| ***Innovation*** | New products or services | 18.9% | 24.8% |
| | New patents | 3.3% | 4.4% |
| ***Market Penetration*** | Improvement in company's image and reputation | 50.3% | 58.4% |
| | Acquisition of new clients | 25.8% | 31.8% |
| ***Network*** | New partnerships | 23.3% | 30.1% |
| | New international collaborations | 8.8% | 13.1% |
| | Co-patenting | 0.7% | 0.9% |
| ***Final outcomes (Performance)*** | | | |
| ***Revenues*** | Increased sales volume | 39.1% | 52% |
| ***Business Development*** | New types of activities | 15.3% | 17.7% |
| | Start-ups or spin-offs | 6.3% | 7.1% |
| | Entry in new markets | 22.7% | 26.4% |
| | Increasing in market shares | 19.3% | 22.5% |
| | Reduction of the time to market | 6% | 7.3% |
| ***Employment*** | New temporary hiring in relation to INFN activities (Ph.D. students, stage, scholarship, apprenticeship, temporary workers) | 5% | 5.3% |
| | New permanent hiring in relation to INFN activities | 13.3% | 17% |

Source: authors' elaboration on survey data

## 5. Research Design

We frame our study as a mixed-methods research project (see e.g. Creswell and Clark, 2017; Starr, 2014) that involves both quantitative and a qualitative analyses. In the quantitative part we perform econometric and Bayesian network analysis based on the information collected through the online survey. Then, in the qualitative phase we provide evidence from five case-studies based on direct interviews.

### 5.1 Econometric analysis

As the first step of the quantitative investigation, we performed an econometric analysis. We used logit and ordered logit models to study the correlation between INFN suppliers' performance (revenues, business

development, and employment) and a set of explanatory variables which include procurement features, intermediate outcomes, and firm-level controls.
According to the nature of the dependent variable, we estimated different econometric models.
Specifically, when firms' performance is measured by the dichotomous variable *"Revenues"*, we estimated a logit model which takes the form:

$$Pr(y_i = 1|\mathbf{X}_{ic}) = \Lambda(\mathbf{X'}_{ic}\boldsymbol{\beta}) = \Lambda(\beta_0 + Int\_Out_i'\beta_1 + Proc_i'\beta_2 + X_i'\beta_3 + \sigma_r) \quad (1)$$

where $\Lambda$ is the cumulative distribution function of the standard logistic distribution. $y_i$ takes value 1 if respondent companies declared to have experienced a rise in revenues after the beginning of the collaboration with INFN, and 0 otherwise.
$Int\_Out_i$ is a vector including the ten indicators for intermediate outcomes described in section 4 (see Table 1).
$Proc_i$ is a vector of variables accounting for the procurement relationship features. It includes, as indicator of main interest, a dummy variable taking value 1 if the collaboration is classifiable as PPI and 0 if it is regular procurement. Variables accounting for the collaboration duration and intensity (ongoing vs sporadic), and whether the INFN is perceived as a distinct partner, with specific needs with respect to the other clients, are included as controls.
$X_i$ is a vector of firm-level covariates, including the sector of activity (based on the NACE 2-digits classification), three size dummies classifying companies into small, medium and large/very large[10], a dummy variable indicating whether there are employees involved in R&D activities and the amount of intangible assets, which are used as a proxy for company R&D investments (see Leoncini et al., 2017; Marin, 2014). Lastly, $\sigma_r$ is a set of dummy variables accounting for unobservable heterogeneity stemming from firms' geographical location.
Table A2 (see Appendix) provides the full list of regressors included in equation (1), with their detailed description and source.

The other performance variables we are interested in are "*Business development*" and *"Employment"*.
The variable *"Business development*" aims at capturing suppliers' development activities and it is the sum (with equal weights) of five binary items related to: "New types of activities", "Start-ups or spin-offs", "Entry in new market", "Increasing in market shares" and "Reduction of the time to market" (see Table 1). Therefore, it ranges from 0 to 5.
Similarly, the variable *"Employment"*, which summarizes suppliers' performance in terms of increased human capital, is constructed as the sum of the two binary items "New temporary hiring" and "New permanent hiring" (see Table 1), hence ranging from 0 to 2.
When the outcomes of interest are "*Business development*" and *"Employment"*, which are ordinal variables, we estimate ordered logit models (see e.g., McCullagh, 1980 and Greene, 2012). For the generic $j^{th}$ value assumed by the outcome variable $y_i$, ordered logit models take the form:

$$Pr(y_i = j|\mathbf{X}_{ic}) = \Lambda\left(\mu_j - \mathbf{X'}_{ic}\boldsymbol{\beta}\right) - \Lambda\left(\mu_{j-1} - \mathbf{X'}_{ic}\boldsymbol{\beta}\right) \quad (2)$$

where $\mu's$ are unknown threshold parameters to be estimated with $\boldsymbol{\beta}$. According to the specification considered, the outcome variable $y_i$ is either the *"Business Development*" or the *"Employment"* performance indicator. The set of regressors included in $\mathbf{X}_{ic}$ is the same used in equation (1).

[10] Such classification is provided by the AIDA and Orbis databases exploiting information on the amount of total assets, operating revenues and the number of employee. We incorporate large and very large firms in only one category since just five firms in our sample are classified as very large.

### 5.2 Bayesian Network analysis

We perform a Bayesian Network (BN) analysis to identify the specific channels and mechanisms leading to improvements in company performance.

BNs are probabilistic graphical models that estimate a joint probability distribution over a set of random variables entering in a network and then represent such variables and their conditional dependencies via a directed acyclic graph (see Ben-Gal, 2007; Salini and Kenett, 2009).

These statistical tools, which are increasingly gaining attention in the socioeconomic disciplines (see e.g. Ruiz-Ruano Garcıa et al., 2014; Cugnata et al., 2017; Florio et al., 2018), enable an effective representation of the whole set of interdependencies among the random variables *without* distinguishing between dependent and independent ones. Hence, they are suitable to explore the chain of mechanisms by which effects are generated.

