Firm Productivity and Innovation: From a Micro to a Macro Entrepreneurship Ecosystems [1]

Abstract

Research on the role of contextual factors such as entrepreneurship ecosystems and firm characteristics such as productivity in their ability to generate firm's innovation is a response to the rapidly growing interest in the subject. Although the focus of prior research has been on regional ecosystems, building on industrial clusters, local networks and agglomeration literature, there has been no study bridging regional, macro and global innovation and entrepreneurship ecosystems and how collaboration with ecosystem actors within and beyond regional boundaries changes firm innovation? This study demonstrates the importance and limits to external knowledge collaboration for innovation across regional, macro and global entrepreneurship ecosystems and for the most innovative UK firms with different level of productivity. Traditionally this issue has presented a challenge for the regional studies on innovation, entrepreneurship and open innovation literatures, in terms of firstly identifying the phenomenon and secondly in measuring it.

We propose and estimate a structural model that estimates the innovation production function with knowledge inputs and outputs combining both firm characteristics and contextual influences (knowledge spillovers, knowledge collaboration). Our sample includes 29,805 observations and 17,859 firms mainly from the UK Innovation survey and Business registry. We demonstrate that knowledge spillovers as well as knowledge collaboration and may bestow a significant advantage for innovation, but there are diminishing returns to collaboration related to firm's productivity and the entrepreneurship ecosystem where a partner is located. Least productive firms are more likely to exploit regional entrepreneurial ecosystems collaborations, while most productive firms go global. Our findings call for further research on innovation and revision of national and regional innovation policies.

1. Introduction

Innovation and productivity is known to fuel economic growth (Marshall, 1920; Delgado et al. 2010). Firms that are more innovative and productive may play an important role for regional economic development, reducing unemployment and creating new jobs (Audretsch et al. 2006; Fritsch and Mueller, 2008; Audretsch et al. 2015), they can also become distributors of new knowledge, serving a conduit for the knowledge spillover of entrepreneurship (Audretsch and Feldman, 1996; Jaffe, 1993; Acs et al. 2009, 2013). Interestingly, while reaching the production productivity frontier (PPF) may be the ultimate and most desired objective for firm managers, from the public policy perspective approaching PPF is important to challenge incumbents and put them through competitive pressure, achieving wider economic benefits for the industry and regions (Marshall, 1980; Jaffe, 1983). Clusters of new knowledge could be formed within the region with new products and services entering the local markets and creating more market opportunities for new business creation (Aldrich 1999; Carree and Thurik 2006; Brixy 2014). High rates of innovation and productivity may represent the emergence of clusters of knowledge (Delgado et al. 2010)

[1] The use of these data does not imply the endorsement of the data owner or the UK Data Service at the UK Data Archive in relation to the interpretation or analysis of the data. This work uses research datasets which may not exactly reproduce National Statistics aggregates.

regionally (e.g. Sillicon Valley, Golden Triangle, Route 128) and nationally (textile cluster in Bangladesh, It cluster in Estonia or financial cluster in Luxembourg or Singapore).
Hence, promotion of factors which will enhance the firm innovation and productivity, allowing a firm to catch up with the top performers in the industry regionally, nationally and internationally has remained a key agenda for the regional and national innovation policy in both developed and developing countries (Storey 2003). Knowledge collaborations and knowledge spillovers have been long seen as facilitators of innovation and productivity (Grilliches, 1979; Audretsch and Feldman, 1996; Bogers, 2011; Cassiman and Veugelers, 2002).
Prior research has demonstrated that firm innovation and productivity is not distributed evenly across countries. In fact the emergence of firms in the South-East Asia, also known as "Asian tigers" and fast growing firms in China, Malaysia, Singapore, Philippines is are often associated with an increased labor productivity, but not necessarily innovation. Emergence of Mittelstand firms in Germany, on the contrary, is associatd with high innovation and a range of firm productivity. Possible factors affecting cross-country differences in economic firm innovation and productivity have been identified in the literature (Aidis et al. 2012; Acs et al. 2014) and they are often associated with the emergence of regional, national and global innovation and entrepreneurship ecosystems (Autio et al. 2014; Stam, 2015; O'Connor et al. 2018). Regional entrepreneurship and innovation ecosystems refer to the networks and institutions linking knowledge production such as universities, suppliers, customers, consultants, competitors, government and other collocated businesses (including within alliances) with innovative firms within a region. Respectively national (global) entrepreneurship and innovation ecosystems refer to the interconnections between the proprietaries of resources and with innovative firms within a country (internationally). Cooke et al. (1997) argue that such interactions between different innovators and their stakeholders will increasing a region's and country's overall innovativeness with a spillovers reaching innovators within and beyond country boundaries (Zahra and Nambisian, 2011).
As documented in the economic development literature, a variation in firm's innovation is related to knowledge inputs (Romer, 1980; Arrow, 1982; Acs and Audretsch, 1990; Bogers et al. 2017), knowledge spillovers (Jaffe, 1989, 1993) as well as regulatory requirements (Audretsch et al. 2018a), institutions (Estrin et al. 2013) and localised competitive advantages (Porter, 1980; Stam, 2015, Spiegel and Stam, 2017). While earlier literature has already observed that the determinants of firm innovation choices may vary across the different stages of firm life cycle (Davidsson 2006; Klonek et al. 2015; Mickiewicz et al. 2016), there is a gap in the literature on combined analysis of the role of firm level characteristics versus contextual influences such as knowledge collaborations with ecosystem actors across different geographical dimensions (Van der Zwan et al. 2010, 2013). For example, it is not clear to what extent do firm characteristics such as productivity influence firm's invention ability and commercialization of innovation?. Accordingly, the role that external partners (e.g. customers, suppliers, enterprise group, universities, government, consultants, public research labs) play in innovation output? (Beers and Zand, 2014; Laursen and Salter, 2014). Unpacking the links between knowledge inputs and knowledge outputs across firms with different levels of productivity , being embedded in multiple entrepreneurship and innovation ecosystems is important for any public intervention and for design of firm innovation policy. More specifically, firm managers and policy makers would like to know, to what extent firm's innovation will rely on the contextual influences, such as collaboration on innovation within regional, national and global ecosystems, knowledge spillovers and institutions (Chesbrough, 2003, 2006; West et al. 2014), or (and) on firm's specific characteristics such as firm's resource availability and productivity. We define collaboration with regional (global) entrepreneurship ecosystem actors as "combinations of social, economic and cultural

collaborations which aim at innovating with customers, suppliers, universities, local government, consultants and competitors" within regional proximity (internationally). Collaboration within regional (global) ecosystems will include direct links between local firm (UK based in our case) with at least one collaboration partners located regionally (internationally). This definition of entrepreneurship ecosystem actors is supported by Audretsch and Belitski (2017), Mason and Brown (2017) and Roundy et al. (2018)) and Spigel (2017).

The way we propose to explore these gaps defines our contribution to regional economic development, entrepreneurship and innovation literature.

Firstly, a particular gap in the literature is that while country level studies on the importance of context (Acs et al. 2014, Autio et al. 2014; Stam, 2018), there is not much evidence of this approach being applied at the firm level and across micro/ macro/global ecosystems where firm's stakeholders are located and where firms sourcing occurs. Given that there is significant variation in firm innovation and productivity not only cross-country but also within regions, an examination of the locus of the innovation inputs (regional/macro/global) helps us to gain an in-depth understanding of the role of the context at every stage of firm's transition to the PPF.

Accordingly, the first objective of this work is to examine whether and to which extent, contextual characteristics such as knowledge collaboration with regional, macro and global entrepreneurship ecosystems actors as well as firm specific characteristics, firm productivity level, will influence a firm decision to innovate and a degree of innovation. To this extent, we draw on the resource-based view (RBV) (Penrose, 1959; Alvarez and Busenitz 2001; Foss 2011) as applied to firm's innovation and of productivity.

Second, we argue that firm's location between the origin and the PPF will explain the diminishing marginal returns to knowledge collaboration and every additional combination of resources will limit innovation output. Although the improvements in productivity may generate more innovation and profits enabling a firm to acquire more valuable, inimitable and scarce resources internationally in a more competitive environment to complement their resources (Audretsch and Belitski, 2019), in short-term production period, fixed resources and managerial capabilities will limit firm's ability to effectively combine collaboration partners and innovate. We posit that resource limitations will matter less for most productive firms, as they are capable in either reducing the costs of collaboration, or their returns to innovation decisions and commercialization is higher, so they engage with more ambitious macro and international entrepreneurship ecosystems (macro/global ecosystems).

Third, understanding to what extent augmenting collaborations is beneficial for firms with different level of productivity and across three geographical dimensions (regionally, nationally and internationally). We control that a decision on combining knowledge collaboration across different geographical dimensions and the innovation output for firms with different level of productivity.

Finally, this study overcomes the limitations in prior literature bridging regional / macro / global ecosystems (Acs et al. 2014) which enables us to explain the contextual and firm level factors behind the decision to innovate and a choice of entrepreneurship ecosystem: regional, macro, global. Our data microfoundations data on a merged sample of 29805 observations during 2002-2014 from the UK Innovation survey (UKIS), and business departmental registry (BSD) allows us for simultaneous testing of the effect of resources at both the firm and the contextual levels (meso/macro/global ecosystems) along the PPF. We show that the returns to knowledge collaboration with various ecosystem actors change along the firm's transition towards the PPF, with resources from local stakeholders becoming less important for innovation output and resources from global stakeholders becoming more important for most productive firms. We attribute this to firm specific characteristics playing a more significant role at the lower level of firm productivity, while global ecosystems collaborators will enhance market opportunity recognition and ability to reduce collaboration costs (Bergmann and Stephan, 2013; Klonek et al. 2015) while transition towards the PPF . Finally, the diminishing marginal returns to collaboration, associated with the properties of PPF and short-run production circle will limit firms innovation output.

This study addresses a call in entrepreneurship ecosystems literature (Acs et al. 2017a) on further developmental work on firm performance and innovation within entrepreneurial ecosystems. Although combining knowledge is important for innovation and the interactions with innovation and entrepreneurial ecosystems actors within region and internationally can complement to knowledge co-creation, factors related to Innovation possibility frontiers, availability of resources in a shirt0term production stage and heterogeneity of knowledge partners willc affct innovation decisions and the way these complementarities can be exploited.

In the section 2, we discuss how this theoretical framework. From this, we derive our hypotheses. Then, we discuss the context, the database and the methodology in section 3. We summarise the results in section 4. Section 5 offers a discussion, policy implications and concludes.

2. Theoretical Framework

2.1. Innovation Possibility Frontier and knowledge collaborations

The literature on innovation originates from two basic models which differ in the way they describe innovation possibilities.

First, as an extension of production possibility frontier (Shephard, 1953; 1970), describing the theory of cost and production functions, Ahmad's (1966) microeconomic model explains the existence of an innovation possibility curve. This curve is the envelope of all unit isoquants which can be developed at a given time with a fixed research budget. Kennedy's (1964) macroeconomic approach describes innovation possibilities by an Innovation Possibility Frontier (IPF), which is a trade-off frontier between capital and labor augmentation rates. Although this approach has led to a formidable theoretical discussion (Binswanger, 1974), but practically no empirical work due to the difficulties of measuring factor augmentation rates econometrically and in particular the role that internal investment in knowledge and external knowledge collaboration play in innovation for most and least productive firms. Moreover, the IPF approach and Production possibility approach has never been merged, and criticised on theoretical grounds Nordhaus (1973). The lack of microeconomic foundations may have caused these problems.

This paper develops a microeconomic model by reformulating innovation possibilities frontier and applying the knowledge collaboration perspective in bridging regional, macro and international collaboration between a firm and its stakeholders. On the basis of a thorough research processes, which have expected pay-off functions in terms of efficiency improvements, and by explicitly introducing collaboration costs and gains within regional, macro and international entrepreneurship ecosystems. This leads to the specifications of knowledge collaboration as an investment problem in which the expected value is maximised. A short term innovation production function is examined under various budget constraints, which have a substantial impact on the decision making to innovate behaviour of the model. Binswanger (1974) evidence is very useful as It is shown that Ahmad's and Kennedy's approaches are special cases of the model and that Kennedy's IPF cannot be stable over time.

