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The contrasting effects of active and passive cooperation on innovation and productivity: Evidence from British local innovation networks

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A R T I C L E I N F O

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A B S T R A C T

This paper studies the contrasting effects on innovations and productivity arising from active cooperation in innovation activities among competitors and from passive cooperation induced by these activities' spillovers. A three-stage productivity function is estimated showing that firms' innovations are supported by their active cooperation within their local innovation network of suppliers and customers and by passive cooperation through sectors' spillovers. Contrary to this, active cooperation in innovation activities among competitors reduces their innovation rates and, indirectly, productivity. Hence, innovation policies and strategies aimed at restraining active cooperation among competitors, while encouraging it within a firm's local innovation network, may contribute to the system-wide introduction of process and product innovations and ultimately productivity.

1. Introduction

When incorporated into production activities, product, process and organizational innovations operate as the key engine of economic growth and increased productivity leading to comparative advantages of nations, regions, cities and, obviously, firms. Since the early eighties, this innovation-growth link has been modelled using increasing returns production functions leading to potentially unlimited growth. More recently, research on economic growth focussed on assessing the different roles played by separate production inputs in affecting productivity. Among these factors, the set of a firm's innovation activities, often described as *its intangible capital* (Corrado et al., 2005), is of particular interest in explaining productivity dynamics (Van Reenen et al., 2005). Innovative activities, such as expenditure on internal and external R & D and training towards innovation play a direct role for the successful introduction of innovations, assisting in building a firm's capacity for absorbing innovation knowledge produced elsewhere (Cohen and Levinthal, 1989; D'Souza and Kulkarni, 2015). This absorptive capacity facilitates innovation knowledge exchanges, both explicitly, through *active cooperation* and implicitly, via the spillovers arising from the interaction with other actors within their *local innovation network (LIN)*. Given their emphasis on cooperation linkages, LINs can be traced back, on the one hand to the Value Chain Networks as organizations whose performance revolves around the modalities of partners' selection (Talluri et al., 1999) and, on the other, to the Local Supply Chain Networks defined by the direct cooperative interconnections used in the provision of digital commodities (D'Ignazio and Giovannetti 2014). To emphasise the difference between the deliberate firms' choices on *active cooperation* and the implicit knowledge benefits arising from innovation spillovers, this paper conceptualises the latter as a form of *passive cooperation*.

Despite of its positive knowledge transfer benefits, the introduction of innovations may also exert a negative impact on the profitability of the market competitors of an innovating firm's product, due to the strategic effects associated with increased *product market rivalry* (Bloom et al., 2013; Aghion et al., 2005). Hence, competitors could have an incentive to reduce their joint innovation efforts and may implement this objective by using *active cooperation* as a strategic coordination device.

To disentangle these, potentially opposite, effects of *passive* and *active cooperation*, this paper estimates an innovation production function (Crépon et al., 1998) for a panel of UK firms across the main sectors of the UK economy. This function links innovation survey data on intangibles (Expenditure on internal and external Research and Development (R & D), on training for innovative activities and on advertising) and data on *active* firms' cooperation choices with a firm's introduction of product, process and organizational innovations. Once the predicted innovation levels are obtained, the model then assesses the direct and indirect impact of these innovations on firms' productivity.

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This paper's main findings will show that: when *active cooperation* in innovative activities takes place among product market competitors, one observes an indirect negative impact on innovation and productivity, confirming the hypothesis that cooperation can be used as a coordination device to reduce the market rivalry that would otherwise result from higher innovation rates. These negative effects on innovation, due to *active cooperation* among competitors, are contrasted with the empirical findings about the positive effects on innovation and productivity observed when firms *actively* cooperate in innovative activities within their *local innovation network,* composed by the set of relevant customers, suppliers, research institutions and public bodies. Hence, the paper, extending the insights from Link and Marxt (2004) on the risks of cooperation for networked organizations, shows that the impact of *active cooperation* on innovations and productivity will be substantially different, depending on the nature of the relations between the cooperating firms.

Contrary to the results observed for *active* cooperation, this paper will also show that, when cooperation is *passive*, through spillovers of innovative activities, its effects on innovation are positive, independently of the nature of the relation among firms, confirming the notion that spillovers do not arise as the outcome of a strategic decision but as the by-product of supply chain proximity. The remainder of the paper is structured as follows: section two briefly revises the relevant theoretical framework and introduces the main hypotheses to be tested. Section three describes the data utilised for the micro-evidence on innovation activities, innovation outcomes and productivity at firm level in the UK. Based on these data, section four develops the three-stage econometric model separately estimating the effects on innovations and productivity exerted by *passive* and *active, network* and *horizontal* cooperation. Section five discusses these estimations results and, finally, section six contains the conclusions, indicating the relevant policy and managerial implications, limitations and possible further development of this research.

2. Related literature and hypotheses development

This section discusses the relevant literature required to develop the research hypotheses that will be subsequently tested and discussed in the paper. The first two subsections will focus on the literature relevant to discuss *active* and *passive* cooperation respectively, while the last one will be discussing contributions linking innovations to productivity.

2.1. Active horizontal cooperation as a coordination device to mitigate the creative destruction of innovation

The negative impact of horizontal cooperation on innovation was recently discussed by Tomlinson and Jackson (2013) in their study on innovation in the North Staffordshire Table and Giftware Sector. Using innovation survey data, these authors interpret this negative relation as resulting from the desire to avoid duplication of innovative efforts. This paper, using innovation survey data for the entire UK, also finds a negative relation between horizontal *active* cooperation and innovation, but the focus is on a strategic, rather than an efficiency, interpretation based on the adverse and disruptive impact of innovation on product market competitors (Aghion and Howitt, 2008). Building on this tradition, this paper considers product, process and organizational innovations as the outcome of the strategic interaction among profit motivated firms who would exploit any available source of active cooperation with suppliers, customers and other actors of the LIN to innovate and outperform competitors, while simultaneously seeking (horizontal) *active* cooperation with their competitors to mitigate the *creative destruction* (Schumpeter, 1942) effects of innovations. Along similar lines,) Giovannetti (2001, 2013) showed that firms could use a strategy of alternating adoptions of cost reducing innovations as a coordination device to mitigate the adverse effects of innovation-induced rivalry. In this setting, *active* cooperation among direct competitors can be used as a coordination device to reduce aggregate innovation levels and their potentially negative impact on collective profitability. This theoretical framework leads to the first testable hypothesis of the paper:

H1. *The impact of active cooperation on innovation outcomes changes, depending on the type of relation between the cooperating firms.*

This hypothesis can be further qualified via two separate hypotheses: the first one, H1.1, stated below, expresses the negative impact of *active* horizontal cooperation on innovation, and a second one, H1.2, stated after a revision of additional literature, focussing, on the contrary, on the positive effects on innovation of *active* cooperation across LINs.

