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Cooperation for innovation in liberal market economies: STI and DUI innovation modes in SMEs in the United Kingdom

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ABSTRACT

This study focuses on the collaboration patterns that small firms hold with other agents within liberal market economies and identifies the collaborative drivers that in this context deliver a superior impact on innovation output measured by product and process innovations. To explore this research question, the study combines the literature on innovation systems with a growing literature on business innovation modes that studies whether businesses are driven by science and technology factors (STI), or experience-based factors such as learning-by-doing, by-using and by-interacting (DUI). In the UK liberal market economy, universities and research centres are expected to play a critical role for innovation well beyond the typical impact they produce in coordinated market economies. This hypothesis is largely verified through our empirical evidence. Methodologically, this research is developed through the application of propensity score matching in the context of the UK longitudinal small business survey (LSBS) for 2015.

1. Introduction

The UK is a unique economy in the European context because traditionally responds to a liberal-market economy – LME – vis-à-vis a wider majority of countries that adopt a coordinated-market approach – CME – (Hall and Soskice 2001; Lorenz 2012). Within this context, the UK economy has developed three important drives that represent the economy's key areas of competitiveness. The first is a strong drive towards firm self-sustainability in open markets based on a set of market-based incentives for business creation in high-growth sectors (Ebner 2016; Lazonick 2007). The second is the important drive towards the service sector, due to its acquired leadership in specific knowledge-intensive business services such as finance and higher education (Lee and Miozzo 2019). Finally, the UK shows a quite strong sector of large companies/business groups that represent only 0.1% of businesses, but control 40% of employment and 52% of turnover (House of Commons 2019). This leaves SMEs to fill secondary tiers of supply in global value chains, market niches or more traditional and less remunerative markets.

Within the afore-mentioned UK LME, innovation has become a key asset for competitiveness as firms – including SMEs – compete with global firms of all sizes and industries (especially after Brexit). For this reason, we plan to investigate the innovation patterns in UK SMEs, which are likely to be distinctive vis-a-vis other economies. We do it in relation to a novel strand of the literature that derives from the innovation system literature and that depicts the science and technology-based business innovation mode (STI) vs the business innovation mode based on learning-by-doing, by-using and by-interacting (DUI) (Jensen et al. 2007; Chen, Chen, and Venhaverbeke 2011; Nunes and Lópes 2015; Parrilli and Alcalde 2016). The application of these business innovation modes is likely to vary significantly across different innovation systems and their economies. This variation is what we aim at identifying with this study. In general, this study aims at providing the following contributions: (1) identification of the business innovation modes adopted by UK SMEs. In this liberal market economy (LME), the STI mode is likely to influence effectively the innovation output as businesses and universities hold a more proactive approach than in the case of CMEs (Parrilli and Radicic 2020; Thomä 2017). (2) The assessment of which innovation mode has the highest impact in relation to complex (radical and incremental) vs simple/incremental innovations (Isaksen and Trippl 2017; Hervás-Oliver, Sempere-Ripollo, and Boronat-Moll 2021). Here, we aim at identifying the actors that – in this LME – help accomplish complex innovations that deliver a real competitive edge. Finally, it provides: (3) the identification of the typical innovation mode adopted by SMEs – and their effectiveness – in the service sector vis-à-vis the manufacturing industry where the former represents the most competitive sector in the UK economy (Lee and Miozzo 2019). These research questions and related contributions are developed by analysing the UK longitudinal small business survey (LSBS) for 2015. We use a propensity score matching to address the issue of endogeneity of external knowledge sources (Vivas and Barge-Gill 2015; Parrilli and Radicic 2020).

In the next section, the literature on SME innovation and business innovation modes is presented. Next, our arguments and hypotheses are purported. The methodology and the main findings are then presented in sections four and five. We conclude the study with policy implications and suggestions for future research.

2. SMEs and business innovation modes

2.1. Innovation systems and business innovation modes

A large literature on innovation has been produced in the management literature (Laursen and Salter 2006; Tether and Tajar 2008; among others) as well as the economics of innovation (Asheim and Gertler 2005; Cooke, Heidenreich, and Braczyck 2004; Martin et al. 2018; among others). In both cases, the scholars have identified the need for firms to innovate to compete in global markets and offset the cost/resource advantage of emerging economies (Porter 2008).

Within the economics of innovation, the concept of innovation systems was developed by Lundvall (1992), and Nelson (1993) and then re-formulated along regional (Asheim and Gertler 2005; Cooke 2001), sectoral (Malerba and Orsenigo 2002) and technological nuances (Carlsson and Jacobsson 1994). These scholars emphasized the importance of systemic innovation vis-à-vis the mere sum of the innovation efforts of individual

businesses. Institutions and interactions play a central role in these systems (Lundvall 1992). In more recent years, this literature has evolved in three directions: the assessment of the efficiency of the system (Rodriguez-Pose and Crescenzi 2008; Fritsch and Slavtchev 2011); the discussion of the prospective trajectories available to different types of systems (Alberdi, Gibaja, and Parrilli 2016; Isaksen and Trippl 2017); and the development of dynamic innovation policy approaches (Flanagan, Laranja, and Uyarra 2011; Flanagan and Uyarra 2016).

In the second half of the 2000s, a new sub-stream emerged within the literature of innovation system. It is the business innovation mode literature that focuses on whether firms tend to take a science and technology-based approach to innovation (STI) or an innovation approach based on practice and interaction along the supply chain (learning-by-doing, by-using and by-interacting or DUI) (Chen, Chen, and Venhaverbeke 2011; Jensen et al. 2007; Isaksen and Karlsen 2010). The first relies on investments in R&D and skilled human capital as well as on collaborations with universities and research centres; the second relies on the contribution of all employees in the company as well as on collaborations with clients, suppliers and competitors.