In our setting, BNs allow shedding light on all the possible interlinkages existing among the different sets of variables considered in the analysis: procurement features, firm-level characteristics, intermediate outcomes, and company performance. Therefore, exploiting this further approach we can disentangle the specific impact of each variable on the others, producing results that can significantly enrich those obtained with the logit and ordered logit models.

### 5.3 Case studies

To support the results of the quantitative analysis, we complement our empirical investigation with a case-study methodology which is a suitable research design to investigate complex processes and analyze the technological learning and innovation benefits in the RI-supplier dyads (see e.g Autio et al., 2004; Vuola and Hameri, 2006 ). In fact, conveying the direct view/experience of supplier firms' staff can help us to have a deeper understanding of the INFN-supplier relationship and uncover the mechanisms leading to enhancements in suppliers' performance.

We selected five relevant case-studies from the sample of companies that took part in the survey, with the help of INFN researchers and the Head of INFN technology transfer division. The selection criterion relies on a sampling strategy which aims to achieve a significant range of variation over a set of dimensions related to procurement features and company characteristics (Eisenhardt, 1989).

Such dimensions are:

i. *Type of products*: it refers to the type of goods/services produced and commercialized by the supplier company.
ii. *Size of the company*: companies are classified into three categories (small, medium and large/very large) according to the criterion described in Section 5.1.
iii. *Type of procurement*: it refers to the technological novelty of the order delivered by the supplier company, distinguishing between "regular procurement" and "PPI".
iv. *Technological maturity when the relationship started*: it refers to the company technological know-how and to the technological complexity of its products/services at the time the collaboration started.
v. *Investment in R&D when the collaboration started*: it refers to human and financial resources involved in R&D activities at the moment the collaboration started.
vi. *Intensity of the relation established*: it distinguishes between episodic/sporadic relationships versus ongoing collaborations.

Once companies were selected, we sent them an email explaining the interview's aim and the protocol and asking to identify a suitable informant. Therefore, informants were chosen by the companies themselves. Table 5 provides an overview of the selected case-studies and shows the companies features along the dimensions listed above. We interviewed informants by phone-calls following a semi-structured questionnaire and taking notes of the answers. Based on the information collected we assembled a cross-case database for qualitative analysis. For the sake of confidentiality, companies' names are not disclosed.

# 6 Results

## 6.1 Econometric Analysis

Table 3 shows the results of the logistic regressions used to study the correlation between the probability that suppliers experienced a revenue increase after the beginning of the collaboration with INFN and a set of determinant variables, which we grouped into three categories: procurement features, intermediate outcomes, and firm-level characteristics.

Five different specifications are considered: in the first four columns, intermediate outcomes are included one by one, while in the last column their impact is considered jointly.

As expected, among the procurement features, a positive and statistically significant impact is exerted by the technological novelty of the order delivered: PPI is likely to push supplier companies to develop new products and services at the frontier of science, which may later be sold to other customers and find application also in fields very different from the ones they were initially intended for (see Battistoni et. al. 2016; Nielsen and Anelli, 2016), generating additional revenues for suppliers.

On the other hand, the duration and intensity of the collaboration established do not influence firms' revenues, while the perception of INFN as a specific partner is positive but statistically distinguishable from zero only in some specifications.

Focusing on intermediate outcomes' coefficients, as it can be noticed from columns 1-4, the development of new products/services, the learning of new technical and managerial competencies, the acquisition of new clients and the engagement in new partnerships are positively associated with the probability of incremental revenues with statistically significant coefficients. However, when we consider these variables simultaneously (columns 5), it turns out that the increase in revenues depends mainly on two factors. First, the capability to develop new goods/services, widening the array of products that can be delivered to satisfy clients' needs, may increase company sales. Second, the acquisition of new clients which, in turn, might be explained by the development of new products and improved company reputation, may contribute to the rise of suppliers' sales.

Looking at firm-level characteristics, firm size is positively correlated with the probability of experiencing higher revenues: larger firms can exploit relevant economies of scale in the innovation process which leads to the development of new products/services (see Fernández-Olmos and Ramírez-Alesón, 2017). Intangible assets, used as a proxy for R&D effort, exert a positive and often significant impact on revenues because they can affect firms' absorptive capacity (see Autio et al.2014). The same reasoning may hold for the presence of skilled workers employed in R&D activities, whose impact is positive but not statistically distinguishable from zero.

Sectorial dummies, whose coefficients are not reported because of space constraints, are often statistically significant, while company geographical location do not to play any role.

Table 4 shows how the set of determinant variables considered affects the business development indicator which, as already mentioned, is the sum of five items: new types of activities, start-ups or spin-offs, entrance in new markets, increased market shares, and reduction of the time to market.

Looking at the full specification in column 5, PPI is positively and significantly correlated with business development, suggesting that its different dimensions are affected when the order entails some technological content. On the contrary, the coefficients of the other collaboration features and firms' characteristics are not statistically distinguishable from zero.