H1.1. *Active horizontal cooperation towards innovation, among firms competing in the same sector reduces innovations.*

Moving to the findings on the positive impact of *active* cooperation on innovation, De Propris (2002), using survey data focussing on small firms in the West Midlands region of the UK, found that production networks between buyers and suppliers characterising "vertical cooperation" along the supply chain exert a positive impact on the probability of introducing innovations. Although De Propris (2002) also distinguishes between the effects of cooperation on radical and incremental innovations (see OECD/Eurostat, 2005), this paper does not focus on this relevant distinction as it introduces a model that jointly estimates the impact of cooperation on product, process and organizational innovations and, for these last types of innovations such distinction is not appropriate and data not available. Similarly, Freel and Harrison (2006), using data on cooperative ties and innovation in small and medium-sized manufacturing and service firms in Northern England and Scotland, also found a positive impact on innovation of collaboration along the supply chain. Building on these results, this paper also finds a positive impact of *active* cooperation within a *LIN* on innovation. This is addressed through the next hypothesis.

H1.2. *Active cooperation towards innovation among firms in the same LIN favours innovations.*

2.2. Passive cooperation from spillovers and innovation

The study of the relations between firms engaging in innovative activities is central to the literature on *open innovation networks* (OINs) emphasising the multi-relational, cooperative and open nature of contemporary innovation activities (Chesbrough, 2003). However, these cooperative relations forming the building blocks of an OIN, not only change due to the nature of the relation between firms, as discussed under H1, but also depend on the mode of cooperation.

Cooperation can be either explicit (*active*) as discussed above, or implicit (*passive*) due to *spillovers* in innovative activities. *Spillovers*, first discussed in Marshall (1890) as arising from agglomeration, were modelled by Arrow (1962) as the result of learning by doing. They were then linked to a firm's innovation processes by Nordhaus (1969) and explicitly incorporated into an endogenous growth model by Romer (1986). Sena (2004) provides an insightful review of the empirical literature on spillovers identifying three main routes for innovation knowledge to flow across firms. The first is based on intermediate input flows between firms, seen as the means of knowledge transmission (Nadiri, 1993). Following Los and Verspagen (2000) and Keller (2002) this paper also models these flows as spillovers based on a *trade-proximity* metrics for the transmission of productive knowledge. As emphasised in Bartelsman et al. (1994), these externalities capture both suppliers and customers' driven spillovers, the role of customers having been initially identified in the pioneering studies of Von Hippel, (1976, 1988) on scientific instrument innovations, finding that approximately 80% of these innovations were due to users of the instrument rather than by instrument manufacturers. Building on this literature, this paper measures production's proximity spillovers by calculating production space distance metrics based on the UK Input Output tables, as these provide the degrees of value chain integration across different sectors of the economy.

The second route for the diffusion of the spillovers, identified by Sena, focuses on imitation of the R & D performed by other innovating firms, either in the same sector (Bernstein and Nadiri, 1988) or across different sectors using a shared technology. This paper takes account of this additional route, by explicitly including estimates for the amount of R & D performed, both in the same and in related sectors, as a key input for the innovation production function.

Finally, the third route for the diffusion of spillovers focuses on the role of geographic proximity (Jaffe et al., 1993). Proximity is relevant as it facilitates *face to face* interaction among employees from different firms, and this can be a powerful means of diffusion of tacit knowledge. In reviewing the vast literature on geographic spillovers, Crescenzi and Rodrıguez-Pose (2012) concluded that in Europe “knowledge flows tend to be driven more by commuting patterns and temporary proximity than by the migration of ‘knowledgeable’ individuals” interpreted by Dosi et al. (2006) in terms of the lower propensity towards relocations characterising the European labour markets with respect to the US one. Based on this evidence, this paper adopts the *Travel to work areas* (TTWAs) as defining the geographic boundaries needed to identify the range of geographic spillovers. The TTWAs are constructed using observed workers' commuting patterns (Office for National Statistics, 2011) and are used in this paper to model the boundaries for the effective circulation and spread of ideas, due to casual workers' interaction.

The literature on spillovers shows how these may result from the location of a firm in a wider set of relations, indicating proximity either in the production or in the geographic space. In particular, the relevance of cities in defining these externalities was emphasised in the work by Jacobs (1969), focussing on the role played by the diversity of the technological base, typical of cities, and on its relevance to facilitate experimentation, spillovers and hence new innovation. The paper's focus on the difference between the effects on innovation exerted by *active* and *passive* cooperation, fills a relevant gap in the literature and leads to the second key research question, asking whether the effects of cooperation on innovation also differ depending on the modality of cooperation, i.e. whether cooperation is the result of an explicit decision, linked to profit seeking behaviour, or the passive consequence of the presence of spillovers. To address this research question the paper will focus on a second set of hypotheses.

H2. *Passive cooperation, based on innovative activities' spillovers, facilitates innovations.*

Building on the literature discussed above, this paper will separately consider spillovers due to geographic and production proximity. Hence, it is possible to refine H2 into two different hypotheses.