Several studies have followed and produced refinements and empirical evidence based on specific country surveys and case studies (Trippl 2011, on Austria; Isaksen and Nilsson 2013, on Sweden; Fitjar and Rodriguez-Pose 2013; and Haus-Reve, Fitjar, and Rodriguez-Pose 2019, on Norway; Parrilli and Elola 2012; and Parrilli and Alcalde 2016, on Spain; Nunes and Lópes 2015, on Portugal, Apanasovich 2016, 2017 on Belarus; Thomä 2017, on Germany; Trott and Simms 2017; and Lee and Miozzo 2019, on the UK).

In relation to SMEs, the study of German SMEs has shown the existence of a variety of groups of firms that adopt different modes of learning and produce similar economic performance in non-high growth industries (Thomä and Zimmermann 2019). Only the very high-growth-oriented businesses that focus on R&D activities obtain higher performance, though these represent a tiny percentage of SMEs. Similar results are produced in a study implemented in Spain (Parrilli and Elola 2012). The previous work by Thomä (2017) on German SMEs showed the more direct involvement of these firms with the DUI mode as based on a more cost-effective practice that responds to their typical budget limitations. These findings align well with former studies on German SMEs that were found to succeed without internal R&D activities thanks to the use of human resource management tools and teamwork (Rammer, Czarnitzki, and Spielkamp 2009).

However, the recent broad study by Parrilli and Radicic (2020) on innovation modes across SMEs versus large firms in Europe and the US shows the effective approach of SMEs in benefiting from both STI and DUI drivers. SMEs adopt internal and external STI and DUI drivers, with a prevalence of internal drivers. Instead, large firms take a more selective approach in which they rely mostly on their internal resources. Alhusen and Bennat (2020) support the view that SMEs can combine STI and DUI drivers based on a high absorptive capacity.

3. STI and DUI modes in liberal market economies

3.1. Product and process innovation in liberal market economies

Within this literature, there is scope for research that identifies new drivers of innovation across SMEs. Some studies have highlighted the context-specificity of business

innovation modes (Jensen et al. 2007; Parrilli, Fitjar-Dahl, and Rodriguez-Pose 2016; Parrilli, Balavac, and Radicic 2020), while other studies have taken a global approach to firms across large geographies (Parrilli and Radicic 2020). However, the critical differentiation between LMEs (e.g. US or UK) versus coordinated-market economies – CMEs – (e.g. Germany or Scandinavian countries) first identified by Hall and Soskice (2001) and later rediscussed by Akkerman, Castaldi, and Los (2009), Boschma and Capone (2015) and Lorenz (2012) has not been considered within this literature. This divergent economies may call for different approaches to innovation because in LMEs firms and universities traditionally take the lead in value chain activities, including innovation, while in CMEs intermediary organizations take the lead (e.g. technology centres, cluster organizations; Cooke 2004).

In recent research, the varieties of capitalism are found to matter for the type of industrial and innovation strategy. Boschma and Capone (2015) found that LMEs tend to promote unrelated diversification across their industries, while CMEs favour the development of related varieties. The latter's institutional configuration with thicker networks of formal non-profit organizations in different domains (e.g. industrial relations, corporate governance, inter-firm relations) produces path-dependent practices and outcomes (e.g. industrial specialization) vis-à-vis LMEs that rely on short-term exchanges based on complete contracts. Simultaneously, Akkerman, Castaldi, and Los (2009) studied the innovation output realm and found more nuanced results vis-à-vis the original contribution of Hall and Soskice (2001). Radical innovation depends very much on the type of industry, i.e. where an economy has a strong specialization in chemicals, semiconductors and software radical innovations are more likely to occur than in the context of more traditional industries, such as machine tool or transportation systems. The former is often the case of LMEs vis-à-vis CMEs.

In LMEs, where market-based exchanges are privileged, and contractual obligations are enforceable, entrepreneurial innovation systems operate. This correlation comes from the proactivity that universities and businesses take in key innovation-led domains such as technological innovation, education and training, and finance/investments. Although important regional variations can be identified (Ebner 2016; Zhang and Peck 2016), we still frame these within an overarching framework that characterizes each country's economy and that entails a multi-scalar set of institutions, where the type of innovation system (e.g. EIS or IIS) represents the institutional configuration of the economy (LME or CME) in relation to business innovation and start-up.

In the UK EIS context, university-industry relationships tend to be direct and effective, while in CMEs – where institutional innovation systems function – some intermediaries (e.g. technology centres; spinoff services) are required to help firms and universities understand each other and work together for objectives that are sometimes quite different (see Bennat and Sternberg 2020). This peculiarity depends on both the recognition of the international leadership of UK universities, and the attention these pay to professional practice (Breznitz 2011; Goddard and Vallance 2013). In the UK, firms rely on universities and other research centres for projects that lead to targeted innovation outputs. This generates the distinction between entrepreneurial versus institutional innovation systems (EIS vs IISs) discussed in the literature on regional innovation systems (Asheim and Gertler 2005; Cooke, Heidenreich, and Braczyck 2004). In the former, like the UK or the US, we expect university-industry collaborations

to have a large impact on product and process innovation. This is different from what is found in IISs (e.g. Europe) where process innovation is aligned with non-technological innovation (commercial and organizational) in that they are based on user-producer interactions and learning-by-doing and by-using (Hervás-Oliver, Sempere-Ripollo, and Boronat-Moll 2021; Parrilli, Balavac, and Radicic 2020). In the UK EIS, universities and research centres are likely to connect directly with firms and SMEs to generate impact on both product and process innovation with no need for intermediate organizations to step in to promote such collaboration. Therefore, we formulate the following hypothesis:

> H1: In the UK context, STI collaborations generate a significant impact on both product and process innovation.

