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The Role of Firm R&D Effort and Collaborations as Mediating Drivers of Innovation Policy Effectiveness

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Abstract. This paper studies empirically the effect of public incentives to company R&D activity and innovative performance. Compared with the vast theoretical and empirical literature on the subject, we aim at moving some steps forward towards three main directions: (i) First, we provide a new framework incorporating the existence of two *mediating effects* lying between policy and innovation: one related to the effect of the policy on firm R&D activity (the so-called *input-additionality*); the other related to the impact of the policy on firm collaborative R&D strategy (normally defined as *behavioral-additionality*). (ii) Second, we consider the level of company own R&D and the R&D cooperation as "endogenous" (thus not "exogenous") outcomes of a (direct) innovation policy. (iii) Third, we estimate a regression where R&D and collaboration first-step "additionalities" are considered as innovation predictors along with their combined "interaction". The novelty of this approach stands in allowing for identifying possible *synergy* or *weakening mechanisms* between the R&D additionality and the collaboration additionality on the innovation output. This may returns relevant implications for policy making: for instance, it is possible to know whether the two mediating drivers are positively or negatively inter-dependent and whether there exists a statistically significant magnitude of this dependence. A policymaker might find it out useful to know about this inter-relation for bettering future innovation policy fine-tuning.

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1. Introduction: research questions and related literature

The paper studies empirically the effect of public incentives to company R&D activity (investment and collaboration) and innovative performance, using a panel merging the third and fourth wave of the Italian Community Innovation Survey (CIS 3 and 4) referring to the three-year window 1998-2000 and 2002-2004 respectively.

Within the current state-of-the-art, authors have generally studied the effect of an R&D policy on technological output by assuming a "direct" impact of public policy on company innovation (*output-additionality*)[1]. As exception, however, some scholars (Czarnitzki and Hussinger (2004) and Cerulli and Potì (2012)) have provided some improvement by adopting a two-step method for assessing the effectiveness of a policy in fostering innovation *via* its capacity in promoting companies' R&D additionality first.

The present paper outlines a framework incorporating the existence of two *mediating effects* laying between policy and innovation: one related to the effect of the policy on firm R&D investment (*input-additionality*); the other related to the impact of the policy on firm collaborative R&D strategy (*behavioral-additionality*). We consider jointly: the input, the behavioral and the output additionality (Antonioli and Marzucchi, 2012).

We consider the level of own R&D and the R&D cooperation as "endogenous", i.e. the intermediate outcomes of a "financial based" innovation policy. Differently from our approach, Hynloopen (2000) studies the impact on company R&D level of two different policies, subsidy innovation policy and a legal framework allowing firms to develop R&D cooperation, without a public financial support. Czarnitzki et al. (2007) compare the impact of a public incentive policy and that of companies' collaboration strategy (taken as "exogenous" from the policy) on firms R&D level and patenting. Both papers find out that R&D collaboration strategy has a general higher positive effect than subsidy, although strengthened when accompanied with a subsidy.

In this paper we refer to a general subsidy based innovation policy, which includes policies explicitly encouraging the formation of cooperative arrangements in R&D and innovation projects. What we are firstly interested in finding out is "collaboration additionality" promoted by the policy, i.e. the different "quality" of cooperation between supports (or treated) and unsupported (or untreated) companies, which we measure as the number of different cooperating partners weighted by the relevance that the single innovating firm attributes to each type of cooperation. This is a core aspect, since we do not know policy evaluation studies distinguishing R&D cooperation by type, while there are many contributions in the literature looking at the heterogeneity in cooperation

[1] See, for instance, Merito, Giannangeli and Bonaccorsi (2007) and Bronzini and Piselli (2013).

mainly for exploring the determinants of the cooperation type (Belderbosa et al., 2004; Cassiman and Veugelers, 2002; Fritsch and Rolf, 2001) or the effects in terms of cooperation failure vs. survival or of R&D level (Pisano, 1990; Kogut, 1988; De Bondt and Veugelers, 1991). Notwithstanding this, within the literature we find a justification for a policy of subsidy of R&D cooperation in case of more complex collaborative agreements (Lhuillery and Pfister, 2009) and it is also recognized that more heterogeneous cooperation, even if more risky, can produce a deeper innovation effect (Feldman and Kelley, 2006). The qualitative change in collaborative behavior, which can be generated by the policy (for treated and for untreated firms) in our framework, finally impact on the propensity to innovate. We choose not to explore the effect on the innovation sales or profit, which could mean to treat the output as a black box in absence of other variable explaining the firm environment.