H2.1. *Passive cooperation, based on innovative activities' spillovers arising from production proximity, facilitates innovations. And,*

H2.2. *Passive cooperation, based on innovative activities' spillovers, arising from geographic proximity based on workers commuting patterns, facilitates innovations.*

2.3. Linking cooperation, innovation and productivity

The third and final stage of the model introduced in this paper studies the direct effects on productivity of process, product and organizational innovations and the direct and indirect ones of innovative activities, their spillovers and the different forms of active and passive cooperation discussed in the previous sections. Sena (2004) estimated similar spillovers' effects on productivity for a panel of Italian firms using *the Malmquist index of productivity growth* (Caves et al., 1982; Fare et al., 1992) and focusing on knowledge transfers between low and high tech firms. While leading to interesting estimation of the spillovers effects on productivity, this approach does not allow to capture the potential differences of impact on productivity between *active* and *passive cooperation,* as hypothesised in this paper. More recently, the impact on productivity of both agglomeration forces and knowledge externalities was estimated by Autant-Bernard et al. (2011) using the *Luenberger Productivity Indicator* for a dataset of French firms. Starting from a similar perspective, this paper moves these authors' research question one step forward by asking whether the effects on innovation and productivity of spillovers capturing informal and implicit cooperation, are actively contrasted through explicit *active cooperation* strategies. In estimating these effects, this paper utilises two different accounting measures of productivity: gross value added (GVA), and the gross profit margin (GPM) normalised by the firm's total turnover. Both measures identify a proxy for a firm's profitability and are often used in productivity analysis (Medda and Piga, 2014).

The potentially multifaceted nature of the relation between cooperation in innovation and productivity leads to the final set of hypotheses tested in the paper:

H3. *The impact of cooperation on productivity depends both on the modalities of cooperation and on the relations between the cooperating firms.*

Hypothesis H3 can be further refined by focussing on the different potential effects of *passive* and *active cooperation* on productivity and, by separately considering whether the actively cooperating firms are competitors or other actors of the *local innovation network*:

H3.1. *The impact on productivity of active cooperation among firms competing in the same sector is indirect and negative.*

H3.2. *The impact on productivity of active cooperation among non-competing firms, part of a local innovation network, is indirect and positive.*

H3.3. *The impact on productivity of passive cooperation in innovation activities among firms is indirect and positive.*

3. Data sources

All the data was accessed through the Secure Access system of the UK Data Archive. The main data source was the UK Community Innovation Survey (CIS) (Department for Business, Innovation and Skills and ONS, 2015). These data provide a detailed decomposition of a firm's innovation activities into different *intangible assets,* identified as enablers in building a firm's capacity of absorbing knowledge produced elsewhere. The same data also provide survey evidence of explicit cooperation towards innovation, classified according to the existing relations between the cooperating firms.

The data used for the estimations cover four different CIS releases: CIS 4 (period 2002–2004), CIS 5 (period 2004–2006), CIS 6 (period 2006–2008) and the CIS 7 (period 2008–2010). Each CIS questionnaire allows to identify a firm's location, sector of activity, innovation-related activities such as R & D and training for innovations and, crucially for the hypotheses discussed in the previous sections, a set of questions about the active forms of cooperation in innovation activities chosen by the firms. The CIS data are merged with the Annual Respondents Database (ARD) dataset (Office for National Statistics, 2012) to obtain additional information on firms' turnover, employment, costs, capital expenditures and the derivation of sales and profits. The Business Enterprise Research and Development (BERD) dataset, (Office for National Statistics, 2015) was instead used to construct total annual measures of R & D expenditure, aggregated either at the sector or at geographical level.

Sector spillovers of innovative activities, capturing *passive cooperation* through production proximity, were constructed by multiplying the total values of each sector's R & D and training, by a matrix of sector weights derived from the ONS Input-Output matrix of the UK economy (Office for National Statistics, 2017). Geographic spillovers were similarly calculated using a matrix of weights based on the inverse of the distance between *TTWAs* (Office for National Statistics, 2011, map V2).

The key independent variables used to test the paper's hypotheses are:

- The sector spillovers due to investment in intangibles innovation activities (R & D and training); as a proxy for *passive cooperation,* and
- The set of cooperative relations: with customers, suppliers and competitors, as explicitly reported by the firms in the CIS surveys, showing *active cooperation.*

In detail, these active cooperation variables are defined from the answers to question 16 of the CIS Innovation Survey. This asks “Did your business co-operate on any innovation activities with any of the following: A. other businesses within your enterprise group? B. suppliers of equipment, materials, services or software? C. clients, customers or end users? D. competitors or other businesses in your industry? E. consultants, commercial labs, or private R & D institutes? F. universities or other higher education institutions? G. government or public research institutes?” CIS (2010).

The data on product innovations, used to obtain this intermediate stage dependent variable are provided by each firm's answer to the relevant question in each one of the four CIS waves; for example: question 6 of the CIS (2010) questionnaire, asks to: “Include all new or significantly improved goods or services e.g., improvement in quality or distinct user benefits. The innovation, although new to this business, does not need to be new to the market. Include all product innovations, regardless of their origin.” CIS (2010). From the answers to these questions, the first dependent variable is obtained:

- *Product innovations:* a binary dependent variable indicating whether a firm introduced new or significantly improved goods or services.

  Similarly, each firm was asked, for example in question 10 of the CIS (2010) questionnaire, to include both incremental and radical process innovations, defined as: “All new or significantly improved methods for the production or supply of goods or services. The innovation, although new to the business, does not need to be new to your industry. Include all process innovations, regardless of their origin.” CIS (2010). From the answers to these questions, the second dependent variable is obtained:
- *Process innovations:* a binary dependent variable indicating whether a firm introduced new or significantly improved methods for the production or supply of goods or services.

  Finally, also for organizational innovations each firm was asked in question 3 of the CIS (2010) questionnaire to “Include all new and significantly improved forms of organisation, business structures or practices aimed at raising internal efficiency or the effectiveness of approaching markets and customers.” CIS (2010). From the answers to these questions, the third dependent variable is obtained:
- *Organizational innovations*: a binary dependent variable indicating whether a firm introduced new business practices for organising procedures and new methods of organising work responsibilities and decision making or new methods of organising external relationships with other firms or public institutions.

It is important to notice that this question asks firms to list the introduction of both incremental and radical innovations (OECD/Eurostat, 2005) and our estimates do not further differentiate between radical and incremental innovations as the paper's focus is on the joint estimation of all product, process and organizational innovations and, for this last type of innovation there is no specific question providing information on whether an innovation was radical or incremental. We are grateful to an anonymous referee for clarifying this point.