3.2. Complex vs pure incremental innovations

Within LMEs and EISs, our analysis shifts to the type of innovation produced. In general, SMEs typically produce incremental product and process innovations (Hervás-Oliver, Sempere-Ripollo, and Boronat-Moll 2021; Trott and Simms 2017). However, radical innovations represent transformations that deliver a competitive edge to firms (Radicic 2020), and yet they require resources and absorptive capacity (Hervás-Oliver, Sempere-Ripollo, and Boronat-Moll 2021). The innovation management literature has long discussed this aspect and identified a number of key drivers such as the combination of complex technologies, industries and firms, and the participation of heterogeneous networks of agents (Hervas-Oliver et al. 2012), as well as important internal-to-the-firm drivers such as senior leadership, organizational culture and architecture, product launch (Slater, Mohr, and Sengupta 2014). In our contribution, we want to identify collaborative actors and drivers of complex innovation.

Universities and research institutes typically focus on analytical knowledge, which is more likely to result in complex product innovation. It is the case of research groups working on the Covid-19 vaccine. This consideration is supported by scholarly research that shows that radical product innovation is related to university-industry collaboration (STI) as these organizations target the generation of knowledge which produces major changes in industrial practices (Fitjar and Rodriguez-Pose 2013; Radicic 2020). Differently from CMEs and IISs, in the UK LME where EISs are in place, universities are likely to produce significant impact also on complex process innovation thanks to the more direct relation they maintain with businesses. Therefore, we introduce the following hypothesis:

> H2a: In the UK LME, STI collaborations are likely to generate the highest impact on both complex product and complex process innovations.

Cooperation with customers has also been found to have an important impact on radical product innovation as customers and users add diverse and even conflicting information that helps to produce radically new outputs (Arnold, Fang, and Palmatier 2011; Fitjar and Rodriguez-Pose 2013). This is also shared by Belderbos et al. (2015), who consider this type of agents relevant for reducing risks of introducing (radical) innovations in the market. In contrast, cooperation with suppliers is often focused on cost reductions to achieve productivity gains, thus tend to produce an impact on incremental process innovation (Belderbos et al. 2015).

In CMEs collaboration with competitors is problematic due to potential knowledge leakage (Radicic, Pugh, and Douglas 2020). This issue is relevant for radical innovation, given that firms need to invest substantial resources for this type of innovation. Moreover, SMEs are vulnerable to opportunistic behaviour, as they seldom use patents as a means of protection (Radicic and Pugh 2017; Radicic, Pugh, and Douglas 2020). However, collaboration with competitors can often be motivated by sharing R&D costs and pooling complementary resources (Belderbos et al. 2015). In the UK LME, which is additionally prone to low-intensity competition based on the common focus on international markets (Ritala 2012), collaboration with competitors is likely to generate complex innovations (Hall and Soskice 2001). On these bases, we set the following hypothesis:

> H2b: DUI collaborations with customers and competitors are likely to generate a positive impact on complex product innovation, while DUI collaborations with suppliers are likely to have a strong impact on incremental process innovation.

3.3. Services vs manufacturing industries

The third element of analysis refers to the industrial characterization of the UK production system, where the service industry dominates. Regarding the manufacturing sector in China, Chen, Chen, and Venhaverbeke (2011) studied high-technology (e.g. IT, pharmaceuticals) versus low-technology industries (e.g. footwear), where the first rely on STI and DUI drivers, while the second on DUI drivers only. In contrast, Parrilli and Elola (2012) study on Spanish SMEs did not deliver significant variations across different industry sectors (e.g. machine tools vs metal products). In a study on low technology British food and packaging industries, Trott and Simms (2017) discovered that these firms benefit from adaptive R&D, which is different from formal R&D as it is based mostly on collaborations for technology upgrading. Therefore, we posit the following:

> H3a: In manufacturing sectors, STI collaborations and the collaboration with customers are likely to have the largest effect on complex product and process innovation, whilst DUI collaborations, particularly suppliers, have the largest effect on incremental process innovation.

Over the past decades, UK services have grown significantly, while manufacturing has gradually shrunk. As manufacturing is mostly about the production of tradable goods, it shows special sensitivity to product innovation, thus we expect the role of STI collaborations to matter, especially for complex product and process innovations. Unlike goods produced by manufacturing firms, services are inherently intangible, thus have high information content and their production and use are usually inseparable (Cainelli, De Marchi, and Grandinetti 2020; Radicic 2020). To compensate for lower levels of R&D activities, service firms cooperate with external partners (Leiponen 2012; Mina, Bascavusoglu-Moreau, and Hughes 2014). Abreu et al. (2010) have shown that services tend to depend on soft drivers, such as the capacity to assist customers pre- and post-sale. Therefore, taking on a 'demarcation approach' (Cainelli, De Marchi, and Grandinetti 2020), they rely on DUI interactive drivers more than on STI factors (Parrilli, Balavac, and Radicic 2020).

In the UK LME, Lee and Miozzo (2019) made a more specific study on the service sector and focused on KIBS where they found different trends depending on what type of KIBS is involved; while R&D services are sensitive to STI drivers, legal and

marketing services depend on DUI drivers. In any case, this outcome is significantly different from IISs in CMEs where services rely primarily on DUI drivers (Parrilli, Balavac, and Radicic 2020). As a consequence, we would expect the service industry to respond to soft drivers based on interaction with clients and other complementary agents (e.g. law courts for legal services, transportation means for logistics services). Therefore, we set the following hypotheses:

> H3b: In the service sector, we expect DUI collaborations, with the prominence of customers, to have the largest effect on both product and process innovation.

4. Methodology

This study analyses data from the 2015 wave of the UK Longitudinal Small Business Survey (LSBS).[1] It is a large-scale telephone survey of 15,502 owners and managers of UK SMEs[2] commissioned by the Department of Business Innovation and Skills (BIS, 2016; Idris and Saridakis 2018). The survey is based on a stratified sample within England, Wales, Scotland and Northern Ireland. Targets were set according to firm size and sectors based on the Standard Industrial Classification (SIC). Detailed information about the survey method and instruments can be found in the SBS report (BIS, 2016).

