

Big science, learning, and innovation: evidence from CERN procurement

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Abstract

We study the way in which public procurement by big research infrastructures enhances suppliers’ performance. Using survey data on 669 CERN’s suppliers, we built a unique data set to analyze, through an ordered logit model and Bayesian networks, the determinants of suppliers’ sales, profits, and development activities. We find that collaborative relations between CERN and its suppliers improve suppliers’ performance and increase positive spillovers along the supply chain. This suggests that public procurement as a mission-oriented innovation policy should promote cooperative relations and not only market mechanisms.

JEL classification: O31, O33, O38, C11

1. Introduction

We are interested in studying the mechanisms through which technological procurement by government-funded science organizations can have an impact on learning, innovation, and, ultimately, performance in their supplier firms. Inquiry into these mechanisms is important for several reasons. The pursuit of an innovation-led economic growth requires mission-oriented innovation policies that co-shape and cocreate markets (Mazzucato, 2016; and in this issue; Lember et al., 2015). Such policies give an explicit catalytic role to governments and public organizations for providing the basis for private investments, including their ability to make bold demand-side policies to change consumption and investment behavior. As Mazzucato (2017: 16) points out, the public procurement is one of the key instrument of demand-oriented innovation policies that the public sector has used for the direct creation of markets, stimulating and promoting innovation and allowing new technologies to diffuse (Edler and Georghiou, 2007; Martin and Tang, 2007; Aschhoff and Sofka, 2009; Knutsson and Thomasson, 2014). Such purchases have historically occurred in a wide range of sectors such as defense, energy, health, and transport by national agencies (Anadon, 2012; Georghiou et al., 2014) and in basic research by national and supranational organizations (e.g., NASA and CERN) (Andersen and Åberg, 2017). Similarly, Edler and Georghiou (2007) underline that public procurement for

innovation (PPI, henceforth) can take different forms and, in general, is meant to stimulate innovation by shaping the demand environment and the economic landscape in which suppliers operate (Uyarra and Flanagan, 2010).

In fact, contracts with procuring organizations that require the development of non-routine technologies are likely to cause radical changes in suppliers' activities, challenging them to supply cutting-edge products (Perrow, 1967; Salter and Martin, 2001). In such a context, the firm may need to adjust organizational structure and production and develop technological solutions to meet the public procurer's request. PPI is thus likely to lead to radical innovations and lay the foundations for new markets, particularly in areas where market interest is suboptimal owing to high risk and uncertainty (Lember *et al.*, 2015; Mazzucato, 2016).

But how exactly does PPI affect a firm's performance? The evidence concerning its effectiveness is largely anecdotal, lacking a clear theoretical and empirical basis for understanding how public procurers actually influence firms' innovation capabilities and performance and the channels through which this creates spillovers in the market (Georghiou *et al.*, 2014; Åberg and Bengtson, 2015).

This article aims to fill that gap. We address the basis of the innovation procurement process by inquiring into what works and how. Our focus is on the mechanisms that explain how public procurers can support learning and innovation in their industrial partners and how these buyer–supplier relationships influence the latter's performance.

In this article we propose a conceptual framework rooted in the PPI literature on interaction modes between economic actors (i.e., public buyers and private suppliers) as fundamental drivers of innovation and firms' potential success (Rothwell, 1994; Lundvall, 1985; Swink *et al.*, 2007; Paulraj *et al.*, 2008; Williamson, 2008; Edquist and Zubala-Iturriagoitia, 2012; Edquist *et al.*, 2015; Sorenson, 2017). The literature on the procurement of science organizations that operate large-scale research infrastructures (RIs)¹ offers interesting insights on the way in which such centers act as risk takers, reducing suppliers' perceived risk in undertaking projects at the frontier of science (Unnervik, 2009); it underlines industrial knowledge spillovers generated in the economy through their procurement activity (Schmied, 1977; Bianchi-Streit *et al.*, 1984; Autio *et al.*, 2004; Nilsen and Anelli, 2016). Industrial suppliers benefit from demand-side learning and interactions with the research organizations, which, in turn, can strengthen their own performance. The benefits acquired by first-tier suppliers can then be transferred onward to other companies that are part of the supply network (Nordberg *et al.*, 2003; Science|Business, 2015).

The testing ground for our study is the European Organization for Nuclear Research (CERN), the world's leading laboratory for experimental particle physics. For our purposes, CERN offers an ideal case study. The convention that established CERN in 1954² laid down the main missions for the Organization. They are probing the fundamental structure of the Universe, bringing nations together through science by promoting contacts between scientists and interchange with other laboratories and institutes, and training the scientists of tomorrow through educational and training programs at many levels. The convention also states that CERN shall advance the frontier of technology and maximize the impact of the science, technology, and know-how that it produces on industry and the society as a whole (see also Lebrun and Taylor, 2017). The CERN Council is the highest authority of the Organization and sets the direction of CERN's missions. It controls CERN's activities in scientific, technical, and administrative matters. The Council appoints the Director-General, which manages the CERN Laboratory. Similarly to other mission-oriented organizations like DARPA (Defense Advanced Research Project Agency) or NASA in the United States, established in the post-World War II, CERN is an example of “big science deployed to meet big problems” (Ergas, 1987; see also European Commission, 2018: 4). In fact, several technologies developed for CERN have found applications in other sectors—from aerospace to medicine—and have addressed (grand) societal challenges in health, energy, environment, and other fields (Amaldi, 2015). Importantly, CERN is a “learning environment” for industrial supplier companies. Autio (2014) and Bianchi-Streit *et al.* (1984) show the Organization's impact on suppliers' capacity to develop new products, generate organizational innovation, and acquire technological and market learning. This is in line with Ergas (1987), who discusses how in the case of the United States, procurement practices of

- 1 Major examples of large-scale RIs are the International Space Station, the Square Kilometre Array (SKA), the Human Genome Project, and the last generations of large-scale particle accelerators. de Solla Price (1963) coined the term “Big Science” to describe the large-scale character and complexity (i.e., the technological and engineering challenges and the capital-intensive research projects) of modern science, in contrast to the old “Little Science.”
- 2 For details, see CERN's website <https://council.web.cern.ch/en/content/convention-establishment-european-organization-nuclear-research>

Department of Defense played important role in commercializing DARPA-supported developments (see also Bonvillian in this issue).

To answer our research questions, in 2017, we conducted an online survey addressed to CERN suppliers, building a unique database on the types of goods and services delivered by each firm, the type of relationship established with CERN, the variety of learning and performance benefits enjoyed, and the benefits to second-tier suppliers.

Initially, we test a set of research hypotheses with an ordered logit model to investigate the correlations of CERN suppliers' performance (sales, profits, and development activities) with determinants suggested by the PPI literature. Then, we use Bayesian network analysis (BN) (Pearl 2000; Ben-Gal 2007) for a more in-depth examination of the interlinks between the variables that explain suppliers' performance.

We contribute to the literature on PPI as a mission-oriented innovation instrument from at least three standpoints. First, we offer a work on an underresearched area in the economic literature on the impact of PPI at firm level, by disentangling some of the channels through which this effect may be produced and pointing out some interactions among them.

Second, we innovate methodologically both by constructing new indicators and by showing that multiple causal linkages between the procurement relations are better captured by combining BNs as a complement to standard econometric models, in line with the idea that the proper evaluation of public investments and their results "requires new methods, metrics and indicators" (Mazzucato, 2015: 9).

Third, we put "some more meat on the bones" of the question of governance structure. To the best of our knowledge, this is the only article that accords proper importance to the different governance structures and to their differential impact on suppliers' performance in a context of risky, uncertain, innovative, and transaction-specific mission-oriented investments.