Finally, the last two dependent variables used to measure productivity were obtained from the ARD database:

- *Gross value added* (GVA), obtained as the difference between total revenues and the cost of materials and labour, and
- *Gross profit margin* (GPM), which is equal to the GVA minus capital expenditures.

4. The econometric model: a three-stage approach

The econometric model introduced in this section focuses on the possibly conflicting roles played by *active* and *passive cooperation,* on the probability of introducing innovations and then on productivity across three separate estimation stages. A similar sequential approach was introduced by Crépon, Duguet and Mairesse (1998) to estimate a knowledge production function (Pakes and Griliches, 1984). Czernich et al. (2011) and Hall et al. (2012) also followed a multistage estimation approach to address the role of ICT in R & D and overall growth. The main benefit of concentrating on this sequential approach is that it provides a finer understanding of the channels, both positive and negative, used by innovative activities to percolate through the production system.

The sequence of estimation stages used in this paper is articulated as follows:

- In the first stage of the estimation strategy, due to the censored nature of the observations from the CIS sample, four separate Tobit models, are used to predict, the intensities of four different types of innovative activities: 1) Internal R & D, 2) External R & D, 3) Training expenses and 4) Advertising. The relevant covariates used in this stage, focus on *active cooperation* and on *passive cooperation* arising from geographic spillovers.
- In the second step of the model, an innovation production function is estimated using a *multivariate probit model.* This model's main covariates are the predicted values of R & D, training and advertising intensities, obtained in the first stage. We include these predicted values of the intangibles intensities to account for the firms that while not reporting them still perform some innovation efforts (Griffith et al., 2006). As additional covariates this stage includes the sector spillovers in R & D activities as a proxy for *passive cooperation.* The model allows to jointly estimate the probability of introducing the three forms of innovations.

$$y_{i,j} = \beta_1 RX^* + \beta_2 TX^* + \beta_3 AX^* + \beta' X + u_{i,j} \quad (1)$$

where $y_{i,j}$ represents three, not mutually exclusive, types of innovations: product, process and organizational innovations [1] for firm *i*:

$y_{i,j} \in \{0, 1\}$ and $j = \{New\ product;\ New\ process,\ Organizational\ innovation\}$.

The terms RX*, TX*, AX*, in Eq. (1) are the latent variables, respectively for the R & D, Training and Advertising efforts, proxied by the predicted values calculated in the Tobit regression estimates obtained in the first stage and the term *X* collects all the remaining covariates, including those indicating active and passive cooperation.

- The third, and last, stage of the model estimates the impact of the

[1] This decomposition is possible as the CIS questionnaires allow to select any combination of answers about these three different innovation typologies. Also, we allow for these three decisions, whether or not to introduce any combination of these three forms of innovation, to be correlated so that we assume that the random error terms: u_{i0}, u_{i1}, u_{i2} are jointly trivariate normal. The estimation of the probabilities of introducing process, product and organizational innovations is a joint estimation that exploits the correlations between these binary variables.

Table 1
First stage estimates: the effects of *active* and *passive* cooperation on the predicted intangibles: Internal R & D, External R & D, Training for innovation and Advertisings. *Pooled estimations*. CIS (2004)– (2010). These pooled data cover all the available CIS waves, between 2004 and 2010. The full list of control variables is available from the authors.

Dependent variables **Active cooperation covariates**	***MODEL 1 Internal R & D/ turnover***	***MODEL 2 External R & D/ turnover***	***MODEL 3 Training / turnover***	***MODEL 4 Advertising / turnover***
Coop - Group	0.381** (2.08)	0.373** (2.43)	−0.00666 (−0.12)	−0.165 (−1.25)
Coop - Suppliers	0.476*** (2.85)	0.533*** (3.70)	0.178*** (3.34)	0.0828 (1.02)
Coop - Customers	0.556*** (3.44)	−0.00339 (−0.02)	−0.0208 (−0.41)	−0.108 (−0.66)
Coop - Other firms	−0.854*** (−3.09)	−0.435** (−2.05)	0.115* (1.78)	0.192** (1.98)
Coop - Consultants	0.756*** (3.54)	1.063*** (7.32)	0.105* (1.70)	0.254** (2.22)
Coop - Universities	1.151*** (3.69)	0.630*** (3.96)	0.109 (1.63)	−0.129 (−1.16)
Coop - Government	−0.156 (−0.56)	0.0872 (0.39)	0.0465 (0.59)	−0.214** (−2.01)
Passive Cooperation Covariates				
R & D Geog. Spillovers	0.0270 (0.54)	0.0155 (0.38)	−0.0506*** (−3.24)	0.0152 (0.79)
Training Geog. Spillovers	−0.0292 (−0.54)	−0.0301 (−0.76)	0.0472*** (2.89)	−0.0101 (−0.44)
Control Variables				
Output destination: Regional Markets	0.505*** (4.10)	0.0226 (0.28)	0.344*** (6.98)	−0.0948 (−1.42)
National Markets	0.952*** (6.25)	0.220 (1.53)	0.280*** (5.86)	0.143** (2.27)
EU Markets	0.521*** (3.17)	0.371*** (2.60)	0.0456 (0.86)	0.0598 (0.75)
International Markets	1.037*** (8.33)	0.614*** (5.47)	0.0166 (0.29)	0.111* (1.68)
Log Employment	−0.776*** (−5.80)	−0.774*** (−5.47)	−0.297*** (−6.19)	0.0536** (2.12)
Age	0.0227 (0.92)	−0.00824 (−0.37)	−0.00551 (−0.78)	−0.0140 (−1.17)
Age, squared	−0.000938 (−1.63)	−0.0000693 (−0.13)	0.000102 (0.62)	0.000261 (0.99)
Motive to innovate: Better products	0.578** (2.07)	0.356 (1.25)	0.259*** (3.02)	−0.108 (−1.12)
Better production	−0.0298 (−0.14)	0.0218 (0.10)	0.181*** (2.66)	−0.00488 (−0.05)
Improve Profit	1.052*** (2.98)	0.790** (2.25)	0.249*** (3.18)	0.221** (2.25)
Meet Regulation	−0.0504 (−0.22)	−0.0887 (−0.51)	0.122** (2.22)	−0.176** (−2.15)

