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The role of firm R&D effort and collaboration as mediating drivers of innovation policy effectiveness

Giovanni Cerulli[a], Roberto Gabriele[b] and Bianca Potì[a]

[a]IRCRES-CNR, Rome, Italy; [b]Department of Economics and Management, University of Trento, Trento, Italy

ABSTRACT
This paper investigates the impact of firm R&D policies supporting R&D investment and collaboration on company innovation performance. Individual and cooperative R&D investments are considered as intermediate outcomes (input and behavioural additionality, respectively) contributing to the final outcome (probability of product innovation). We use a treatment random coefficient model to estimate the policy additionality on a panel data-set merging the third and the fourth wave of the Italian Community Innovation Survey. Results show a significant and positive policy impact on company propensity to product innovation only for the input additionality and for the interaction between the input and the cooperative additionality. This occurs when company cooperation scores overcome a given threshold, in accordance with the assumption that cooperation entails benefits but also coordination costs.

KEYWORDS
R&D collaborations; R&D policy; additionality; average treatment effect

JEL CODE
O31; O38

1. Introduction

The literature on R&D and innovation programme evaluation has studied the impact of policy intervention directed to increase companies' innovative performance by mainly focusing on input additionality (Aerts and Czarnitzki 2004, 2006; Aerts and Schmidt 2008; Almus and Czarnitzki 2003; Busom 2000; Czarnitzki and Fier 2002; Duguet 2004; González, Jaumandreu, and Pazó 2005; Gonzalez and Pazo 2008; Görg and Strobl 2007; Heijs and Herrera 2004; Hussinger 2008; Kaiser 2004; Lach 2002; Lööf and Heshmati 2005; Suetens 2002; Wallsten 2000). Relatively less attention has been paid to output additionality (Bronzini and Piselli 2013; Corsino et al., 2015; Merito, Giannangeli, and Bonaccorsi 2007), often regarded as a direct effect of the policy, and even less to behavioural additionality (Busom and Fernandez-Ribas 2008; Cerulli and Potì 2012; Clarysse, Wright, and Mustar 2009; Czarnitzki and Hussinger 2004; Georghiou and Clarysse 2006).

Moreover, such literature has studied the input, output, and behavioural additionality effects separately, with the consequences that – especially when looking at output effects – biased conclusions arise, as factors different from the intervention can influence the empirical findings. When looking only at the input additionality (R&D resources), one

CONTACT Roberto Gabriele roberto.gabriele@unitn.it

cannot assure that this had an effect also on the output (measured, for instance, as innovation products). In both cases, relevant information concerning how R&D activities (e.g. R&D projects) were implemented is lost.

The term additionality, generally used for identifying the three types of effects, refers to something (e.g. additional investment in input resources such as R&D, additional innovative output, and change in company's behaviour) attributable only to the public support that a company would not have realised in its absence. Generally, a counterfactual econometric approach is then appropriate to obtain a measure of such effects.

Behavioural additionality was introduced in the literature around the mid-1990s as a complement to the other two types of effects (i.e. input and output additionality) in order to identify modifications induced by public support in various types of company behaviours (Buisseret, Cameron, and Georghiou 1995).

Although researchers still lack a common agreement on the meaning of behavioural additionality, a firm's cooperative behaviour with other partners has emerged as an appropriate measure, both for its theoretical relevance and its popularity in applications (Busom and Fernandez-Ribas 2008; Cassiman and Veugelers 2002; OECD 2006).

Cooperation entails an increase in agents' capabilities and knowledge base, bringing about a better innovative performance through persistent learning. Moreover, the relation between firm additional R&D cooperation and additional R&D input investment can be of a complementary or of a substitution type, depending on the characters of the cooperation. It is thus relevant to analyse the interrelation between these two types of effect (when simultaneously present), as this can better inform policy-makers about the transmission mechanisms of the policy.

R&D cooperation can also convey costs, partly in the form of adjustment costs due to organisational changes (including fixed costs, generally larger for small firms) and partly represented by drops in R&D expenditures due to the reduction of duplications or to cartel agreements. It is therefore relevant to understand to what extent an additional R&D investment can be negatively compensated – or positively complemented – by cooperation costs – or by cooperation investments (Cassiman and Veugelers 2002).

In Research and Development investments (RDI) evaluation literature, we find a gap in relating the whole range of additionality effects within a counterfactual frame. The aim of this paper is to propose a way to fill that gap by a *two-step* approach, firstly assessing the impact of general subsidy policies sustaining R&D activities on input and behavioural additionality taken as intermediate outcomes, and then looking at how they contribute to the final innovative result (output additionality).

The purpose of this study is twofold and sequential. First, we evaluate the effect of a general RDI supporting policy (not specifically directed to R&D cooperation) on firms' R&D collaborations (behavioural additionality) and R&D input investments (input additionality). Second, we provide an assessment of how the previous two intermediate effects result in an improved company innovation performance when these effects are introduced either separately or jointly.

In order to measure the degree of collaboration additionality promoted by the policy, i.e. the difference in the *quality* of cooperation between supported (or treated) and unsupported (or untreated) companies, we propose a novel measure of firms' collaboration effort. We compute it as the number of different cooperating partners of a company, weighted by the relevance that the single innovating company attributes to each of these partners.

The data-set used for this study is based on a panel data structure merging the third and fourth waves of the Italian Community Innovation Survey (CIS3 and CIS4), referring respectively to the 3-year windows of 1998–2000 and 2002–2004.

The organisation of the paper is as follows: Section 2 presents the literature review, Section 3 introduces the research design and the methodology, Section 4 presents and discusses the data, and Section 5 describes the results. Finally, in Section 6, we put forward and discuss the conclusions of the paper.

2. Literature review

In order to give to our model proper theoretical and evidence-based underpinnings, we organise the review of the literature around three main subjects: (i) the effect of R&D subsidisation on input and output additionality, (ii) the behavioural additionality of firms and its relation with input and output additionality, and (iii) the relationship between R&D subsidisation, R&D cooperation (either subsidised or not), and firm innovation performance.

2.1. *The effect of R&D subsidisation on input and output additionality*

Evaluations of technology programmes and subsidy schemes have to determine whether public resources generate additional activities by the recipient firms. Additionality can be defined as the change in firm-financed R&D spending, company behaviour, or performance that would not have occurred without the public intervention (Georghiou and Clarysse 2006). Typically, the additionality concept rests on the market failure argument: left to themselves, firms would under-invest in innovative activities (Metcalfe, Georghiou, and James 1997). Public subsidies are then needed to overcome the reluctance firms have when they come to invest in innovation. Hence, by subsidising innovative activities, policy measures can increase the private rate of innovation, thus making it closer to the socially optimal one.