We attain three main results.

1. In line with the predictions of transaction cost theory, recently revived by the Global Value Chains literature (Gereffi et al., 2005), our findings indicate that CERN's procurement has a significant impact on suppliers' performance when cooperative relations are in place, and a more modest impact in the case of arm's length market relations;
2. The benefits of Big Science procurement spillover to second-tier suppliers, creating more widespread impact on firms across the entire innovation supply chain;
3. The heterogeneity of firms does matter. The impact on the suppliers' performance depends critically on their absorptive capacity.

The rest of the article proceeds as follows. Section 2 briefly presents CERN's procurement practices and organization. Section 3 presents the conceptual model and our research hypotheses. Against the background outlined in Section 3, Section 4 describes the research design, the descriptive statistics of the survey responses, and the statistical approaches to processing them. The results are presented in Section 5. Section 6 concludes with a discussion of policy implications, caveats, and suggestions for future research.

2. CERN procurement practices and organization

CERN was founded in 1954 as one of the Europe's first Intergovernmental Organization with the mission, among others, of seeking and finding answers to questions about the universe and advancing the frontiers of technology, as previously underlined. The CERN is publicly funded by its member states according to a share of their gross domestic product. In turn, member states expect an industrial return in proportion to their own contribution. It follows that the fair distribution of the benefits of technological innovation between the member state is a relevant precondition for collaboration with CERN (Andersen and Åberg, 2017; Unnervik and Rossi, 2017).

CERN is entitled to establish its own internal rules necessary for its proper functioning, including the rules under which it purchases equipment and services (for a detailed description of the CERN procurement rules, see CERN website; Åberg and Bengtson, 2015). CERN's tendering procedures are selective, and they are, in principle, limited to firms established in the member states, with only a few exceptions (Unnervik and Rossi, 2017).

Depending on the size of the contract, procurement will either be handled through price enquiries (purchases between 10,000 CHF and 200,000 CHF price) or invitations to tender (purchases above 200,000 CHF). In both cases,

the contract is awarded to the bidder, which is evaluated as the most technically and financially qualified. CERN also checks whether the bid is not too large with respect to the bidders' turnover to avoid that firms depend too much on CERN projects. The financial criteria also require that the bid must not exceed the lowest bid by more than 20%.

In sum, transparency requirements and distributive justice among member states are likely to influence/restrict CERN's selection of firms. However, the interaction between CERN and the selected firms as well as the chosen governance mode opens up a room of maneuver, which is fully in the CERN's domain. As we shall see in Section 3.1, such a peculiar form of procurement is relevant in the formulation of our research hypotheses.

3. The conceptual framework: theoretical foundations and research hypotheses

Innovation is a complex process that takes time and is influenced by multiple factors (Dosi et al., 1988; Phillips et al., 2006; Håkansson et al., 2009). This complexity induces firms to interact with other organizations for knowledge exchange and technological learning, so that interactive learning becomes a fundamental driver of innovation (Lundvall, 1985, 1993, Rothwell, 1994; Edquist, 2011; Cano-Kollmann et al., 2017). Chesbrough (2003) defines open innovation as an intentional exchange of inflows and outflows of knowledge between a firm and external parties to accelerate the firm's internal innovation. Von Hippel (1986) observes that the users and suppliers were sometimes more important as functional sources of innovation than the product manufacturers themselves. Emphasizing the need for communication with the user side of innovations, Von Hippel introduced the term "lead-users," defined as "users whose present strong needs will become general in a market place months or years in the future" (Von Hippel, 1986: 791).

This line of argument implies not only that the development and diffusion of innovations through PPI depend on user-producer interaction in the procurement process (Mowery and Rosenberg, 1979; Newcombe, 1999) but also that science organizations, such as CERN, can be seen as "lead-users" acting as learning environments for suppliers, who often strive to meet the stringent technological specifications of the projects planned (Unnervik, 2009). Autio et al. (2004) argue that communication and interaction in the dyad consisting of big science and industry mainly take the form of technological learning by the latter from the former.

In the same vein, Edler and Georghiou (2007) discuss the rationales for the use of public procurement as an important innovation policy tool. Elaborating on a taxonomy of the different forms PPI can take, they highlight the advantage of "pre-commercial procurement" in terms of innovation generation. The pre-commercial procurement is defined as a procurement "that targets innovative products and services for which further R&D needs to be done" (Edler and Georghiou, 2007: 954). Such a procurement typology, by giving procurers plenty of freedom in deciding the interaction with supplier, as it is the case of CERN, enhances the potential to spur innovation at firms' level.

3.1 Relationships and governance structures

The most common way in which PPI has been seen as influencing innovation has been as a channel for the flow of information and interactions among economic actors (Nordberg et al., 2003; Edquist and Zubala-Iturriagoitia, 2012; Georghiou et al., 2014). The neo-institutional theory of the firm sees procurement as a form of outsourcing in a context of incomplete contracts aimed at minimizing transaction costs (Coase, 1937; Grossman and Hart, 1986; Williamson, 1975, 2008). The extent of the interchange of knowledge among companies varies considerably according to their mode of participation in the supply network and depends on the type of relations they entertain with other firms. The firms' own way of operating within the network is then embedded in the notion of governance structures of the supply network (Williamson, 1991), which determines bilateral dependency among the members of a supply network, the degree to which they interact and cooperate, and hence the possibility of mutual learning.

Williamson (2008: 10) indicates that the heterogeneous set of buyer-supplier relationships can be simplified into five main governance structures, i.e., *markets*, *credible (or modular)*, *benign (or relational)*, *muscular (or captive)*, and *hierarchy*³: as bilateral dependency is built up through transaction-specific investments, the efficient governance of contractual relations moves from simple market exchange to hybrid contracting (e.g., modular and captive),

3 Names in brackets are those formulated by Gereffi et al. (2005), who elaborate on Williamson (1991) and rename governance structures as market, modular, relational, captive, and hierarchy. In this article we adopt Gereffi et al. (2005) classification.

then to relational and finally to hierarchy (Williamson, 2008) to eliminate the risk of agents' opportunistic behavior. The hierarchical structure is characterized by vertical integration and fully in-house production. In the context of our study, we focus on the relationship between CERN and its supplier firms, and between these suppliers and other firms as subcontractors. That is, we leave aside the hierarchical mode of governance and focus on the others. In particular, we distinguish between market governance, relational governance, and hybrid governance.

- *Market governance* involves simple transactions that are not difficult to codify in contracts and where the central governance mechanism is price. Such transactions require little or no formal cooperation or dependency actors.
- *Relational governance* implies that buyer and supplier cooperate regularly to deal with complex information that is not easily transmitted or learned. This produces frequent interactions and knowledge sharing to remedy the incompleteness of contracts and flexibly deal with all possible contingencies. Relational governance consists of linkages that take time to build and that generate mutual reliance, so the costs and difficulties of switching to a new partner tend to be high.
- *Hybrid forms of governance* comprise modular and captive governance forms. Both are hybrid forms lying somewhere between market and relational governance, in which transactions may incorporate some degree of cooperation and knowledge exchange between the parties, depending on the complexity of the information to be exchanged. In this case linkages between the public procurer and suppliers are more substantial than in simple markets, but less than in relational governance.

Our hypothesis is that, in the context of large-scale RI procurement, these systems of governance between science organizations and supplier firms are shaped by the level of innovation in procurement orders and the money volume of the orders received by the suppliers. Innovativeness and the size of orders are mainly related to the CERN's core mission to study the basic constituents of matter. It asks for groundbreaking instruments that often do not exist in the market place and it falls to scientists themselves to develop "proof of concept," i.e., demonstrate the feasibility and functionality of much of the equipment they require and the validity of some constituent principles which such equipment is built on (Vuola and Boisot, 2011). Supplier firms are then contracted to manufacture the required instruments.