(continued on next page)

Table 1 *(continued)*

***Dependent variables* Active cooperation covariates**	***MODEL 1* Internal R & D/ turnover**	***MODEL 2* External R & D/ turnover**	***MODEL 3* Training / turnover**	***MODEL 4* Advertising / turnover**
Expansion	0.836***	0.114	−0.0200	0.280***
	(4.78)	(0.51)	(−0.32)	(3.73)
Observations	23845	23845	23845	23845
Pseudo R-squared	0.136	0.152	0.100	0.006

* $p < 0,1$
** $p < 0.05$
*** $p < 0.01$

predicted probabilities to innovate, obtained in the second stage, and of other covariates on productivity. Using the predicted probabilities, as opposed to the actual values of the three innovation variables, is done to address the potential problems associated with the endogeneity due to simultaneity between innovations and productivity. In this sense, the variables included in the second stage, but excluded from the third, operate as instruments for the (possibly endogenous) innovation variables in the productivity equation. As controls, each model also includes the firm size, expressed as the log of the number of employees, and the firm age (also squared to capture possible non-linear effects). As discussed above, the dependent variables for this estimation stage are: GVA and GPM both normalised by the firm's total turnover.

Given the panel structure that the various cohorts of the CIS allow, the productivity equations were estimated using the observations from the CIS for which annual balance sheet data from the Annual Respondents Database could be matched. The full sample includes 23,845 observations, which amounts to about 40% of the total observations in the four waves of the CIS. Finally, each equation was estimated using two different panel estimation techniques: Fixed Effects (FE) and Random Effects (RE). The FE estimator concentrates on differences that, over time, characterise a single firm. This is why the FE estimator is also referred to as the 'within' estimator. That is, it explains to what extent a given firm's change in a variable of interest affects its own productivity. Thus, the FE estimator does not account for possible differences that exist across firms at a given point in time and thus does not identify the factors capturing why, for instance, the productivity of firm *i* is different from that of firm *j*. This is not the case of the RE estimator, whose estimates are obtained by weighing the 'within' effect with the 'between' effect, which allows us to identify the factors that explain the differences between the firms in the panel. Thus, the RE estimates should provide a more exhaustive scenario of the drivers of productivity in our sample. However, the possibility of a simultaneity bias induced by unobservable factors often suggests that the FE estimates may be preferred.

5. Results

This section discusses the results for the three stages of the model relating them to the hypotheses introduced in Section 2 about the contrasting impact of the different type and modes of cooperation.

5.1. First stage results

Table 1 presents the first stage estimates of the four separate Tobit models for the dependent variables capturing intangible innovative activities: 1) Internal R & D, 2) External R & D, 3) Training expenses and 4) Advertising, all normalised over turnover.

The independent variables are divided according to the modalities of cooperation, focusing on whether these are *active* or *passive*. Data on *active* cooperation is captured through the answers to the specific CIS survey questions of whether a business co-operated towards innovation activities with any of the relevant actors forming a firm's *local innovation network*. *Passive* cooperation, at this stage, is instead captured by the spillovers in *R & D* and *Training expenses* weighted by the geographic distance between the centres of different *Travel to work areas*.

Focussing on the variable of primary interest, Table 1 estimates show that the impact of *active* cooperation with competitors (variable Coop - Other firms) has a significant and negative association both with internal and external R & D intensities. These results indicate that active collaboration with competitors takes place among firms characterised by a lower level of total R & D intensity, supporting previous result from Tomlinson and Jackson (2013) and hypothesis H1.1 that, contrary to the other forms of *active* cooperation, cooperating with the competitors can be used to reduce innovative efforts to mitigate the *creative destruction* effects of the innovation processes. Moreover, cooperation with competitors also shows a positive and significant association with a firm's advertising intensity, indicating that advertising might be used as signalling to facilitate coordination.

Concerning the other forms of *active* cooperation, hypothesis H1.2 stated that *Active cooperation towards innovation among firms in the same LIN favours innovations*. The results in this first stage provide empirical support to H1.2. In more detail, Table 1 shows that cooperation with firms of the “same enterprise group” (variable Coop – Group) has a significant and positive association with internal R & D intensity indicating the presence of *internalised* positive externalities. This covariate also shows a significant and positive association with external R & D intensity, confirming the relevance of the internal cooperation in terms of absorptive capacity (Cohen and Levinthal, 1989; D’Souza and Kulkarni, 2015). Cooperation with suppliers (variable Coop – Suppliers) is also significant and positive for both internal and external R & D indicating the presence of positive complementarities along the vertical dimension of the innovation value chain as indicated by De Propris (2002). Cooperation with suppliers also shows a significant and positive association with a firm's training intensity, indicating a possible interpretation for these expenses as enablers for cooperation with the upstream suppliers of a firm. Cooperation with customers (variable Coop – Customers) also exerts a positive impact on internal R & D intensity. These results jointly indicate a *local innovation network* that receives reinforced positive complementarities, both from the downstream customers, in accordance with Von Hippel (1976) results, and from the upstream suppliers (Freel and Harrison, 2006). Cooperation with customers, however, does not show any significant association with external R & D intensity. This result is interesting as it indicates that external R & D might be more supplier-driven while internal R & D tends to be more customer-driven. As far as other dimensions of the *local innovation networks* are concerned, the estimation results show that cooperation with consultants (variable

Table 2
Second Stage results: the introduction of product process and organizational innovations Pooled estimation, of predicted innovation outcomes, data source CIS releases: CIS 4 (period 2002–2004), CIS 5 (period 2004–2006), CIS 6 (period 2006–2008) and the CIS 7 (period 2008–2010), Department for Business, Innovation and Skills and ONS (2015).