Policy-makers and academics are interested in evaluating whether government R&D expenditures and company-financed R&D behave like substitutes or complements (David, Hall, and Toole 2000; Georghiou and Roessner 2000). If subsidised firms increase their level of R&D investments, then public resources complement private funds, and the technology programme under evaluation has input additionality effects.

An extensive body of empirical literature has studied the impact of R&D policies on input additionality. Among them, several studies rejected full crowding-out effects (Aerts and Czarnitzki 2004, 2006; Aerts and Schmidt 2008; Almus and Czarnitzki 2003; Czarnitzki and Fier 2002; Duguet 2004; González, Jaumandreu, and Pazó 2005; González and Pazó 2008; Görg and Strobl 2007; Hussinger 2008; Lööf and Heshmati 2005). Others found support for partial crowding-out of private investments (Busom 2000; Heijs and Herrera 2004; Kaiser 2004; Lach 2002; Suetens 2002; Wallsten 2000).

An increase in private R&D due to a public subsidy does not necessarily translate into technological progress (Aerts and Czarnitzki 2006); therefore, there is the need to also look at the R&D output. Output additionality may be defined as the proportion of firm outputs that would not have been achieved without public support.

Input and output additionality have been the preferred performance measures in the evaluation of technology programmes. While input additionality is quite straightforward to measure in relation to specific R&D projects, output additionality raises a number of problems concerning in particular the presence of many unobserved determinants that might have impacted on the output generated by a given R&D project.

Some authors have studied the effect of an R&D policy on technological output (output additionality) by assuming a direct impact of public policy on company innovation (Bronzini and Piselli 2013; Corsino, Gabriele, and Giunta 2015; Merito, Giannangeli, and Bonaccorsi 2007).

Other scholars (Cerulli and Potì 2012; Czarnitzki and Hussinger 2004) have provided an improvement by adopting a two-step method assessing the effectiveness of a policy in fostering innovation via its capacity in firstly promoting companies' input additionality.

Georghiou (2002) suggested, however, that the focus on input or output additionality overlooks a third fundamental effect, the learning activated within a technology programme. This learning takes place within the company in the short term, but it is also a fundamental driver of the input and output additionality in the long term. Such learning effect translates into an adjustment of companies' internal R&D processes, routines, competences, and strategies, leading in this way to persistent changes in entrepreneurial behaviour (behavioural additionality).

2.2. Behavioural additionality and its relation with input and output additionality

The introduction of the concept of behavioural additionality took place around the second half of the 1990s (Buisseret, Cameron, and Georghiou 1995; Georghiou 2002). In the definition given by Buisseret, Cameron, and Georghiou (1995), behavioural additionality deals with 'the change in a company's way of undertaking R&D, which can be attributed to policy action.' It gives more detailed information on firms' R&D strategies or management. The concept aims to complement and not to replace the traditional input and output additionality concepts, and its theoretical foundations stem from the behavioural and resource-based theory of the firm (Barney 1991; Teece, Pisano, and Shuen 1997).

Other scholars (Clarysse, Bilsen, and Steurs 2006; Steurs et al. 2006) have considered behavioural additionality as a complement to input and output additionality, but have given it a larger meaning, referring to the Rosenberg's (1982) black box and to a broader set of processes of the firms.

Most of the literature has associated behavioural additionality to the possibility of going beyond input and output approaches, which evaluate what is measurable, rather than what should be measured (Gok and Edler 2010).

In 2006, a large OECD project, including 12 pilot studies from 11 member countries and the European Union, placed great interest on behavioural additionality and gave it considerable visibility and centrality.

Notwithstanding this, the evaluation literature has paid relatively little attention to the behavioural additionality concept, for at least three reasons. First, the evaluation of behavioural additionality remains difficult; the survey-based approach widely used in innovation policy evaluation is not sufficient (Georghiou 2007) and tends to under-evaluate the contribution of R&D (Aho et al. 2006). Second, the lack of an extensive discussion on the theoretical content of behavioural additionality has resulted in its underutilisation (Gok and Edler 2010). The evaluation literature using behavioural additionality has mainly focused on measurement, while the concept's definition remains intuitive. Moreover, the different understandings of the concept present difficulties also in the measurement, due to the absence of a common practice formulation. Third, the ad hoc use of behavioural additionality (Gok and Edler 2012) means that it can be simply adopted to demonstrate a good result.

The concept has been used with different interpretations and dimensions. Gok and Edler (2010, 2012) indicated the following four main interpretations:

- an extension of input additionality (behaviour of increasing scale and scope of R&D or of acceleration in project realisation);
- change in non-persistent behaviour related to R&D activities;
- change in persistent behaviour related to R&D; and
- change in the general conduct of firms.

In turn, the OECD (2006) project weighted this list of different dimensions:

- project additionality (launch of new projects);
- speed additionality (project conducted more speedily);
- scale and scope additionality (an extension of the project);
- challenge additionality (assumption of higher risk);
- network additionality (more or more extended collaborations); and
- management additionality (improved management).

Behaviour additionality is one of many ways to explain the presence of an additional effect on a firm's investment in R&D, induced by policy grants. A firm can in fact invest more than simply the liquidity added by the public subsidy (neutrality effect) under one of the following circumstances: a positive reaction of financial markets to the policy signal represented by the subsidy (a higher and/or cheaper supply of external funds); a change of firm behaviour towards risk or opportunity (better capacity to grasp opportunities and/or higher propensity to risk); the possibility of sustaining indivisible costs; and, last but not least, the fact that the cost of the change is lower than the advantage brought by the injection of liquidity due to the policy intervention.

Clarysse, Wright, and Mustar (2009) focused on the behavioural effect of subsidy policy and defined it as the changes in management practices of innovation process within the company. They showed that organisational learning is a useful theory to explain the mechanisms through which behavioural additionality emerges. These scholars found that input and behavioural additionality are strongly correlated, and they explained this result by noting that companies which aim to change their R&D management methods are also those more oriented to spend on R&D and research personnel.

Clausen, Ljunggren, and Madsen (2008) examined the relationships between input, output, and behavioural additionality using longitudinal data from a large-scale evaluation of an R&D tax-credit scheme in Norway. They found that these three concepts are strongly interrelated and that the behavioural additionality is a prerequisite to gain *indirect* input additionality (as, for instance, the ability to launch additional new R&D projects) and output additionality. These findings showed that behavioural additionality may be of high relevance for understanding the overall effect of any R&D and innovation policy scheme.

Finally, Antonioli and Marzucchi (2012) analysed the concept of behavioural additionality in the light of the evolutionary theory of *system failure*, as opposed to the neo-classical market failure approach. They reviewed some recent econometric and quantitative studies dealing with the measurement of behavioural additionality at firm level and supported the need to jointly analyse input, output, and behavioural additionality, as they are strictly interdependent, thus stressing at the same time the importance of a better understanding and measurement of agents' interrelations within a systemic approach.