The level of innovation is a multifaceted construct, related to the notions of technological novelty and technological uncertainty. Technological novelty refers to the product's newness with respect to the supplying firms' competencies and to the worldwide state of the art. The level is a crucial element in relationship outcomes—it is expected to be positively associated with learning potential (Schmied, 1977, 1987; Autio et al., 2004; Autio, 2014). Technological uncertainty refers to the likelihood of the products' specifications being achieved. Both novelty and uncertainty play key roles in the willingness of parties to share knowledge and are expected to impact positively on the innovation capabilities of suppliers. In the case of CERN, for instance, the laboratory has often helped firms to develop new product lines by testing prototypes and taking the full responsibility of developing cutting-edge projects without any real project development and commercial risk for contracted firms. This proactive approach has both reduced the uncertainty surrounding the order (Unnervik, 2009) and provided an initial impetus to the firm's innovation capability. The size of the order (or the sum of the value of orders received by the same company) is also expected to shape the interaction modes between science public organizations and industrial suppliers (Åberg and Bengtson, 2015; Andersen and Åberg, 2017). This leads to our first research hypothesis⁴:

Hypothesis 1: The level of innovation and the value of orders shape the relationship between CERN and its suppliers. Specifically, the larger and the more innovative the order, the more likely the CERN and its suppliers are to establish relational governance as a remedy for contract incompleteness, agents' opportunism, and suboptimal investments on both sides.

- 4 In general, relational/hybrid governance mode is established for highly innovative PPI. However, exceptions exist, such as, for instance, the so-called blanket contracts issued by CERN. They run for a specified period of time and are usually used for the supply of standard products. One example can be found in Andersen and Åberg (2017: 355), who report the case of a blanket contract between CERN and the company Asea Brown Boveri (ABB). A relational governance was in place as the interaction between the parties was intense and cooperative. Although such interaction did not lead to significant innovation outcomes from the products point of view, the effect was significant in terms of know-how acquired by ABB.

3.2 Innovation and market outcomes

Potential outcomes accruing to suppliers from their relationships with science organizations are likely to vary considerably according to the governance structures. Following [Autio et al. \(2004\)](#) and [Bianchi-Streit et al. \(1984\)](#), we distinguish two categories of cooperation outcomes.

Innovation outcomes include both product and process innovations. The first ones relate to the development of new products, services and technologies, and changes in the technological status of the suppliers (e.g., the acquisition of patents or other forms of intellectual property rights, or IPRs). Process innovations relate to the acquisition of technical know-how, improvement in the quality of products and services, changes in production processes, organizational and management activities initiated thanks to the supply relationships.

Market penetration outcomes include both the direct acquisition of new customers and market benefits in terms of improved reputation, as the Big Science center acts as a marketing reference for the company.

The achievement of one or more of these outcomes by suppliers depends on the governance structure that shapes the RI–company dyad. For instance, high technological novelty and transaction-specific investments characterize highly structured types of governance (i.e., relational). Thus, we expect innovation outcomes to be associated with tighter interfirm linkages. By contrast, market-related outcomes are likely to accrue also to those companies that establish a less structured relationship with the science organization. In fact, [Autio et al. \(2004\)](#) and [Bianchi-Streit et al. \(1984\)](#) document that reputational benefits are likely to accrue simply from becoming the supplier of a world-renowned laboratory like CERN. In that case, firms exploit the science organization as a signal for other potential customers in the market. These leads to our second research hypothesis:

Hypothesis 2. The relational governance of procurement is positively related to innovation outcomes for the suppliers of large-scale science centers.

3.3 Supplier's performance

Governance structures are instrumental to innovation and market outcomes. These outcomes, which we call “intermediate,” impact, in turn, on suppliers' performance ([Bianchi-Streit et al., 1984](#); [Autio et al., 2004](#)). To investigate this specific aspect, we look at different performance variables: sales, profit dynamics, and business development (i.e., establishing a new R&D unit, starting a new business unit, and entering a new market).

[Nordberg et al. \(2003\)](#) and [Bianchi-Streit et al. \(1984\)](#) provide evidence that the rigorous technical requirements of large-scale RIs may lead firms to make significant changes in their production processes and activities, which may have adverse effects on their performance, in some extreme cases even resulting in bankruptcy. However, we argue that the effects of innovation and market penetration on economic performance (sales and/or profits) and development activities are expected to be generally positive. This is reflected in our third research hypothesis.

Hypothesis 3. Innovation and market penetration by the large-scale science centers' suppliers are likely to impact positively on their performance.

3.4 Governance structures and outcomes in second-tier suppliers

A few studies have shown that innovation and knowledge diffusion in the RI–industry dyad is not limited to first-tier suppliers but can spread throughout the entire supply network ([Nordberg et al., 2003](#); [Autio et al., 2004](#)). As in the case of first-tier suppliers, the extent to which second-tier suppliers benefit from innovation and market outcomes depends heavily on the governance structures they establish with the first-tier suppliers. We look at the outcomes for second-tier suppliers, such as increased technical know-how, product and process innovation, and market outcomes. Thus, we formulate our last hypothesis:

Hypothesis 4. In the case of relational governance of procurement, the innovation and market outcomes are not confined solely to first-tier suppliers but spread to second-tier suppliers as well.

Our research hypotheses finalize our conceptual model, which is shown in [Figure 1](#).

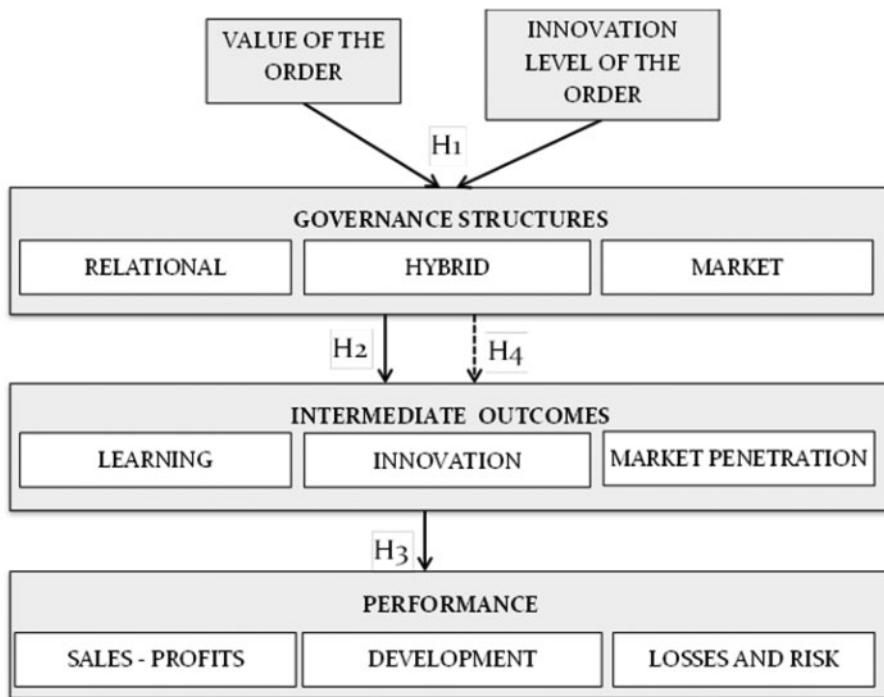


Figure 1. Conceptual model.