The issue of endogeneity of external knowledge sources is discussed in detail in Vivas and Barge-Gill (2015), although is rarely addressed in empirical studies (Haus-Reve, Fitjar, and Rodriguez-Pose 2019). One source of endogeneity is that firms select themselves into using external knowledge (Vivas and Barge-Gill 2015). Another source of endogeneity is potential reverse causality between cooperation for innovation and innovation performance (Haus-Reve, Fitjar, and Rodriguez-Pose 2019; Parrilli and Radicic 2020). Regarding an appropriate empirical strategy, few studies that address the issue utilise an instrumental variable (IV) approach, while omitting to discuss the validity of used instruments(s) (Vivas and Barge-Gill 2015). An alternative option, in case of a cross-sectional analysis, is to apply matching estimators. The advantage of this approach is that it does not require an exclusion restriction, whereas the disadvantage is that it relies on the assumption of observed heterogeneity (Parrilli and Radicic 2020).

To address the selection bias arising from firms' self-selection, we implement a propensity score matching methodology, which is the most commonly applied evaluation method in innovation studies (Radicic 2019). Matching approach is based on two identifying assumptions. The first is the conditional independence assumption (CIA) or selection on observables, which posits that the outcome of the control group of firms that did not receive treatment (Y_0) is independent of treatment assignment, conditional on matching (control) variables X (Imbens and Wooldridge 2009). That is,

$$Y_0 \coprod^{D} |X \tag{1}$$

where X represents a vector of matching (control) variables and D is the treatment assignment.

The second assumption is associated with the overlap or common support condition, where the estimated propensity scores take values between zero and one (see Equation 2) (Heckman and Vytilacil 2007). The overlap condition implies that both treatment and

control firms have a positive probability (*P*) of receiving a treatment (D = 1) or not receiving a treatment (D = 0).

$$0 < P(D = 1|X) < 1 \qquad (2)$$

The treatment of interest is the Average Treatment Effect on the Treated (ATT), which is equal to the difference in outcomes of the treated firms with and without treatment:

$$ATT = E[Y_1|D = 1] - E[Y_0|D = 1] \qquad (3)$$

The first term on the right-hand side of Equation (3), $E[Y_1|D = 1]$, is the expected outcome for treated firms, while the second term $E[Y_0|D = 1]$ is the expected outcome had treated firms not received the treatment. This second term refers to a counterfactual outcome that cannot be observed and thus needs to be estimated.

Before estimating treatment effects, we need to select matching (control) variables *X*. The literature suggests that observed variables that simultaneously affect treatment assignment and the outcome should be included. After the selection of matching variables, the next step is the estimation of the propensity score model using either probit or logit models as they usually yield similar results (Caliendo and Kopeinig 2008).

Next step is the selection of the matching algorithm. The preferred estimator is a propensity score nearest-neighbour matching combined with entropy balancing (Hainmueller and Xu 2013) and exact matching (Iacus, King, and Porro 2012) on firm size categories. Entropy balancing is a method of pre-processing data, whereby the objective is to achieve a well-balanced sample prior to the estimation of causal effects. A well-balanced sample is found by adjusting the covariate distribution of the control group by reweighting or discarding control units until the covariate distribution of the comparison group is as similar as possible to the distribution of the treatment group (Iacus, King, and Porro 2012). Entropy balancing has an advantage over other preprocessing methods, as it achieves the best balance on all important covariates (Iacus, King, and Porro 2012). Furthermore, we matched treated firms to all possible control units that belong to the same firm size category, either micro or small firms.[3] This procedure prevents e.g. micro firms being matched with small or medium-sized firms.

The impact of STI and DUI innovation modes is estimated on six outcome variables (Table 1). Variable 'Product innovation' is equal to 1 if a firm introduced new or significantly improved goods or services in the last three years before the survey (zero otherwise). To examine the effects of STI and DUI innovation modes in complex and simple (pure) innovators, several dependent variables are defined. The variable 'complex product innovation' is equal to 1 if a firm introduced product innovations either new to the market or new to the firm (zero otherwise), while variable 'Incremental product innovation' is equal to 1 if a firm introduced product innovations new to the firm (zero otherwise) (Cowling 2016; Roper and Hewitt-Dundas 2017). Similarly, the variable 'Process innovation' is equal to 1 if a firm introduced new or significantly improved processes for producing or supplying goods or services (zero otherwise). The variable 'complex process innovation' is equal to 1 if a firm introduced process innovations either new to the market or new to the firm (and zero otherwise), while the variable 'Incremental process innovation' is equal to 1 if a firm introduced process innovations new to the firm (zero otherwise) (see Reichstein and Salter 2006). While product innovation focuses on the novelty of a new product, which should be validated by consumers

Table 1. Variable description and summary statistics.