In sum, this section shows the multi-meaning of behavioural additionality together with its general relevance to understand the overall effects of a policy oriented to financially sustain a firm's innovation. Within the different conceptual definitions of behavioural additionality, we choose as relevant that of cooperative relations with other partners. R&D collaborations can be considered a central issue in most behavioural additionality studies, within and out of the evaluation literature (e.g. Busom and Fernandez-Ribas 2008; Clarysse, Bilsen, and Steurs 2006; Falk 2006; Georghiou and Clarysse 2006; Hyvärinen 2006; Madsen and Brastad 2006; Malik, Georghiou, and Cameron 2006; Shin 2006). In general, firms' R&D cooperation has the aim of sharing risk and improving competencies, so allowing firms to better implement their projects and to reach a good performance. In choosing R&D cooperation as the more meaningful definition of behavioural additionality for R&D policy, we agree with the idea, belonging to the evolutionary framework, that overcoming problems that limit the cognitive capacity of agents is the main rationale of an innovation policy (Bach and Matt 2005). We also share the consideration of Cunningam, Gok, and Laredo (2013), arguing that an innovation policy is successful if it increases the capacities of agents that are crucial for innovation activity and performance (cognition, networking) and by doing so leads to persistent effects.

2.3. The relation between R&D subsidies, R&D cooperation, and innovation

Cooperative R&D and public funding have been examined by only a few empirical studies. Some studies have looked at the effect of subsidies to promote cooperation. Government R&D policy can be directed to correct the distortion created by R&D spillover among firms and also to incentivise cooperation when its cost and risk are high. Geroski (1993) interestingly stated that since there is no presumption that benefit of R&D joint venture is large or easy to reach, the design of the policy is of a critical stance. Authors looking at the determinant of voluntary R&D cooperation have shown that firm size and innovation cost sharing increase the likelihood of partnership, but especially that of cooperation with public research organisations (Cassiman and Veugelers 2002). The possibility of benefiting from incoming spillovers increases the likelihood of cooperation with public research organisations, but not with private partners (Lopez 2008), and the effectiveness of strategic protection methods is the most important determinant for cooperation with competitors.

More compliant with our work, other studies have compared the effect of individual R&D subsidies, R&D cooperation (subsidised or not), and the innovation output.

Folster (1995) studied the effectiveness of subsidies on cooperation, answering also the question of whether a subsidy that requires cooperation increases incentives to conduct R&D. The scholar extended the analytical model of Katz and Ordover (1990), who expressed the joint venture as an agreement to share both costs and technology, to other forms of R&D cooperative arrangements. Empirical results showed that a subsidising cooperation policy that does not require a specific cooperative form (for instance, result sharing) and therefore resembles voluntary cooperation can increase incentive to R&D, but in the same way as individual R&D subsidies.

D'Aspremont and Jacquemin (1988), in their two-stage model, assumed that in case of voluntary cooperation firms jointly choose the level of R&D to maximise the joint profits and the level of spillovers influences the outcome: when they are relatively large, both the investment and the output are greater within the R&D cooperation regime than within the R&D competition regime. The implication for policy-makers is therefore that when some research activity is recognised ex-ante as a source of large spillover, it is worthwhile to subsidise R/D cooperation agreements.

Both these contributions argued that voluntary R&D and subsidised voluntary-like R&D cooperation increase incentive to invest in R&D. Other scholars have looked explicitly to a comparison of the effect on R&D expenditures among individual and cooperative R&D subsidies.

Hinloopen (2001) disagreed with D'Aspremont and Jacquemin's (1988) results and their policy implication. The scholar argued that R&D cooperation has many drawbacks; for instance, R&D cooperation partners can collectively decide to reduce R&D if the increase in the innovating firm's profit does not compensate enough for the profit loss of the other firms (Geroski 1993; Katz and Ordover 1990). Hinloopen (2001) used D'Aspremont and Jacquemin's model (1988) but generalised it. The scholar compared three policies: providing individual R&D subsidies, sustaining the formation of R&D cooperatives, and subsidising R&D cooperatives. The results showed that subsidising individual R&D is more effective in raising R&D effort than sustaining (by legal instruments) R&D cooperation. Subsiding cooperative R&D brings to the same level of R&D when subsidies are given to individual research activities.

Czarnitzki, Ebersberger, and Fier (2007) studied the impact of R&D subsidy policy and of voluntary R&D collaboration on R&D investment and on patents in two countries, Germany and Finland. They considered collaborations and subsidies as heterogeneous treatments and conducted a treatment effect analysis by distinguishing and simultaneously analysing voluntary R&D collaborations, individual R&D subsidies, and the interaction of subsidies *times* collaboration. Their results are slightly different between the two countries. In Germany, the interaction of collaboration and subsidy led to improved performance (R&D intensity) over only subsidy or only voluntary collaboration; in contrast, in Finland, R&D subsidy performed better than voluntary collaboration. However, when the patent outcome was considered, in both countries the combination of collaboration and subsidy would give better results than subsidy alone.

Some authors have been interested in evaluating the effect of a general innovation policy, not specifically directed to cooperation projects, on firms' R&D cooperation behaviour (behavioural additionality), looking to the characters of this cooperation in terms of the type of partners rather than on the impact on R&D investment. Busom and Fernandez-Ribas (2008) studied the effect of public support on firms' propensity to cooperate with other firms or with public research organisations (PROs). These scholars aimed to assess whether general R&D public subsidies (i.e. measures not specifically devoted to R&D cooperation) are able to trigger a behavioural cooperative additionality. They did not include policies explicitly directed to support R&D cooperation, such as EU programmes, because participation and cooperation in that case is an identical event and such inclusion could produce a perfect predictor problem. Their paper concerned only national R&D policy, which included both R&D cooperation incentives and public subsidy not conditional on cooperating. The results showed that national subsidies increase the rate of cooperation mostly with PROs, lesser with other firms, and basically when firms have intangible knowledge assets embodied in international patents. Using the Spanish CIS, this study underlined CIS limitations, mostly concerning the difficulty of using CIS for a longitudinal analysis, thus limiting the possibility of checking results' robustness under alternative procedure to address endogeneity and firm heterogeneity. Interestingly, the authors also concluded that 'even if public funding increases the development of partnerships, output additionality generated by these partnerships has to be verified before concluding that public subsidies are the most efficient tool to reach the goal of increasing innovation' (Busom and Fernandez-Ribas 2008, 253).

The OECD (2006) study investigated the behavioural effect of public-funded R&D cooperation in Germany, thus assessing whether public R&D funding stimulated firms' cooperative behaviour change (through new partners or new types of partnerships) and the duration of joint R&D projects. The results showed that only a small percentage of firms would choose a business-to-business collaboration strategy if granted a public subsidy, while newly initiated R&D cooperation with universities and research centres was more diffused.