Our research goal is that of studying the ultimate effect of R&D and innovation policy support on company invention and innovation propensity (*output additionality*) through the *mediating effect* the subsidy has had on company own R&D (*input additionality*) and R&D cooperation strategy (*behavioral additionality*). The possibility of a contemporary presence of two intermediate effects (input additionality and collaborative behavior additionality) allows us to explore their relations towards the propensity to innovate. The novelty of our approach stands in allowing for identifying possible *synergy* or *weakening mechanisms* between the R&D additionality and the collaboration additionality on the innovation output. This may returns relevant policy making implications: for instance, it is possible to know whether the two mediating drivers are positively or negatively inter-dependent and whether there exists a statistically significant magnitude of this dependence. Does a more heterogeneous cooperation or a cooperation, which is recognized as important by firms (representing our meaning of cooperation additionality) have always a positive impact on the effect that an additional investment on R&D produces on the firm's propensity to innovate? And when (in presence of which factors) this is the case? The literature doesn't give a convergent answer: asymmetries, for instance in terms of technological capabilities, may seriously influence the costs and benefits from cooperation; partners need each other to realise synergies, but at the same time heterogeneity exacerbates coordination problems (Doz, 1988). The empirical literature on failure of cooperation (Kogut, 1988; Harrigan, 1988) suggests that similarities between partners, defined by size, technological origin and nationality, increase the duration of cooperation, leading to more stable arrangements. Sinha and Cusumano (1991) find that complementarity increases the incentives to cooperate and big firms have a larger incentive to cooperate than small firms. Moreover, some studies including variables for cooperation in their models for explaining innovative sales, have a mixed evidence. Klomp and van Leeuwen (2001)

find a positive impact of a cooperation dummy variable on the innovation output of firms. Janz et al. (2004) analyze the determinants of innovation performance in Sweden and Germany and include variables for cooperation among firms in their equation for the determinants of innovation sales per employee, but they don't find a significant impact of R&D cooperation with suppliers, customers, universities, or research institutes on innovation performance in the same period, while R&D cooperation with competitors has a negative effect on innovative sales.

2. Research design, methodology and data

As stated in the previous section, our research goal is that of studying the ultimate effect of R&D and innovation (RDI) support on company invention and innovation activity (*output additionality*) through the *mediating effect* the subsidy has had on company own R&D (*input additionality*) and RDI cooperation strategy (*behavioral additionality*). The causal path-diagram of our model is represented below (Fig. A).

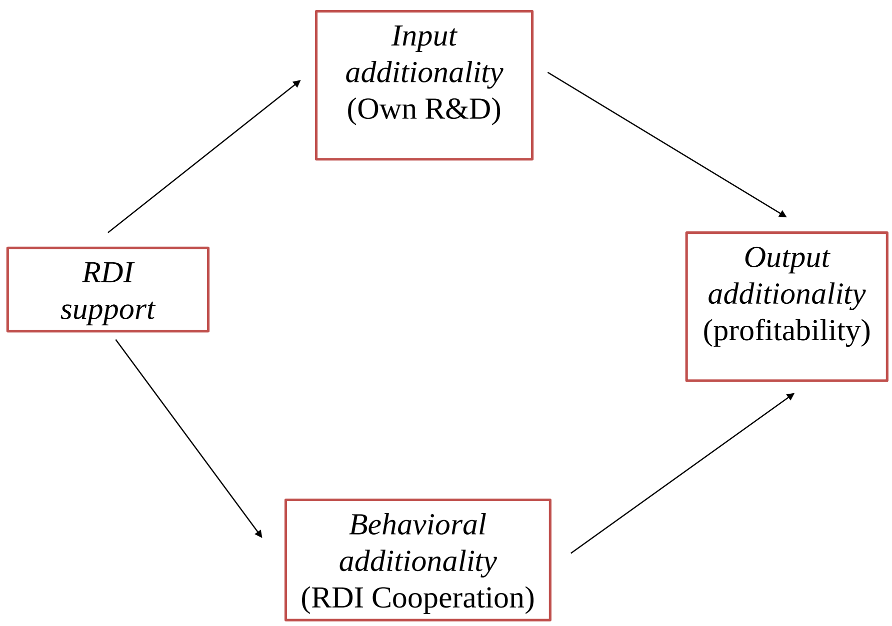


Figure A. Path-diagram of the model.