Variable name	Variable description	Full sample Mean (SD)	Manufacturing firms Mean (SD)	Service firms Mean (SD)
Outcome (dependent) variables				
Product innovation	DV = 1 if a firm introduced product innovation in good or services in the last three years; 0 otherwise	0.870 (0.336)	0.846 (0.361)	0.873 (0.333)
Radical product innovation	DV = 1 if a firm introduced product innovation that is new to the market in the last three years; 0 otherwise	0.278 (0.448)	0.360 (0.480)	0.267 (0.442)
Incremental product innovation	DV = 1 if a firm introduced product innovation that is new to the firm in the last three years; 0 otherwise	0.587 (0.492)	0.485 (0.500)	0.601 (0.490)
Process innovation	DV = 1 if a firm introduced process innovation in the last three years; 0 otherwise	0.529 (0.499)	0.631 (0.483)	0.514 (0.500)
Radical process innovation	DV = 1 if a firm introduced process innovation that is new to the market in the last three years; 0 otherwise	0.118 (0.322)	0.125 (0.331)	0.117 (0.321)
Incremental process innovation	DV = 1 if a firm introduced process innovation that is new to the firm in the last three years; 0 otherwise	0.411 (0.492)	0.505 (0.500)	0.398 (0.490)
Treatment variables				
Cooperation with customers	DV = 1 if a firm collaborated with customers in the private or public sector in the last three years; 0 otherwise	0.534 (0.499)	0.448 (0.498)	0.546 (0.498)
Cooperation with suppliers	DV = 1 if a firm collaborated with suppliers in the last three years; 0 otherwise	0.552 (0.497)	0.603 (0.490)	0.545 (0.498)
Cooperation with competitors	DV = 1 if a firm collaborated with competitors in the last three years; 0 otherwise	0.212 (0.409)	0.150 (0.357)	0.221 (0.415)
Cooperation with universities	DV = 1 if a firm collaborated with universities in the last three years; 0 otherwise	0.130 (0.336)	0.137 (0.344)	0.129 (0.335)
Cooperation with research institutes	DV = 1 if a firm collaborated with government or public research institutes in the last three years; 0 otherwise	0.066 (0.249)	0.053 (0.224)	0.068 (0.252)
Matching (control) variables				
Growth_decrease	DV = 1 if a firm answered 'Decreased' to the question 'Compared with the previous 12 months, has your turnover in the past 12 months increased, decreased or stayed roughly the same'; 0 otherwise	0.164 (0.370)	0.189 (0.392)	0.160 (0.366)
Growth_increase	DV = 1 if a firm answered 'Increased' to the question 'Compared with the previous 12 months, has your turnover in the past 12 months increased, decreased or stayed roughly the same'; 0 otherwise	0.470 (0.499)	0.486 (0.500)	0.468 (0.499)
Growth_same	DV = 1 if a firm answered 'Same' to the question 'Compared with the previous 12 months, has your turnover in the past 12 months increased, decreased or stayed roughly the same'; 0 otherwise	0.366 (0.482)	0.325 (0.469)	0.372 (0.483)
Micro firms	DV = 1 if a firm has less than 10 employees; 0 otherwise	0.477 (0.500)	0.288 (0.453)	0.504 (0.500)
Small firms	DV = 1 if a firm has more than 10 and less than 50 employees; 0 otherwise	0.287 (0.452)	0.380 (0.486)	0.273 (0.446)
Medium firms	DV = 1 if a firm has more than 50 and less than 250 employees; 0 otherwise	0.236 (0.424)	0.332 (0.471)	0.223 (0.416)
Age_10	DV = 1 if a firm has been in operation for less than 10 years; 0 otherwise	0.258 (0.438)	0.174 (0.379)	0.271 (0.444)
Age_10_20	DV = 1 if a firm has been in operation for more than 10 years and less than 20 years; 0 otherwise	0.187 (0.389)	0.145 (0.351)	0.192 (0.393)

(*Continued*)

Table 1. Continued.

Variable name	Variable description	Full sample Mean (SD)	Manufacturing firms Mean (SD)	Service firms Mean (SD)
Age_more20	DV = 1 if a firm has been in operation for more than 20 years; 0 otherwise	0.555 (0.497)	0.681 (0.466)	0.537 (0.499)
Urban	DV = 1 if a firm is located in an urban area; 0 otherwise	0.752 (0.432)	0.733 (0.443)	0.755 (0.430)
Rural	DV = 1 if a firm is located in a rural area; 0 otherwise	0.248 (0.432)	0.267 (0.443)	0.245 (0.430)
Exports	DV = 1 if a firm exports goods or services in the last 12 months; 0 otherwise	0.298 (0.457)	0.628 (0.484)	0.251 (0.434)
East Midlands	DV = 1 if a firm is located in East Midlands; 0 otherwise	0.072 (0.258)	0.107 (0.309)	0.067 (0.250)
East of England	DV = 1 if a firm is located in East of England; 0 otherwise	0.110 (0.312)	0.134 (0.340)	0.106 (0.308)
London	DV = 1 if a firm is located in London; 0 otherwise	0.134 (0.340)	0.049 (0.216)	0.145 (0.353)
North East	DV = 1 if a firm is located in North East; 0 otherwise	0.027 (0.161)	0.028 (0.165)	0.027 (0.161)
North West	DV = 1 if a firm is located in North West; 0 otherwise	0.093 (0.291)	0.096 (0.295)	0.093 (0.290)
South East	DV = 1 if a firm is located in South East; 0 otherwise	0.168 (0.374)	0.143 (0.351)	0.172 (0.377)
South West	DV = 1 if a firm is located in South West; 0 otherwise	0.119 (0.323)	0.103 (0.304)	0.121 (0.326)
West Midlands	DV = 1 if a firm is located in West Midlands; 0 otherwise	0.081 (0.272)	0.106 (0.307)	0.077 (0.267)
Yorkshire & Humber	DV = 1 if a firm is located in Yorkshire & Humber; 0 otherwise	0.071 (0.256)	0.088 (0.283)	0.068 (0.252)
Scotland	DV = 1 if a firm is located in Scotland; 0 otherwise	0.067 (0.250)	0.066 (0.248)	0.067 (0.251)
Wales	DV = 1 if a firm is located in Wales; 0 otherwise	0.030 (0.172)	0.035 (0.184)	0.030 (0.170)
Northern Ireland	DV = 1 if a firm is located in Northern Ireland; 0 otherwise	0.028 (0.168)	0.045 (0.206)	0.027 (0.162)

and thus lead to higher revenues, process innovation is oriented towards cost reduction (and thus production efficiency), and an increase in product quality. From this perspective, greater competition in prices or in product quality could motivate firms to focus on process innovation (Abreu et al. 2010).