Firms benefit from R&D cooperation if the cooperation positively affects their economic success enough to outweigh the costs of cooperation (e.g. transaction and coordination costs). Thus, it is important to analyse the effects of cooperation on the outcome measures in addition to its effects on inputs (Aschhoff and Schmidt 2008). Lööf and Broström (2008) found that the collaboration between universities and firms not only increases the probability that firms will apply for a patent in the future, but it also has a positive impact on the innovative sales per employee. Gemünden, Ritter, and Walter (1997) investigated the relationship between sales due to product innovations and cost reductions through process innovations. They found that cooperating firms have higher sales attributable to product innovations than non-cooperating firms.

In sum, the empirical results about how subsidised R&D cooperation impacts on firms' R&D investment differ, showing that the impact is not always positive (firm's increase of R&D), that individual R&D subsidies can give similar or better results than subsidised R&D cooperation, and that the relation between individual R&D subsidy and voluntary cooperation does not always improve R&D intensity, although it can improve the patent outcome. Empirical studies looking at R&D cooperative behavioural additionality in terms of organisational characters have also shown that cooperation is mostly established with public research organisations, thereby introducing basic research competences. From these studies and others, the advice is not to stop at examining the effect in terms of partners or R&D intensity, but to look at the output effects.

3. Research design and methodology

Assuming the previous literature review as reference, our research goal is to study the ultimate effect of R&D and innovation (RDI) support on company propensity to innovate (*output additionality*) through the *mediating effect* the subsidy has had on the company's own R&D (*input additionality*) and RDI cooperation strategy (*behavioural additionality*). The causal path diagram of our model is represented in Figure 1.

This is a two-step model, where: (i) the first step defines how the subsidy impacts on private R&D investment and on the cooperation behaviour of firms; here, we obtain two (generated) regressors $\mathrm{ATE}_{\mathrm{input}}(\mathbf{x}_i)$ and $\mathrm{ATE}_{\mathrm{behavioural}}(\mathbf{x}_i)$ representing the causal counterfactual effects of the policy considered on the R&D effort and on the R&D cooperation degree. (ii) The second step performs a regression of the output variable (i.e. the innovation propensity of firms) on the two regressors $\mathrm{ATE}_{\mathrm{input}}(\mathbf{x}_i)$, $\mathrm{ATE}_{\mathrm{behavioural}}(\mathbf{x}_i)$, plus their interaction

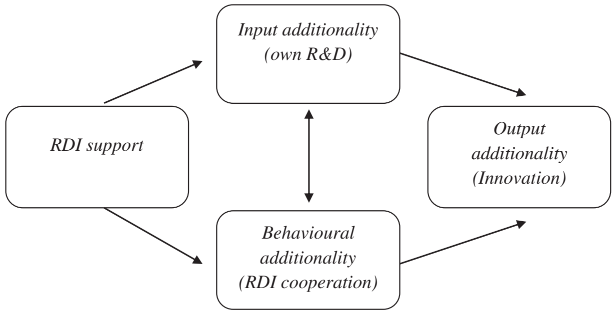

Figure 1. Path diagram of the model.

and a group of control variables; from this regression, we obtain an estimation of the sign and magnitude of the additional effect generated by the subsidy policy through the two mediating variables *cooperation* and *R&D effort*, respectively.

As an econometric counterpart of the previous diagram, we use a *treatment random coefficient model* (see Wooldridge 2010, 945–51), implemented in Stata through the routine IVTREATREG by Cerulli (2014). This model allows us to estimate, for each company, an idiosyncratic effect of the support on R&D and cooperation, formally defined as the Average Treatment Effect conditional on a vector of covariates $\mathbf{x}$. In standard regression models, these effects cannot be estimated individually, but only as a common (and thus singleton) parameter (typically, the ATE). This is the advantage of using a random coefficient approach.

This estimation strategy permits us to identify, for each company i, two distinct effects:

(1) $\text{ATE}_{\text{input}}(\mathbf{x}_i)$ = average treatment effect of RDI support on company i R&D (idiosyncratic *input additionality*), and
(2) $\text{ATE}_{\text{behavioural}}(\mathbf{x}_i)$ = average treatment effect of RDI support on company i degree of cooperation (idiosyncratic *behavioural additionality*).

Once the previous two variables are calculated, we can exploit them as predictors (*mediating effects*) in an invention/innovation regression function of this type:

$$\begin{aligned} Y = & a + \sum_{p=1}^{P} b_p \left[\text{ATE}_{\text{input}}(\mathbf{x})\right]^p + \sum_{q=1}^{Q} c_q \left[\text{ATE}_{\text{behavioural}}(\mathbf{x})\right]^q \\ & + d \cdot \text{ATE}_{\text{input}}(\mathbf{x}) \cdot \text{ATE}_{\text{behavioral}}(\mathbf{x}) + \mathbf{ew} + \text{error} \end{aligned} \tag{1}$$

where the index i is omitted for the sake of simplicity. In Equation (1): Y is a binary innovation outcome measuring the presence/absence of product innovation; $\mathbf{w}$ is a vector of covariates explaining invention/innovation performance; a, b_p, c_p, d, and $\mathbf{e}$ are regression parameters; and P and Q are the maximum polynomial order one can consider in the regression for the two types of additionality.

Observe that Equation (1) also shows an interaction between $\text{ATE}_{\text{input}}(\mathbf{x})$ and $\text{ATE}_{\text{behavioural}}(\mathbf{x})$. Thus, in terms of derivatives, we obtain:

$$\frac{\partial E(Y|\mathbf{x},\mathbf{w})}{\partial \text{ATE}_{\text{input}}(\mathbf{x})} = \sum_{p=1}^{P} p \cdot b_p \left[\text{ATE}_{\text{input}}(\mathbf{x})\right]^{p-1} + d \cdot \text{ATE}_{\text{behavioural}}(\mathbf{x}) \tag{2}$$

$$\frac{\partial E(Y|\mathbf{x},\mathbf{w})}{\partial \mathrm{ATE}_{\mathrm{behavioural}}(\mathbf{x})} = \sum_{q=1}^{Q} q \cdot c_q \left[\mathrm{ATE}_{\mathrm{behavioural}}(\mathbf{x})\right]^{q-1} + d \cdot \mathrm{ATE}_{\mathrm{input}}(\mathbf{x}) \quad (3)$$

In the simple case in which $p = 1$ and $Q = 1$, we have:

$$\frac{\partial E(Y|\mathbf{x},\mathbf{w})}{\partial \mathrm{ATE}_{\mathrm{input}}(\mathbf{x})} = b_1 + d \cdot \mathrm{ATE}_{\mathrm{behavioral}}(\mathbf{x}) \quad (4)$$

$$\frac{\partial E(Y|\mathbf{x},\mathbf{w})}{\partial \mathrm{ATE}_{\mathrm{behavioural}}(\mathbf{x})} = c_1 + d \cdot \mathrm{ATE}_{\mathrm{input}}(\mathbf{x}) \quad (5)$$

Equations (2) and (3) clearly show that the effect of the input additionality on product innovation depends on the behavioural additionality, and vice versa. Our approach will therefore allow us to take into account potential 'synergistic' or 'weakening' effects of combined input and behavioural additionality on output performance.