A probability of innovation increases with an investment in knowledge in-house and external collaboration (Faems et al. 2005). Knowledge collaboration is viewed as the number of connections m, the expected pay-off from the collaboration activity is the largest yield increase found in the sample. All other collaborations can then be discarded since only the one collaboration partner within a certain geographical of functional dimension with the highest yield will be used for new product development. Given the mean, t and variance C of the distribution of potential yield increases, one can define ex ante the expected pay-off from collaboration as the expected first-order statistic of a sample of collaborative partners of size m, which is a function of the collaboration partners sample size:

$$E(\Delta Y_m) = f\ (m, \mu, \vartheta) \qquad (1)$$

where ΔY_m is the largest yield increase in innovation due an increase in a sample of collaborative partners (ecosystems) increasing function of m, but the marginal pay-offs decline as the sample size of knowledge collaborators increases. This holds for all distributions with finite variance, i.e.

$$\partial E(\Delta Y_m)/\partial m \geq 0 \quad ; \partial E(\Delta Y_m)/\partial m^2 \leq 0 \qquad (2)$$

A manager who maximises expected returns from knowledge collaboration will equate marginal expected pay-off with the marginal cost of it. Expected pay-off functions of knowledge collaboration which behave like equations (1) and (2) can also be assumed research problems which do not fit the sampling model of knowledge collaboration well, such as engineering processes. Then m can also be interpreted as the amount of resources devoted to the knowledge collaboration rather than as sample size of collaborators. The model developed in this study may serve to explain both the innovation PPF as both a combination of resources used in new product development and a sample of partners across various entrepreneurship ecosystem where firm operates.

There are two sources of uncertainty in this model: the manager will generally not know the distribution of potential innovation outcomes, neither the yield. This distribution will be subjective and its parameters μ, ϑ in equation (1) and will have an expected mean and variance. The other source of uncertainty comes from the variance of the expected first-order statistic, which would exist even if the underlying distribution of new product development and yield was known with certainty. For example, risk aversion would lead to lower knowledge collaboration levels than the solutions to the model below would indicate. It would tend to turn knowledge collaboration away from particularly risky partners, which might lead to biases if collaboration in one direction was less risky than in the other direction as in the research model introduced by Evenson and Kislev (1971).

To adapt the resource view of knowledge collaboration to the innovation problem, we have to specify the implications of collaboration processes for factor proportions. In a factor augmenting innovation production function

$$Y = f(\frac{K}{\theta_A}; \frac{L}{\theta_B}) \qquad (3)$$

We can make the reduction in the augmentation parameters a function of knowledge collaboration. Mathematically it would be the way to assume that the reduction in θ_A is a function of one knowledge collaboration (i.e. within regional entrepreneurship ecosystem), while the reduction of θ_B is a function of another knowledge collaboration (i.e. within national or international entrepreneurship ecosystem) or a knowledge externality (knowledge spillover). In the real world, the decisions to increase a likelihood of innovation are rare the decisions to augment a factor, but decisions to pursue a different type of knowledge collaboration or with a different partner (functionally and / or geographically) which result in embodiment of some new finding or quality in a physical factor of production (i.e. hiring scientists, investment in software, machinery and technology).

It is an assumption that the factor into which the new quality is embodied be the one and only one which is augmented. A capital embodied technical change usually augments all factors in various degrees. The physical quantity of new products needed to produce one unit of output may or may not decrease, but the amount of other factors needed will most likely decrease at any set of factor proportions given the scarcity of resources. If a knowledge collaboration result from a process is embodied in a certain geographical proximity (region) or type of collaboration (with suppliers, university, government), new collaboration within a different geographical proximity (inter-region or internationally) may decrease other factor in innovation production. An ability and efficiency of a substitution of one resource with another resource depends on the distance to production possibility frontier (PPF).
An outward shift of the PPC is possible as a result from growth of the availability of m and other inputs μ, ϑ, such as capital investment, labour, industry competition or from innovative technology of how to transform m, μ, ϑ into Y. Such a shift may reflect firm growth already operating at its full capacity and productivity (on the PPF), which means that more of m can now be produced during the specified period of time without sacrificing the output of either m. Most microeconomic contractions reflect not that less can be produced but that the firm has started operating below the frontier, as typically, both labor and capital are underutilized. All innovation production in real time occurs in the short run. In the short run, a firm is able to increase innovation output Y if marginal cost of m is less than marginal returns from such collaboration in terms of (ΔY_m). A firm will stop to innovate if a decrease in marginal cost of m is greater than marginal benefits. While moving towards a PPF, a firm will face the diminishing returns to scale, that arises in the context of a firm's production function. Diminishing returns to scale will consrain the firm to further innovate diven an increase in inputs. In a short run, most productive firms will face an innovation increase by the lower rate than changes in the inputs (knowledge collaboration, spillovers). At the same time, firms away from the PPF are expected to increase its innovation output by more than that proportional change in knowledge collaboration and other inputs (increasing returns to scale). Although this is a plausible assumption, firms far away from the PPF are unlikely to have enough resources to develop collaboration, and if they do the quality of collaboration also matters. Least performing firms close to PPF origin will not be able to achieve an increasing returns to scale, as resources are sub-optimal and complementarities in inputs is not achieved. While aquiring more resources, building absorptive capacity and managerial experience , firm's innovation will start increasing by more than the proportional change in all inputs, including knowledge collaboration , firm will experience growth and can exploit complementarities in inputs mosrt efficidntly. Increasing returns to colalboration will eventually enable a firm to approach the PPF.
In mainstream microeconomics, the returns to scale faced by a firm are purely technologically imposed, however in management literature, managerial capabiliies matter. Augmenting (3), we can simplify that one knowledge collaboration augments another one factor (knowledge collaboration, spullover). The model will therefore assume that every knowledge collaboration affects both the other knowledge collaboration and knowledge spillovers as well as other factor augmentation coefficients. In the most general case one would like to define the knowledge collaboration pay-off functions as follows:

$$\begin{cases} \theta_A = \theta_A^*(m, n, \ldots. q) \\ \theta_B = \theta_B^*(m, n, \ldots. q) \end{cases} \tag{4}$$

Where m, n and q and research collaborations and

$$\theta_A^* = (\theta_{A0} - \theta_{A1})/\theta_{A0} \quad , \theta_B^* = (\theta_{B0} - \theta_{B1})/\theta_{B0} \tag{5}$$

The subscript zero refers to the coefficients before knowledge collaboration refers to the coefficients after collaboration. A technological advance corresponds to positive values of θ_A^* and θ_B^*.
Equations (3) and (4) would lead to a very general model. Such a formulation proved to be quite intractable. The following simplifying assumptions are therefore introduced:
(a) The production function is of fixed proportions, i.e.,
$Y = min(\frac{K}{\theta_A};\frac{L}{\theta_B})$ so that θ_A^* and θ_B^* are simply input-output ratios.
(b) Research results are additive, i.e., the results from one knowledge collaboration can be implemented independent of the results from the other process.
(c) Knowledge collaboration is subject to decreasing marginal returns, when the distance between firm production output (ρ_i) and a production output of a firm at PPF ($\widehat{\rho_i}$) approaches zero.
(d) Only two types knowledge collaborations are considered at a time (collaboration within regional and national entrepreneurial ecosystems; international and regional; knowledge spillovers and regional collaboration, etc.) and they are subject to the same scale function.In brief we hypothesize that:

H1: Firms will experience diminishing marginal returns to knowledge collaboration while approaching the PPF, which will limit its innovation output

$$\partial E(\Delta Y_m)/\partial m \geq 0 \quad ; \partial E(\Delta Y_m)/\partial m^2 \leq 0 \text{ if } (\rho_i - \widehat{\rho_i}) \to 0 \tag{6}$$

The most straightforward insights originating from H1a and H1b is that most of innovation outcome will be made by firms away from the origin, but not at the PPF, when combining knowledge inputs (via collaboration or spillovrs) from different partners will facilitate innovation and trigger more synergies between managerial resources, capital and labor. It is likely that firms at PPF will face the situation when marginal cost of knowledge collaboration will be equal to marginal benefits. A firm fill stop its movement forward outside PPT as it is limited with existing resources and technology. In this case it is the location in relation to PPF and the origin will determine innovation output.

2.2. Heterogeneity in resource inputs and Innovation

Knowledge collaboration (m) is heterogeneous, and collaboration within local entrepreneurial ecosystem may have limited resources and knowledge to supply, while collaboration internationally may offer greater variety and quality of knowledge but also highr collaboration risks. This collaboration may take place with regional and national firms M_{reg} (national and regional ecosystems) or international firms M_{world} (global ecosystems) Production inputs are rare, valuable and non-substitutable and they are unlikely to be made available freely (Barney 1991; Barney et al. 2001), which differentiate the returns to knowledge collaboration and limits access to resources (Marschall,1890; Romer, 1980). Davidsson (2009) sees production inputs as resources that ae broadly defined assets to be utilised in production (Mickiewicz et al. 2016). These resources when combined with firm's decision to source such knowledge via knowledge collaboration with proprietors of such resources (universities, customers, suppliers, public research labs, external organizations within enterprise group, etc.) results in new product development (Faems et sl. 2005, 2010; Bogers , 2011).

The entrepreneurial ecosystem approach here can be helpful to understand who are the proprietors of resources. The regional development literature has looked at regional ecosystems (Marshall 1920, like industrial districts, regional industrial clusters, and regional innovation systems (Stam and Spigel 2017; Terjesen et al. 2017) to explain the importance or regional knowledge and local networks for innovation as well as knowledge interactions between the community members. Based on this conceptualisation, the regional development literature of entrepreneurship and innovation (Stam, 2015) as well as the resource-based view of innovation may explain why certain firms will liaise with resource providers locally I their attempt to exploit marginal benefits and decrease marginal costs, and other firms will not (Alvarez and Busenitz 2001). According to regional innovation ecosystems literature (Audretsch and Belitski, 2017; Stam and Spigel 2017) the outcome is determined by location, while the RBV of a firm emphasizes the role of firms specific characteristics per se, such as internal resources and dynamic capabilities (Zahra and George, 2002) that facilitate first the recognition of external knowledge and enables them to increase marginal returns to collaboration (Veugelers , 1997; Cassiman and Veugelers, 2002; Cassiman and Valentini, 2016; Colombo et al. 2016). While creating of a new product a firm will decide where most valuable resources are, with the answer – not necessarily locally. The process of decision-making is similar to how absorptive capacity works in the knowledge spillover theory of entrepreneurship (Audretsch and Keilbach, 2005, Qian, 2012) when firm's absorptive capacity and performance relative to competitors will plays an important role where resources will be in – outsourced (Cassiman and Valentini, 2016).
In order to test H1a and H1b, resource-based view offers important insights with focus on firm's capabilities and production inputs. At various locations in relation to PPF origin firm's inputs and resources change. For example, firms that are least productive (PPF origin) will search for opportunities, discovery and recognition in the more narrow markets, usually within close geographical proximity. Interaction between the community of people and here are the strongest within a territorial entity, usually a region , borough, county (Becattini 1990) in order to be able to access international markets later. These firms will rely on the presence of geographically bounded knowledge spillovers (Audretsch and Feldman, 1996) and the degree of competition as the main channels through which local context factors may impinge on the level innovation and productivity (Syverson, 2011; Chanda and Dalgaard, 2008) Firms will aim to reduce costs on verification of new ideas and engage with local customers and suppliers, which is also facilitated by cognitive and cultural proximities. Notably, local collaboration partners may provide important social capital which could serve as a resource itself for low productive firms to succeed and appropriate their value from collaboration. Prior research on competition may also help us to understand why low productive firms will collaborate locally (Bernard, Jensen, & Schott, 2006; Bloom & Van Reenen, 2010; Eslava, Haltiwanger, Kugler, & Kugler, 2004). It demonstrated that the intensity of competition is greater in international ecosystems, while it is smaller in localized markets, where low productive firms may still innovate due to building trust and cognitive proximities with local stakeholders (e.g. local knowledge on the product, preferences for local food, jobs to local people, etc.) (Balland et al. 2015). Fernandes (2007) and Verhoogen (2008) in their studies on competition demonstrate that only best and most productive companies who survived locally will outreach global partners within the global ecosystems, while least productive companies will exit the market. In regional ecosystems more efficient firms will not be able to outcompete all least productive firms due to cognitive and cultural proximity to regional stakeholders, most importantly customers, enabling low productive firms to innovate and commercialize new knowledge. A comprehensive list of possible forms of proximity facilitating knowledge collaboration within regional/macro/global ecosystems motivated by Boschma (2005) on geographical, cognitive, social, institutional and organizational

proximity. In addition, Balland et al. (2015) argued that collaboration with cognitively similar partners is likely to be associated with higher levels of trust and transparency, while other firms may not be able to organize activities at arm's length (Uzzi, 1996).