As econometric counterpart of the previous diagram, we employ a *treatment random coefficient model* (see Wooldridge, 2010, p. 945-951), implemented in STATA through the routine IVTREATREG by Cerulli (2012). This model allows to estimate, for each company, an idiosyncratic effect of the support on R&D and cooperation: formally, it is defined as the Average

Treatment Effect conditional on a vector of covariates **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) $ATE_{input}(\mathbf{x}_i)$ = average treatment effect of RDI support on company *i* R&D (idiosyncratic input additionality)

(2) $ATE_{behavioral}(\mathbf{x}_i)$ = average treatment effect of RDI support on company *i* degree of cooperation (idiosyncratic behavioral 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:

$$Y = a + b\ ATE_{input}(\mathbf{x}_i) + c\ ATE_{behavioral}(\mathbf{x}_i) + d\ ATE_{input}(\mathbf{x}_i)\ ATE_{behavioral}(\mathbf{x}_i) + e\ \mathbf{w} + error \quad (1)$$

where:

Y: is a binary innovation outcome measuring the presence/absence of product innovation;

w: is a vector of covariates explaining invention/innovation performance.

Observe that equation (1) shows also an interaction between $ATE_{input}(\mathbf{x}_i)$ and $ATE_{behavioral}(\mathbf{x}_i)$ so that, in terms of derivatives, we have that:

$$\Delta Y/\Delta\ ATE_{input}(\mathbf{x}_i) = b + d\ ATE_{behavioral}(\mathbf{x}_i) \quad (2)$$

$$\Delta Y/\Delta\ ATE_{behavioral}(\mathbf{x}_i) = c + d\ ATE_{input}(\mathbf{x}_i) \quad (3)$$

Equations (2) and (3) clearly show that the effect of the input additionality on invention/innovation depends (linearly) on behavioral additionality and vice versa. Therefore, our approach will allow us also for taking into account potential synergistic or weakening effects of combined input and behavioral additionality on output performance.

Finally, this treatment model can be used to calculate input and behavioral additionality on two sub-populations of interest: supported and unsupported companies. It would be possible, for instance, to know whether the input and behavioral additionality have been higher for supported rather than unsupported companies. Answering this question has immediate 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 program have picked up companies to support having lower additionality potential.

The dataset employed is a panel built merging the third and fourth wave of the Italian Community Innovation Survey (CIS 3 and 4) collecting a large set of innovation and R&D-related variables for the three-year window 1998-2000 and 2002-2004 for a sample of manufacturing and services companies. This dataset is then merged with company balance sheet data (AIDA dataset). All the fundamental target and control variables needed for applying our model are available in CIS 3 and 4 plus AIDA, and the RDI subsidy takes the form of a binary variable (supported vs. non-supported).

A particular attention should be devoted to the definition of our variable measuring the intensity of collaborations. We used the question about the collaboration activities of firms, respectively the questions: 10.1 in CIS3 and 6.4 in CIS4. First, we build an indicator according to the number of different type of collaboration carried on in the three years of the survey, which ranges from 0 –no collaborations at all– to 6 –all the types of cooperation are present. The different typologies are those defined by different kind of partner, namely: other firms of the same groups, suppliers, customers, competitor firms, consultants, public research institutes. Secondly, we weighted the indicator assigning more weight to the type of collaborations that firm declares to be more important from the point of view of its relevance as a source of information for innovation[2]. The weights range in the discrete set {1/4; 2/4; 3/4; 4/4}. More formally, we built for each firm the following indicator[3]:

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

where the index k=1,...,6 spans over all the different typologies of collaboration; $\mathrm{I}(\mathrm{coop}_k = 1)$ is an indicator variable that assumes the value 1, if the typology of collaboration is present for firm and 0 otherwise; w_k is the weight that firm assigns to the k^{th} type of collaboration. The indicator ranges from 0 to 6.

3. Results

Table 1 and 2 show the results on the behavioral additionality and R&D intensity using the RDI cooperation variable defined above and the R&D intensity (total intra-muros R&D expenditure on

[2] We refer to question 11.1 in CIS3 and 6.1 in CIS4.
[3] We suppress the subscript *i* for sake of clarity.

turnover) respectively. Due to an abundant presence of missing values the sample size drops to around 1,100 companies.