4. Research design, descriptive statistics, and methods

4.1 The survey

To test our hypotheses, we developed a broad online survey addressed to CERN's supplier companies, conducted between February and July 2017. CERN granted us access to its procurement database, producing a list of the suppliers that received at least one order larger than EUR 6100⁵ between 1995 and 2015. The database counts some 4200 suppliers from 47 countries and a total of about 33,500 orders for EUR 3 billion. About 60% of the firms (2500) had a valid e-mail contact at the time of the survey.

Following our conceptual model, we structured the online questionnaire in three sections, bearing, respectively, on: (i) the relationship between the respondent supplier and CERN; (ii) the impact of CERN's procurement on the supplier's performance as perceived by the supplier; (iii) the relationship between the firm and its subcontractors. We used both closed-ended questions and five-point Likert scale questions to enable companies to say how much they agreed or disagreed with every statement.

Respondents numbered 669, or 25% of the target population (i.e., companies with an e-mail contact). This response rate can be considered satisfactory for this kind of survey and is of comparable size to similar previous surveys (Bianchi-Streit et al., 1984; Autio et al., 2003).

In the survey, we did not include questions related to negotiations and interactions between CERN and suppliers that might have taken place before the signing of the contract. However, we did include in the survey and both in the logit and the BN quantitative analyses questions/variables (see Table 3) that capture, to a certain extent, pretending interactions.

4.2 Descriptive statistics

The survey produced responses from 669 suppliers in 33 countries, mainly from Switzerland (27%), France (20%), Germany (14%), Italy (8%), the UK (7%), and Spain (5%).

5 Like similar previous studies (Schmied, 1977; Bianchi-Streit et al., 1984), ours excludes the smallest orders. This threshold, corresponding to CHF 10,000, was agreed with CERN procurement office.

Table 1. Innovation level of products delivered to CERN⁸

Innovation level of products and services	N
Products and services with significant customization or requiring technological development	331
Mostly off-the-shelf products and services with some customization	239
Advanced commercial off-the-shelf or advanced standard products and services	172
Cutting-edge products/services requiring R&D or codesign involving the CERN staff	158
Commercial off-the-shelf and standard products and/or services	110

Table 2. Governance structure

Governance structure	N	%
During the relationship with CERN, we carried out the project(s) on the basis of: the specifications provided, but with additional inputs (clarifications and cooperation on some activities) from CERN staff	349	52
The specifications provided with full autonomy and little interaction with CERN staff	181	28
Frequent and intense interactions with CERN staff	133	20

Table 3. Specific aspects of the supply relationship

Question	N	Mean	% of suppliers that agree or strongly agree
During the relationship with CERN . . .			
We were given access to CERN laboratories and facilities	668	3.18	43
We always knew whom to contact in CERN to obtain additional information	669	4.24	86
We always understood what CERN staff required us to deliver	669	4.21	87
CERN staff always understood what we communicated to them	669	4.19	87
During unexpected situations, CERN and our company dialogued to reach a solution without insisting on contractual clauses	668	3.91	68

Note: Scale: 1 = strongly disagree; 5 = strongly agree.

Respondent firms are mainly medium-sized and small companies (43% and 26%, respectively). Large companies made up 23% of the sample and very large companies the remaining 8%.⁶ On average, each supplier processed 12 orders (standard deviation = 36) and received EUR 63,000 per order (standard deviation = EUR 126,000). Before becoming a CERN supplier, 45% of the respondents stated that they had had previous experience in working with large laboratories such as CERN.

The sample includes firms that supplied a highly diversified range of products and services to CERN, from off-the-shelf and standard commercial products to highly innovative, cutting-edge products and services (Table 1). In the delivery of the procurement order, 52% received some additional inputs from CERN staff, besides the order specifications, and 20% engaged in frequent cooperation with CERN (Table 2).

To examine the relationship between CERN and its suppliers more closely, we asked about specific aspects of their mode of interaction (Table 3).

6 The size of the respondent firms is taken from the Orbis database. Very large firms are those that meet at least one of the following conditions: Operating revenue \geq EUR 100 million; Total assets \geq EUR 200 million; and Employees \geq 1000. Large companies: Operating revenue \geq EUR 10 million; Total assets \geq EUR 20 million; and Employees \geq 150. Medium-sized companies: Operating revenue \geq EUR 1 million; Total assets \geq EUR 2 million; and Employees \geq 15. Small companies are those that do not meet any of the above criteria. Orbis data on size were missing for 34 supplier companies in our sample, but we retrieved the size of 25 from their websites. The size of the remaining nine companies is missing.

Table 4. Innovation outcomes and economic performance

Question	N	Mean	% of suppliers that agree or strongly agree
Process innovation			
Thanks to CERN, supplier firms . . .			
Acquired new knowledge about market needs and trends	668	3.19	35
Improved technical know-how	668	3.54	55
Improved the quality of products and services	669	3.41	48
Improved production processes	669	3.14	31
Improved R&D production capabilities	669	3.19	34
Improved management/organizational capabilities	669	3.12	28
Product innovation			
Because of the work with CERN, supplier firms developed:			
New products	282		
New services	203		
New technologies	138		
New patents, copyrights, or other IPRs	22		
None of the above	65		
Market penetration			
Because of the work with CERN, supplier firms . . .			
Used CERN as important marketing reference	669	3.61	62
Improved credibility as supplier	669	3.68	62
Acquired new customers—firms in own country	669	2.73	23
Acquired new customers—firms in other countries	666	2.69	23
Acquired new customers—research centers and facilities like CERN	668	2.66	24
Acquired new customers—other large-scale research centers	669	2.49	14
Acquired new customers—smaller research institutes/universities	669	2.71	22
Performance			
Because of the work with CERN, supplier firms . . .			
Increased total sales (excluding CERN)	669	2.63	18
Reduced production costs	669	2.30	3
Increased overall profitability	668	2.51	12
Established a new R&D team/unit	669	2.22	6
Started a new business unit	669	2.14	6
Entered a new market	669	2.46	16
Experienced some financial loss	669	2.04	7
Faced risk of bankruptcy	339	1.56	1

Note: Scale: 1 = strongly disagree; 5 = strongly agree.

Suppliers were asked about the impact that the procurement relationship with CERN had on their company (Table 4). In terms of process innovations, 55% said that thanks to the relationship, they had increased their technical know-how; 48% reported that they had improved products and services. Product innovations were achieved because of new knowledge acquired; 282 firms stated they had managed to develop new products; new services or new technologies were introduced, respectively, by 203 and 138 suppliers.⁷

7 For this question, respondents could select up to two options. A total of 710 responses were received. We test the networks upon different sets of variables, and we alternatively included the original variables in the questionnaire or more complex constructs summarizing one or more of the original variables. Further tests, where control variables were alternatively included or were not, were also performed. These checks show that the main relations, presented in the BNs, remain stable enough.

Table 5. Innovation level of products and governance structure within the second-tier relationship

Question	N	%
Innovation level of products and services		
Mostly off-the-shelf products and services with some customization	80	31
Significant customization or requiring technological development	44	20
Advanced commercial off-the-shelf or advanced standard products and services	40	16
Commercial off-the-shelf and standard products and/or services	32	13
Cutting-edge products/services requiring R&D or co-design involving the CERN staff	8	3
Mix of the above	52	20
Total	256	100
Governance structure		
Our subcontractors processed the order(s) on the basis of . . .		
Our specifications, but with additional inputs (clarifications and cooperation on some activities) from our company	119	46
Our specifications with full autonomy and little interaction with our company	87	34
Frequent and intense interactions with our company	50	20
Total	256	100

Table 6. Benefits for second-tier suppliers as perceived by first-tier suppliers

Question	N	Mean	% of suppliers that agree or strongly agree
To what extent do you think that your subcontractors benefitted from working with your company on CERN project(s)? Our subcontractors . . .			
Increased technical know-how	256	3.14	37
Innovated products or processes	256	2.91	23
Improved production process	256	2.89	18
Attracted new customers	256	2.89	21

The responses on market penetration outcomes reveal that 62% of firms used CERN as a marketing reference and declared that they improved their reputation as suppliers. Around 20% of the firms declared they had gained new customers of different types.