**Table 2 - Logit estimates – Dependent Variable: Revenues**

| | (1) Increased Revenues | (2) Increased Revenues | (3) Increased Revenues | (4) Increased Revenues | (5) Increased Revenues |
|---|---|---|---|---|---|
| PPI | 1.226** | 0.897 | 1.789*** | 1.248** | 1.462** |
| | (0.557) | (0.598) | (0.615) | (0.573) | (0.671) |
| Duration of the collaboration | -0.0155 | -0.0116 | -0.0127 | -0.00257 | -0.0169 |
| | (0.0332) | (0.0267) | (0.0246) | (0.0332) | (0.0349) |
| Ongoing collaboration | 0.388 | 0.773 | 0.144 | 0.387 | -0.203 |
| | (0.575) | (0.538) | (0.609) | (0.575) | (0.710) |
| INFN specific partner | 1.376** | 1.108** | 0.736 | 1.192** | 0.990 |
| | (0.539) | (0.544) | (0.561) | (0.535) | (0.673) |
| New products or services | 2.570*** | | | | 3.206** |
| | (0.884) | | | | (1.454) |
| Improved market knowledge | | -0.453 | | | -1.123 |
| | | (0.689) | | | (0.967) |
| New technical competencies | | 1.323** | | | 0.593 |
| | | (0.577) | | | (0.731) |
| New managerial competencies | | 1.360* | | | -0.670 |
| | | (0.741) | | | (1.153) |
| Improved image and reputation | | | 0.367 | | 0.158 |
| | | | (0.564) | | (0.655) |
| New clients | | | 1.968*** | | 2.569*** |
| | | | (0.593) | | (0.890) |
| New partnerships | | | | 1.572*** | 0.977 |
| | | | | (0.601) | (0.797) |
| New international collaborations | | | | 0.546 | 0.120 |
| | | | | (0.715) | (0.830) |
| Size: medium | 2.546*** | 2.635*** | 2.365*** | 2.423*** | 3.327*** |
| | (0.692) | (0.756) | (0.718) | (0.703) | (1.030) |
| Size: large/very large | 2.035*** | 1.679** | 1.264* | 1.578** | 1.957** |
| | (0.659) | (0.774) | (0.752) | (0.719) | (0.952) |
| Intangible assets (bln) | 1.08*** | 1.20* | 0.0473 | 0.209 | 0.552* |
| | (0.324) | (0.727) | (0.252) | (0.344) | (0.302) |
| Skilled employees in R&D | 0.129 | 0.492 | 0.618 | 0.405 | 0.478 |
| | (0.525) | (0.568) | (0.581) | (0.538) | (0.699) |
| Sector | Yes | Yes | Yes | Yes | Yes |
| Geo Location | Yes | Yes | Yes | Yes | Yes |
| Constant | -0.167 | -0.999 | -0.793 | -1.763 | -0.0347 |
| | (1.586) | (1.711) | (1.606) | (1.961) | (1.949) |
| *N* | 132 | 132 | 132 | 132 | 132 |
| *Pseudo* $R^2$ | 0.329 | 0.327 | 0.346 | 0.314 | 0.468 |
| *AIC* | 162.73 | 169.10 | 161.77 | 167.53 | 161.72 |
| *Brant test* ($P>Chi^2$) | 0.383 | 0.344 | 0.323 | 0.376 | 0.357 |
| *% correct predictions* | 78.79 | 78.79 | 81.13 | 77.27 | 84.09 |

Robust Standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Several intermediate outcomes are relevant to explain the achievement of business development. On the one hand, a positive impact is exerted by the development of new products/services which may encourage companies to undertake new types of activities and create start-ups or spin-offs. On the other hand, increased market knowledge, improved image and reputation and the acquisition of new clients may favor the entrance in new markets or increase firm's shares in markets where the firm is already active. In addition, the involvement in international partnerships may promote the development of new activities and the entrance in new markets due to the creation of joint ventures with companies operating in different sectors.

**Table 3 - Ordered logistic estimates – Dependent Variable: Business Development**

| | (1) Business Development | (2) Business Development | (3) Business Development | (4) Business Development | (5) Business Development |
|---|---|---|---|---|---|
| PPI | 1.471* | 2.867*** | 0.611 | 1.140 | 2.997** |
| | (0.760) | (1.041) | (0.869) | (0.746) | (1.281) |
| Duration of the collaboration | 0.0231 | 0.0612** | 0.0561** | 0.0428 | 0.0500 |
| | (0.0257) | (0.0286) | (0.0279) | (0.0283) | (0.0324) |
| Ongoing collaboration | 0.625 | 0.571 | -0.779 | 0.665 | -0.729 |
| | (0.568) | (0.667) | (0.673) | (0.602) | (0.836) |
| INFN specific partner | 1.577** | 0.487 | 0.891 | 1.166 | 1.464 |
| | (0.688) | (0.715) | (0.761) | (0.710) | (0.965) |
| New products or services | 1.991*** | | | | 1.902* |
| | (0.602) | | | | (1.034) |
| Improved market knowledge | | 2.677*** | | | 2.253** |
| | | (0.773) | | | (0.944) |
| New technical competencies | | 1.768** | | | 0.371 |
| | | (0.691) | | | (0.934) |
| New managerial competencies | | 0.923 | | | -0.496 |
| | | (0.835) | | | (1.174) |
| Improved image and reputation | | | 2.856*** | | 2.514*** |
| | | | (0.762) | | (0.862) |
| New clients | | | 3.328*** | | 2.832*** |
| | | | (0.713) | | (0.850) |
| New partnerships | | | | 0.598 | -0.0573 |
| | | | | (0.607) | (0.752) |
| New international collaborations | | | | 2.354*** | 1.850** |
| | | | | (0.756) | (0.885) |
| Size: medium | 0.774 | 0.851 | 0.180 | 0.880 | 0.937 |
| | (0.655) | (0.765) | (0.747) | (0.667) | (0.979) |
| Size: large/very large | 0.432 | 0.429 | -0.523 | 0.451 | -0.456 |
| | (0.697) | (0.781) | (0.813) | (0.697) | (0.986) |
| Intangible assets (mln) | 0.181 | 0.00954 | 0.239 | 0.196 | 0.0826 |
| | (0.179) | (0.188) | (0.185) | (0.289) | (0.225) |
| Skilled employees in R&D | 0.368 | 0.119 | 0.728 | 0.584 | -0.279 |
| | (0.594) | (0.667) | (0.658) | (0.631) | (0.746) |
| Sector | Yes | Yes | Yes | Yes | Yes |
| Geo Location | Yes | Yes | Yes | Yes | Yes |
| Constants | Yes | Yes | Yes | Yes | Yes |
| *N* | 101 | 101 | 101 | 101 | 101 |
| *Pseudo* $R^2$ | 0.243 | 0.309 | 0.354 | 0.254 | 0.473 |
| *AIC* | 224.73 | 215.76 | 203.46 | 235.31 | 196.40 |
| *Brant test* ($P>Chi^2$) | 0.376 | 0.404 | 0.393 | 0.422 | 0.375 |
| *% correct predictions* | 58.41 | 57.52 | 59.29 | 55.75 | 60.18 |

Robust Standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Lastly, we investigate the determinants of a possible rise in company employment, even if only few firms in our sample declared to have hired new labour force due to the activities undertaken for the INFN. Looking at the full specification (column 5), the acquisition of new technical competencies and the involvement in new partnerships seem to be the main drivers of new hiring. The development of new sophisticated products may force companies to hire new skilled workers, like engineers or managers, to handle the challenges arising from the new technologies adopted. Indeed, the coefficient of the indicator "*New products or services*" is positive and (weakly) statistically significant when such variable is included as the only intermediate outcome (column 1) while the association disappears when the variable "*New technical competencies*" is

added. This suggests that these two intermediate outcomes are correlated with each other, as confirmed by the correlation matrix in the Appendix (Table A3). The improvement of image and reputation and the acquisition of new clients are positively correlated with new hiring (column 3), but the significance of this association vanishes when we include the other intermediate outcomes.