Table 1 sets out a positive and strong significance of receiving RDI support (our binary treatment variable) on cooperation. The level of ATE is – in this case – around 0.37. As said above, to get this result we make use of a treatment random-coefficient model as proposed by Wooldridge (2010, p. 945-951) implemented in Stata by Cerulli (2012). 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 (to be interpreted as "confounding variables") whose meaning is clearly evident: *size* – measured as number of employees – identifies company scale economy in its collaborative 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 overcome liquidity constrains through accessing bank loans and is a fundamental asset shaping the capital structure of the firm; *knowledge* – measured as the stock of capitalized 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; finally, *size*, *sector* and *location* dummies are also considered in the regression estimation but not reported in the table.

Table 1. Behavioral additionality. Result on the Average Treatment Effect emphasized in grey. Dep. Var.: "coop".

Linear regression	
Number of obs	= 1106
F(59, 1043)	= .
Prob > F	= .
R-squared	= 0.2278
Root MSE	= .93983

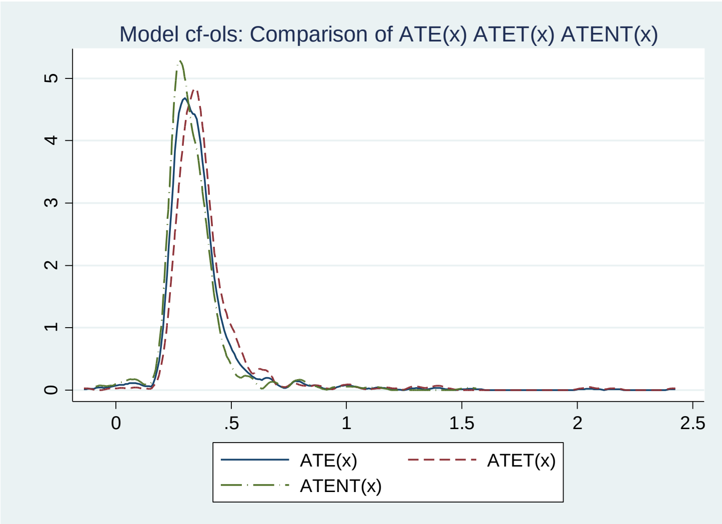
coop	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
treatment	.3662396	.0608791	6.02	0.000	.2467801	.4856992
size	.0000688	.0000594	1.16	0.248	-.0000479	.0001854
cash-flow	.0010851	.0008374	1.30	0.195	-.0005581	.0027283
debt	.1832657	.1813152	1.01	0.312	-.1725185	.5390498
knowledge	-6.83e-06	.0000405	-0.17	0.866	-.0000864	.0000727
foreign	-.0195174	.0751174	-0.26	0.795	-.1669159	.1278811
age	-.1103275	.1886217	-0.58	0.559	-.4804487	.2597937

Note: size, sector and location dummies included.

Table 1 shows that the significance of these control variables is poor. Observe moreover that they are measured at the outset on the two time windows selected, i.e. 1998 for CIS 3 and 2002 for CIS 4, to take them as pre-treatment variables as much as possible.

Table 2 reports results for R&D intensity (or input) additionality, using the same control variables. Also in this case results show a highly significant and positive effect of RDI support on R&D performance with a value of ATE around 0.016. As in the case of behavioral additionality confounders are poorly significant. Figure 2, similarly to figure 1, shows the distribution of ATE(**x**) when R&D intensity is considered as target variable. The well bell-shaped form centered in 0.016 is easily visible.

Figure 1. Distribution of ATE(**x**) for the behavioral additionality.



More interestingly, Table 3 sets out an estimation of Equation (1). As said above, we regress the binary innovation variable *inno* – taking one for companies performing some product innovation in the period covered by CIS3 and CIS4 and zero otherwise – on behavioral additionality (ATE(**x**) for cooperation), input additionality (ATE(**x**) for R&D intensity) plus their multiplicative interaction along with size, sector and location controls.

It is worth noticing that, we also tried a third-degree polynomial specification of the *y*-equation in order to test whether the relation between the previous two equations is or is not linear. We found no significance of squared and cubic terms. Therefore, we can accept the linear relation as a good proxy.