In line with our hypotheses, we expected an improvement of suppliers' performance thanks to the work carried out for CERN. And in fact, 18% of firms reported that they increased sales in other markets (i.e., apart from sales to CERN). Most of firms interviewed experienced no financial loss and did not face risk of bankruptcy because of CERN procurement.

Table 5 and Table 6 report responses related to the relationship between the respondent firms (first-tier suppliers) and their subcontractors (second-tier suppliers), focusing on the type of benefits accruing to the latter.

More specifically, firms were asked whether they had mobilized any subcontractor to carry out the CERN project(s), and, if so, to list the number of subcontractors and their countries as well as the way in which the subcontractors were selected. In all, 256 firms (38%) mobilized about 500 subcontractors (averaging two per firm) in 26 countries. Good reputation, trust developed during previous projects, and geographic proximity were the most commonly reported means of selection of these partners. The remaining 413 firms (62%) did not mobilize any subcontractor, mainly because they already had the necessary competencies in-house.

The types of product provided by subcontractors to the firms interviewed are listed in Table 5 under the label "Innovation level of products and services." For instance, 80 firms (31%) declared that their subcontractors supplied them with mostly off-the-shelf products and services with some customization; only 3% said that they had supplied cutting-edge products and services.

As regards the governance structure between first-tier and second-tier suppliers, 46% of the firms gave their subcontractors additional inputs beyond the basic specifications, such as clarifications or cooperation on some activities; 34% said that the subcontractors operated with full autonomy, while 20% established frequent and intense interactions with their subcontractors.

According to the perception of, respectively, 37% and 23% of the supplier firms, subcontractors may have increased their technical know-how or innovated their own products and services, thanks to the work carried out in relation to the CERN order (Table 6).

4.3 The empirical investigation

The data were processed by two different approaches. The first was standard ordered logistic models, with suppliers' performance, variously measured, as the dependent variable. The aim was to determine correlations between suppliers' performance and some of the possible determinants suggested by the PPI literature. Second was a BN analysis to study more thoroughly the mechanisms within the science organization or RI-industry dyad that could potentially lead to a better performance of suppliers.

BNs are probabilistic graphical models that estimate a joint probability distribution over a set of random variables entering in a network (Ben-Gal, 2007; Salini and Kenett, 2009). BNs are increasingly gaining currency in the socio-economic disciplines (Ruiz-Ruano García et al., 2014; Cugnata et al., 2017; Florio et al., 2017; Sirtori et al., 2017). By estimating the conditional probabilistic distribution among variables and arranging them in a directed acyclic graph (DAG), BNs are both mathematically rigorous and intuitively understandable. They enable an effective representation of the whole set of interdependencies among the random variables without distinguishing dependent and independent ones. If target variables are selected, BNs are suitable to explore the chain of mechanisms by which effects are generated (in our case, CERN suppliers' performance) producing results that can significantly enrich the ordered logit models (Pearl, 2000).

4.4 Variables

We pretreated the survey responses to obtain the variables that were entered into the statistical analysis, in line with our conceptual framework (see the full list in Table 7). The type of procurement order was characterized by the following variables:

- *High-tech supplier* is a binary variable, taking the value of 1 for high-tech suppliers, i.e., those companies that in the survey reported having supplied CERN with products and services with significant customization or requiring technological development, or cutting-edge products/services requiring R&D or codesign involving the CERN staff.
- *Second-tier high-tech supplier*. We apply the same methodology as for the first-tier suppliers.
- *EUR per order* is the average value (in euro) of the orders the supplier company received from CERN. This continuous variable was discretized to be used in the BN analysis. It takes the value 1 if it is above the mean (EUR 63,000) and 0 otherwise.

Two types of variable were constructed to measure the governance structures. One is a set of binary variables distinguishing between the *Market*, *Hybrid*, and *Relational* modes of interaction. The second is a more complex construct that we call *Governance*.

- *Market* is a binary variable taking the value 1 if suppliers processed CERN orders with full autonomy and little interaction with CERN, and 0 otherwise. The same codification was used for the second-tier relationship (*second-tier market*).
- *Hybrid* is a binary variable taking the value 1 if suppliers processed CERN orders based on specifications provided but with additional inputs (clarifications, cooperation on some activities) from CERN staff and 0 otherwise. The same codification was used in the second-tier relationship (*second-tier hybrid*).
- *Relational* is a binary variable taking the value 1 if suppliers processed CERN orders with frequent and intense interaction with CERN staff and 0 otherwise. The same codification was used in the second-tier relationship (*second-tier relational*).
- *Governance* was constructed by combining the five items reported in Table 3. Each was transformed into a binary variable by assigning the value of 1 if the respondent firm agreed or strongly agreed with the statement and 0 otherwise. Then, following Cano-Kollmann et al. (2017), the *Governance* variable was obtained as the sum

Table 7. Econometric analysis: list of variables

Variable	N	Mean	Minimum	Maximum
<i>EUR per order</i> ***	669	0.34	0	1
<i>High-tech supplier</i>	669	0.58	0	1
Governance structures				
<i>Market</i> ***	669	0.27	0	1
<i>Hybrid</i>	669	0.53	0	1
<i>Relational</i> ***	669	0.20	0	1
<i>Governance</i> **	669	3.72	0	5
Intermediate outcomes				
<i>Process Innovation</i> ***	669	2.30	0	6
<i>Product Innovation</i>				
<i>New products</i> ***	669	0.54	0	1
<i>New services</i> ***	669	0.39	0	1
<i>New technologies</i> ***	669	0.27	0	1
<i>New patents-other IPR</i> ***	669	0.04	0	1
<i>Market penetration</i>				
<i>Market reference</i> ***	669	1.23	0	2
<i>New customers</i> **	669	1.05	0	5
Performance				
<i>Sales-profits</i> **	669	0.33	0	3
<i>Development</i> ***	669	0.28	0	3
<i>Losses and risk</i> *	669	0.06	0	1
Second-tier relation variables				
<i>Second-tier high-tech supplier</i>	256	0.37	0	1
Governance structures				
<i>Second-tier market</i> *	256	0.20	0	1
<i>Second-tier hybrid</i>	256	0.46	0	1
<i>Second-tier relational</i> *	256	0.34	0	1
<i>Second-tier benefits</i> *	256	3.14	1	4
<i>Geo-proximity</i>	256	0.48	0	1
Control variables				
<i>Relationship duration</i> **	669	0.30	0	1
<i>Time since last order</i>	669	0.20	0	1
<i>Experience with large labs</i> **	669	0.70	0	1
<i>Experience with universities</i> *	669	0.85	0	1
<i>Experience with nonscience</i>	669	0.96	0	1
<i>Firm's size</i>	669	1.83	1	4
<i>Country</i>	669	2.03	1	3

Note: Asterisks denote statistical differences in the distribution of variables between high-tech and low-tech suppliers. *** $P < 0.01$; ** $P < 0.05$; * $P < 0.10$. Depending on the distribution of variables, both Pearson's χ^2 test and Fisher's exact test were used.

of the five binary items (its value accordingly ranging from 0 to 5). We test the internal reliability of this variable by using Cronbach's alpha, which worked out to 0.74, hence above the commonly accepted threshold value of 0.7 (Tavakol and Dennick, 2011), indicating a high degree of internal reliability that the items examined are actually measuring the same underlying concepts. Thus, the higher the value of this variable, the more the interaction mode between suppliers and CERN approximates a relational-type governance structure.