**Table 4 - Ordered logistic estimates – Dependent Variable: Employment**

| | (1) Employment | (2) Employment | (3) Employment | (4) Employment | (5) Employment |
|---|---|---|---|---|---|
| PPI | 0.165 | 0.309 | 0.0639 | 0.0707 | 0.449 |
| | (0.726) | (1.039) | (0.844) | (0.888) | (1.569) |
| Duration of the collaboration | 0.0428 | 0.0633* | 0.0575* | 0.0983*** | 0.122** |
| | (0.0282) | (0.0349) | (0.0315) | (0.0362) | (0.0524) |
| Ongoing collaboration | -0.171 | -0.345 | -1.268 | -1.521* | -1.954 |
| | (0.710) | (0.861) | (0.906) | (0.913) | (1.289) |
| INFN specific partner | 0.689 | -0.210 | 0.0674 | 0.606 | -0.787 |
| | (0.779) | (0.908) | (0.844) | (0.911) | (1.301) |
| New products or services | 1.274* | | | | -1.598 |
| | (0.733) | | | | (1.381) |
| Improved market knowledge | | 1.774 | | | 2.735* |
| | | (1.080) | | | (1.546) |
| New technical competencies | | 2.820** | | | 4.365** |
| | | (1.189) | | | (2.023) |
| New managerial competencies | | -0.00459 | | | 0.0332 |
| | | (1.228) | | | (1.752) |
| Improved image and reputation | | | 1.504* | | 1.522 |
| | | | (0.874) | | (1.228) |
| New clients | | | 1.929** | | 1.353 |
| | | | (0.757) | | (1.082) |
| New partnerships | | | | 2.481*** | 3.431** |
| | | | | (0.902) | (1.504) |
| New international collaborations | | | | 0.612 | -1.166 |
| | | | | (0.868) | (1.222) |
| Size: medium | 2.261* | 2.175 | 2.309* | 2.051 | 2.745 |
| | (1.178) | (1.403) | (1.265) | (1.388) | (1.870) |
| Size: large/very large | 1.314 | 0.940 | 0.693 | 1.551 | 0.680 |
| | (1.244) | (1.429) | (1.339) | (1.432) | (1.791) |
| Intangible assets (mln) | 0.138 | 0.0720 | 0.226 | 0.0398 | -0.0611 |
| | (0.204) | (0.230) | (0.213) | (0.222) | (0.289) |
| Skilled employees in R&D | -0.157 | -0.626 | 0.347 | -0.0796 | -0.420 |
| | (0.762) | (0.982) | (0.849) | (0.899) | (1.528) |
| Sector | Yes | Yes | Yes | Yes | Yes |
| Geo Location | Yes | Yes | Yes | Yes | Yes |
| Constants | Yes | Yes | Yes | Yes | Yes |
| *N* | 103 | 103 | 103 | 103 | 103 |
| *Pseudo* $R^2$ | 0.235 | 0.358 | 0.311 | 0.367 | 0.492 |
| *AIC* | 147.53 | 139.14 | 141.35 | 133.93 | 139.38 |
| *Brant test (P>Chi²)* | 0.290 | 0.369 | 0.301 | 0.228 | 0.284 |
| *% correct predictions* | 69.49 | 72.03 | 72.03 | 68.64 | 73.73 |

Robust Standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

The econometric analysis presented above offers a useful insight to explain how INFN procurement affect suppliers' performance. However, it has some limitations: some intermediate outcomes are correlated with each other (see Table A3 in the Appendix), making it difficult to disentangle their specific impact. Moreover, a causal interpretation of our findings might be problematic due to simultaneity and reverse causality issues.

Hence, in the following we test the mechanisms and speculations suggested in this section using a BN analysis and case studies.

### 6.2 Bayesian network analysis

To shed light on all the possible interlinkages among variables, as well as on the "direction" of their association, we carry out a BN analysis. This statistical procedure makes it possible to test the hypothesis underlying our conceptual framework, disentangling the specific roles played by intermediate outcomes, procurement-specific and firm-specific characteristics. Hence, it allows to investigate more in-depth the channels leading to improvements in suppliers' performance.

Figure 3 shows the directed acyclic graph (DAG) of a BN estimated with the Bayesian Search algorithm (see Heckerman et al., 1994). The thickness of the arrows highlights the strength of the relationship among the variables: the thicker the arrow, the stronger the dependency. Variables showing no links are excluded from the graph.

According to the DAG, PPI plays a direct role in increasing company technical competencies. By contrast, it is not linked with market penetration outcomes, suggesting that reputational and market benefits are not strictly due to PPI but can be experienced also with regular procurement.

Moreover, it can be noticed that PPI is linked to the presence of employees devoted to R&D: this might suggest that INFN innovative procurement targets R&D-intensive companies. However, since a procurement collaboration can last for many years, it is also possible that it pushes companies to widen their R&D divisions. In other words, the presence of R&D employees might be either a "screening signal" for the INFN or a consequence of the innovative order commissioned[11]. The duration and intensity of the collaboration are not linked with intermediate outcomes, confirming the results of the logit and ordered logit regressions.

According to our hypothesis, intermediate outcomes should positively affect firm performance. The DAG reveals that two intermediate outcomes are linked with final outcomes: the development of new products/services and the new managerial competencies acquired during the procurement relationship promote company business development, while the acquisition of new clients, determined by an improvement of company image and reputation, causes a revenue increase.