While prior research argues that it is the further improvements in productivity when exploitation of resources could be continued and costs of experimentation and management reduced (Kor et al. 2007; Tambe et al. 2012), the economising template of organizational, transation and cognitive costs may not yet be utilised (Cassiman and Valentini, 2016). We posit that reduction of different costs (Bogers, 2011) is associated with the least productive firms, that may not be able to afford to outreach more diverse and valuable resources , they will remain locked into regional ecosystems.

The fact that low productive firms will innovate using local market knowledge is also in line with the perspective adopted by Cassiman and Veugelers (2002) and Bogers (2006, 2011) who observed that collaboration with external partners poses significant risks and burden on firms. We posit that firms further away from PPF will be less likely to access rare, valuable and non-substitutable resources, which may be available outside of the regional ecosystem freely or at low cost (Barney 1991; Barney et al. 2001) Low productivity firms are more likely to be constraint in management the following four risks and costs of collaboration.

First, low productive firms, unlike more productive are characterized by very long knowledge search and product development cycles, which may take them longer and make it more costly of knowledge search and adoption within international ecosystems (Zucker et al. 1994).

Second, low productive firms will require more time to coordinate innovative effort, knowledge search and accumulation, product adaptation, adoption, testing and finally introducing it to the market. The long process of standardization, validation and experimentation in international markets or when collaborating internationally will increase costs (Bogers, 2006). Local stakeholders and local market will offer a "safe harbor" to operate on a larger scale and with a longer time horizon (Aron, 2000). The costs could be significantly reduced die predictability of institutions, instead redirecting the effort to working higher complexity and knowledge intense products.

Third, low productive firms will opt for a shorter period of product exploration and exploitation, again as a cost reduction strategy, while higher productivity firms may allow for a significant gap between an investment in knowledge collaboration and returns to this investment (market sales, job creation, market expansion, etc.) (West et al. 2014).

Fourth, the experience of doing business within well-defined legal framework and in collaboration with the local government will reduces uncertainty and transactions costs of firms that cannot afford them, facilitates production, promotes accumulation of physical and human capital (Rodrik, Subramanian, & Trebbi, 2004) and increases experimentation "at a low cost" (Efendic, Mickiewicz, & Rebmann, 2015)

Above factors will make low productive firms to do the cost–benefit analysis can be detected at the start of knowledge collaboration with the proprietor of resources when deciding whether knowledge collaboration should take place locally, between regions or internationally. Our contribution, however, is to stress that the fundamental concept of cognitive, organizational transaction cost when deciding on knowledge collaboration(Cassiman and Valentini, 2016). We posit that low productive firms will be more limited than high productive firms in handling managerial, operational, exploration, synchronisation of costs related to international collaboration. It does not mean they cannot do it, but the efficiency of doing so will be lower than in highly productive firms who are better in synchronising operations, finance and managing collaboration costs (Bogers, 2011; Bogers et al. 2017). The main reason is lack of resources to bear collaboration costs, as well they are less likely to attract external funding, in particular venture capital (Cumming et al. 2016) due to unattractive balance sheets.

That said, firms away from PPF may benefit more from stakeholders collaboration and in particular within local communities (Acs et al. 2017a) with costs may also have a critical impact on the firm's decision to introduce new products or services.
Reaching beyond regional ecosystems to wider and more diverse knowledge banks may prove particularly useful to expand markets, increase sales and productivity.
For firms close to the PPF that operate across countries will risk of knowledge lock-in, and therefore maintaining short-distance interactions within a specific region or cluster will limit knowledge inputs, and lead to fall in firm productivity and innovation (Bathelt et al. 2004; Menzel and Fornahl, 2010). As both low and high productivity have limited resources to invest in development of knowledge in-house and external sourcing of knowledge (Laursen and Salter, 2006, 2014), in a dynamic setting, one can expect that increasing local market innovation on the one hand, may increase proximity to international suppliers, customers, universities and other knowledge collaborators on the other hand. This will distance firm from their ecosystem partners, resulting in shrinking the knowledge and market. This means that the proximity to global innovation and entrepreneurship ecosystems for high productivity firms is crucial to maintain heterogeneity of resources embedded into their collaboration partners and locations and cross-fertilize the dynamics between collaboration actors (Adner and Kapoor 2010). We hypothesize:
H2a: Collaboration with regional ecosystems partners (m) increases innovation output for least productive firms.

$$\partial E(\Delta Y_m)/\partial M_{reg} \geq 0 \qquad \text{if } (\rho_i - \widehat{\rho_i}) \rightarrow max \qquad (7a)$$

H2b: Collaboration with regional ecosystems actors limits innovation output for most productive firms.

$$\frac{\partial E(\Delta Y_m)}{\partial M_{reg}} \leq 0 \qquad \text{if } (\rho_i - \widehat{\rho_i}) \rightarrow 0 \qquad (7b)$$

As firm acquires knowledge and absorptive capacity (Cohen and Levinthal, 1989) to venture and crate new products to market it moves towards the PPF, learning from competitors regionally , nationally and internationally (Bogers and West, 2006; Bogers, 2011) known as the 'productivity ladder' (Van der Zwan et al. (2010), Therefore, an opportunity to draw from the local context (Szrb et al. 2013; Stam, 2014, 2015; Audretsch and Belitski, 2017) is most critical in the earliest stages of firm growth when firm productivity is low . As emphasised by Mickiewicz et al (2016) and Wasdani and Mathew (2014), and applied to entrepreneurs, discussing one's own ideas with those who are experienced in it across different markets and with different customers enhances opportunity recognition and facilitates new market entry. In the similar vein Klonek et al. (2015) pointed that engaging with external partners plays an important role in enhancing the efficiency of doing business.
Why would high productive firms will achieve higher innovation output within global ecosystems and not in regional ecosystems? Heterogeneous knowledge made available while interacting with collaboration partners in different countries serves as a complement to what has been learnt away from the PPFs in earlier periods of further evolution. International knowledge adds to what was is lacking in-house and what impedes knowledge creation (Schamberger et al. 2013; Roper and Hewitt-Dundas, 2015; Beers and Zand, 2014). Diversity of knowledge when operating within global ecosystems further facilitates the absorptive capacity of a firm and adding to firm productivity (Driffield et al. 2014), secures competitive advantages in foreign markets and the ability to recognize heterogeneous opportunities (Ketchen et al. 2007). The importance of knowledge sourcing from international partners in achieving higher productivity has been reflected in knowledge management and economic

geography literature in a way it demonstrated the channel of building stronger apbsorprive capacity and getting access to rare resources (Mowery et al.1998; Barney et al. 2001; Miotti and Sachwald, 2003). These benefits from collaboration with global players have been illustrated in open innovation literature (Bogers et al. 2017; Beers and Zand, 2014; West et al. 2014), and demonstrated why only high productive firms can exploit them.

First, knowledge collaboration in global ecosystems increases risks and transaction costs, as it requires highly qualified R&D personnel to recognize heterogeneous knowledge challenges firms in-house capabilities in a way of their synchronisation and adaptation to knowledge of global partners.

Second, knowledge collaboration with international partners requires costly innovation development in-house and labor inputs to attract globally competitive labour internationally to join a firm. In addition to high complexity of products, firms need international expertize to develop innovation (Roper et al., 2017).This is in addition to hiring high quality labour in-house, which takes a lot of managerial effort and labor search costs. Operating at the PPF firm will need to risk and bear R&D sunk costs, high fixed costs of product development (e,g, labs, expensive materials, R&D personnel, etc.) to keep up with international competition , where only high profitable and highly efficient firms may afford. This means operating at frontier with high market sunk costs, high uncertainty, risks and volatility to be managed. When approaching the PPF, positive macro and global ecosystems externalities may to some extent be traded off by the impact of competition and a cost associated with maintaining high competitiveness at the frontier. Also, improvements in productivity may generate higher revenues and profits in a more competitive environment, where price elasticity of demand tends to be higher. An additional effect of operating at the frontier and a larger firms' innovation and productivity may stem from the increased incentive for workers, provided that product market rents are shared with workers in the form of higher wages or reduced effort (Haskel & Sanchis, 1995). This motivation is unlikely to be offered by low productive firms due to a significant increase of cost and low rent to share. Rent sharing and poaching workers may bring additional benefits when collaborating internationally for both imitation and new products. Such knowledge collaboration strategies duplicated by low productive firms will be limited by the cost firms can afford to take.

Unlike low productivity firms, who will have imited capabilities to move towards PPF, high productivity firms may be able to recycle previously used technology and product lines elsewhere, which is not anymore used for innovation within the ecosystem they operate. In collaboration with international partners and having assets across different technology cycle, high productivity firms will be able to move technologies across borders to create new production lines abroad. Once introduced to multiple markets , these recycled technologies will further generate income and lead to higher productivity as part of the new product life cycle. This is known as externalizing and technology sourcing effects (Granstrand, 2000).

We argue that a number of factors that result in diminishing marginal returns to collaboration while moving towards PPF, may facilitate regional and inter-regional collaboration within the country.

First, regional and national ecosystems are where the market knowledge is relevant for majority of firms which target local markets. Bogers (2011) discussed that both knowledge spillovers and the configuration of local knowledge bases are important for entrepreneurial dynamics.

Second, in regional and national ecosystems have lesser competition and the level of protection which enables further experimentation with new products, and least productive firms will aim to reduce costs by experimenting locally. Regional ecosystems will be used by these firms as a testing ground for new products and services before scaling up internationally and demonstrate product to international collaborators (Rugman and Verbeke, 2001).

Least productive firms will be more comfortable to enforce regulation within regional ecosystems by making aware all community memebers on collaboration and making it more transparent, as opposed to global entrepreneurship ecosystems with different intellectual property standards, regulation and intense competition (Nooteboom et al. 2007).
Third, regional and national entrepreneurship ecosystems offer customised services and provide a firm with information and knowledge valid for national market and ready to be implemented, which lowers the cost of R&D investment by firms who struggle to afford experimentation globally.
Fourth, in order to sustain collaboration with global entrepreneurship ecosystems actors, while reducing the costs of collaboration (Cassiman and Valentini, 2016), a greater trust between partners is needed (Gulati, 1995) which may not be the case for firms at the origins of PPF. These firms have higher incentive to mimic as they were productive and of high quality. This may damage trust relationship within global ecosystems and becomes very costly to "mimic rich" when collaborating internationally. Least productive firms will be more likely to co-locate themselves together with local partners, who follow them internationally. For example, firms that go international are likely to be bounded with local suppliers from the country of origin and then often relocate together (Rugman and Verbeke, 2001; Govindarajan and Ramamurti, 2011). We hypothesize:
H3a: Collaboration with macro/global ecosystems actors increases innovation output for most productive firms

$$\partial E(\Delta Y_m)/\partial M_{world} \geq 0 \text{ if } (\rho_i - \widehat{\rho_i}) \to 0 \qquad \text{(8a)}$$

H3b: Collaboration with macro/global ecosystems actors limits innovation output for least productive firms.

$$\frac{\partial E(\Delta Y_m)}{\partial M_{world}} \leq 0 \text{ if } (\rho_i - \widehat{\rho_i}) \to max \qquad \text{(8a)}$$

3.Data and method

3.1. Sample

To test our hypotheses we used six pooled cross-sectional datasets Business Structure database known as Business Register and the UK Innovation Survey (UKIS) over 2002-2014. Although two datasets were pooled together and constructed from two different sources they are matchable. First, we collected and matched six consecutive UKIS waves of the dataset UK Innovation surveys (UKIS) (UKIS 4 2002-04, UKIS 5 2004-06, UKIS 6 2006-08, UKIS 7 2008-10, UKIS 8 2010-12 and UKIS 9 2012-14) each conducted every second year by the Office of National Statistics (ONS), United Kingdom (UK) on behalf of the Department of Business Innovation and Skills (BIS) were included in this study. Second, we used Business Structure database (BSD) data for years 2002, 2004, 2006, 2008, 2010 and 2012 were matched to a correspondent CIS survey waves with the data from BSD taken for the initial year of UKIS period. The Business Structure Database includes firm legal status, ownership (foreign or national firm), alliance information (firm belongs to a larger enterprise network), export, turnover, employment, industry at 5 digit level and a firm location by the postcode. Given the availability of data and our research question we work with three data samples: "innovative sales" sample available for all variables of interest (21702 obs.), restricted sample of innovation sales, excluding firms in London (19043 obs.) and full sample of firms reporting product innovation (29805 obs.). The distribution of firms across industries, regions and years of survey is 95 percent overlap and hence we do not provide data description for our sample (excluding London firms). Table 1 illustrates the industrial split across an original (baseline) sample (89518 obs.), full "innovative sales" sample (21702 obs.) and product innovator sample (29805 obs.). We use two ONS samples of 89518 observations and the innovative sales sample of 21,702 observations to compare and contrast the distribution of firms across industries, regions and years. Most of firms in both samples come from are from high-tech manufacturing (15.1% and 19.44% accordingly), constriction (9.9% and 10.2% accordingly), wholesale and retail trade (16.8% and 16.0% accordingly), real estate and business activities (14.4% and 12.3% accordingly) as well as public services (including healthcare and defence) (11.1% and 10.1% accordingly). Sectors where firms from both samples are underrepresented are mining and quarrying (<1%), utility electricity (<1%), education (approx. 1%).