Equations (4) and (5) show, respectively, the output increment due to input additionality for each level of behavioural additionality and the output increment due to behavioural additionality for each level of input additionality.

This treatment model can be used to calculate input and behavioural additionality on two sub-populations of interest: *supported* and *unsupported* companies. It would be possible, for instance, to know whether the input and behavioural additionality have been higher for supported than unsupported companies, thus providing interesting policy implications. For example, finding out that unsupported units have had a higher performance would show that company self-selection and/or agency-selection into programme have taken out companies having lower additionality potential.

4 Data and variables

4.1 Data

The data-set employed in this study was a panel data-set built by merging the third and fourth waves of the Italian Community Innovation Survey (CIS3 and CIS4) which collected a large set of innovation and R&D-related variables for the 3-year windows of 1998–2000 and 2002–2004 for a sample of manufacturing and services companies. This data-set was then merged with company balance sheet data (AIDA data-set). All the fundamental target and control variables needed for applying our model are available in CIS3 and CIS4 plus AIDA, and the RDI subsidy takes the form of a binary variable (supported vs. non-supported) including all regional, national, and European support.

4.2 Collaboration variables

Particular attention should be devoted to the definition of our key variable measuring the intensity of collaborations. We relied upon the CIS questions about the collaboration activities of firms, respectively, the 10.1 in CIS3 and 6.4 in CIS4. These questions asked firms to define the kind of collaboration they agreed upon according to the typology and geographical localisation of the partner.

First, we built an indicator measuring the number of different types of collaborations carried out in the 3 years of each survey (variety of collaboration indicator), which ranged from 0 (no collaborations at all) to 6 (the firm has collaborations covering all the types of partners). The different typologies were those defined by a different kind of partners, namely: other firms of the same groups, suppliers, customers, competitor firms, consultants, and public research institutes.[1] Note that we have a construct which is similar in spirit to that of Laursen and Salter (2006), who defined in the same way a proxy of the *breadth* of knowledge sources used by firms. In our case, this measure referred to the active participation to joint and cooperative R&D and not generally to the drawing upon external sources of information.

Secondly, we weighted this indicator by assigning more weight to the type of collaborations that a firm declared to be "more important from the point of view of its relevance as a source of information for innovation." The weights range from 'not important' and 'low degree of importance' to 'medium importance' and 'high relevance,' where the modalities were taken from question 11.1 in CIS3 and question 6.1 in CIS4. This step mimicked another variable used in the literature that is a proxy of the *depth* of search in the space of knowledge (Laursen and Salter 2006), in our case representing also the degree of the cooperative interactions.

We re-coded previous relevance statements into the numerical values $w_k = \{0.25; 0.5; 0.75; 1\}$ representing the relative intensity of the relevance of each source of knowledge. Note that we decided to weight with 0.25 an existing collaboration of a firm even if it was judged by the firm as 'not important' in order to keep all collaborations in the indicator. In other words, we made this assumption to stay as close as possible to the literature that has investigated the role played by collaborations, regardless of their importance and nature. More formally, we built for each firm the following weighted collaboration indicator as in Equation (6):

$$\mathrm{Coop} = \sum_{k=1}^{6} I(\mathrm{coop}_k = 1) \cdot w_k \tag{6}$$

where the index $k = 1, \ldots, 6$ spans over all the different typologies of collaboration; $I(\mathrm{coop}_k = 1)$ is an indicator variable that assumes the value 1 if the typology of collaboration is present for the firm and 0 otherwise; w_k is the weight that a firm assigns to the kth type of collaboration. This indicator ranges from 0 to 6, where the minimum is reached when a firm declares not to have any collaboration, i.e. $I(\mathrm{coop}_k = 1) = 0$, for $k = 1, \ldots 6$. The maximum of this indicator is obtained when a firm declares to have all the types of collaborations, i.e. $I(\mathrm{coop}_k = 1) = 1$, for $k = 1, \ldots, 6$, and declares that each collaboration is 'highly relevant' as a source of information, i.e. $w_k = 1$ for $k = 1, \ldots 6$. Our indicator *coop* summarises in a sense both the variety and the intensity of use of each source of knowledge. See Appendix 1 for further details on the indicator and for a numerical example.

Such procedure is in tune with that proposed by Laursen and Salter (2006), who suggested researchers consider not only the variety of sources of knowledge, but also the intensity of

[1]We grouped in one category the two types of partners given by universities and public research institutes – modalities (f) and (g) of this specific CIS question.

Table 1. Summary statistics of the weighted collaborations indicator (Coop) for firms in CIS3 and CIS4.

	Obs	Mean	SD	Min	Max
Coop (CIS3)	2372	.232	.656	0	5.250
Coop (CIS4)	2100	.337	.855	0	5.125

their use. Notice that we also follow their contributions in the use of the variable: we use the collaboration indicator as a mediator in shaping the impact of additionality of R&D investment, induced by R&D subsidies, on innovative output. They tested the mediating effect of the breadth and the depth of the search of knowledge in shaping the effect that R&D effort can exert in innovative output (see Hypothesis 5 in Laursen and Salter 2006).

Nonetheless, some differences between Laursen and Salter's and our approach emerge in the way they quantified the two knowledge dimensions and in their choice of keeping them separated. Moreover, they focused on firms' search processes; thus, they interpreted as sources of knowledge the partners of firm research activity. In sum, jointly considered, the two variables they defined represent the openness of firms' external search processes (see Brown and Duguid 2000).

Table 1 presents the summary statistics for this indicator calculated within the CIS3 and CIS4 in our sample of firms.

4.3 Control variables

We include in the regression model a set of potential factors that could affect the relationship under investigation. The number of employees (*size*) should capture size effect. The financial constraints of firms help shape the R&D investment of firms, and we control for this effect using the rescaled cash-flow as a proxy (*cash_flow*) as measured by firm operating profits minus costs over the number of employees. Another important factor that could influence the R&D investment level is the level of the firm's debt through its effect, for instance, on the availability of internal funds. We use the total liabilities of the firm over its total assets as a relative measure of indebtedness (*debt*). We take into account the stock of knowledge accumulated in the firm using a measure for the stock of accumulated knowledge as the value of R&D investment plus the patents at book value (*knowledge*). We control for the firm's involvement in international activity (e.g. export) using a dummy variable that takes the value of one when the firm has positive export flow (*foreign*). Moreover, we control for the age of the firm (*age*) given that on average younger firms are more active from an innovative point of view. Finally, we include in the models location and sector dummies.