However, we can also observe that the business development indicator has an influence on some intermediate outcomes (specifically, the acquisition of new clients, and the involvement in new partnerships and international collaborations). On the one hand, this is a reasonable finding since some of the items included in this indicator, as the entrance in new markets and the development of new types of activities, may, in turn, favour the acquisition of new customers and broaden company network. On the other hand, it confirms the simultaneity and reverse causality concerns that may affect our econometric analysis, as speculated at the end of section 6.1.

Some linkages among the intermediate outcomes emerge: the development of new products/services leads to the acquisition of new managerial competencies (likely needed to handle the new productive process), which are in turn linked with improved market knowledge. Acquiring new technical competencies promotes the development of new products/services and the involvement in new partnerships.

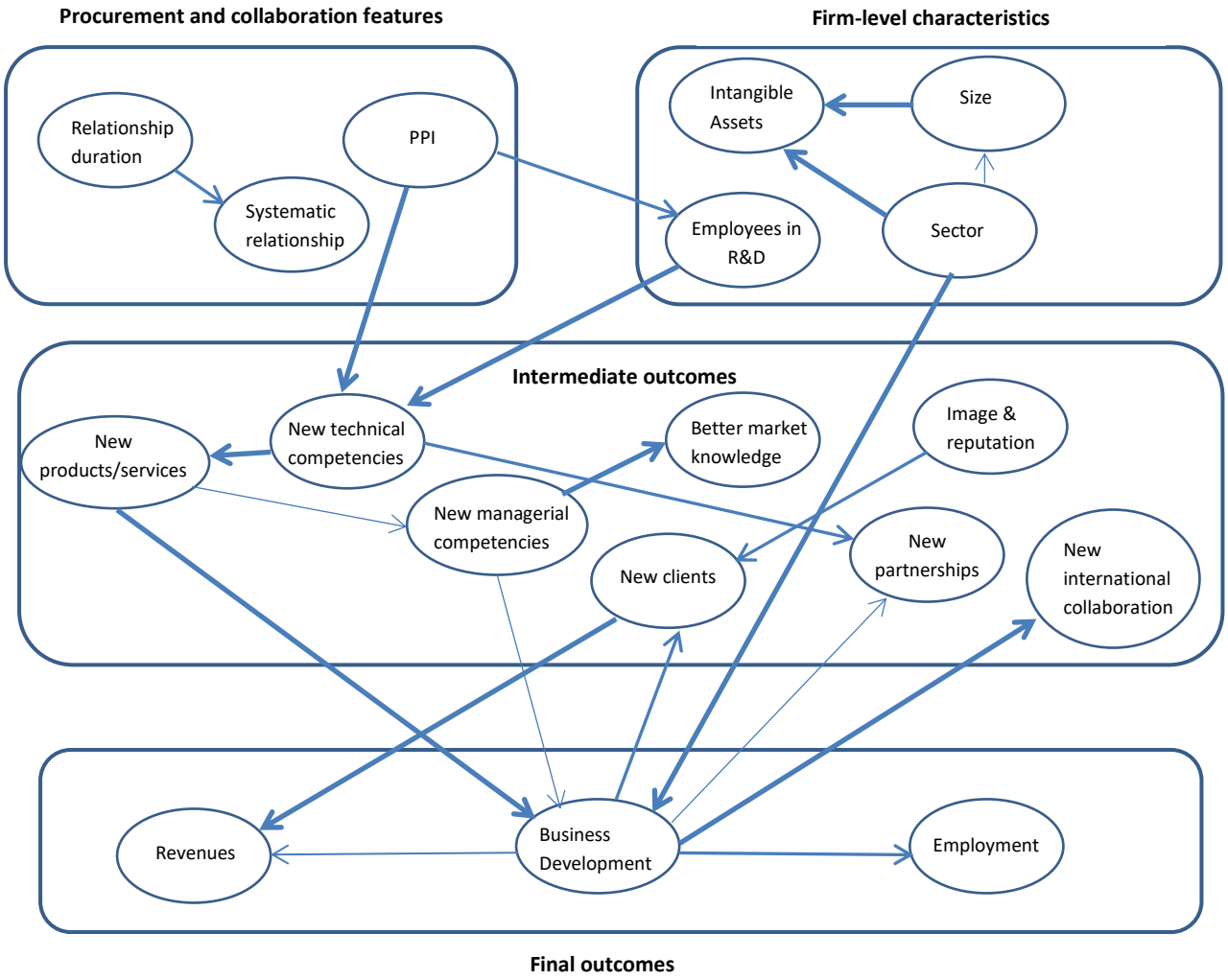
The BN analysis also shows that the variables measuring suppliers' performance are linked with one another: business development influences both revenues and employment. This result suggests that the impact of the collaboration with the INFN tends to be an overall enhancement of firms' performance, rather than gains involving specific aspects.

Lastly, looking at firm-level characteristics, it is interesting to note that both company size and amount of intangible assets are influenced by the sector where they operate, which has an impact also on company business development. Firm-level controls are not connected with intermediate outcomes, with the only

[11] The cross-sectional structure of our survey does not allow to clarify this issue.

exception of the presence of employees in R&D which is linked with the acquisition of new technical competencies, suggesting this is a good proxy for firms' absorptive capacity.

**Figure 3 – Results of the Bayesian Network Analysis**




### 6.1 Case studies

Case A. A is a medium-size company that produces devices for electronic measurement and cyber security. Specifically, the company provided INFN with spectrum analyzers, oscilloscopes, network analyzers, and power sensors. Most of the products were already on the company's catalogue and they have been ordered "of-the-shelf" by INFN researchers. The relationship of company A with INFN can therefore be labelled as "regular procurement".

This company is one of the historical suppliers of the INFN: their relationship started more than 25 years ago. At that time, there was a personal knowledge between the company and INFN researchers that favoured the building of a solid relationship.

Once a public tender is won and the order is placed, the relationship between INFN researchers and the company is systematic, involving several contacts in a month, until the order is delivered. Moreover, the relationship is usually managed directly, using both formal and informal channel of communication (e.g. phone calls and emails).