TABLE 1 ABOUT HERE

Most of firms in two samples are located in the South East of England (11.5% in the original sample and 10.9% in innovative sales sample), London (12.7% and 9.5% accordingly), the North-West (9.5% and 9.2% accordingly) and East England (8.7% and 8.9% accordingly). Wales (<6%), Scotland (<9%) and Northern Ireland (<8%) are least represented in both samples. Interestingly that the share of firms from London drops the most from 12.7% in the original sample to 9.5% in the final sample, most of these companies did not report sales of new products. The industrial and geographical composition of firms does not change across multiple samples which illustrates that the reduced sample are representative of the original one (89,518 obs.). The major differences were observed across survey waves 2002-2014. Most of observations in our sample come from the first UKIS4 round (2002-2004) - 57.8% in the (innovative sales) sample, while its only 18.4% in the original sample. Although there is a symmetric distribution of firms in both samples and after the UK2002-2004 wave, we find that the wave 2010-2012 (post-crises) is least representative for both samples (16.1% and 6.1% accordingly). It is likely that the share of new product innovators (Colombelli et al. 2016) as well as the number of firms who responded to a survey dropped significantly in post-crises period. This period is characterised by servicing strategies of innovators, exploitation strategy and the use of previous innovations and investments in R&D. Firms which respond to survey questions on innovation positively are likely to be the top performers with a significant increase in a share of those firms that implement collaboration strategy (post crises). Most of firms which were included in our sample as they reported innovation inputs and outputs.

TABLE 2 ABOUT HERE

3.2. Variables

Description of variables including the source of variable is provided in Table 3, while the summary statistics is in Table 4.

TABLE 3 ABOUT HERE
TABLE 4 ABOUT HERE

Table 4 demonstrated that the mean and standard deviations for all variables are consistent across three samples and are compatible with the original sample of 89,518 obs. The major differences we found between innovation sales sample (21,702 obs.) and the reduced sample

(excluding London firms=19,043 obs.) for the robustness check. In particular the share of employees with university degree and above drops when we exclude London firms.
Beneath table 4 we explain how Incoming spillover components (0- not applicable to 3 high) were matched and their summary statistics to create Incoming spillover. As we control for a sample selection bias, Table 4 also illustrates summary statistics for the variables which were used as instruments in the selection equation of Heckman procedure (1979). Our first dependent variable (DV) is the commercial success of the innovation (innovative sales) [0-,100], while our second DV is product crated which was new to a firm. Innovative sales does not measure technological innovation, but is more biased towards commercialization of innovation. A turnover-based measure enables us to integrate the highly variable commercial value of these innovations (Negassi, 2004). Given the potential endogeneity between collaboration variables and innovation, descriptive statistics across all sample is provided for the chosen instruments used in first stage of IV Tobit estimation. The distribution of means and standard deviations for these variables across four sample illustrate the degree of representativeness of the samples we use in our analysis.
We use firm's labour productivity relative to its industry average to measure firm performance. This is appealing for a number of reasons. Industry competitors are most likely to face similar conditions and experience common shocks to performance. By comparing a firm's performance to the performances of its industry peers, common industry shocks can be removed while still maintaining a strong baseline of comparability. Interestingly, in their study of relative performance evaluation, Gibbons and Murphy (1990)do not find evidence of the use of relative performance evaluation at the industry level. They find more evidence of the use of relative performance evaluation at the level of the stock market as a whole.
What can explain this finding? Aggarwal and Samwick (1999) contend that firms in the same industry not only experience common shocks to performance and similar business conditions, but they also directly compete with each other. Relative performance evaluation compensates a manager not only for how well she performs, but also for how badly the benchmark performs. In this case, the industry is the benchmark, and the manager does have some control over how badly the industry performs
The distribution of labour productivity across firms in a sample of product innovators and all UK firms is illustrated in Figure 1. Both distributions were used to calculate a distance from the PPF and allocate firms across 10percentile we created for our analysis. Left side of figure 1 is a histogram of the deviation density between firm's innovation and average innovator's labour productivity in the industry (2 digit SIC 2007). The right side of figure 1 illustrates the deviation density between firm's innovation and average labour productivity in the industry (2 digit SIC 2007) calculated for all UK firms (above three million of firms annually and 90 SICs).

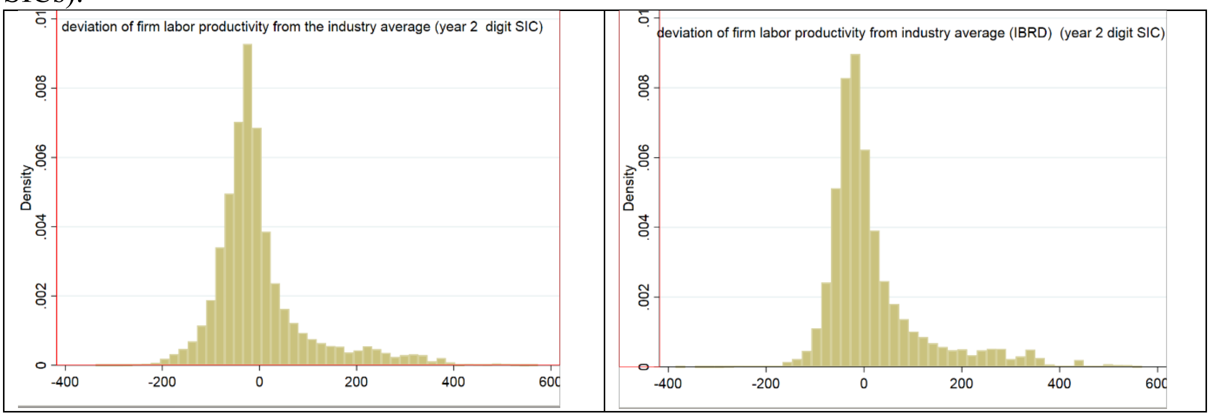

Figure 1: Firm productivity as deviation from the industry average labour productivity for innovators (left) and all UK firms (right).

Table 5a illustrates the average values of innovation output between product innovators and firms which do not innovate in their average sales, number of full time employees (FTEs), labor productivity, difference between firm's labor productivity and average labour productivity in 2 digit SIC 2007 (sector) for innovators and for all firms. Its important to emphasize that two measures of firm productivity were calculatd, such as deviation of firm's sales per employees from the average within industry, calculated using innovators only (UKIS data) and a deviation of firm's sales per employees from the average within industry, calculated using all firms for that year industry in the Unitd Kingdom (above three million firms sample each ear) using BSD data.
TABLE 5A ABOUT HERE
Table 5b illustrates the average values of innovation inputs between product innovators and firms which do not innovate in their average incoming knowledge spillover, internal R&D, share of firms which collaborate with regional, national and international partners (Europe and other world). Our findings are both interesting and unexpected. Firm's outputs in terms of sales, FTEs, labour productivity and deviation fom the industry average on firm's productivity do not vary between product innovators and non innovators. This demonstrates that product innovation and sales is not a necessary condition for productivity 9compard within industry) , outreaching the PPF and firm size (sales, share of employees). In fact, we found that investment in knowledge in-house, knowledge spillovers as well as knowledge collaboration were at least 3 times higher or innovators than non-innovators. While innovation is known to boost productivity, we argue that knowledge collaboration and internal investment in knowledge are key factors for innovation, while the ability to invest and generate innovation depends on the collaboration partner (type and location) as well as firm's location in relation to PPF and its origin, ability to benefit by increasing returns to collaboration, resource complementarity and growth.

TABLE 5B ABOUT HERE

The two main determinants of the position of the firm at PPF is at any given time are the state of technology and management expertise (which are reflected in the available production functions) and the available quantities of factors of production (materials, direct labor, and factory overhead). Only points on or within a PPF are actually possible to achieve in the short run. In the long run, if technology improves or if the supply of factors of production increases, the firm's capacity to manage more combinations of resources and collaborations may increase. If this potential is realized firm innovation occurs. That increase is can be demonstrated by a shift of the production-possibility frontier to the right.

3.3.Method

3.3.1. Innovation production function

We estimate the innovation production function using a random-effects Tobit model with a dependent variable y_i (firm's innovation) and an endogenous variable m_i (knowledge collaboration):

$$y_i = \beta_0 + \beta_i x_i + \omega_i m_i + u_i \qquad (9)$$

We can also call it structural equation to emphasize that we are interested in β_i and that the equation to be measured as causal. Variables x_i and m_i are explanatory variables of firm's innovation, including collaboration and knowledge spillovers and u_i is an error term. x_i is exogenous and not correlated with u_i, while m_i is likely to be correlated with u_i (Wooldridge, 2009: 517). m_i is a binary variable if a firm reports collaboration on innovation with at least one or all external partners innovation (suppliers, clients, competitors, consultants, universities, government (0– no collaborators , max. 6) and each within a specific geographical dimension (regional, national and international) (Beers and Zand, 2014; Choi and Contractor, 2017).

3.3.2. Endogeneity issue

A firm decide whether to collaborate on knowledge strategically and (or) to assimilate knowledge via incoming knowledge spillover, and firms with high levels of innovation output are more likely to source knowledge externally and rely on knowledge spillovers (Bogers and West, 2014; West et al. 2014). This raises a possible endogeneity issue. In order to analyse the relationship between external knowledge collaboration and innovation as well as between incoming knowledge spillover and innovation at the firm level, we estimate an innovation production function in two steps (Wooldridge, 2009) to correct for endogeneity. We split productivity variable (ρ_i) across ten percentiles (see Tables 5a and 5b) and estimate selectively seven innovation production functions for 10%, 30% , 50%, 70%, 80%, 90% and 100% percentiles of firm productivity. We estimate innovation production function correcting for endogeneity and as a robustness check we estimate it without correcting for endogeneity with the original values of knowledge collaboration and spillovers.

First stage estimation

The first stage concerns external innovation collaboration (Leiponen and Helfat, 2010) when firms decide o collaboration (Santamaria et al. 2009). We instrument m_i with two exclusion restrictions (exogenous variables) assuming that ϱ_1 (legal protection in the industry) and ϱ_2 (industry level of collaboration within each geographical proximity), that do not appear in (1) and are uncorrelated with the error u_i. In the reduced form of equation φ_i is estimated as:

$$m_i = \pi_0 + \beta_i x_i + \pi_1 \varrho_1 + \pi_2 \varrho_2 + v_i \qquad (10)$$

where $E(v_i) = 0$, $cov(\varrho_1, v_i) = 0$, $cov(\varrho_2, v_i) = 0$. For this IV not to be perfectly correlated with ϱ_1 we need $\pi_2 \neq 0$ and not to be perfectly correlated with ϱ_2 we need $\pi_1 \neq 0$. The identification requires that $\pi_1 \neq 0$ and $\pi_2 \neq 0$ or both (Wooldridge, 2009: 523).