4.4 Outcome variable

As outcome variable, this study considers a binary covariate signalling, in the period under study, the presence/absence of a new product within the firm (*inno*). Therefore, we are ultimately interested in the probability of introducing a new product. As policy variable, finally, we consider a binary covariate indicating whether or not the firm benefited from an R&D subsidy during the time period under examination.

Table 2. Input and behavioural additionality. Result for the Average Treatment Effect.

	(1)	(2)
	Input	Behavioural
Treatment	0.01***	0.34***
	(0.00)	(0.07)
Size	0.00	0.00***
	(0.00)	(0.00)
Cash-flow	0.00	0.00
	(0.00)	(0.00)
Debt	0.01	0.19
	(0.01)	(0.17)
Knowledge	0.00	0.00
	(0.00)	(0.00)
Foreign	−0.00	−0.02
	(0.00)	(0.08)
Age	−0.00	−0.20
	(0.00)	(0.15)
N	1130	1130
R^2	0.45	0.21
F-test	n.a.	n.a.

Notes:Dep. Var.: 'R&D intensity' and 'Cooperation'. Size, sector, and location dummies included, but not reported. Standard errors in parentheses. n.a.= not available.***$p < 0.01$.

4.4.1. Timing of the variables

Each wave of the CIS used in this study covers a 3-year period (1998–2000 for CIS3; 2002–2004 for CIS4). As for the employed dependent variables, both information on innovation and collaborations are measured over the whole 3-year period, while R&D spending is measured in the last year (2000 in CIS3; 2004 in CIS4). In order to avoid direct simultaneity between the dependent variables and the covariates, the latter are measured – whenever possible – in the first year of each wave; this is the case for balance sheet data (including firm number of employees). Some variables are available only in the last year (such as the *foreign* dummy). Other variables, finally, are considered exogenous and thus measured within the same time span of the dependent variables (sector, age, location). In sum, our model specification should be sufficiently robust against possible simultaneity bias and thus endogeneity problems.

5. Results

Table 2 shows the results on the input and behavioural additionality using the RDI cooperation indicator presented above for the behavioural additionality, and the R&D intensity (total intra-muros R&D expenditure on turnover) for the input additionality. Due to an abundant presence of missing values, the sample size dropped to around 1,100 companies.

The table sets out a positive and strong significant effect of receiving RDI support (our binary treatment variable) on cooperation. The level of ATE is, in this case, around 0.34. As stated above, in order to get this result, we made use of a treatment random-coefficient model as proposed by Wooldridge (2010, 945–51) implemented in Stata by Cerulli (2014). Figure 2, plotting the distribution of ATE(**x**) for this regression, clearly shows that the average of that distribution coincides with ATE. The model specification considers a set of covariates (observable confounding variables), whose meaning is clearly evident: *size* (measured as the number of employees) identifies company scale economy in its collaborative

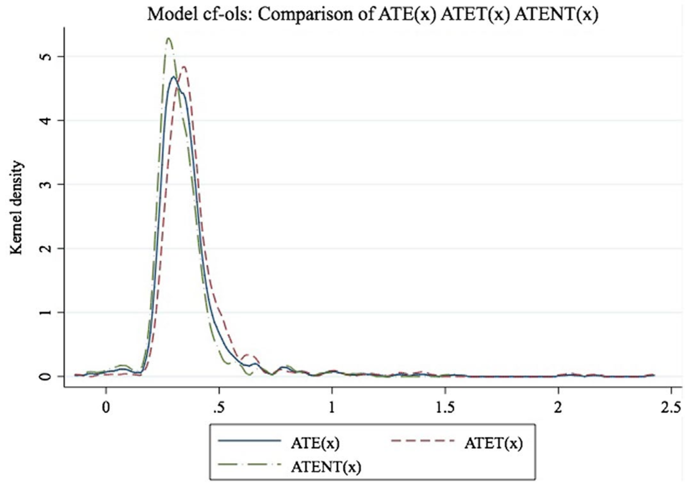

Figure 2. Distribution of ATE(x) for the behavioural additionality.

performance; *cash-flow* (measured as revenues minus costs on turnover) catches the role played by liquidity in promoting collaborative projects; *debt* (measured as the sum of short- and long-run indebtedness on turnover) gauges company reliance on overcoming liquidity constrains through accessing bank loans and is a fundamental asset shaping the capital structure of the firm; *knowledge* (as measured by the stock of capitalised R&D and acquired intellectual property) is a variable approximating firm experience and capacity in doing R&D and innovation over time; *foreign* is a binary variable taking on value one for foreign companies and zero for home companies; and finally, *size*, *sector*, and *location* dummies are also considered in the regression estimation but not reported in the table.

The previous table also reports results for the R&D intensity (or input additionality), using the same control variables. Also in this case, results show a highly significant and positive effect of the RDI support on firm R&D performance, with a value of ATE around 0.016. As in the case of the behavioural additionality, confounders are poorly significant.

Similar to Figure 2, Figure 3 shows the distribution of ATE(**x**) when the R&D intensity is considered as the target variable. The bell-shaped form centred on 0.016 is clearly illustrated.

Table 3 sets out an estimation of Equation (1) according to different polynomial orders. We regress the binary innovation variable *inno* (i.e. propensity to product innovation), taking one for companies performing some product innovation in the period covered by CIS3 and CIS4 and zero otherwise, on behavioural additionality (ATE(**x**) for cooperation), input additionality (ATE(**x**) for R&D intensity), and their multiplicative interaction (*interaction*) along with size, sector, and location controls.

In Table 3, we show the results on various polynomial specifications (until a third-degree polynomial) to test whether the relationship in Equation (1) is linear. We found no significance of squared (Table 3 models P2Q2, P2Q1, and P1Q2) and cubic terms (Table 3 model P3Q3). Therefore, we accept the linear form of Equation (1) as a good proxy (see the results in the P1Q1 column).

Our results stress a significant effect of the input additionality and of the interaction between input and behavioural additionality, but no significance for the coefficient of

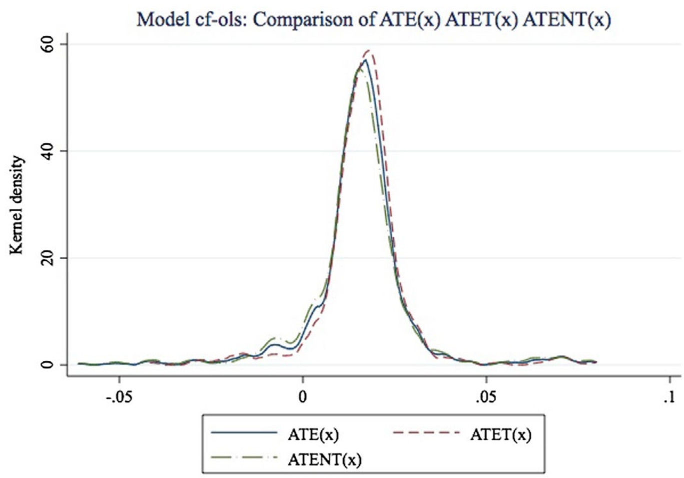

Figure 3. Distribution of ATE(x) for the input additionality.