Thanks to the collaboration with INFN, company *A* experienced benefits on different intermediate outcomes, that is learning, innovation and market penetration. In terms of learning and innovation, the frequent contacts with INFN researchers allowed acquiring new technical knowledge that Company *A* exploited to improve existing products. Examples are the development of an improved oscilloscope and upgraded spectrum analyzers, that enriched its product catalogue. This has, in turn, strengthen its presence on the market, by increasing market shares.
As a result, company A has experienced a revenue increase, mainly due to the selling of upgraded products: to date, the interviewed person affirms that company sales would have been lower if the collaboration with INFN was not in place.

*Case B.* Company *B* is a small family-owned company (only 2 employees), active in the distribution of electronic components and in the provision of integrated circuits. These products were typically already included in the company's catalogue and directly ordered by INFN researchers. Therefore, though the contents of the order are typically high-tech products, the procurement relation can be classified as "regular procurement" since no product development nor customization occurred.
Company *B* is a historical supplier of INFN: although episodic (i.e. contacts occurred less than once a month), the procurement relationship started more than 30 years ago. Contacts between researchers and company B are sporadic and, when an order is placed, the collaboration between the two parties is managed mainly through informal channels, particularly using direct phone calls and on-site visits.
The procurement relation with INFN had an impact on three main intermediate outcomes of company *B*: learning, innovation and market penetration. First, the interviewed reported that the direct meetings with INFN researchers, during which discussions about the specification of the products to be delivered took place, favoured the acquisition of new technical knowledge. This, in turn, allowed the generation of innovation outcomes, which came from the improvement of existing products. According to the interviewed, the company technological growth would have been lower and not so fast as it was without collaboration with the INFN. The collaboration also favoured company B market penetration, by enhancing its reputation.
The improvement in these three intermediate outcomes has led to company B business development, while the recognized impact on revenues is limited.

*Case C.* Company *C* is a medium-size company whose business includes computation, data storage, and digital networking. It collaborated with different experiments carried out by the INFN (e.g. ATLAS, "A Toroidal LHC ApparatuS" and CMS, "Compact Muon Solenoid"), providing both customized and newly developed products in the field of high-performance computing systems. Therefore, the collaboration between company *C* and INFN can be classified as a PPI-like relationship.
Such a relationship lasts since company *C* incorporation and has continued until nowadays, through systematic and frequent personal contacts and in-loco visits to understand which are the technological requirements needed by INFN and how to face the challenges posed by the development of new products or customization of existing ones.
The collaboration with INFN produced several impacts on the intermediate outcomes of company *C*. The frequent and direct contacts with INFN researchers favoured the generation of learning outcomes due to the transfer of technical knowledge, in particular in the field of high-performance computing systems. This had an impact on company *C* innovation output thanks to the improvement in its products technological content.
The impact on network and market penetration outcomes was also remarkable: company *C* reputation improved since the collaboration with INFN acted as leverage for the rapid growth of the company image. This, together with the new competencies gained during the collaboration with INFN, allowed company *C* to enter the market of research, acquiring new clients and starting partnerships with other research centers like CERN, CNR (Consiglio Nazionale delle Ricerche), and INGV (Istituto Nazionale di Geofisica e Vulcanologia). Second, the development of new products allowed the company to increase its market shares

and to enter new markets, through a process that the interviewed defined "*from the research market to the enterprises*".
The positive effect on company *C* intermediate outputs affected also its final outcomes. As a consequence of the company's technological growth, the personnel employed in R&D activities rose. Regarding this aspect, the interviewed also affirmed that working in collaboration with INFN researchers improved company awareness of the importance of investing in R&D and led to better quality and managerial practices of the company's R&D processes.
Lastly, the acquisition of new clients, especially in the market of research, boosted company *C* revenues.

*Case D.* Company *D* is a medium size company which currently has a quite differentiated products' portfolio, including high-vacuum chambers, magnets, beamlines, current leads, and synchrotrons. Specifically, the procurement contracts signed with the INFN concerned the provision of high-vacuum chambers and magnets.
The procurement relation can be classified as PPI: in almost all of the orders delivered the company had to customize already existing products to meet the demanding technical requirements of INFN.
The collaboration with INFN is long-lasting and, after a tender is won by the company, the contacts between the two parties are frequent (once a week) and systematic. Specifically, contacts generally exploit informal channels, like phone calls and meetings.
The collaboration with the INFN produced several benefits to company *D* intermediate outcomes. As far as the learning and innovation outcomes are concerned, the relationship with INFN researchers favoured the acquisition of technical knowledge. This occurred thanks to the frequent meetings with researchers, used to discuss the technical requirements needed to customize products. The process of customization allowed company *D* to improve the quality of its products and to enlarge the product portfolio, favouring its overall technological growth.
Company *D* experienced relevant benefits also in terms of market penetration. Before the beginning of the procurement relationship, company *D* mainly supplied the aeronautic and civil aviation industry. The technical knowledge acquired during the collaboration with the INFN allowed the company to enter a further collaboration with the CERN. From that moment on, company *D* has acquired new clients among the research centers (e.g. ENEA, "Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile") and definitely established itself in the research industry.
Moreover, company image and reputation improved: the interviewee affirms that being a supplier of INFN and other world-renowned research institutes like the CERN is recognized as a guarantee of company's products quality.
The improvement of intermediate outcomes has in turn affected all the final outcomes considered. The need to customize existing products to meet researchers' technological requirements forced company *D* to increase its R&D investments and activities. To date, five new employees devoted to R&D activities have been hired due to the collaboration with INFN.
The entry in the market of research, the enlargement of products' portfolio and the acquisition of new clients enhanced company *D* business development and generated a relevant economic impact in terms of increased sales volume. As reported by the interviewee, nowadays the sales to the research market are the main source of company revenues.

*Case E*. Company *E* is a large company that provides a wide range of products in the field of electronic components, connectors, cables, automation system, mechanical appliances, and information technology. Most of these products have been ordered directly by INFN researchers and were already available in the company's catalogue. Since no new product development nor products modification occurred, the procurement relationship between INFN and company E can be classified as "regular procurement".