Using panel data element and, due to the nature of the dependent variables from the UKIS we used four multivariate probit models to predict the collaboration intensity ($\widehat{m_i}$). We also use two exclusion criteria ϱ_1 (legal protection in the industry) and ϱ_2 (industry level of incoming knowledge spillover) to predict the endogenous incoming spillover. In addition to ϱ_1 , ϱ_2 which are exclusion restrictions, other explanatory exogenous variables x_i are included as well as a set of time and legal status fixed effects. Regional dummies were not used, because our dependent variable $\varphi_i$in model (9) is regional and national collaboration, which is a linear combination of city-region dummies. The results of the first stage IV estimation across three geographical dimensions and incoming knowledge spillover are reported in Table A1 in the Appendix, including the post-estimation test (chi2) of a joint significance of chosen instruments. Table A1 (specifications 1-4) in the Appendix illustrates the evidence for the first condition being satisfied with the coefficients of the chosen instruments and significant and positively associated with endogenous variable m_i and knowledge spillover, ceteris paribus. Firms located in the industry with a higher level of collaboration with regional partners (β=4.28, p<0.001), higher level of collaboration with national partners (β=3.22, p<0.001), and higher level of collaboration internationally (β=3.44, p<0.001) are more likely to decide on knowledge collaboration with partners. Firms which located in industry with higher level of industry protection measured as industry level appropriability will accordingly collaborate less regionally (β=-0.44, p<0.001) and will collaborate more internationally (β=0.68, p<0.001), where IP protection is more important to appropriate the results of collaboration. Interestingly, firms located in industry with higher level of incoming knowledge spillovers (β=0.70, p<0.001) are more likely to exploit these spilloveres themselves, while higher level of approprioability of knowledge naturally limits firm's incoming spillover (β=-0.25, p<0.001).

Second stage estimation

IV Probit first "purges" m_i of its correlation with u_i before doing the second stage Tobit ad Probit regressions in (9). Table 6 reports the second-stage IV estimation with $\widehat{\varphi_i}$ and $x_i$as explanatory variables. Having estimated (9) we save u_i to provide the evidence of the second condition for IV to hold: ϱ_1 and ϱ_2 to be uncorrelated with u_i corr(ϱ_i,u_i) = 0, any linear combination is also uncorrelated with u_i (Wooldridge, 2009). We estimate equation (11), where the dependent variable is u_i from equation (1) regressed on the chosen instruments (ϱ_1, ϱ_2):

$$u_i = \beta_0 + \beta_i z_i + \rho_1 \varrho_1 + \rho_2 \varrho_2 + \epsilon_i \qquad (11)$$

where u_i is error from equation (1). Variables z_i are control variables such as regional, year and industry 2 digit SIC fixed effects, firm ownership status variable and ϵ_i is an error term. Coefficients ρ_1 and ρ_2 were not statistically significant and we conclude that corr(ϱ_i,u_i) = 0, thus ρ_1 and ρ_2 are valid instruments for φ_i.

4. Results

4.1. External collaboration and innovation in firms

We start by estimating equation (9) using IV probit across collaboration with regional , national and international partners within seven groups of productivity (percentiles). Results are reported in Table 6 (spec. 1-7) illustrate the direct effect of knowledge collaboration on firm's product innovation.

TABLE 6 ABOUT HERE

The benefits from external collaboration are different across different productivity level of firms, the coefficients of regional collaboration are consistently positive (β=0.66-0.83, p<0.01) for firms with the negative deviation from the industry average (10-80 percentile), supporting H2a. Interestingly, both least productive and most productive firms benefit from collaboration with national partners, where knowledge is significantly diverse, but embedded within a common market and institutional setting (β=1.18-1.64, p<0.01). Firms close to production frontier (90 and 100 percentile) will not benefit by collaboration within regional ecosystems with the coefficients positive, but not statistically significant, supporting H2b. These firms benefit from international partners collaboration (β=0.41-0.63, p<0.01), supporting H3a, than firms closer to the origin of PPF (10-70 percentile) with the coefficients of international collaboration are not statistically significant within 10-70 percentiles, supporting H3b. In other words, collaboration with global ecosystem partner is likely to increase the probability of product innovation up to 61% for firms with on average £9,000 higher sales per employee than their industry average. Collaboration with global ecosystem partners does not differentiate the likelihood of innovation for firm with the sales per employee £9,000 below the industry average.

In order to test a trade-off frontier between capital augmentation rates and labor augmentation rates which is represented by an increase in m (an additional collaboration partner) to Innovation Possibility Frontier we turn to the results in Table 6 (spec. 1-7) on the right side of the table. The results of interaction analysis confirm that an augmentation of knowledge collaboration changes innovation outcomes and that this change depends on where the firm is located at PPF. The following patterns were analysed.

First, return to collaboration with regional ecosystems partners when we augment it with an international collaboration decreases innovation outcome with the movement towards the PPF. We found that augmenting regional collaboration with international does not change the probability of innovation for least performers (10-30th percentile) with the values vary between 1.31-1.62 ($p<0.01$), while there is an additional negative effect of augmentation which limits innovation outcome starting from the 50th percentile i.e. 0.52 (β=1.45-0.93, $p<0.01$) with the likelihood of further innovation approaching zero after 70th percentile i.e. 0.07 (β=1.96-1.89, $p<0.01$) and 80th percentile i.e. 0.06 (β=1.05-1.11, $p<0.01$). We evidence a decrease in marginal returns to international and regional collaboration supporting H1, which states that firms will experience diminishing marginal returns to knowledge collaboration while approaching the PPF, which will limit their innovation output. The key word here is marginal as we observe every additional change in a probability of innovation while we add an additional m (collaboration partner).
Second, for firms that collaborate with international partners (Europe and other world) an augmentation of their collaboration with regional ecosystem partner (m) will negatively affect the likelihood of innovation. For least productive firms (10th percentile) the returns to international collaboration innovation are β=1.16 ($p<0.01$), while no additional benefits observed when augmenting the function with a regional partner. For the 50th percentile the effect of augmentation is negative 0.28 (β=0.67 -0.95, $p<0.01$), negative 0.76 (β=1.13-1.89, $p<0.01$) for 70th percentile, and back to positive 0.99 (β=2.10-1.11, $p<0.01$) for 80th percentile and 0.54 (β=1.82-1.28, $p<0.01$) for firms at the PPF. The results demonstrate that collaboration with international partners on its own is more profitable and allows for a higher probability of innovation than augmenting global ecosystem collaborations with collaboration with regional partners, supporting H1a. While moving towards PPF a law of decreasing marginal returns is at play as every additional input, ceteris paribus, which means when other factors such as capital and labor remain unchanged, will decrease returns to every additional input with marginal cost of collaboration approaching marginal benefit from collaboration, what we observe in case of the UK innovative firms.
Third, firms which collaborate with global ecosystem partners will experience negative trade-off when augmenting their collaboration by allowing for incoming knowledge spillover when they are at both extremes of PPF – in the origin and at PPF. Interestingly, for firms in the 50th-70th percentile augmentation its international and regional collaborations with incoming knowledge spillover will not decrease the probability to innovate. Firms in the origins with low resources risk of not being able to capitalize on their collaboration and knowledge spillovers due to lack of absorptive capacity (Cohen and Levinthal, 1989) to effectively manage both knowledge collaboration and knowledge spillovers. First, innovators at PPF will experience allocative dis-efficiencies when augmenting its regional or international ecosystem collaboration with knowledge spillover. Interestingly, its only firms with close to industry average productivity will be able to benefit by augmenting its collaboration with knowledge spillover. The effect is stronger for firm that add knowledge spillover to its existing global ecosystem collaborations rather than regional ecosystem collaborations.
Figure 2 illustrates the interplay between regional and international entrepreneurship ecosystems collaboration, as well as augmenting regional and international collaboration with incoming knowledge spillover and how it changes the likelihood of innovation outputs across firms with different level of productivity.

FIGURE 2 ABOUT HERE

4.2. External collaboration and commercialization of innovation

The results of IV tobit estimation (Table 7, spec. 1-7 left side) illustrate the direct effect of collaboration with regional and international partners on firm's innovative sales, while Table 7, spec. 1-7 right side) demonstrates interaction analysis of a role that augmentation in collaboration (m) plays in innovative sales.

TABLE 7 ABOUT HERE

The benefits from external collaboration are different across firms with different productivity and regional collaboration coefficients are consistently positive (β=3.30-10.10, $p<0.01$) for firms at the origin of PPF, supporting H2a. Starting from 30th percentile firms are able to commercialize on collaboration with national partners (β=7.14-14.79, $p<0.01$). While moving to PPF (50th percentile and above), collaboration within regional ecosystem does not increases innovation sales, supporting H2b. Most productive innovators will only be able to benefit from international ecosystems partnerships (β=2.21-5.44, $p<0.01$), supporting H3a, Firms closer to the origin of PPF (90-100 percentile) will better exploit international knowledge while firms below (80th percentile of productivity) will be less likely to commercialize the results of such collaboration supporting H3b.

In order to test a trade-off frontier between capital augmentation rates and labor augmentation rates which is represented by an increase in m (an additional collaboration partner) to Innovation Possibility Frontier we analyse Table 7 (spec. 1-7 right side). The results of interaction analysis confirm that an augmentation of knowledge collaboration changes innovation outcomes and that this change depends on how productive is the firm. The following patterns were analysed.

First, return to collaboration with regional ecosystems partners when we augment it with an international collaboration decreases innovation outcome for firms at 10-80th percentile of productivity. In fact the effect is likely to be negative at both spectrums of PPF.

The results support findings for product innovation and support H1, which states that firms will experience diminishing marginal returns to knowledge collaboration while approaching the PPF.

Second, firms that collaborate with international partners (Europe and other world) will only be able to capitalize on collaboration starting from the 70th percentile of productivity (9000£ greater than industry average). In addition to international collaboration augmented with regional will limit returns to international collaboration (β=10.48-10.14=0.34, $p<0.01$), supporting H1. Interestingly, for the firms with an average productivity (70thpercentile) and above average (90th percentile) the effect of international collaboration is positive, but augmentation dos not result in an increase in innovative sales

While moving towards PPF a law of decreasing marginal returns is at play as every additional input, ceteris paribus, which means when other factors such as capital and labor remain unchanged, will decrease returns to every additional input. Innovative sales will decrease by the amount if no additional collaboration was in place. Results overwhelmingly support H1 on the diminishing marginal returns to collaboration, in this case with respect to both the likelihood of innovation and commercialization of innovation – innovative sales. Location at PPF will define the ability of firms to benefit by a combination of resources.

5. Discussion and Conclusion

Innovation, regional development and entrepreneurship ecosystem literatures in their current development have not been able to assess whether collaboration with the proprietaries of resources from the direct geographical surrounding (region and country) or globally lead to higher innovative output for firms at different level of productivity. Therefore, we theoretically debate and empirically test the returns to collaboration with regional, national and global ecosystems actors challenging the current literature.