Our treatment variables are proxies for DUI and STI innovation modes. In relation to the former, empirical models include three variables: cooperation with customers; suppliers and competitors. A dummy variable *DUI* is equal to 1 if a firm cooperated with any of these partners, and zero otherwise (see, e.g. Jensen et al. 2007; Parrilli and Radicic 2020). Concerning STI modes, we focus on cooperation with universities and public research institutes. Consequently, a dummy variable *STI* is equal to 1 if a firm cooperated for innovation with either of these, and zero otherwise (Fitjar and Rodriguez-Pose 2013; Haus-Reve, Fitjar, and Rodriguez-Pose 2019; Parrilli and Alcalde 2016).

Our measures of STI and DUI innovation modes should be regarded as proxies given that they capture firms' interaction with external organisations. These proxies do not include internal indicators of innovation modes (e.g. R&D expenditure and personnel for the STI mode) (Alhusen et al. 2021). In addition, the literature does not offer comprehensive measures for the DUI mode. For instance, Apanasovich (2016) identified

13 DUI indicators, while Alhusen et al. (2021) identified 15 indicators, divided into knowledge flows and facilitators. The dataset used in our study contains information about external knowledge flows, such as in the case of Fitjar and Rodriguez-Pose (2013) and Parrilli and Alcalde (2016). These limitations in STI and DUI proxies suggest that our results might underestimate the true impact of innovation modes (Alhusen et al. 2021). In this respect, our empirical findings should be considered as conservative, lower-bound estimations of the effectiveness of innovation modes.

With respect to matching (control) variables that capture firm and market characteristics, we include the following variables. As SMEs are a heterogenous group of firms with respect to their innovation capacity (Parrilli and Radicic 2020; Radicic and Pugh, 2017), the estimated models include three dummy variables to control for firm size – for 'micro firms' with less 10 employees, 'small firms' with more than 10 and less than 50 employees, and 'medium-sized firms' with more than 50 and less than 250 employees (the reference category). To account for firm performance, three binary variables capture what has happened with firms' turnover in the current year relative to the last year: 'growth_decrease' (if turnover decreased in 2015 relative to 2014); 'growth_same' (if turnover stayed the same in 2015 relative to 2014; the reference category); and 'growth_increase'. Variable 'Exports' is a binary variable equal to 1 for exporting firms and 0 otherwise. Exporters might have more incentive to innovate as a result of competitive pressures in international markets (Radicic et al. 2019). In addition, exporters potentially have a larger network of cooperation partners than do non-exporting firms (Orlic, Radicic, and Balavac 2019). Firm age is captured by three dummy variables – for firms founded less than 10 years ago, for those founded between 10 and 20 years ago (the reference category), and for those that are older than 20 years. These firm age dummies are included to control for the learning effect, whereby mature firms can be more innovative than younger firms, due to improvements in past routines and capabilities (Coad, Segarra, and Teruel 2016). We also control whether a firm is located in the urban or rural areas, and in which UK region a firm is located. The literature on agglomeration suggests that firms located in cities are more conducive to innovation than firms located in rural areas because cities enable firms to engage in diverse local networks (Meili and Shearmur 2019). Finally, sector effects, based on the 2-digit SIC 2007 categorization, are captured by 71 dummies for each sector in the sample.[4]

5. Empirical findings

5.1 . Descriptive statistics

Table 1 shows summary statistics for the full sample, as well as for subsamples of firms operating in manufacturing and service sectors. Our samples include only innovative firms (introduced either product or process innovation), as non-innovative firms did not answer the survey question on cooperation for innovation. 87% of firms introduced total product innovations. A higher proportion of firms introduced incremental product innovations (58.7%), vis-à-vis complex product innovation (27.8%). Looking at the subsamples of manufacturing and service sectors, the proportions are similar, although a larger number of manufacturing firms introduced complex innovation, while service firms focus more on incremental innovation. With respect to process innovation,

52.9% introduced total process innovation. A much higher proportion of firms introduced incremental process innovation (41.1%) vis-à-vis complex process innovation (11.8%). Similar proportions are seen in manufacturing and services. With respect to treatment variables, the largest number of firms cooperated with suppliers (55.2%) and customers (53.4%), followed by competitors (21.2%) and universities (13%); the smallest number of firms cooperated with research institutes (6.6%). Again, similar proportions can be seen in both manufacturing and service firms.

This descriptive information shows that most SMEs are focusing on incremental product innovation, while a minority produces complex innovations. Collaborations with universities and other research centres are also developed by a lower proportion of SMEs. This information gives an insight on the scope for improvement of SME competitiveness in the UK.

5.2. Econometric analysis

5.2.1. Total product and process innovation

The correlation matrix is presented in Table A1 (Appendix). The correlations are low to moderate suggesting that multicollinearity is unlikely to occur. The estimated ATTs for the full sample (Table 2) shows that in the UK LME, the types of collaboration for innovation matter to different extents. Differently from the overall analysis of European and US SMEs produced in the study by Parrilli and Radicic (2020) that has shown an overwhelming impact of most of these collaborations on SMEs, this study shows that the UK economy has a more selective approach to innovation.

The importance of SME collaborations changes when we consider coefficients and confidence intervals. We observe that the nature of innovation matters as the drivers that mostly influence product innovation differ from those that impact on process innovation (Parrilli, Balavac, and Radicic 2020). Collaborations with universities tend to be

Table 2. The estimated average treatment effects on the treated (ATTs) in the full sample ($N = 7047$).