Results stress a significant effect of the input additionality and of the interaction between input and behavioral additionality, but no significance for the coefficient of the behavioral additionality alone. As such, this result suggests that only Equation (2) can be estimated significantly. As stressed above, this equation represents the increment (or decrement) of company innovative performance for any unit change in the input additionality, at a given level of behavioral additionality.

Table 2. Input additionality. Result on the Average Treatment Effect emphasized in grey. Dep. Var.: "R&D intensity".

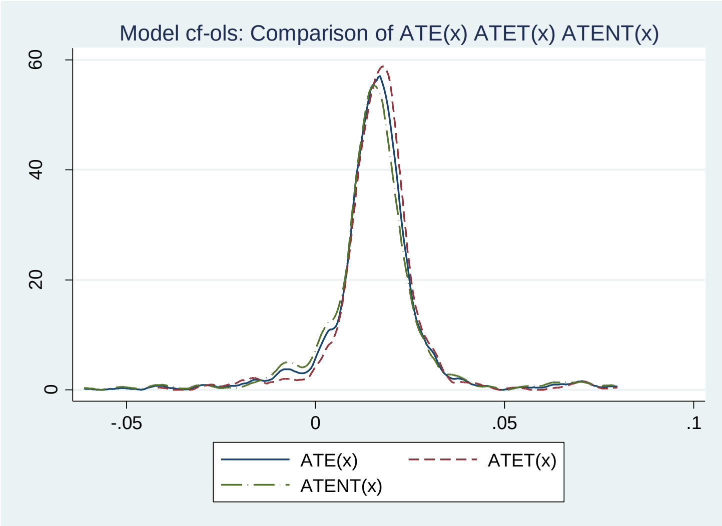
```
Linear regression                                      Number of obs =    1106
                                                       F( 59,  1043) =       .
                                                       Prob > F      =       .
                                                       R-squared     =  0.4925
                                                       Root MSE      =  .04658

------------------------------------------------------------------------------
             |               Robust
RD_intensity |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   treatment |   .0158098   .0032757     4.83   0.000      .0093821    .0222375
        size |   6.79e-07   1.16e-06     0.58   0.560     -1.60e-06    2.96e-06
   cash-flow |   .0000825   .0000647     1.27   0.203     -.0000445    .0002095
        debt |    .014536   .0105415     1.38   0.168     -.0061489     .035221
   knowledge |   2.03e-07   7.47e-07     0.27   0.786     -1.26e-06    1.67e-06
     foreign |  -.0000184   .0030228    -0.01   0.995     -.0059498     .005913
         age |  -.0031927   .0046908    -0.68   0.496     -.0123971    .0060118
```

Note: size, sector and location dummies included.

The plot of this equation is visible in Figure 3, where a clear significant increasing pattern is found out. It means that, as soon as the behavioral additionality increases, the reactivity of innovation to input additionality increases too. Nevertheless, a *threshold* is found out for a level of the behavioral additionality (labeled as "ate_x_coop") around 0.45: indeed, for values lower than this threshold the previous derivative is negative (i.e. negative effect of input additionality on innovation), while for values higher than this threshold the derivative is positive (i.e. positive effect of input additionality on innovation). It means that, in order to reap an innovation gain from their R&D activity, companies have to perform above a certain level of behavioral additionality.

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



Does it means that firms have to increases their number/quality of cooperation 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 behavioral additionality threshold. Results in Table 4 clearly show that firms below the threshold perform an average cooperation index of 0.42, while those above perform an average of 1.13 that is around three time higher. Moreover, Table 4 shows that the most part of the sample is located below the threshold, thus indicating that cooperation induces costs and uncertain results.

Given this picture, we can conclude quite soundly that: (i) companies getting a higher behavioral additionality are also those getting a higher cooperation score (that is higher quantitative/qualitative degree of cooperation); (ii) companies with higher cooperation scores are also those able to reap positive effect of their input additionality on innovation.

Overall, in our framework, these results seem to suggest that the main driver of higher innovative performance is the RDI cooperation activated by the public support: it seems to emerge a “synergy” between this form of behavioral additionality and company capacity to profit of higher R&D additionality.

Table 3. Regression for the innovation performance with input, behavioral and their interaction as covariates.