The literature differs in two important aspects. First, the regional development literature explicitly focuses on the geographical boundedness of interactions between actors and innovative firms, while open innovation and strategic entrepreneurship literature demonstrates the importance of a global context for innovators (Zahra and Nambisan 2011; Laursen and salter, 2005, 2014; Bogers et al. 2017; Audretsch and Belitski, 2019). Second, the geography of innovation literature aims to explain differences in returns to collaboration within local communities and agglomeration economies, industrial clusters (Marschal, 1920; Jacobs, 1969), while this study focuses on the complementarity between actors located across different geographical proximities with a final choice of collaboration brought down to collaboration costs (Bogers, 2011; Cassiman and Valentini, 2016) and firm's location in relation to PPF. Highly productive firms allow for better access to resources, including human capital and their combination in the most efficient ways in order to manage the cost of interactions within close and distant proximities and across actor types (Beers and Zand, 2014). In doing so most productive firms are able to better assimilate (Cohen and Levinthal, 1989) as well as appropriate knowledge (Hall and Sena, 2017) which results in the development of new products and services. If regional and global ecosystem are managed well, the value of the local resources may be increased but also access to global ecosystems is less costly. This study integrates the (firm focused) resource-based approach and the concept of knowledge collaboration for innovation with the (ecosystem focused) concept of interactions between innovators and stakeholders within regional, national and global innovation and entrepreneurial ecosystems. Thus, the novelty of the ecosystem approach lays in the focus on firm's productivity when deciding on costs of collaboration and the benefits. In contrast to earlier studies (Isenberg, 2010; Stam, 2015, O'Connor et al. 2018) innovation emerges as an output of knowledge collaboration with ecosystem stakeholders , with those interactions not geographically bounded. There are several important findings in this paper. First, least productive firms benefit more from collaboration within regional entrepreneurship ecosystems than most productive firms, which do not benefit by regional collaborations. Second, most productive firms (90-100th percentile) will benefit from collaborating across micro and global ecosystems, however adding additional dimension of collaboration dos not help them to further advance innovation, because they are limited by PPF. Interestingly, both least and most productive firms benefit from collaboration within national ecosystems partners, where the market is broad enough to scale up, cognitive and institutional proximity to collaborators is close, and costs of collaboration are smaller, compared to international partnerships. Third, we contend that returns to collaboration are conditional on the geographical proximity of ecosystem actors and firm's location in relation to the origin of PPF. This confirms prior research on the benefits of co-location and industrial clusters (Marshal, 1920; (Stam and Spigel 2017), in particular for younger and smaller firms, including knowledge spillovers (Arrow, 1962; Audretsch and Feldman, 1996) from localised networks and knowledge (Crescenzi et al. 2016; Roper et al. 2017; Giovanetti and Piga, 2017).

Fourth, the most productive firms will effectively engage with actors globally, including through physical or virtual means (Evans and Schmalensee 2016), this diminishes the role of firm size in the ability to assimilate and co-create knowledge with local and international partners and the knowledge accessibility. Virtual platforms and other means may further facilitate collaborations internationally and combining different collaboration partners, while this change will be associated with a long term production function.

Finally, collaboration with external partners within close geographical proximity may become is an efficient mechanism for the least productive innovators to nurture innovative ideas with local partners, while collaboration with international partner may be associated with higher transaction and organizational costs as well as appropriability risks.

This study helps us to answer the following important questions: Can low productive firms benefit from global collaborations with international partners? Yes. Can high productive firms continue to benefit from micro and regional collaborations with partners? No. Given an existing level of collaboration, would adding knowledge spillover facilitate innovation further? Yes, and unlike knowledge collaborations, knowledge spillover will facilitate innovation for firms at different level of productivity. What will be the additional factors bridging the efficiency and returns to both regional and global collaborations? In the short term, the number of such factors is limited as complementarities will increase costs and slow down innovation process.
Future research should answer a question: how can firms increase their productivity to be able to engage themselves in knowledge collaboration across national and global entrepreneurship ecosystems? More specifically, changes in technology, collaboration tools and managerial capabilities may significantly affect such possibilities, while this is unlikely to take place in a short-term production circle. Further measures of firm productivity should be employed, including gross margins, value added to demonstrate whether changes in the supply chains, including the global supply chains , may further intensify international collaborations? What will b the implications of increase in firm's productivity for global value chains? Will it mean that international collaborations will eventually be more important and that if markets are fully liberalized, will it drive higher global trade, collaboration and affect firm' productivity? Further research should pay more attention on explaining the differences in decision making on knowledge collaborations and then how these decisions will change the way firms innovate and grow. Innovation output across firms with different level of productivity has demonstrated diminishing marginal returns to investment in collaboration and augmenting firm's resources through collaborations. We wonder, whether this is an industry story (high tech manufacturing firms will have on average higher innovation and productivity), or a managerial capabilities story (independently on the level of absorptive capacity and size , firm will not be able to infinitely exploit knowledge collaborations and spillovers, as decision making capacity is limited. Managerial implications are as follows. Finally, firm age matters for knowledge collaborations. Newly establishes firms when collaborating with regional partners are more likely to achieve higher innovation performance quickly , than dispersing their effort thinly across multiple and distant collaborations
Firms, which operate under higher resource constraints and have the smallest productivity aim at tapping into the external global ecosystems partnerships need to first develop their capabilitis locally (Delgado-Márquez et al. 2018). Aquiring further competencs will decrease the costs of switching to most expensive national and international collaborations. Least productive firms should embed themselvces within regional entreprenurship ecosystems and carefully search for knoldge spillovers to further strengthen its efficiency and innovation. (Stam, 2015; O'Connor et al. 2018; Rogers, 2004).
Innovators that are less productive will find co-creation, adoption, modification and implementation of new knowledge easier when geographical proximity of collaboration is aligned with institutional and cognitive proximities (Boschma, 2005; Nooteboom et al. 2007; Lahiri, 2010) as this will not require an investment in understanding regulation, innovation culture and networks (Delgado-Marquiz et al. 2017). Low productivity firms will find it easier to leverage their resource constraints when building the localised networks, creating competitive advantages and securing customers' loyalty (de Massis et al. 2018).
As firms approach the PPF, new, diverse partnerships may become available which drives innovation and helps commercialization. The benefits of internationalization will only emerge when resources become available and expertise to exploit such resources adding them to new knowledge.

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Table 1: Three samples sector divisions (by SIC 2007)

Sector divisions	Baseline	%	Innovative sales	%	Product innovator sample	%
1 – Mining & Quarrying	486	0.65	175	0.81	205	0.69
2 - Manufacturing basic	4025	5.41	1277	5.88	1738	5.83
3 - High-tech manufacturing	11682	15.70	4218	19.44	5479	18.38
4 – Utility	780	1.05	170	0.78	228	0.76
5 – Construction	7370	9.90	2229	10.27	2925	9.81
6 - Wholesale, retail trade	12530	16.84	3481	16.04	4789	16.07
7 - Transport, storage	4792	6.44	1195	5.51	1654	5.55
8 - Hotels & restaurants	5400	7.26	1174	5.41	1572	5.27
9 – ICT	4441	5.97	1434	6.61	1980	6.64
10 - Financial intermediation	2651	3.56	850	3.92	1480	4.97
11 - Real estate & other business activities	10728	14.41	2682	12.36	3844	12.90
12 - Public admin, defence	8305	11.16	2196	10.12	3093	10.38
13 – Education	213	0.29	152	0.70	212	0.71
16 - Other community, social activity	1024	1.38	469	2.16	656	2.20
Total observations	**74427**	**100.00**	**21,702**	**100.00**	**29,805**	**100.00**

Note: Due to missing values on firm's sector the total amount of observations (once controlled for sectors\) in the baseline sample is 74,427 obs.

Source: Department for Business, Innovation and Skills, Office for National Statistics, Northern Ireland. Department of Enterprise, Trade and Investment. (2018). *UK Innovation Survey, 1994-2016: Secure Access*. [data collection]. *6th Edition.* UK Data Service. SN: 6699, http://doi.org/10.5255/UKDA-SN-6699-6 (hereinafter UKIS- UK Innovation survey)

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Table 2: Three samples regional distribution (by 10 UK regions, Scotland and Northern Ireland) and distribution over survey waves

Regions	Baseline	%	Innovative sales	%	Product innovator sample	%
North East	4731	5.28	1171	5.40	1752	5.88
North West	8506	9.50	1997	9.20	2707	9.08
Yorkshire and Humber	7142	7.98	1758	8.10	2455	8.24
East Midlands	6708	7.49	1749	8.06	2364	7.93
West Midlands	7562	8.45	1890	8.71	2549	8.55
Eastern England	7776	8.69	1946	8.97	2708	9.09
London	11369	12.70	2064	9.51	2898	9.72
South East	10353	11.57	2367	10.91	3242	10.88
South West	7229	8.08	1813	8.35	2510	8.42
Wales	5203	5.81	1432	6.60	2000	6.71

Scotland	7487	8.36	1700	7.83	2395	8.04
Northern Ireland	5452	6.09	1815	8.36	2225	7.47
Total	89518	100.00	21702	100.00	29805	100.00
Years						
UKIS4 (2005)	16445	18.37	12557	57.86	12554	42.12
UKIS5 (2007)	14872	16.61	2425	11.17	6264	21.02
UKIS6 (2009)	14281	15.95	1454	6.70	4734	15.88
UKIS7 (2011)	14342	16.02	2773	12.78	2853	9.57
UKIS8 (2013)	14487	16.18	1174	5.41	1509	5.06
UKIS9 (2015)	15091	16.86	1319	6.08	1891	6.34
Total observations	**89,518**	**100.00**	**21,702**	**100.00**	**29,805**	**100.00**

Source: UKIS- UK Innovation survey; BSD- Business Structure Database.

Table 3: Description of variables

Variable (source)	Definition-
Productivity	
Innovative sales (UKIS)	% of firm's total turnover from goods and services that were new to the market (%)
Product innovator (UKIS)	Binary variable=1 if firm reports positive firm's turnover from goods and services that were new to the market or new to the firm , zero otherwise
Patenting (UKIS)	How effective were patents as a method for maintaining or increasing the competitiveness of product and process innovations: patents (0 – not applicable to 3 – high)?.
Incoming spillovers (UKIS)	Sum of scores (0 to 3) of how important to innovation activities was information from: conferences, trade fairs or exhibitions; professional and industry associations; technical, industry or service standards; scientific journals and trade/technical publication (rescaled between zero and one) . The individual variables are described below.
Associations (UKIS)	**Incoming spillovers component:** how important to innovation activities was information from: professional and industry associations (0 – not applicable to 3 – high)
Standards (UKIS)	**Incoming spillovers component:** how important to innovation activities was information from: technical, industry or service standards (0 – not applicable to 3 – high)
Conferences (UKIS)	**Incoming spillovers component:** how important to innovation activities was information from: conferences, trade fairs or exhibitions (0 – not applicable to 3 – high)
Publications (UKIS)	**Incoming spillovers component:** how important to innovation activities was information from: scientific journals and trade/technical publications (0 – not applicable to 3 – high)
	Other variables
Collaboration regional (UKIS)	Binary variable=1 if firm collaborates on innovation regionally within enterprise group, suppliers; clients or customers; competitors; consultants, commercial labs, private R&D institutes; universities; government and public research institutes, zero otherwise
Collaboration national (UKIS)	Binary variable=1 if firm collaborates on innovation nationally within enterprise group, suppliers; clients or customers; competitors; consultants, commercial labs, private R&D institutes; universities; government and public research institutes, zero otherwise

Collaboration international (UKIS)	Binary variable=1 if firm collaborates on innovation in Europe and other world within enterprise group, suppliers; clients or customers; competitors; consultants, commercial labs, private R&D institutes; universities; government and public research institutes, zero otherwise
R&D intensity (UKIS)	The amount of expenditure for internal Research and Development (000s), to total sales (000s pound sterling)
Software (UKIS)	The amount of expenditure for purchasing advanced machinery , equipment and software (000s) to total sales (000s pound sterling)
Age (BSD)	Age of a firm (years since the establishment)
Employment (BSD)	Number of full time employees , in logarithms
High-tech manufacturing (UKIS)	Binary variable equal one if SIC2007 (2 digit): 21, 26, 30, zero otherwise
Med-tech manufacturing (UKIS)	Binary variable equal one if SIC2007 (2 digit): 20, 22-25, 27-29, 32, zero otherwise
Risk barrier (UKIS)	Binary variable=1 if firm has experienced constraining innovation activities such as excessive perceived economic risks, zero otherwise
Cost barrier (UKIS)	Binary variable=1 if firm has experienced constraining innovation activities such as cost of finance, zero otherwise
Technology barrier (UKIS)	Binary variable=1 if firm has experienced constraining innovation activities such as lack of information on technology, zero otherwise
Scientist (UKIS)	The proportion of employees that hold a degree or higher qualification in science and engineering at BA / BSc, MA / PhD, PGCE levels
Exporter (UKIS)	Binary variable=1 if a firm sells its products in foreign markets, 0 otherwise
Survival 2017 year *(BSD)*	Binary variable=1 if a firm survived as an independent unit or as a part of a group until year 2017, 0 otherwise
HHI *(BSD)*	The Herfindahl–Hirschman Index, HHI, is a measure of the size of firms in relation to the industry by employment at two-digit SIC 2007 (0-1).
Variables used as instruments at the first stage regression	
Protection industry (UKIS)	Mean of legal protection at industry level. Industry level is defined as two-digit SIC 2007. Legal protection is sum of scores of effectiveness of following methods for protecting new products and processes: (0 – no protection to 3 - high) , patenting, design registration, copyright, trademarks.
Incoming spillover (UKIS)	Mean of Incoming spillover variable at industry level for each year. Industry level is defined as two-digit SIC 2007.
Collaboration regional industry (UKIS)	Mean of collaboration with regional partners at industry level for each year. Industry level is defined as two-digit SIC 2007.
Collaboration national industry (UKIS)	Mean of collaboration with national (UK) partners at industry level for each year. Industry level is defined as two-digit SIC 2007.
Collaboration international industry (UKIS)	Mean of collaboration with international (Europe and world) partners at industry level for each year. Industry level is defined as two-digit SIC 2007.