The collaboration with INFN started more than 20 years ago and, although based on the purchase of "off-the-shelf" products, the contacts between the two parties are frequent and systematic. Contacts occur mainly through informal channels, typically personal meetings with INFN researchers.
The procurement relationship with INFN generated benefits mainly on a specific company intermediate outcome, that is market penetration: the improvement of the company reputation and "brand awareness" was indeed recognized by the interviewed as the most relevant impact. Moreover, the interviewed identified a positive impact on company organizational structure, in particular with respect to the communication channels with clients. In fact, to satisfy the tight delivery time required by INFN researchers, they created a web interface for direct contacts with INFN. Given the success of this organizational innovation, a similar web interface was implemented also for other clients with specific needs.

All in all, the evidence collected from the five case-studies suggests that companies engaged in a PPI-type relationship experienced benefits mainly in three intermediate outcomes: learning, innovation and market penetration. On the one hand, the development of new technological products commissioned by the INFN improves their technical know-how and often pushes companies to increase their R&D investments. On the other hand, being an INFN supplier act as a market reference, allowing to acquire new clients in the market for research. However, benefits are experienced also by companies involved in a RP relationship. Even if this kind of procurement does not imply the development of new products/services, technological transfer from the INFN may take place thanks to the close collaboration with INFN researchers and allows suppliers to improve their products. Market benefits, related to an improvement of company reputation, are recognized to be the most relevant impact by two out of the three RP suppliers interviewed. In a specific case, also organizational gains are experienced.
The advancement in the intermediate outcomes affects final outcomes: three out of five suppliers obtained a revenue increase while in two cases business development and rise in employment are experienced.
Table 5 below summarizes the key features and findings of the five case studies analysed.

**Table 5 – Overview of the selected case-studies**

| ID | Interviewed | Main products commercialized | Size | Type of Procurement | Technological maturity when collaboration started | Length and intensity of the collaboration | Main intermediate outcomes | Main final outcomes |
|---|---|---|---|---|---|---|---|---|
| *A* | Sales Engineer | Instruments for electronic measurement, cyber security | Medium | Regular procurement – high tech procurement | Advanced | More than 25 years - Systematic | Learning; Innovation; Market penetration | Revenue increase |
| *B* | Commercial Director | Electronic components and accessories, wiring, optoelectronics | Small | Regular procurement - high tech procurement | Medium | More than 30 years - Episodic | Learning; Innovation; Market penetration | Business development |
| *C* | Commercial Director | Server systems, storage, computing systems, and ethernet | Medium | PPI – high tech procurement | Low | More than 15 years - Systematic | Learning; Innovation; Market penetration; Network | Revenue increase; Employment |
| *D* | Business and Financial Manager | High-vacuum chambers, magnets, beamlines, current leads, synchrotrons | Medium | PPI – high tech procurement | Medium | More than 50 years - Systematic | Learning; Innovation; Market penetration | Revenue increase; Business development; Employment |
| *E* | Marketing and commercial manager | Mechanical components, measuring instruments | Big | Regular procurement – low tech procurement | Low | More than 20 years - Episodic | Market penetration | - |

## 7. Conclusions and policy implications

This paper provided new empirical evidence on the benefits that companies involved in a procurement relationship with government-funded science organizations may experience. Specifically, it aimed to shed light on the channels through which possible performance gains may arise.

The analysis was carried out using a mixed-method approach: three distinct but complementary methodologies were employed, combining quantitative and qualitative evidence. In the quantitative part econometric and Bayesian Network analyses were performed, based on the information collected through an online survey to suppliers and additional firm-level data extracted from online databases. The qualitative section used case-studies based on phone-call interviews to provide mode detailed evidence from five suppliers.

Both quantitative and qualitative results of our study suggested that companies benefited from the collaboration with a large-scale RI. Furthermore, our findings pointed out some of the mechanisms underlying this performance enhancement.

Increased revenues and business development are the final benefits for suppliers and are mediated by intermediate outcomes. Specifically, increased revenues are mediated by the development of new products and the acquisition of new clients, while business development is driven also by improved reputation and market knowledge.

Furthermore, procurement characteristics differently affect the mechanisms underlying companies performance gains. In the case of PPI technological learning is the main driver for business development: the collaboration with INFN and the effort to satisfy its requests allows companies to acquire new technical skills, that is used to customize existing products or develop new ones. In addition, companies experience market benefits from PPI. Specifically, they are more likely to enter the market of research and start collaborating with other research centres.

However, regular procurement could advantage companies as well. In particular, the relationship with INFN represents a reference and improves companies' image and reputation. Consequently, companies acquire new customers and increase their stream of revenues.

These results bring about some policy and managerial implications. At the policy level, our study provides further evidence on the role of PPI as a demand-side policy tool to foster companies' innovation, suggesting that policy incentives should be introduced to support the collaborations between firms and RIs. As pointed out in a previous study on the LHC (Florio et al., 2018), the positive impact of PPI on supplier companies seems to be particularly relevant in the case of Big Science centers, like the INFN, where experiments push technology beyond the existing frontier acting a learning environment for companies.

At the managerial level, our findings have implication both on internal and external accountability. Regarding internal accountability, they highlight the need to increase awareness about positive impacts of basic research on industrial partners to encourage public managers to develop procurement relationships and maximize its benefits. Concerning external accountability, at the light of government pressure towards measuring the impact of publicly funded research, our results suggest that public managers should divulge to external stakeholders information on the benefits/losses that companies have eventually experienced due to the procurement relationship.

## 8. Limitations of the study and future research avenues

The present work represents a first attempt to examine a novel topic in the field of PPI. Specifically, it aims to clarify the learning mechanisms triggered by a PPI relationship and their subsequent impact on firms' performance. Despite the novel contribution to this topic, some limitations should be acknowledged.

First of all, part of our analysis is based on the data collected through an online survey. Every survey of company managers provides some statistical evidence but is likely to be affected by self-selection as well as respondents' judgment and memory. Specifically, there might be sample selection issues due to the fact that only companies that experienced a very positive (or very negative) relationship with the INFN decided to answer the online survey. Moreover, some companies might have gone bankruptcy over time, hence are not included in the sample.