Intermediate outcomes are captured by the following variables (Table 4):

- *Process innovation*. Each of the six items in this category of outcomes was transformed into a binary variable, and then combined into a variable obtained as the sum of the six binary items, ranging in value from 0 to 6 (alpha = 0.90).

- *Product innovation*. This was measured by four binary variables taking the value 1 if the respondent ticked the corresponding option (new products, new services, new technologies, new patents, or other IPRs) and 0 otherwise.
- *Market penetration* is measured by two variables:
 - *Market reference*, defined as the sum of two binary items, hence ranging in value from 0 to 2 ($\alpha = 0.78$). The items were “used CERN as an important marketing reference” and “improved credibility as a supplier.”
 - *New customers*. Like learning outcomes, this variable was constructed as the sum of five binary items, hence ranging in value for 0 to 5 ($\alpha = 0.88$). The items were “new customers in our country,” “new customers in other countries,” “research centres similar to CERN,” “other large-scale research centres,” and “other smaller research institutes.”

Suppliers’ performance was measured by the following variables (Table 4):

- *Sales–profits* is the sum of three binary items: “increased sales,” “reduced production costs,” and “increased overall profitability” ($\alpha = 0.84$). Its value ranges from 0 to 3 and measures suppliers’ performance in terms of financial results.
- *Development* is the sum of three binary items: “Established a new R&D team/unit,” “Started a new business,” and “Entered a new market” ($\alpha = 0.86$). Ranging in value from 0 to 3, this variable measures suppliers’ performance from the standpoint of development activities relating to a longer-term perspective than sales–profits.
- *Losses and risk* is a binary variable taking the value 1 if the firm agreed or strongly agreed with the statement “experienced some financial losses” and 0 otherwise.
- *Second-tier benefits* is a variable constructed as the sum of four binary items ($\alpha = 0.89$) and thus ranges in value from 0 to 4. It captures outcomes within second-tier suppliers (Table 6).

We control for several variables that may play a role in the relationship between the governance structures and the suppliers’ performance.

- *Firm’s size* is coded as 1 if the supplier is small, 2 if medium-sized; 3 if large, and 4 if very large.
- *Previous experience*. This is measured by three binary variables, whose value is 1 if the supplier ticked the corresponding option and 0 otherwise. The options were related to previous working experience with:
 - large laboratories similar to CERN (*experience with large labs*);
 - research institutions and universities (*experience with universities*); and
 - non-science-related customers (*experience with non-science*);
- *Relationship duration* is calculated as the difference between the years of the supplier’s last and first orders from CERN. It takes the value 1 if it is above the mean (5 years) and 0 otherwise.
- *Time since last order* is calculated as the difference between the year of the survey (2017) and the year in which the supplier received its last order. It takes the value 1 if it is above the mean (4 years) and 0 otherwise.
- *Geo-proximity* is a binary variable measuring whether the supplier selected its subcontractors based on geographical proximity.
- *Country* is coded 1 if the supplier is located in a very poorly balanced country, 2 if the country is poorly balanced, and 3 if it is well balanced. According to CERN’s definition, a “well-balanced” member state is one that achieves “well balanced industrial return coefficients.” The return coefficient is the ratio between the member state’s percentage share of procurement and the percentage share of its contribution to the budget. Receiving contracts above this ratio means being well balanced; below, the country is defined as poorly balanced. CERN’s procurement rules tend to favor firms from poorly balanced countries over those in well-balanced countries.

5. The results

5.1 Ordered logistic models

We used ordered logistic models to analyze correlations between CERN suppliers’ performance and a set of determinant variables indicated by the PPI literature. Specifically, we looked at the impact of different governance

Table 8. Ordered logistic estimates

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Governance structures							
<i>Relational</i>	1.17 (0.27)***	0.96 (0.29)***	0.38 (0.36)	0.40 (0.39)			
<i>Hybrid</i>	0.61 (0.24)**	0.43 (0.25)*	0.13 (0.31)	0.08 (0.33)			
<i>Governance</i>					0.44 (0.10)***	-0.06 (0.28)	-0.14 (0.29)
<i>Access to CERN labs and facilities</i>		0.43 (0.18)**	-0.09 (0.22)	0.07 (0.24)		0.02 (0.38)	0.27 (0.41)
<i>Knowing whom to contact in CERN to get additional information</i>		0.27 (0.32)	0.69 (0.43)	0.73 (0.46)		0.75 (0.48)	0.88 (0.51)
<i>Understanding CERN requests by the firm</i>		0.33 (0.42)	-0.30 (0.47)	-0.27 (0.49)		-0.26 (0.55)	-0.14 (0.59)
<i>Understanding firm requests by CERN staff</i>		0.27 (0.39)	0.26 (0.48)	0.32 (0.50)		0.32 (0.61)	0.47 (0.63)
<i>Collaboration between CERN and firm to face unexpected situations</i>		0.47 (0.21)**	-0.09 (0.28)	-0.17 (0.30)		-----	-----
Intermediate outcomes							
<i>Process innovation</i>			0.14 (0.06)**	0.11 (0.06)*		0.15(0.06)**	0.11(0.06)*
<i>Product innovation</i>							
<i>New products</i>			0.57 (0.28)**	0.65 (0.28)**		0.55 (0.27)**	0.63 (0.28)**
<i>New services</i>			0.67 (0.27)**	0.60 (0.28)**		0.69 (0.27)**	0.62 (0.27)**
<i>New technologies</i>			-0.01(0.28)	0.006 (0.29)		0.00 (0.27)	0.02 (0.27)
<i>New patents-other IPR</i>			0.77 (0.40)*	0.86 (0.50)*		0.83 (0.50)*	0.93 (0.50)*
Market penetration							
<i>Market reference</i>			0.49 (0.19)**	0.58(0.21)***		0.50 (0.19)***	0.59 (0.21)***
<i>New customers</i>			0.50 (0.07)***	0.50 (0.07)***		0.50(0.07)***	0.49 (0.07)***
<i>Euro per order</i>				0.07 (0.12)			0.07 (0.12)
<i>High-tech supplier</i>				-0.04 (0.27)			0.02 (0.26)
Control variables							
<i>Relationship duration</i>				-0.02 (0.02)			-0.02 (0.02)
<i>Time since last order</i>				0.02 (0.02)			0.02(0.02)
<i>Experience with large labs</i>				0.13 (0.27)			0.17 (0.27)
<i>Experience with universities</i>				-0.21 (0.37)			-0.21 (0.37)
<i>Experience with nonscience</i>				0.15 (0.75)			0.13 (0.76)
<i>Firm's size</i>				-0.01 (0.13)			-0.02(0.12)
<i>Country</i>				-0.20 (0.12)			-0.19 (0.11)
Constants	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	669	668	668	660	669	668	660
Pseudo R ²	0.02	0.04	0.20	0.21	0.03	0.20	0.21
Proportional odds HP test (P-value)	0.911	0.294	0.220	0.02	0.285	0.123	0.00

Note: Dependent variable: *Sales-profits*. Robust standard errors in parenthesis. ***, **, and * denote significance at the 1%, 5% 10% level, respectively. HP, hypothesis.