Source: UKIS- UK Innovation survey; BSD- Business Structure Database.

Table 4: Summary statistics for variables used in this study across four samples

Sample	Baseline sample (collected by the ONS) = 89518 obs.			Innovative sales = 21,702 obs.		Innovative sales = 19,043 obs. (excluding London)		Product innovator [0,1] sample = 29,805 obs.	
Variables		Mean	St.dev	Mean	St.dev	Mean	St.dev	Mean	St.dev
Productivity (all firms)	77884	18.82	103.86	8.63	87.79	5.38	83.58	10.17	90.81
Innovative sales	33969	4.68	13.67	4.24	12.79	4.20	12.61		
Product innovator	89518	0.24	0.43	0.41	0.49	0.42	0.49	0.36	0.48
Incoming spillover	89518	0.19	0.27	0.29	0.27	0.29	0.27	0.29	0.28
Collaboration regional	73435	0.13	0.34	0.14	0.35	0.15	0.35	0.15	0.35
Collaboration national	73431	0.18	0.39	0.18	0.39	0.18	0.39	0.19	0.40
Collaboration international	89518	0.09	0.29	0.12	0.32	0.11	0.32	0.12	0.32
Age	64192	18.32	10.80	17.93	9.78	17.98	9.76	18.25	9.76
Employment	89505	4.09	1.52	4.02	1.49	3.95	1.43	4.07	1.51
High-tech manufacturing	89518	0.01	0.09	0.01	0.06	0.01	0.06	0.01	0.07
Med-tech manufacturing	89518	0.07	0.25	0.06	0.23	0.06	0.24	0.06	0.25
Risk barrier	67951	1.16	1.18	1.18	1.13	1.17	1.13	1.15	1.14
Cost barrier	68162	1.13	1.14	1.10	1.09	1.10	1.08	1.08	1.10
Technology barrier	67753	0.80	0.88	0.76	0.83	0.76	0.83	0.75	0.83
Scientist	66559	6.79	16.26	7.20	17.02	6.89	17.02	7.18	17.00
Exporter	89518	0.31	0.46	0.38	0.48	0.37	0.48	0.37	0.48
Survival 2017 year	89518	0.49	0.50	0.57	0.49	0.58	0.48	0.59	0.49
HHI	89518	0.05	0.07	0.04	0.05	0.03	0.04	0.04	0.06
R&D intensity	45321	0.01	0.06	0.01	0.05	0.01	0.04	0.01	0.05
Apropriability	89518	0.29	0.76	0.43	0.91	0.43	0.90	0.40	0.96
Software	47476	0.01	0.05	0.01	0.04	0.01	0.04	0.01	0.04

Foreign	64211	0.24	0.42	0.43	0.50	0.42	0.49	0.42	0.49
Incoming spillover components (0- not applicable to 3 high)									
Associations	89518	0.61	0.93	0.92	0.96	0.91	0.96	0.89	0.97
Standards	89518	0.65	0.98	0.96	1.03	0.96	1.02	0.95	1.03
Conferences	89518	0.58	0.91	0.89	0.97	0.89	0.97	0.86	0.97
Publications	89518	0.50	0.82	0.80	0.90	0.80	0.89	0.77	0.90
Instruments used in first stage of IV Tobit estimation									
Incoming spillover industry	89518	0.19	0.09	0.24	0.08	0.24	0.08	0.23	0.09
Collaboration regional industry	89517	0.14	0.07	0.11	0.06	0.11	0.05	0.12	0.06
Collaboration national industry	89517	0.19	0.12	0.14	0.10	0.14	0.10	0.16	0.11
Collaboration international industry	89518	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08
Protection industry	89518	0.09	0.08	0.12	0.09	0.12	0.09	0.12	0.09

Source: UKIS- UK Innovation survey; BSD- Business Structure Database.

Table 5a: Average values of the innovation output variables across product innovators and non-innovators

Productivity percentile	Sales		FTE		Labor productivity (000s per FTE)		Dev. from the industry mean productivity (innovators)		Dev. from the industry mean productivity (all firms)	
	Innovator	No	Innovator	No	Innovator	No	Innovator	No	Innovator	No
1	16322	7297	377	180	47.52	48.25	-123.81	-124.51	-79.25	-78.72
2	6961	8328	200	198	44.60	44.17	-73.81	-73.85	-47.90	-51.39
3	10786	8481	185	157	56.38	51.19	-53.26	-53.22	-31.11	-36.62
4	14345	11125	227	163	61.55	56.48	-38.42	-38.45	-19.71	-25.85
5	18445	10433	268	213	64.71	53.59	-26.44	-26.39	-12.82	-20.42
6	18163	17906	266	312	70.61	56.52	-15.17	-15.84	-4.86	-13.50
7	32615	17381	411	234	86.45	78.29	-2.46	-2.58	9.95	3.84
8	51363	25073	411	209	119.37	115.38	20.69	19.82	37.56	32.54
9	83479	45763	396	217	186.92	191.75	72.65	74.10	94.96	96.27
10	2110000	1365000	310	186	371.86	385.33	233.97	243.64	264.35	274.95

Table 5b: Average values of the innovation input variables across product innovators and non-innovators

Productivity percentile	Internal R&D intensity		Software intensity		Incoming spillover		Collab. regional		Collab. national		Collab. intern	
	Innovator	No	Innovator	No	Innovator	No	Innovator	No	Innovator	No	Innovator	No
1	0.034	0.012	0.018	0.004	0.43	0.13	0.30	0.07	0.41	0.09	0.23	0.04
2	0.044	0.009	0.020	0.006	0.40	0.12	0.30	0.08	0.40	0.08	0.22	0.03
3	0.032	0.006	0.019	0.007	0.40	0.13	0.31	0.07	0.40	0.07	0.24	0.03
4	0.025	0.004	0.021	0.008	0.40	0.14	0.29	0.07	0.42	0.08	0.21	0.03
5	0.026	0.004	0.018	0.006	0.39	0.14	0.28	0.06	0.39	0.07	0.23	0.03
6	0.022	0.004	0.019	0.007	0.40	0.13	0.30	0.06	0.39	0.07	0.22	0.03
7	0.020	0.004	0.014	0.005	0.41	0.14	0.26	0.06	0.39	0.07	0.25	0.03
8	0.022	0.004	0.013	0.006	0.44	0.16	0.29	0.07	0.46	0.09	0.31	0.05

9	0.020	0.007	0.011	0.004	0.45	0.16	0.27	0.08	0.47	0.11	0.37	0.07
10	0.017	0.005	0.009	0.004	0.45	0.16	0.28	0.07	0.50	0.11	0.39	0.07

Source: UKIS- UK Innovation survey; BSD- Business Structure Database.

Table 6– Results of Probit regression for innovation production function across firm's with different percentile of productivity. DV: product innovator

Spec.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percentile	10	30	50	70	80	90	100	10	30	50	70	80	90	100
Method	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic	Logistic
Incoming Spillover	1.760***	1.687***	1.558***	1.089***	1.808***	1.669***	2.009***	2.328***	2.308***	1.771***	1.512***	2.250***	2.269***	2.967***
	(.31)	(.35)	(.27)	(.29)	(.34)	(.31)	(.37)	(.36)	(.4)	(.32)	(.34)	(.39)	(.38)	(.47)
Collab regional	0.799***	0.838***	0.844***	0.898***	0.666**	0.293	0.431	1.628***	1.312***	1.451***	1.965***	1.055*	0.570	0.902
	(.2)	(.22)	(.18)	(.21)	(.22)	(.19)	(.24)	(.35)	(.38)	(.38)	(.48)	(.46)	(.43)	(.49)
Collab national	1.186***	1.204***	1.017***	1.643***	1.620***	1.020***	1.550***	1.385***	1.980***	1.273***	2.484***	2.296***	1.668***	2.636***
	(.23)	(.24)	(.19)	(.25)	(.26)	(.2)	(.26)	(.36)	(.41)	(.35)	(.46)	(.47)	(.4)	(.48)
Collab international	-0.141	0.180	0.426	0.238	0.630**	0.415*	0.522*	1.166*	1.692**	0.673	1.131*	2.100***	1.066**	1.821***
	(.26)	(.26)	(.23)	(.22)	(.24)	(.19)	(.24)	(.52)	(.58)	(.5)	(.5)	(.58)	(.41)	(.5)
Internal R&D	2.432*	6.577**	8.207***	0.0344	3.432	-0.0819	8.386**	2.993*	6.524**	8.057***	0.599	3.791	-0.0368	9.448**
	(1.2)	(2.2)	(2.1)	(1.5)	(2)	(1.4)	(3.2)	(1.2)	(2.2)	(2.1)	(1.4)	(2)	(1.4)	(3.4)
appropriability	3.094***	1.915***	2.004***	2.921***	3.422***	2.036***	3.714***	3.007***	1.873***	2.037***	2.939***	3.429***	1.979***	3.720***
	(.58)	(.58)	(.46)	(.52)	(.58)	(.45)	(.62)	(.57)	(.57)	(.47)	(.53)	(.59)	(.46)	(.64)
Software intensity	3.662**	5.695***	5.487***	3.428*	4.230*	3.616*	-1.145	3.157*	5.532***	5.622***	3.435*	4.370*	3.471*	-1.310
	(1.4)	(1.6)	(1.3)	(1.5)	(1.8)	(1.7)	(2.2)	(1.3)	(1.5)	(1.3)	(1.5)	(1.8)	(1.7)	(2.2)
Collab regional x Incoming Spillover								-1.986**	-0.945	-0.956	-0.949	-0.0741	-0.451	0.180
								(.67)	(.72)	(.72)	(.8)	(.83)	(.75)	(.92)
Collab national x Incoming Spillover								-0.506	-1.943**	-0.670	-1.842*	-1.641*	-1.371	-2.747**
								(.69)	(.75)	(.69)	(.79)	(.82)	(.73)	(.85)
Collab international x Incoming Spillover								-2.361*	-2.441*	0.611	-0.355	-2.048*	-1.382	-1.763*
								(.92)	(1)	(.92)	(.89)	(.97)	(.79)	(.87)
Collab international x Collab Regional								-0.362	-0.616	-0.938*	-1.898***	-1.114*	-0.0140	-1.285**
								(.46)	(.5)	(.46)	(.46)	(.46)	(.38)	(.49)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-3.357***	-5.583***	-20.63	-4.230***	-2.853**	-2.530**	-4.967***	-2.938**	-5.640***	-20.42	-4.623***	-3.142**	-2.826**	-5.480***
	(.95)	(1.5)	(5159)	(1.1)	(1)	(.86)	(1.2)	(.91)	(1.4)	(3633)	(1.2)	(1.1)	(.91)	(1.3)
lnsig2u	0.159	0.391	-0.00294	0.690	0.913*	0.127	0.781	0.0718	0.304	0.196	0.812	0.972*	0.290	0.834
	(.64)	(.72)	(.64)	(.51)	(.45)	(.61)	(.44)	(.68)	(.72)	(.58)	(.47)	(.44)	(.57)	(.44)
N	2779.000	3027.000	3251.000	3176.000	2964.000	2644.000	2363.000	2779.000	3027.000	3251.000	3176.000	2964.000	2644.000	2363.000
chi2	110.8388	83.47508	.	95.40532	90.67032	121.7129	108.5648	113.5621	90.0848	128.2994	95.32171	89.91393	115.2454	102.9909
chi2_c	4.582686	3.983438	3.85994	8.84041	13.41981	4.663643	12.77911	3.98366	3.812156	5.120508	11.02604	14.8084	5.846053	12.9252
ll_c	-1287.095	-1349.993	-1547.604	-1535.264	-1456.204	-1339.96	-1098.091	-1270.92	-1331.36	-1543.901	-1514.727	-1443.165	-1330.841	-1077.165