Table 3. Estimation of Equation (1) according to different choices of P and Q.

	(1)	(2)	(3)	(4)	(5)
	P3Q3	P2Q2	P2Q1	P1Q2	P1Q1
	Full model: cubed terms for IA and BA	Only squared and first degree terms for IA and BA	Only first degree terms for IA and BA plus BA squared	Only first degree for IA and BA terms plus IA squared	Only first degree for IA and NO BA term
ATE_behavioural	−0.73	−0.38	−0.30	−0.11	−0.11
	(0.59)	(0.25)	(0.24)	(0.09)	(0.09)
ATE_input	−1.42	−2.25	−3.58*	−2.15	−3.33*
	(2.83)	(2.05)	(1.85)	(2.05)	(1.83)
ATE_behavioural^2	0.58	0.14	0.10		
	(0.68)	(0.12)	(0.12)		
ATE_input^2	−49.13	−53.07		−43.98	
	(47.99)	(35.15)		(34.28)	
ATE_behavioural^3	−0.13				
	(0.21)				
ATE_input^3	−406.54				
	(961.36)				
Interaction	8.32*	8.37*	8.40*	6.96*	7.34*
	(4.96)	(4.34)	(4.34)	(4.17)	(4.16)
N	1090	1090	1090	1090	1090
R^2	0.10	0.09	0.09	0.09	0.09
AIC	1516.10	1512.63	1513.03	1512.07	1511.80
F-test	0.0001	0.0000	0.0000	0.0000	0.0000

Notes: Standard errors in parentheses. The dependent variable is *inno*, the binary product innovation dummy. Size, sector, and location dummies included, but not reported. BA: behavioural additionality; IA: input additionality.*$p < 0.1$.

the behavioural additionality when it stands alone. As such, this result suggests that only Equation (4) can be significantly estimated in our data. This equation represents the increment (or decrement) of company innovative performance for any unit change in the input additionality, at each level of behavioural additionality.

Figure 4 reports the plot of this equation, where a significant increasing pattern is discovered. This means that as soon as the behavioural additionality increases, the reactivity of

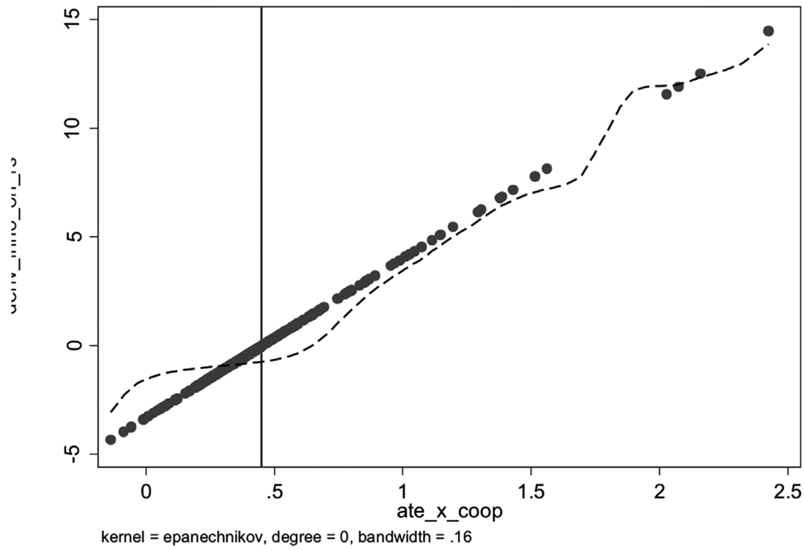

Figure 4. Derivative of firm innovation performance of input additionality at each behavioural additionality point.

Table 4. Mean of 'coop' above and below the behavioural additionality threshold (0.045).

	Obs	Mean	SD	Min	Max
Above	152	1.12	1.41	0	5.25
Below	954	.424	.930	0	5.12

product innovation propensity to input additionality increases accordingly. Nevertheless, a *threshold* is found out for a level of the behavioural additionality (labelled as *ate_x_coop* in the figure) which is around 0.45. Indeed, for values lower than this threshold, the previous derivative is negative (i.e. negative effect of input additionality on product innovation propensity), while for values higher than this threshold, the derivative is positive (i.e. positive effect of input additionality on product innovation propensity). This implies that in order to reap an innovation gain from their R&D activity, companies have to perform above a certain level of behavioural additionality.

Does this finding mean that firms have to increase their number/quality of cooperation efforts to better exploit the effect of their input additionality on innovation? To answer this question, we have calculated the average of our cooperation variable for companies *below* and *above* the 0.45 behavioural additionality threshold. Results in Table 4 illustrate that firms located below the threshold obtain an average cooperation index of 0.42, while those above the threshold obtain an average of 1.13, which is around three times higher. Moreover, Table 4 shows that most of the sample is located below the threshold, thus indicating that cooperation induces also costs and uncertain results.

Given this picture, we can conclude quite soundly that: (i) companies getting a higher behavioural additionality are also those getting a higher cooperation score (that is, a higher score on the cooperation index); and that (ii) companies with higher cooperation scores are also those able to reap the positive effect of their input additionality on their product innovation propensity.

Overall, these results seem to suggest that the main driver of higher innovative performance is the RDI (additional) cooperation activated by the public support: a synergy between this form of behavioural additionality and companies' capacity to profit from higher R&D additionality emerges.

6. Conclusions

The main contribution of this paper is that of providing a more comprehensive understanding of the aetiology behind the impact of R&D support policies on innovation. More specifically, we aimed at clarifying why and how an R&D policy has an additionality impact on private innovation performance. To this end, we have extended the classical framework in which R&D subsidies are mainly meant as tools to relax firm financial constraints (as in David, Hall, and Toole 2000) by assuming that R&D support may have an intermediate impact on R&D spending and collaborations (Busom and Fernandez-Ribas 2008) before determining firm innovation performance.

We suggest that a proper RDI policy evaluation should take into account that various mediating factors are in place when a policy is implemented, and that those factors play a key role in determining the final outcome (e.g. innovation). Thus, policy-makers should consider not only the impact a subsidy can have on firm financial constraints (the usual precondition for an RDI policy to be effective), but also the possible impact on collaboration efforts, as well as the interaction of the two different mediators (i.e. input and the behavioural additionality).