As already mentioned in Section 6.1 our econometric analysis is affected by some limitations: some intermediate outcomes are correlated with each other and simultaneity and reverse causality issues may arise. This problem is partly tackled by the subsequent Bayesian Network Analysis carried out in Section 6.2.

Another issue is related to the use of dummy variables in our regressions: while the use of dichotomous variables as answer options in the survey allowed to maximized the number of participants, there are statistical drawbacks related to the use of dummy variables instead of categorical or continuous ones (see Rucker et al., 2015). First, potentially useful variability is discarded and second, this loss of variability reduces the precision of in-sample and out-of-sample predictions. When categorical variables are summarized by a dichotomous one, there might be a reduction in statistical power, which increases the chance of both Type-I (false positive) and Type-II error (false negative).

Lastly, our study does not investigate the possible difficulties that companies might experience during the collaboration. Future research should analyse in depth the criticalities that may arise in a procurement relationship with a RI. In particular, for firms which did not experienced any gain, it would be relevant to understand which factors may have resulted in an obstacle. Organizational factors, the technological complexity of the order received, high investment costs that put under pressure suppliers financial constraints, the high degree of products' customization that prevents their exploitation in other markets, are possible explanations that deserve further investigation.

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## Appendix

## Table A1. The questionnaire sent to companies

| GENERAL INFORMATION (single choice questions) | |
|---|---|
| **Duration of relationship** | Year of beginning of the collaboration |
| **Intensity of relationship** | Episodic < 5 years |
| | Episodic > 5 years |
| | Systematic < 5 years |
| | Systematic > 5years |
| **Content of the order** | Low temperature and space |
| | Mechanics |
| | Specialized instrumentation |
| | Materials |
| | Customized electronics |
| | Logistic support to research |
| | General procurement |
| | Other |
| **Type of procurement relationship** | Regular procurement, i.e. purchase off-the-shelf products |
| | Innovative procurement (PPI), i.e. modification of existing off-the-shelf products and/or development (or co-development) of existing products |
| **Perception of INFN as a customer** | Specific partner |
| | As any other client |

| PROCUREMENT IMPACT (multiple choice questions) | |
|---|---|
| **Economic impact** | Increased sales volume |
| **Learning and innovation** | Patents |
| | New products or services |
| | Acquisition of new technical competencies |
| | Acquisition of new managerial competencies |
| | Improvement of market knowledge |
| **Relationship with the market** | Improvement in company's image and reputation |
| | Acquisition of new clients |
| | Entry in new markets |
| | Increased market share |
| | Reduction of time to market |
| **Alliances and network** | New partnerships |
| | New international collaborations |
| | Co-patenting |
| **Social impact** | New temporary hiring in relation to INFN activities and specifically:<br>– Temporary worker<br>– Scholarship<br>– Ph.D. students<br>– Apprenticeship<br>– Stage |
| | New permanent hiring in relation to INFN activities |
| | New types of activities (thanks to the collaboration of INFN) |
| | Start-up (thanks to the collaboration of INFN) |
| | Spin-off (thanks to the collaboration of INFN) |

**Table A2 – List of regressors**

| | Variable | Variable type | Description | Source |
|---|---|---|---|---|
| **Intermediate outcomes** | Acquisition of new technical competencies | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | Acquisition of new managerial competencies | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | Improvement of market knowledge | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | New products or services | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | New patents | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | Improvement in company's image and reputation | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | Acquisition of new clients | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | New partnerships | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | New international collaborations | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | Co-patenting | dichotomous | 1 if "yes", 0 if "no" | online survey |
| **Features of the procurement relationship** | Type of procurement | dichotomous | 1 if PPI, 0 if general procurement | online survey |
| | Duration | continuous | number of years | online survey |
| | Ongoing vs sporadic | dichotomous | 1 if "ongoing", 0 if "sporadic" | online survey |
| | INFN distinct partner | dichotomous | 1 if "yes", 0 if "no" | online survey |
| **Supplier characteristics** | Sector of activity | categorical | 1-9, according to NACE rev. 2 economic activities classification (1-digit level). 1=reference category | AIDA/Orbis |
| | Small firm | dichotomous | 1 if the AIDA/Orbis classification (based on total assets, operating revenues and number of employees) is "small firm"; 0 otherwise. Reference category. | AIDA/Orbis |
| | Medium-sized firm | dichotomous | 1 if the AIDA/Orbis classification is "medium-sized firm"; 0 otherwise | AIDA/Orbis |
| | Large or very large firm | dichotomous | 1 if the AIDA/Orbis classification is either "large firm" or "very large firm"; 0 otherwise | AIDA/Orbis |
| | Employees involved in R&D activities | dichotomous | 1 if "yes", 0 if "no" | online survey |
| | Intangible assets | continuous | amount of intangible assets in 2017 (mln euros) | AIDA/Orbis |
| **Geographical effects** | North | dichotomous | 1 if company is located in northern Italy, 0 otherwise | online survey |
| | Centre | dichotomous | 1 if company is located in center Italy, 0 otherwise | online survey |
| | South | dichotomous | 1 if company is located in central Italy, 0 otherwise. Reference category. | online survey |

**Table A3 – Intermediate outcomes correlation matrix**

| | New products or services | Improved market knowledge | New technical competencies | New managerial competencies | Improved image and reputation | New clients | New partnerships | New international collaborations |
|---|---|---|---|---|---|---|---|---|
| New products or services | 1 | | | | | | | |
| Improved market knowledge | 0.2482 | 1 | | | | | | |
| New technical competencies | 0.4310 | 0.2524 | 1 | | | | | |
| New managerial competencies | 0.5161 | 0.5062 | 0.3755 | 1 | | | | |
| Improved image and reputation | 0.3185 | 0.2244 | 0.3421 | 0.1722 | 1 | | | |
| New clients | 0.2302 | 0.2767 | 0.2867 | 0.2704 | 0.3270 | 1 | | |
| New partnerships | 0.3431 | 0.2463 | 0.4364 | 0.2101 | 0.3389 | 0.3559 | 1 | |
| New international collaborations | 0.1905 | 0.2635 | 0.3382 | 0.2961 | 0.1756 | 0.2227 | 0.3541 | 1 |