Table 7 – Results of tobit regression for innovation production function across firm's with different percentile of productivity. DV: Innovation is taken in % and varies from (0-100)

Spec.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percentile	10	30	50	70	80	90	100	10	30	50	70	80	90	100
Method	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit	Tobit
Incoming Spillover	9.165	13.10**	6.409	6.245*	8.128**	12.01***	11.33**	16.42**	18.65***	10.50*	8.657*	14.89***	19.56***	21.24***
	(5)	(4.5)	(3.7)	(3.2)	(3.1)	(3.4)	(4.1)	(5.8)	(5.2)	(4.3)	(3.7)	(3.7)	(4)	(5)
Collab regional	10.10**	3.31*	2.992	2.929	5.747**	2.087	2.044	21.23***	4.43*	4.766	6.819	3.758	-4.565	7.967
	(3.1)	(1.8)	(2.4)	(1.9)	(1.9)	(2.2)	(2.6)	(5.7)	(2.5)	(5.1)	(4.5)	(4.7)	(5.8)	(6)
Collab national	4.619	14.79***	8.458***	7.653***	8.810***	7.144**	8.775***	8.068	24.14***	19.46***	8.341	22.43***	15.63***	17.88***
	(3.4)	(3)	(2.4)	(2.1)	(2)	(2.3)	(2.6)	(6.2)	(5.3)	(4.7)	(4.4)	(4.2)	(4.7)	(5)
Collab international	8.674*	-3.123	5.074	2.620	1.780	5.442*	2.21*	6.749	10.83	3.863	11.45*	4.550	9.655*	10.48*
	(4)	(3.6)	(2.8)	(2.2)	(2.1)	(2.4)	(0.8)	(8.5)	(7.8)	(6.6)	(5.3)	(4.9)	(4.9)	(5.5)
Internal R&D	73.27***	65.36**	104.3***	36.49**	76.84***	47.49**	29.31	78.36***	69.46**	105.6***	40.27***	77.27***	51.08**	33.67
	(16)	(22)	(17)	(12)	(15)	(17)	(21)	(16)	(22)	(17)	(12)	(15)	(17)	(22)
appropriability	36.26***	32.30***	28.05***	36.06***	28.74***	33.20***	33.66***	33.71***	33.06***	27.68***	35.76***	27.68***	31.95***	32.04***
	(8.4)	(8)	(5.9)	(4.7)	(4.6)	(5)	(6)	(8.4)	(8)	(5.9)	(4.7)	(4.6)	(5)	(6)
Software intensity	42.40*	64.92***	8.724	32.22*	35.49*	19.07	1.700	39.73*	63.65**	9.785	30.31	35.31*	20.22	-4.262
	(20)	(20)	(17)	(16)	(17)	(17)	(26)	(20)	(19)	(17)	(16)	(17)	(17)	(26)
Collab regional x Incoming Spillover								-26.42*	5.128	2.494	-1.164	10.62	-0.987	0.162
								(11)	(11)	(10)	(8.4)	(8.1)	(9.2)	(11)
Collab national x Incoming Spillover								-7.056	-23.63*	-27.54**	-2.770	-30.43***	-16.93*	-22.61*
								(12)	(11)	(9.8)	(8.4)	(7.8)	(8.1)	(9.6)
Collab international x Incoming Spillover								5.080	-10.73	11.41	-11.23	-0.523	-10.94	-9.122
								(14)	(13)	(12)	(9.3)	(8.6)	(9.2)	(9.9)
Collab international x Collab Regional								-0.331	-13.49*	-6.785	-7.329	-5.902	5.215	-10.14*
								(6.9)	(6.4)	(5.2)	(3.9)	(3.7)	(4.4)	(5.3)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-37.13*	-72.75***	-141.7	-31.96**	-14.12	-18.49	-42.21**	-37.16*	-75.51***	-141.4	-32.85**	-18.17*	-22.31*	-45.23**
	(15)	(21)	(8195)	(11)	(8.9)	(9.6)	(14)	(15)	(21)	(6666)	(11)	(9)	(9.7)	(14)
sigma(e)	979.1***	774.4***	629.4***	512.7***	491.6***	520.3***	622.4***	970.6***	765.1***	626.7***	512.4***	485.9***	515.8***	618.8***
	(74)	(58)	(43)	(30)	(29)	(33)	(44)	(74)	(57)	(42)	(30)	(29)	(33)	(44)
N	2085.000	2177.000	2388.000	2322.000	2195.000	1919.000	1676.000	2085.000	2177.000	2388.000	2322.000	2195.000	1919.000	1676.000
chi2	815.7835	798.0241	875.9843	1010.154	878.4939	722.0963	595.6264	823.9852	812.0373	886.5845	1018.37	904.4139	738.0444	613.8434
ll	-2427.46	-2414.894	-2865.967	-3549.607	-3444.143	-3071.48	-2503.695	-2423.36	-2407.887	-2860.667	-3545.5	-3431.183	-3063.505	-2494.587
r2_p	.1438593	.1418001	.1325659	.1245663	.1131092	.1051843	.1063046	.1453056	.1442901	.13417	.1255794	.1164464	.1075074	.1095559

Appendix

Table A1 - Results of the first stage Probit regression used for constructing the predicted values of Incoming spillover and knowledge collaboration (regional , national and international) for Tables 6 and 7.

Dependent variable	Collaboration regional	Collaboration national	Collaboration International	Incoming spillover
Model	(1)	(2)	(3)	(4)
Collaboration regional industry	4.283*** (.27)			
Collaboration national industry		3.220*** (.14)		
Collaboration international industry			3.440*** (.20)	
Incoming spillover				0.709*** (.03)
Protection industry	-0.440* (.19)	-0.095 (.19)	0.687** (.24)	-0.258*** (.02)
Age	-0.012** (.00)	-0.011** (.00)	-0.006* (.00)	-0.007 (.00)
Age squared	0.001* (.00)	0.001* (.00)	0.001* (.00)	0.001 (.000012)
Employment	0.059*** (.00)	0.155*** (.01)	0.153*** (.01)	0.021*** (.00)
High-tech manufacturing	-0.198 (.14)	-0.187 (.13)	-0.144 (.14)	0.003 (.01)
Med-tech manufacturing	-0.057 (.04)	-0.038 (.04)	-0.005 (.07)	-0.011* (.00)
Risk	0.152*** (.01)	0.192*** (.01)	0.168*** (.01)	0.037*** (.00)
Cost	0.095*** (.01)	0.049*** (.01)	0.019 (.01)	0.023*** (.00)
Complementarities	0.135*** (.01)	0.182*** (.01)	0.081*** (.01)	0.055*** (.00)
Scientist	0.004*** (.00)	0.009*** (.00)	0.010*** (.00)	0.002*** (.00)
Exporter	0.179*** (.02)	0.440*** (.02)	0.952*** (.03)	0.0561*** (.00)
Scientist	0.091*** (.02)	0.012 (.02)	0.015 (.02)	0.003 (.00)
Constant	-2.503*** (.07)	-3.06*** (.08)	-3.84*** (.11)	-0.077*** (.00)
N. of obs.	21,702	21,702	21,702	21,702
Year and region fixed effects	Yes	Yes	Yes	Yes
chi2	2012.34	2896.85	2111.62	18859.09
LR test of rho=0 (chi2)	243.67	354.67	275.15	
Log-likelihood	-14905.03	-15682.77	-11295.47	

Note: reference category for legal status is Company (limited liability company). industry (mining), region (North East of England) Robust standard errors are in parenthesis. The coefficients of the regressions (1-3) are the marginal effect of the independent variable on the knowledge collaboration rescaled variable, ceteris paribus. The coefficients of the regression (4) are the marginal effect of the independent variable on the Incoming knowledge spillover, ceteris paribus. For dummy variables, it is the effect of a discrete change from 0 to 1.

Significance level: * $p<0.05$; ** $p<0.01$, *** $p<0.001$

Source: UKIS- UK Innovation survey; BSD- Business Structure Database.

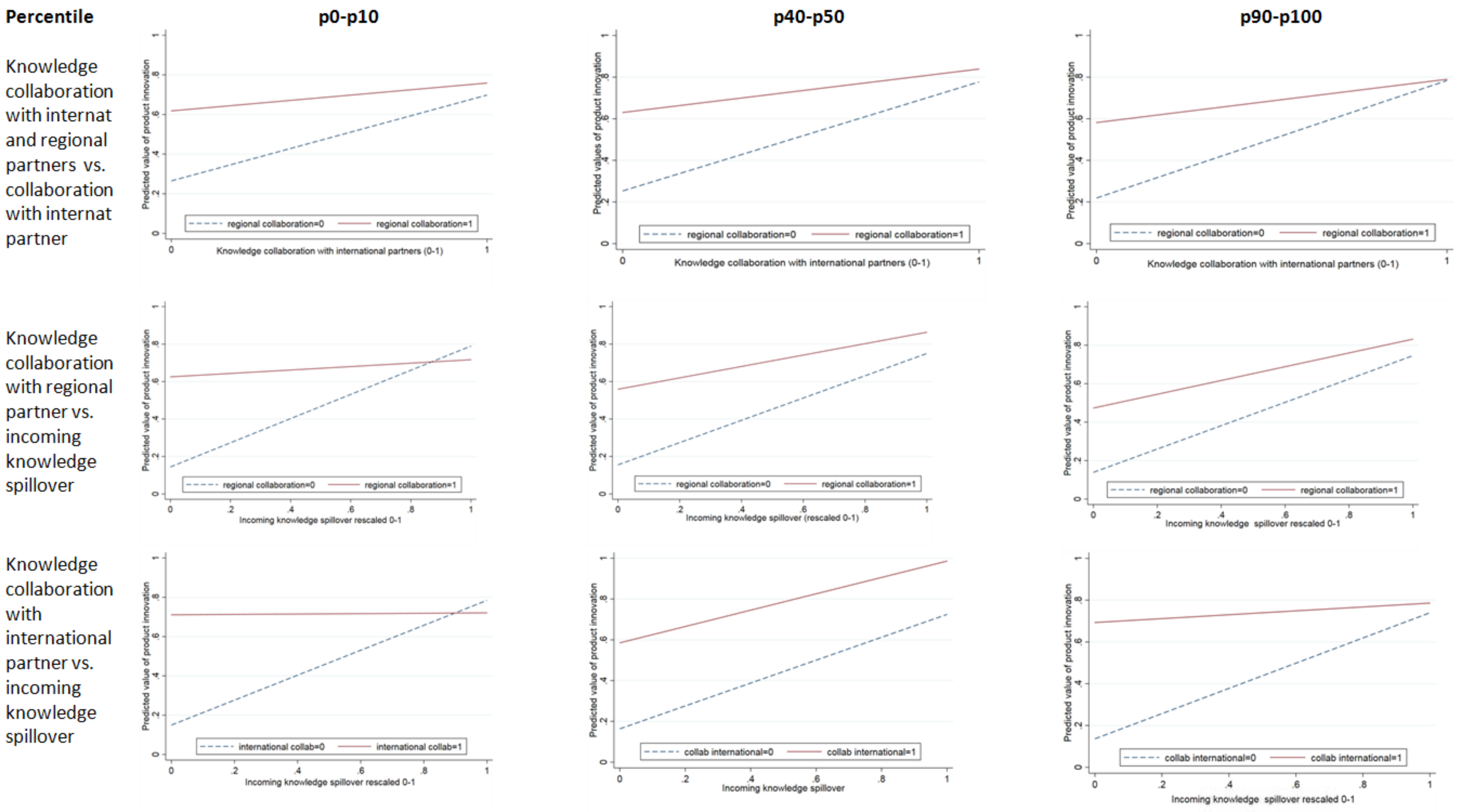

Figure 2: Knowledge collaboration with regional and international entrepreneurship ecosystems, augmenting with incoming knowledge spillover for innovation across firms with different level of productivity.