In this respect, our contribution starting point resided in those studies that consider input, behavioural, and output additionality as related phenomena (Clarysse, Bilsen, and Steurs 2006; Steurs et al. 2006). We carried on our investigation by developing and extending the proposals of Czarnitzki and Hussinger (2004) and Cerulli and Potì (2012). Indeed, we proposed a model and a method to open the black box of the analysis of the 'causes of the effects' of public subsidies. We devoted particular attention to the construction of a measure of intensity and quality of cooperation effort. In this respect, the contribution of Laursen and Salter (2006) is close to our approach given a similar choice of the cooperation dimensions. However, we should underline that there exist substantial differences. First, while Laursen and Salter (2006) investigated only the direct effect of their openness measures on innovation performance, we considered them as mediators of the relationship between R&D subsidies and innovation performance. Second, we built a synthetic measure that summarised cooperation effort and its quality while they kept distinct the different dimensions of cooperation (*breadth* and *depth*).

As a result, we introduced a novel point of view – and a related methodology – to study the causal nexus going from R&D subsidies to innovation outcome. Consequently, we went beyond the previous literature that proposed empirical investigations to study:

(1) if and how much subsidies have a direct impact on input additionality (among others, see Aerts and Czarnitzki 2004, 2006; Aerts and Schmidt 2008; Almus and Czarnitzki 2003),
(2) the effect of R&D subsidies on cooperation (Busom and Fernandez-Ribas 2008; Czarnitzki, Ebersberger, and Fier 2007),

(3) the complementarities between cooperation and R&D effort (Cunningam, Gok, and Laredo 2013),
(4) the effect on innovation of *openness* (Laursen and Salter 2006), and
(5) only the direct effect of R&D subsidies on innovation outcomes (Bronzini and Piselli 2013; Merito, Giannangeli, and Bonaccorsi 2007).

Previous literature has not shown convergent results about the effect of R&D subsidies and of subsidised R&D cooperation on innovation. For instance, some studies have shown that individual R&D subsidies can give similar or better results than subsidised R&D cooperation (D'Aspremont and Jacquemin 1988; Folster 1995; Hinloopen 2001). Other research showed that the relation between individual R&D subsidy and voluntary cooperation does not always improve R&D intensity, although it can improve the patent outcome (Czarnitzki, Ebersberger, and Fier 2007).

Our model – and the related econometric method – allows us to show that the RDI cooperation activated by public support can be the driver of a higher innovative performance (Cunningam, Gok, and Laredo 2013): a synergy seems to emerge between this form of behavioural additionality and the company's capacity to take advantage of higher R&D effort induced by the policy. Interestingly, however, we find that such positive synergistic effect is not easily reached and it takes place only *beyond* a given threshold of cooperation additionality. This threshold identifies a demarcating point, where the level of cooperation additionality produces positive synergistic effects. Indeed, by assuming that cooperating embodies not only benefits but also costs, such threshold may identify the point at which benefits start to overcome costs. Below that threshold, the combination of subsidy and R&D collaboration give in fact negative outcomes (costs overcome benefits). Our results extend those of Czarnitzki, Ebersberger, and Fier (2007) who considered collaboration as an additional treatment and not as in our case a factor that can be influenced from the policy as well. In particular, while their main question was about which treatment was more effective, in our case, the question is if and how much one treatment (subsidies) is able to alter the other factor (the cooperation level) and in turn how the two can eventually have an effect on innovative outcome.

Our results suggest that the presence of collaboration in RDI programmes does not assure per se a successful innovative performance of companies. To be successful, an RDI policy action needs two other pre-conditions: on the one hand, a high level of spillovers, due to the relevance and variety of partners and network linkages (whose costs and risks are supported by the policy); and on the other hand, the presence of an additional R&D investment.

These two conditions are probably more present in large-sized firms, which can face the costs associated with R&D cooperation and organisational change. This implication seems coherent with CIS data, showing that the propensity to develop collaborations among the Italian companies that realised an innovation during the period 1998–2000, was strongly correlated with their size: only 5% of firms with 10–19 employees and 13% of firms with 10–19 employees had a cooperation agreement, while 38% of large firms with more than 250 employees were engaged in such agreements.

This research presents also some limitations. First, the data employed allowed us to explore only short-run dynamics. The time span for mediating effects to deliver an impact can be longer than that assumed in our set-up. Second, a further development of the proposed theoretical model, able to account for other possible underlying relations, could be explored. In the path diagram of Figure 1, for instance, there appears to be a missing link between input and behavioural additionality. This could be properly integrated within our framework to develop a full-fledged structural equation model, to test whether the assumed causal links are actually in place. Third, our estimation of input and behavioural additionality relies on mean conditional independence; relaxing this assumption, by exploiting, for instance, an instrumental variable estimation approach (provided that good instruments are available), may be a valuable alternative. Last but not least, it would be interesting to explore our model's results when other forms/measures of behavioural additionality are considered. This could help to obtain a more complete and clear-cut portrait of the mediating effects introduced in this paper; further, this could lend a better understanding of the overall transmission mechanisms going from an R&D policy action to a firm innovation performance.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Giovanni Cerulli http://orcid.org/0000-0002-5892-3372
Roberto Gabriele http://orcid.org/0000-0003-4819-0758
Bianca Potì http://orcid.org/0000-0001-5743-3665

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Appendix 1

Table A1 presents a numerical example to clarify the procedure followed to build the collaboration indicator used in the paper. The indicator is a weighted average of the sum of the different kinds of collaborations of the firm. In the example, firm 1 and firm 2 have the same number of collaborations (3) with the same kinds of partners, namely other firms of the group, suppliers and public research institutes. Nonetheless, the collaborations have different importance for the two firms. Firm 1 judges highly important the collaboration with suppliers, and not important those with other firms of the group and with public research institutes. Conversely, firm 2 gives high relevance to the collaboration with public research institutes, medium relevance to collaboration with its suppliers, and low importance to that with other firms of the group. Our measure for firm 1 has the value: coop(1) = 1.50 and for firm 2: coop(2) = 2.25. A comparison of these values allows us to conclude that collaborations for firm 2 are more important than for firm 1.

Table A1. A numerical example of the calculation of the cooperation relevance indicator for two firms.

	(a)	(b)	(c)
Type of collaboration	Presence of a collaboration	Importance of collaboration*	*(a)* × *(b)*
Firm 1			
Other firms of the same groups	1	0.25	0.25
Suppliers	1	1	1
Customers	0	0	0
Competitor firms	0	0	0
Consultants	0	0	0
Public research institutes	1	0.25	0.25
Coop(1)			**1.50**
Firm 2			
Other firms of the same groups	1	0.5	0.5
Suppliers	1	0.75	0.75
Customers	0	0	0
Competitor firms	0	0	0
Consultants	0	0	0
Public research institutes	1	1	1
Coop(2)			**2.25**

*Importance of collaboration can assume the following values: 0.25 (not important), 0.5, 0.75, 1 (high importance).