Dependent variables	*Process innovation Training Spillovers*	*Process innovation R & D Spillovers*	*Product innovation Training Spillovers*	*Product innovation R & D Spillovers*	*Organizational innovation Training Spillovers*	*Organizational innovation R & D Spillovers*
Active Cooperation Covariates						
Coop - Group	0.113*	0.119*	0.0896	0.0927	0.233***	0.234***
	(−1.71)	(−1.84)	(−1.31)	(−1.39)	(−3.42)	(−3.45)
Coop - Suppliers	0.290***	0.289***	0.241***	0.246***	0.134**	0.141**
	(−4.32)	(−4.36)	(−3.62)	(−3.75)	(−2.01)	(−2.13)
Coop - Customers	0.159**	0.160**	0.272***	0.291***	0.244***	0.243***
	(−2.44)	(−2.51)	(−4.29)	(−4.71)	(−3.87)	(−3.87)
Coop - Other firms	0.0316	0.00571	0.0377	0.0345	−0.063	−0.0408
	(−0.38)	(−0.07)	(−0.47)	(−0.43)	(−0.78)	(−0.50)
Coop - Consultants	−0.0183	−0.0157	−0.0401	−0.0301	0.204**	0.192**
	(−0.23)	(−0.20)	(−0.50)	(−0.38)	(−2.53)	(−2.4)
Coop - Universities	0.0491	0.0574	−0.126	−0.124	−0.0123	−0.00423
	(−0.51)	(−0.6)	(−1.34)	(−1.33)	(−0.13)	(−0.05)
Coop - Government	−0.0883	−0.0721	−0.147	−0.131	−0.0664	−0.0656
	(−0.86)	(−0.72)	(−1.48)	(−1.32)	(−0.68)	(−0.67)
Passive Cooperation Covariates						
R & D Sector spillover		0.0187***		0.00673		0.00749*
		(−3.32)		(−1.34)		(−1.65)
Training Sector spillover	0.0151		−0.00234		0.00596	
	(−2.11)		(−0.36)		(−1.01)	
Predicted values from the 1st stage						
Predicted Total R & D /Sales	0.0421***	0.0377***	0.0757***	0.0735***	0.0133*	0.0124*
	(−3.08)	(−2.95)	(−6.01)	(−6.09)	(−1.85)	(−1.75)
Predicted Training /Sales	0.110*	0.117**	0.147**	0.102	0.249***	0.223***
	(−1.72)	(−1.98)	(−2.31)	(−1.63)	(−5.17)	(−4.63)
Predicted advertising /Sales	−0.0783**	−0.059	−0.0625*	−0.0411	0.0164	0.0273
	(−2.02)	(−1.53)	(−1.77)	(−1.17)	(−0.54)	(−0.89)
Subsidies over turnover	0.0177*	0.0209**	0.0287***	0.0320***	0.00187	0.00137
Other Control Variables						
Log Employment	0.160***	0.154***	0.151***	0.137***	0.227***	0.216***
	(−7.62)	(−7.63)	(−8.05)	(−7.36)	(−16.33)	(−15.48)
Age	−0.00784	−0.00672	−0.00771	−0.00919	−0.0144**	−0.0145**
	(−0.98)	(−0.85)	(−1.02)	(−1.25)	(−2.21)	(−2.23)
Age squared	0.000161	0.00014	0.000134	0.000185	0.000174	0.000182
	(−0.83)	(−0.73)	(−0.73)	(−1.02)	(−1.09)	(−1.14)
Motive:						
Better products	0.513***	0.530***	0.680***	0.698***	−0.149*	−0.133
	(−4.27)	(−4.43)	(−8.3)	(−8.58)	(−1.72)	(−1.55)
Better production	0.676***	0.671***	0.0194	0.0182	0.200***	0.208***
	(−7.22)	(−7.17)	(−0.27)	(−0.26)	(−2.7)	(−2.8)
Improve Profit	0.305***	0.297**	0.302***	0.309***	0.0611	0.058
	(−2.6)	(−2.55)	(−3.37)	(−3.51)	(−0.67)	(−0.64)
Meet Regulation	−0.330***	−0.320***	−0.365***	−0.356***	0.230***	0.233***
	(−4.54)	(−4.44)	(−5.38)	(−5.39)	(−3.84)	(−3.92)
Expansion	0.0346	0.0354	0.377***	0.379***	0.284***	0.281***

(continued on next page)

Table 2 *(continued)*

Dependent variables	*Process innovation Training Spillovers*	*Process innovation R & D Spillovers*	*Product innovation Training Spillovers*	*Product innovation R & D Spillovers*	*Organizational innovation Training Spillovers*	*Organizational innovation R & D Spillovers*
	(−0.48)	(−0.49)	(−5.56)	(−5.66)	(−4.65)	(−4.63)
Output destination						
Regional Markets	0.0154	0.0216	−0.103**	−0.0994**	0.104***	0.107***
	(−0.35)	(−0.5)	(−2.56)	(−2.50)	(−3.11)	(−3.24)
National Markets	0.147***	0.137***	0.0485	0.0437	0.280***	0.279***
	(−3.02)	(−2.85)	(−1.07)	(−0.98)	(−7.67)	(−7.68)
EU Markets	0.0892	0.0943*	0.186***	0.192***	0.0255	0.0192
	(−1.63)	(−1.74)	(−3.69)	(−3.85)	(−0.56)	(−0.42)
International Markets	0.00402	−0.00727	0.127**	0.130**	0.123**	0.126***
	(−0.07)	(−0.13)	(−2.42)	(−2.5)	(−2.56)	(−2.63)
Observations	23555	23828	23555	23828	23555	23828

* $p < 0{,}1$,
** $p < 0.05$,
*** $p < 0.01$

Coop – Consultants) captures the complementary with private actors in the collaboration on innovative activities. The results also show a significant, clear and positive association between this covariate and three intangibles: internal and external R & D and training intensities. Similarly, cooperation with "Universities or other higher education institutions" (variable Coop – Universities) shows a significant and positive association with both internal and external R & D intensity (Audretsch and Feldman, 1996).

Finally, this estimation stage does not provide empirical evidence in support of the vast literature emphasising the relevance of geographic spillovers (Crescenzi and Rodriguez-Pose, 2012) formalised in hypothesis H2.2, stating that *Passive cooperation, based on innovative activities' spillovers, arising from geographic proximity, based on workers commuting patterns, facilitates innovations*. Table 1 shows that geographic spillovers of R & D activities, exert some negative effects on training expenditure, possibly due to a trade-off between internal expenditure in training and external benefits from R & D spillovers, but also shows the positive impact that geographic spillovers of training activities have on training expenditure, the only significant *passive cooperation* geographic spillovers emerging at this first estimation stage.