Source	SS	df	MS
Model	23.5034103	52	.45198866
Residual	231.777324	1037	.223507544
Total	255.280734	1089	.23441757

Number of obs	=	1090
F(52, 1037)	=	2.02
Prob > F	=	0.0000
R-squared	=	0.0921
Adj R-squared	=	0.0465
Root MSE	=	.47277

inno	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ate_x_coop	-.1084312	.091358	-1.19	0.236	-.2876988	.0708364
ate_x_rs	-3.334911	1.830052	-1.82	0.069	-6.925938	.2561163
interaction	7.339334	4.158188	1.77	0.078	-.8200873	15.49876

Note: size, sector and location dummies included.

Figure 3. Derivative of firm innovation performance of input additionality at each behavioral additionality point.

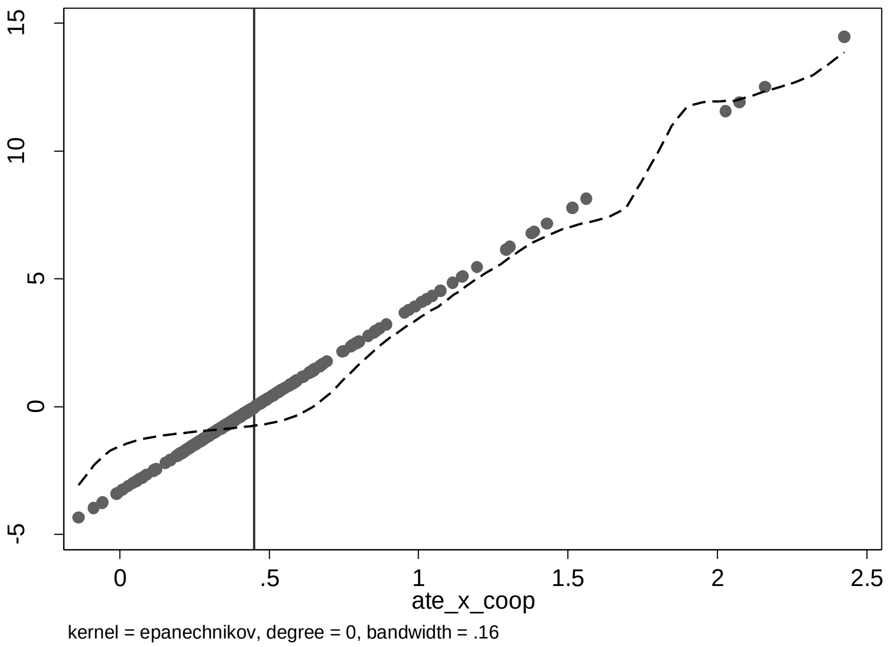


Table 4. Mean of “coop” above and below the behavioral additionality threshold.

Mean of “coop” for companies above the 0.045 behavioral additionality threshold

Variable	Obs	Mean	Std. Dev.	Min	Max
coop	152	1.128289	1.41538	0	5.25

Mean of “coop” for companies below the 0.045 behavioral additionality threshold

Variable	Obs	Mean	Std. Dev.	Min	Max
coop	954	.4240042	.9307172	0	5.125

4. Conclusions and policy implications

The main contribution of the paper is to go towards a more comprehensive understanding of the "etiology" of the impact of R&D support policies on innovation: we aim at clarifying why and how the R&D policy has an additionality impact on private R&D efforts. To do so, we extend the existing framework in which the R&D subsidy has an impact on the level of financial constraints experimented by the firm (David, Hall and Toole, 2000) and assume that R&D subsidies may have a simultaneous impact also on firm R&D collaborations.

We suggest that it is possible to fine tune the policy measure taking into account that various mediating factors are in place and that they can play a key role in determining the final result. Policy makers have to consider the impact of the subsidy on financial constraint experimented by firms, but also the possible effect on their collaboration effort and the interaction of the two different mediators. The treatment effects' interaction allows us to investigate if substitutability or complementarity is in place.

Overall these results seem to suggest that the main driver of higher innovative performance is the RDI cooperation activated by the public support. It seems to emerge a "synergy" between this form of behavioral additionality and company capacity to profit of higher R&D additionality. However, a positive synergistic effect takes place only beyond a threshold value of the cooperation additionality. This threshold identifies a demarcating point where the level of cooperation additionality produces positive synergistic effects. Once assumed that cooperating embodies both costs and benefits, the threshold identifies the point at which benefits overcome costs.

From a policy perspective our results suggest that the selection operated by the policy maker should favor high degree of collaborations where complexity and relevance of a variety of partner and network linkages are substantial. Therefore, the only presence of collaboration in RDI programs does not assure *per se* a successful innovative performance.

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