Types of innovation	Cooperation with customers	Cooperation with suppliers	Cooperation with competitors	Cooperation with universities	Cooperation with research institutes
Total product innovation	0.072***	−0.029**	0.036***	0.066***	0.037*
	(0.011)	(0.012)	(0.013)	(0.014)	(0.021)
	[0.051, 0.093]	[−0.052, −0.006]	[0.009, 0.062]	[0.039, 0.094]	[−0.003, 0.077]
Radical product innovation	0.071***	−0.013	0.035*	0.102***	0.149***
	(0.011)	(0.015)	(0.018)	(0.020)	(0.027)
	[0.049, 0.093]	[−0.041, 0.016]	[−0.000, 0.070]	[0.062, 0.142]	[0.097, 0.202]
Incremental product innovation	−0.001	−0.021	0.004	−0.038*	−0.126***
	(0.013)	(0.016)	(0.020)	(0.021)	(0.028)
	[−0.027, 0.026]	[−0.053, 0.010]	[−0.035, 0.042]	[−0.080, 0.004]	[−0.181, −0.071]
Total process innovation	0.058***	0.176***	0.074***	0.064***	0.102***
	(0.015)	(0.014)	(0.019)	(0.023)	(0.021)
	[0.028, 0.088]	[0.148, 0.204]	[0.038, 0.111]	[0.018, 0.110]	[0.036, 0.168]
Radical process innovation	0.047***	0.037***	0.036***	0.058***	0.110***
	(0.009)	(0.009)	(0.013)	(0.015)	(0.024)
	[0.031, 0.065]	[0.020, 0.055]	[0.010, 0.062]	[0.030, 0.087]	[0.064, 0.157]
Incremental process innovation	0.008	0.142***	0.029	−0.014	−0.016
	(0.014)	(0.013)	(0.019)	(0.021)	(0.033)
	[−0.020, 0.034]	[0.117, 0.167]	[−0.008, 0.067]	[−0.055, 0.027]	[−0.082, 0.049]

Notes: Robust standard errors in parentheses; confidence intervals in brackets; ***$p < 0.01$; **$p < 0.05$; * $p < 0.10$.

the strongest driver of product innovation together with collaborations with customers. In European CMEs, collaborations with customers were the strongest driver for product innovation (Parrilli and Radicic 2020). In contrast, for total process innovation, collaboration with suppliers is the most critical driver, while all other types of collaboration also matter. This is aligned with theoretical expectations on the predominant role of suppliers (Parrilli, Balavac, and Radicic 2020; Tether and Tajar 2008). However, differently from the case of SMEs in CMEs, in the UK LME STI collaborations also matter for process innovation. Therefore, *H1* is confirmed.

5.2.2. Complex product and process innovation

In relation to the complexity of innovation (i.e. radical plus incremental) is analysed in depth. This matters as the drivers that determine radical innovation differ from those that influence incremental innovation. We find that complex product innovation is primarily driven by collaborations with universities and other research centres. This is an important finding for the UK as in most other cases studied in the literature universities matter but do not take the lead in relation to complex innovation for a number of reasons that include the confidentiality of innovation, the duration of projects, and financial budget (Bennat and Sternberg 2020). This outcome is specific to the UK LME in which EISs operate, and the production system promotes direct collaborations with universities and research centres (Asheim and Gertler 2005; Cooke 2004; Hall and Soskice 2001; Lorenz 2012). It is a striking result because it shows a track record of UK universities and research centres working effectively with firms through appropriate agreements or arrangements. Complex product innovation also depends significantly on customers. This is likely to happen in most sectors since customers and users have become strategic partners for the competitiveness of value chains in which producers expect to receive diverse information, advice, and demand from their buyers (Arnold, Fang, and Palmatier 2011). In spite of risks of opportunistic behaviour, and in contrast to other cases (Norway in Fitjar and Rodriguez-Pose 2013), collaborations with competitors matter for both complex product and process innovation, although not to such a high extent as for the former types of collaborations. This is consistent with what Hall and Soskice (2001) envisaged for LMEs in which market exchanges determine inter-firm relations and technological innovation patterns (Akkerman, Castaldi, and Los 2009; Boschma and Capone 2015).

When we turn to incremental product innovation, the importance of collaborations fades away. This means that this type of innovation depends exclusively on internal activities such as contributions from employees, teamwork, or design. These are less demanding as they do not require additional initiatives (e.g. meetings/projects with external partners). The analysis shows that the role of universities and research centres becomes negative in this case, i.e. when SMEs invest in collaborations with these STI partners, they focus on radically new products, thus their attention to pure incremental product innovations is diluted, and the outcome becomes negative (Ocasio 1997). It is interesting because the largest proportion of SMEs focuses on incremental innovation, due to the lower costs involved. For this type of innovation, they do not team up with any partner or – more simply – do not reap significant advantages. Instead, (crucial outcome of this study) the development of collaborations in the UK LME generally leads to producing complex product innovations.

Concerning process innovation, we find similar results with some novelty. Research centres take the lead in promoting complex process solutions. To a lower extent, universities and customers, suppliers and competitors contribute as well. This is the case of new payment methods such as contactless card payment; or the use of robots instead of manpower for loading and unloading packages in warehouses. Once again, we observe that radical transformation in the manufacturing, logistics and distribution of goods benefits from new codified knowledge produced within the most advanced research centres. This is quite extraordinary as process innovation is typically associated with supply chain collaborations (Fitjar and Rodriguez-Pose 2013; Trott and Simms 2017; Parrilli, Balavac, and Radicic 2020). When we turn to pure incremental process innovation, we find a different outcome as suppliers are the key agents in this kind of innovation that is driven by the requirement to reduce slack, waste and increase productivity (Trott and Simms 2017). It is noticeable that no other partner influences incremental process innovation that depends mostly on internal activities (in addition to suppliers).

Overall, our *H2a* and *H2b* are confirmed. These outcomes stand out in the case of the UK LME in which industry-university relationships are much more fluid and effective than in typical CME and IIS (Cooke 2004; Hall and Soskice 2001; Lorenz 2012). This outcome shows that high codified knowledge originating in international poles of knowledge generation (i.e. universities) is required when businesses want to introduce a critical product and process changes (Fitjar and Rodriguez-Pose 2013; Parrilli and Alcalde 2016). These findings align well with the original approach of Hall and Soskice about LMEs. However, this does require the lenses adopted by Akkerman, Castaldi, and Los (2009) and Boschma and Capone (2015) about the sector/industry nuance that applies to economies that are strong in creative industries where the propensity to produce radical transformations is high (e.g. software and media industries, financial services). Of course, these general/national results do not cancel the importance of considering a multiscalar framework, where the regional level can diverge from the national one (Ebner 2016; Zhang and Peck 2016).