5.2. Second stage results

The second stage of the estimation focuses on the impact of the predicted intangibles, together with *active* and *passive cooperation* variables and additional controls on the probability that a firm would introduce: a *process innovation*, a *product innovation* and/or an *organizational innovation*. The estimates in Table 2, below, show the results of two separate model specifications. Each specification uses as independent variables the predicted levels of training, advertising and R & D intensities (this last variable obtained by merging predicted internal and external R & D intensities) resulting from the first stage of the estimation. In addition, one of these models includes a covariate for sectorial *training* spillovers while the other includes one capturing sectorial *R & D* spillovers. These two specifications focus on different types of *passive cooperation*, from training and R & D, both arising from proximity in the production rather than in geographic space.

The first set of covariates relates to the impact of *active* cooperation on the probability of firms introducing the three different types of innovations. In detail, the estimates in Table 2 show that cooperation with both customers and suppliers is significant in its positive relation with the introduction of all types of innovations. This evidence

Table 3
Third Stage estimates: innovations and productivity. The dependent variables: Gross Value Added (GVA) and the Gross Profit Margin (GPM) are divided by a firm's turnover and then multiplied by 100. Fixed Effect panel estimates.CIS releases: CIS 4 (period 2002–2004), CIS 5 (period 2004–2006), CIS 6 (period 2006–2008) and the CIS 7 (period 2008–2010), Department for Business, Innovation and Skills and ONS (2015).

Dependent variables	GVA	GVA	GVA	GVA	GVA	GVA	GPM	GPM	GPM	GPM	GPM	GPM
Covariates												
Pred. Prob. Process Innovation	2.714**			1.930***			2.371**			1.130		
Pred. Prob. Product Innovation.		1.913**			1.330***			2.187**			0.939*	
Pred. Prob. Organizational Innovation			1.558			1.204**			2.422**			0.921
Intangibles	−0.153	−0.148	−0.0775				−0.242	−0.317	−0.328			
Control Variables												
Log Total Employment	1.204**	1.240**	1.244**	1.299**	1.324***	1.298**	0.682	0.664	0.594	0.834	0.844	0.822
Net Capital Exp./ Sales	0.0322	0.0331	0.0334	0.0319	0.0326	0.0331						
Observations	23828	23828	23828	23828	23828	23828	23828	23828	23828	23828	23828	23828

Note: GVA=(gross valued added)*100/(total turnover); GPM =100*(gross valued added – net capital expenditures)/(total turnover)
* $p < 0{,}1$
** $p < 0.05$
*** $p < 0.01$

supports, again, H1.2 implying that all the three different types of innovation are not just the results of the individual efforts of individual firms, but also the outcome of a *LIN* whereby *active cooperation* with customers and suppliers plays a significant and positive role (De Propris, 2002; Von Hippel, 1976).

Active cooperation with competitors is not directly significant at this second stage; however, one can see that its negative impact on innovation, as stated in hypothesis H1.1, is indirect, taking place through the negative impact that *active* cooperation with competitors, induces on total R & D intensity in the first stage. Indeed, the ensuing reduction in R & D, due to *active* cooperation with competitors has a negative impact on all types of innovations, as shown in Table 2 estimates.

Moving to the role of *passive cooperation* through sector spillovers, the estimates in Table 2 show that the total amount of R & D expenditure, performed by other firms in the economy, produces significant positive spillovers effects on the probability that a firm would introduce a process innovation. These spillovers, expressing *passive cooperation*, were weighted according to the *proximity in production* of the different economic sectors, measured through their input-output relations and capturing the circulation of *production-specific* knowledge along the value chains, based on the trade relations each sector has with the others (Bartelsman et al., 1994). Training expenditure performed in the economy, again weighted in relation to input/output trade intensities with the sector a firm belongs to, also generates positive sectorial spillovers that are positively associated with the introduction of process innovations, confirming hypothesis H2.1. However, this result should be qualified as this effect of passive cooperation is only significant for process innovations.

5.3. Third stage results estimating the impact of innovation on productivity

The previous estimation stages have shown that *passive cooperation*, through sector R & D spillovers has a direct impact on the introduction of process innovations and that *active cooperation* with competitors has an indirect negative effect on innovations as it reduces predicted R & D intensity, hence negatively affecting the probability of introducing all types of innovations. This third stage of the model assesses hypotheses H3, i.e., it focuses on the impact of *active* and *passive* cooperation on productivity.

Given the panel structure that the various cohorts of the Community Innovation Survey allow, we estimated the productivity equation using the observations from the CIS for which we could match annual balance sheet data from the Annual Respondents Database. Table 3 reports twelve different estimates obtained from the FE estimators estimates, a set of six each, for two different choices of the dependent variables used to capture productivity: GVA and GPM. The first three model specifications, for each dependent variable, GVA and GPM, include a covariate representing the geometric average of the intangibles, while the last three do not include it. Otherwise, each one of three specifications with intangibles covariate contains only one of the three main independent variables, the predicted probabilities of each of the three possible types of innovation. These are treated separately to avoid multicollinearity due to their high correlations. Similarly, there will be three different specifications per dependent variables, GVA and GPM, each containing one of the predicted values of the probability of introducing an innovation: process, product or organizational, without considering the intangibles covariate.

Table 3's estimates show that *productivity* is positively and significantly related to the three probabilities of introducing an innovation, (product, process and organizational) estimated in the second stage of the model. This evidence confirms the specific hypotheses discussed in Section 2, namely:

- H3.1 *The impact on productivity of active cooperation among firms competing in the same sector is indirect and negative.*

  This hypothesis is supported by the negative impact of cooperation among competitors on R & D intensity (Table 1), followed by the positive effect of predicted R & D intensity on process innovations (Table 2) and by the positive impact of predicted process innovations on productivity (Table 3).
- H3.2 *The impact on productivity of active cooperation among non-competing firms, part of a local innovation network, is indirect and positive.*

  This is due to the positive direct impact of cooperation along the LIN on both R & D (Table 1) and on process and product innovations (Table 2) and, ultimately, on the positive impact of these two variables on productivity (Table 3).
- H3.3 *The impact on prsoductivity of passive cooperation in innovation activities among firms is indirect and positive.*

This impact is due to the positive effects of sectors' spillovers on process innovations and their ensuing positive impact on productivity.