Table 9. Ordered logistic estimates

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Governance structures							
<i>Relational</i>	1.53 (0.29)**	1.33 (0.30)**	0.92 (0.35)**	0.93 (0.40)**			
<i>Hybrid</i>	0.62 (0.27)**	0.46 (0.28)*	0.17 (0.33)	0.14 (0.35)			
<i>Governance</i>					0.30 (0.09)**	-0.28 (0.30)	-0.26 (0.31)
<i>Access to CERN labs and facilities</i>		0.46 (0.20)**	-0.35 (0.26)	-0.25 (0.28)		0.04 (0.41)	0.13 (0.42)
<i>Knowing whom to contact in CERN to get additional information</i>		0.61 (0.41)	0.86 (0.48)*	0.92 (0.56)		1.01 (0.65)	1.11 (0.65)
<i>Understanding CERN requests by the firm</i>		-0.19(0.42)	-0.46 (0.48)	-0.33 (0.56)		-0.19 (0.54)	-0.06 (0.64)
<i>Understanding firm requests by CERN staff</i>		0.12 (0.43)	-0.05 (0.49)	-0.04(0.57)		0.27 (0.60)	0.27 (0.66)
<i>Collaboration between CERN and firm to face unexpected situations</i>		0.39 (0.21)*	-0.31 (0.30)	-0.30 (0.31)		-----	-----
Intermediate outcomes							
<i>Process innovation</i>			0.36 (0.07)**	0.33 (0.07)**		0.36 (0.07)**	0.32 (0.07)**
<i>Product innovation</i>							
<i>New products</i>			-0.01 (0.27)	-0.05 (0.29)		-0.07 (0.27)	-0.03 (0.28)
<i>New services</i>			0.60 (0.28)**	0.68 (0.29)**		0.57 (0.27)**	0.68 (0.28)**
<i>New technologies</i>			0.08 (0.29)	0.10 (0.30)		0.16 (0.28)	0.16 (0.28)
<i>New patents-other IPR</i>			1.02 (0.48)**	1.00 (0.53)**		1.20 (0.49)**	1.19 (0.50)**
<i>Market penetration</i>							
<i>Market reference</i>			0.53 (0.21)**	0.47 (0.21)**		0.60 (0.21)**	0.54 (0.21)**
<i>New customers</i>			0.19 (0.08)**	0.20 (0.08)**		0.18 (0.08)**	0.18 (0.08)**
<i>Euro per order</i>				0.09 (0.12)			0.07 (0.12)
<i>High-tech supplier</i>				0.00 (0.28)			0.12 (0.27)
Control variables							
<i>Relationship duration</i>				-0.04 (0.02)			-0.04 (0.02)
<i>Time since last order</i>				-0.03 (0.03)			0.03 (0.03)
<i>Experience with large labs</i>				0.20 (0.29)			0.20 (0.29)
<i>Experience with universities</i>				-1.00 (0.34)**			-0.98 (0.35)
<i>Experience with nonscience</i>				0.14 (0.64)			0.13 (0.63)
<i>Firm's size</i>				0.18 (0.13)			0.20 (0.11)*
<i>Country</i>				-0.21 (0.13)			-0.21(0.12)*
Constants	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	669	668	668	660	669	668	660
Pseudo R²	0.03	0.04	0.18	0.20	0.01	0.16	0.18
Proportional odds HP test (P-value)	0.931	0.235	0.217	0.020	0.431	0.601	0.003

Note: Dependent variable: *Development*. Robust standard errors in parenthesis. ***, **, and * denote significance at the 1%, 5%, 10% level, respectively. HP, hypothesis.

structures on the performance of first-tier suppliers, controlling for their innovation and market penetration outcomes and other order-specific and firm-specific variables. Table 8 and Table 9 report estimates of these regressions with *Sales–profits* and *Development* as dependent variables.

As Column 1 in Table 8 shows, by comparison with the market interaction modes, the relational and hybrid structures of governance are positively and significantly correlated with the probability of increasing sales and/or profits. These variables remain statistically significant also when the model is extended to include some specific aspects of the CERN–supplier relationship (Column 2). Given the structure of governance, a collaborative relationship between CERN and its suppliers in unexpected situations, enabling suppliers to access CERN labs and facilities, increases the probability of improving suppliers' economic results. Controlling for innovation and market penetration outcomes (Column 3), we find that the governance structures lose their statistical significance, while improvements in sales and/or profits are more likely to occur where there are innovative activities (such as new products, services, and patents). Moreover, the strong significance ($P_{\text{ign.01}}$) of *Market reference* and *New customers* indicates that better economic results stem from the ability to exploit CERN as a “door opener” in the market. The role of these intermediate outcomes is confirmed even when other control variables are added (Column 4). These results still hold when the binary governance structure variables are replaced by the *Governance* construct (Columns 5–7).

In Table 9, the dependent variable is *Development*. These estimates confirm the foregoing results with two differences. One is the very important role of *Process innovation* for developmental activities ($P_{\text{cti.01}}$); the second is the effect of firm size: the larger the supplier, the greater the probability of establishing a new R&D team, new business, or entering new markets ($P_{\text{ark.10}}$).

The ordered logistic models provide interesting insights into the variables that affect suppliers' performance. In particular, they show that innovation and market penetration outcomes are crucial in explaining the probability of increases in sales, reductions in costs, greater profitability, or more developmental activities in CERN suppliers.

5.2 BN analysis

To shed light on all the possible interlinkages between variables and look more deeply into the role of governance structures in determining suppliers' performance, we use BN analysis, which makes it possible to visualize and estimate all direct and indirect interdependencies among the set of variables considered, including those relating to the second-tier suppliers. We test the four hypotheses that underlie our conceptual framework and seek to disentangle the specific roles played by governance structures, intermediate outcomes, and firm-specific and order-specific characteristics in determining firms' performance.

Figure 2 shows the DAG of a BN where the governance structure is measured by the three binary variables *Relational*, *Hybrid*, and *Market*; in Figure 3, instead, the variable used is *Governance*. Both the BNs were estimated by applying the Bayesian Search algorithm (Heckerman et al., 1994). The strength of the relationship between the variables is indicated by the thickness of the arrows: the thicker the arrow, the stronger the dependency. Variables showing no links are excluded from both graphs.

Figure 2 shows that both status as a high-tech supplier (i.e., providing CERN with highly innovative products/services) and the size of the order play a direct role in establishing both *relational* and *hybrid* interaction modes, in line with *Hypothesis 1*. By contrast, there are no strong links with the market-type governance structure.

The BNs also confirm *Hypothesis 2*: product (i.e., new products, new services, new technologies, and new patents) and process innovation depend directly on relational-type interactions. Actually, the variable *Relational* is strongly correlated with the development of new technologies and new products, whereas market-type governance is linked to the use of CERN as marketing reference or gaining increased credibility on the market, which corroborates the idea that the fact of having become a supplier of CERN is likely to produce a reputational benefit.

Some linkages among the intermediate outcomes emerge, suggesting that the cooperation with CERN spurs several changes in suppliers' propensity to innovate. The DAG shows that process innovation (e.g., improvements in technical know-how as well as in R&D and innovation capabilities) is associated with developing new technologies, while developing new patents and other IPRs is linked to the acquisition of new customers.

These intermediate outcomes are expected, in turn, to be associated with better firm performance (*Hypothesis 3*). This correlation, which the ordered logistic models documented, is confirmed and further qualified by the BN analysis. In fact, the development of new products and the acquisition of new customers are linked chiefly to an increase in sales/profits, whereas new patents and other forms of IPR lead not only to higher sales/profits but also to a greater

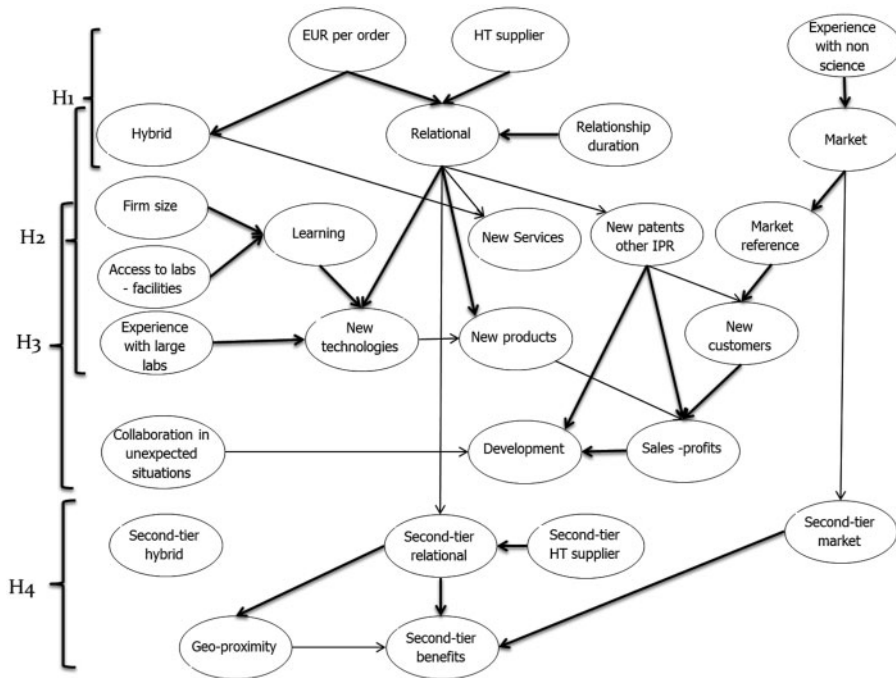


Figure 2. BN: The impact of different types of governance structures on firm performance. Governance structures are proxied by three binary variables: *Relational*, *Hybrid*, and *Market*.



Figure 3. BN: The impact of different types of governance structures on firm performance. Governance is proxied by a five-item construct as described in Section 3.4.

probability of developmental activities. The BN analysis also shows that the variables that measure suppliers' performance are strongly linked with one another, suggesting that the result tends to be an overall enhancement of firms' performance, rather than gains involving only specific aspects.

Hypothesis 4 is tested in the bottom of the DAG, where we look at the modes of interaction between first-tier and second-tier suppliers and the potential benefits accruing to the latter. The BN highlights a positive correlation between the governance structures and benefits for subcontractors, as perceived by CERN's suppliers. An examination of the DAG as a whole clearly shows that the type of first-tier relationship between CERN and its direct suppliers is replicated in the second-tier relationships established between direct suppliers and subcontractors. This holds for both relational governance structures (the arc linking *Relational* and *Second-tier relational*) and market structures (the arc linking *Market* and *Second-tier market*). Presumably, what drives this process is the degree of innovation and the complexity of the orders to be processed: supplying highly innovative products requires strong relationships not only between CERN and its direct suppliers but also between the latter and their own subcontractors to deal effectively with the uncertainty inherent in the development of new technologies at the frontier of science, where the risk of contract incompleteness and defection is very high. Finally, it is worth noting the role of some control variables. Firm's size is linked to the learning outcomes, which in turn related to innovation outcomes. As [Cohen and Levinthal \(1990\)](#) suggest, access to the network by suppliers is a necessary but not sufficient condition for learning, which rather depends on the firm's absorptive capacity. Large firms are more likely to absorb external knowledge and benefit from the supply network, because with respect to smaller companies they generally have higher levels of human capital and internal R&D activity, as well as the scale and resources required to manage a substantial array of innovation activities ([Cano-Kollmann et al., 2017](#)). Moreover, previous experience working with large-scale labs similar to CERN is positively associated with the development of new technologies. By contrast, the suppliers whose previous experience was with nonscience-related customers are more likely to establish market relationships with CERN. The DAG also shows that the possibility of accessing CERN's research facilities is linked to the development of new technologies, while collaborative behavior in unexpected situations heightens the probability of carrying out development activities.

This leads us to the network in [Figure 3](#), where the variable *Governance* encapsulates these specific aspects of the supply relationships. The DAG confirms the main relationships discussed above; that is, the higher the value of the variable *Governance*, the greater the benefits enjoyed by CERN suppliers.

The robustness of the networks was further checked through structure perturbation, which consists in checking the validity of the main relationships within the networks by varying part of them or marginalizing some variables ([Ding and Peng, 2005](#); [Daly et al., 2011](#)).⁵

6. Conclusions

This article develops and empirically estimates a conceptual framework for determining how government-funded science organizations can support firms' performance through their procurement activity. By exploiting both logistic regression models and BN analysis on CERN procurement, we find that: (i) the innovation and market penetration outcomes achieved by suppliers impact positively on their economic performance and development; (ii) the suppliers involved in structured and collaborative relationships with CERN turn in better performance than companies involved in pure market transactions characterized by little or no cooperation. As our BNs reveal, relational-type governance structures channel information facilitate the acquisition of technical know-how, provide access to scarce resources, and reduce the uncertainty and risks associated with complex projects, thus enabling suppliers to enhance their performance and increase their development activities. These relationships hold not only between the public procurer and its direct suppliers but also between the latter and their subcontractors, suggesting that benefits spill-over along the whole supply chain.

Our findings are relevant both for policy makers and RI managers. Given the large scale and complexity of RIs, parties are often unable to precisely specify in advance the features of the products and services needed for the construction of such infrastructures, so that intensive, costly, and risky research and development activities are required. In this context, procurement relationships based solely on market and price mechanisms are not a suitable instrument for governing public procurement, as they would not be able to deal with the uncertainty embedded in innovation procurement. Instead, if parties cooperate during contract execution, and specifically if a relational governance structure is established, not only are the requisite products and services more likely to be developed and delivered but

additional spillover benefits are generated in supplier firms. The patterns of these relationships across members of the supply network influence the generation of innovation, helping to determine whether and how quickly innovations are adopted so as to produce performance improvement in firms.

In addition, we looked at suppliers “from within,” and our results highlight that firms’ heterogeneity is an important factor. The impact on suppliers’ performance produced by CERN procurement depends critically on firm size, on status as high-tech supplier, and on an array of other factors, including the capacity to develop new products and technologies to attract new customers via marketing, and the ability to establish fruitful collaborations with subcontractors.

To be successful, mission-oriented innovation policies entail rethinking the role and the way governments, public agencies, and private agents act in the economy; in particular, there is the need to see innovation strategy as an interaction between multiple actors in both public and private sectors (Mazzucato, 2016, 2017; in this issue). Our study confirms the full adherence of CERN to such a mission, which is also mentioned in its statute: the collaborative interaction with CERN improves suppliers’ technological status and innovativeness and their economic performance and capacity to implement managerial best practices along their own supply chain.

This case study and its results could help other intergovernmental science projects to identify the most appropriate mode for carrying out their mission as a learning environment (e.g., Square Kilometre Array, SKA radio telescope, European Space Agency, International Space Station, ITER—International Thermonuclear Experimental Reactor, and ESFR—European Synchrotron Radiation Facility). At the national level, where RIs and public agencies are subject to procurement regulation and standard practices in a specific country or sector (e.g., NASA and other national agencies operating in the space science, defense, health, and energy), our findings offer to policy makers insights on how better design procurement regulations to enhance mission-oriented policies. Future research is needed for broader and more in-depth inquiry into the effects of RI-related public procurement on second-tier suppliers and possibly other levels of the supply chain.

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