In the next section, the different estimation steps are revisited, exploring the insights to be gained about the nature of the different paths and sequences of relations, linking intangible innovation activities and *active* and *passive* forms of *cooperation* to productivity.

6. Conclusions

This paper introduced a three-stage econometric model to assess the effects *active* and *passive* cooperation in firms' innovation activities on productivity. These effects take place both directly, through the immediate impact that innovations have on productivity and indirectly, through the role that intangible innovation activities play in facilitating the introduction of product and process innovations that, in turn, affect productivity.

The main benefit of concentrating on this sequential approach is that it allows for a finer understanding of the channels and interactions used by innovative activities to percolate through the production system, before exerting their final effects on output and productivity. Along this process, the focus was on the positive effects on innovation of *passive* cooperation, unintentionally taking place through knowledge spillovers, and the negative ones of *active* cooperation with competitors. An additional form of *active* cooperation, developing along the local innovation network with customer and suppliers also featured as a driver for innovation and productivity.

6.1. Direct effects: innovations increase productivity

The estimates of the third and final stage of the model showed that a firm's productivity is positively and significantly related to the introduction of product, process and organizational innovations. The positive relation between productivity and process innovations has an immediate interpretation: improving production processes has the direct objective of raising productivity by reducing costs and increasing efficiencies. Similarly, the estimates showed a clear positive association between productivity and organizational innovation, captured when productivity is measured in terms of *Gross Profits Margin* gains. The interpretation of the positive relation between product innovations and productivity is less immediate but equally relevant and interesting for both its policy and managerial implications. Instead of being related to increased static efficiency, product innovations are more likely to bring increments in *Gross Value Added*, as they enable a firm to extract more consumers' surplus due to the higher willingness to pay that consumers may have for the improved quality of the goods and services resulting from product innovations. Once the direct effects of innovations on productivity are identified, the sequential estimation strategy allows to move one step back to look at the main determinants of these productivity's enhancing factors: the indirect effects.

6.2. Indirect effects: intangibles leading to innovations

The analysis of the indirect effects focuses on the variables affecting process, product and organizational innovations. This paper's findings show that the predicted level of R & D intensity positively affects process innovations. Similarly, *passive cooperation,* captured through R & D spillovers arising from proximity in production space, has positive indirect effects on productivity via its positive impact on process innovations. This finding confirms the positive role that *passive* cooperation, capturing the percolation of production-specific knowledge through the system of business to business exchanges, plays in the innovation stage first and, indirectly, on productivity.

A firm's training expenditure, as well as training spillovers, again due to proximity in production space, have a similar positive effect, showing the complementarities between training and the introduction of process innovations and pointing towards additional indirect positive effects of training on productivity. It is interesting to notice that these indirect effects of training on productivity, mediated via process innovations, are both internal, due to a firm's own investment in training, and external, again as a form of *passive* cooperation linked to the training taking place among the other firms with which a firm interacts.

Other key enablers for process innovations, indirectly and positively affecting productivity, are the *active* cooperation with: firms of the same group, suppliers and customers. This evidence suggests that there is an important dimension of positive feedbacks forming along the members of a *LIN*. The drivers of product innovations are similar to those analysed above in the discussion of process innovation. An interesting difference emerging from the estimates is that *passive* cooperation, expressed by both R & D and training spillovers' impact, loses its statistical significance for product innovations, indicating that knowledge appropriability barriers may be higher for new products than for new processes. Most of the determinants of organizational innovations are similar to those discussed for process and product innovations.

6.3. Further factors affecting intangibles

After the analysis of both direct and indirect effects of innovation activities on productivity, the first stage of the model explored another set of relevant relations, through the analysis of the factors affecting the intangibles investment decisions. It was found that *active* cooperation with firms of the same business group, consultants, customers, suppliers and universities were all positively associated with predicted R & D intensity. On the contrary, this intangible is negatively affected by *active* cooperation between competitors. This last finding implies that reduced competition in the output market, captured by a firm's cooperation with its competitors, is detrimental to R & D intensity and, consequently, to a firm's propensity to innovate and to its productivity. This result is particularly interesting as it highlights the benefits of competition, not only to increase allocative efficiency, but for firms' dynamic performance as well.

6.4. Policy implications

Barnett et al. (2014) discussed the steady British productivity decline throughout the financial crisis. Productivity is a key element to maintain sustainable growth in a framework of increased international competitiveness and can be improved through process innovations increasing a firm's efficiency. Similarly, important are product innovations, as they allow quality differentiation of a firm's products on the international markets. The key driver for process innovations, and hence indirectly of productivity, is firms' investments in R & D activities. It has been shown that process innovations are positively affected by *passive* cooperation, through R & D spillovers, arising from proximity in production space. The relevance of these external effects indicates a clear role for policy intervention in incentivising R & D whenever, due to the low appropriability of the benefits of R & D, private incentives would provide a level of investment below the desired one. This paper also shows how knowledge spillovers percolate through the economy via business to business relations underlying the relevant supply chains. Hence, policy should identify the key sectors, the most central within the supply chain exchanges, whereby subsidies and incentives for R & D would maximise the wider spillovers effects for *passive* cooperation.

Finally, the paper showed that *active* cooperation along the *local innovation network* contributes to the introduction of innovations and productivity. This type of cooperation may suffer from coordination failure, for example due to the presence of asymmetric information among innovating firms. A clear role for a successful innovation policy aiming at overcoming this problem would be to create a favourable institutional setting to facilitate the emergence of this type of *active* cooperation, to avoid the danger of free riding and increase trust along the innovation networks. On the contrary, *active* cooperation among competitors in the output markets is detrimental to innovations and productivity, showing that competition policy not only provides benefits in terms of allocative efficiency but that it can also improves a country's dynamic efficiency.

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