5.2.3. Services vs manufacturing

The third group of hypotheses refers to sectoral nuances of innovation. In relation to manufacturing firms (Table 3), customers, universities and competitors take the lead in promoting total product innovation. The role of customers and universities was expected, while it is a positive surprise that competitors assume a relevant role. This happens when – as in the UK LME – competitors target wider markets and join forces as competition between them is less compelling.

Moving to complex product innovation in manufacturing, universities take a clear leading role. Customers matter to the same extent as universities, whilst suppliers produce a negative impact probably because they are too focused on process innovations. Curiously, pure incremental product innovation only benefits from collaboration with competitors, through direct observation and imitation along similar product lines (Hall and Soskice 2001; Ritala 2012) due to less compelling competition in their target markets.

Total process innovation depends on suppliers and so does simple/incremental process innovation. Instead, for complex process innovation research centres, universities and customers produce the highest impact. Differently from most CMEs in

Table 3. The estimated average treatment effects on treated (ATTs) for manufacturing firms (*N* = 862).

Types of innovation	Cooperation with customers	Cooperation with suppliers	Cooperation with competitors	Cooperation with universities	Cooperation with research institutes
Total product innovation	0.141*** (0.032) [0.078, 0.204]	−0.094*** (0.032) [−0.157, −0.030]	0.119*** (0.045) [0.030, 0.208]	0.092** (0.038) [0.017, 0.167]	0.033 (0.064) [−0.093, 0.158]
Radical product innovation	0.113*** (0.044) [0.028, 0.199]	−0.149*** (0.040) [−0.227, −0.071]	−0.063 (0.069) [−0.197, 0.072]	0.125** (0.062) [0.004, 0.245]	0.183 (0.112) [−0.036, 0.403]
Incremental product innovation	−0.008 (0.047) [−0.099, 0.084]	0.063 (0.040) [−0.014, 0.141]	0.142** (0.066) [0.014, 0.270]	−0.033 (0.059) [−0.149, 0.083]	−0.150 (0.095) [−0.335, 0.036]
Total process innovation	0.012 (0.038) [−0.064, 0.087]	0.207** (0.044) [0.121, 0.294]	0.051 (0.061) [−0.069, 0.171]	0.084 (0.062) [−0.037, 0.205]	0.020 (0.098) [−0.171, 0.212]
Radical process innovation	0.075** (0.029) [0.018, 0.0132]	0.005 (0.031) [−0.055, 0.065]	0.026 (0.044) [−0.059, 0.112]	0.153*** (0.042) [0.071, 0.236]	0.155** (0.066) [0.026, 0.285]
Incremental process innovation	−0.043 (0.043) [−0.128, 0.043]	0.193*** (0.042) [0.111, 0.276]	0.041 (0.065) [−0.087, 0.169]	−0.075 (0.067) [−0.207, 0.056]	−0.154 (0.105) [−0.359, 0.051]

Notes: Robust standard errors in parentheses; confidence intervals in brackets; ***$p < 0.01$; **$p < 0.05$; * $p < 0.10$.

which process innovation tends to be mostly associated with DUI drivers (Fitjar and Rodriguez-Pose 2013; Trott and Simms 2017), in the UK LME complex process innovation strongly depends on STI sources. Universities and research centres are not only focused on the invention of new goods, but also on the structural transformation of machinery and equipment that generate higher productivity and competitiveness. This is due to the importance of knowledge transfer and professional practice that universities have developed over the past decades (Breznitz 2011; Goddard and Vallance 2013).

Table 4. The estimated average treatment effects on treated (ATTs) for service firms (*N* = 6185).

Types of innovation	Cooperation with customers	Cooperation with suppliers	Cooperation with competitors	Cooperation with universities	Cooperation with research institutes
Total product innovation	0.080*** (0.012) [0.057, 0.103]	−0.028*** (0.010) [−0.048, −0.008]	0.028** (0.013) [0.002, 0.055]	0.063*** (0.014) [0.035, 0.091]	0.021 (0.021) [−0.020, 0.062]
Radical product innovation	0.059*** (0.015) [0.030, 0.089]	0.007 (0.015) [−0.022, 0.036]	0.050*** (0.016) [0.018, 0.082]	0.100*** (0.021) [0.059, 0.140]	0.134*** (0.028) [0.079, 0.189]
Incremental product innovation	0.011 (0.018) [−0.024, 0.045]	−0.034** (0.017) [−0.068, −0.001]	−0.016 (0.016) [−0.048, 0.016]	−0.045** (0.020) [−0.084, −0.006]	−0.118*** (0.029) [−0.175, −0.061]
Total process innovation	0.048** (0.022) [0.066, 0.090]	0.182*** (0.014) [0.154, 0.211]	0.073*** (0.017) [0.039, 0.107]	0.049* (0.026) [−0.002, 0.101]	0.122*** (0.032) [0.059, 0.184]
Radical process innovation	0.058*** (0.011) [0.038, 0.079]	0.034*** (0.009) [0.017, 0.0051]	0.039*** (0.012) [0.016, 0.062]	0.059*** (0.016) [0.028, 0.090]	0.104*** (0.027) [0.051, 0.156]
Incremental process innovation	−0.001 (0.017) [−0.035, 0.033]	0.144*** (0.016) [0.112, 0.176]	0.039** (0.018) [0.004, 0.075]	−0.006 (0.023) [−0.051, 0.038]	0.004 (0.030) [−0.055, 0.063]

Notes: Robust standard errors in parentheses; confidence intervals in brackets; ***$p < 0.01$; **$p < 0.05$; * $p < 0.10$.

Table 4 reports findings about the service sector. Based on previous empirical evidence (Abreu et al. 2010), we would expect a general dominance of DUI drivers. Rather surprisingly, we observe that, besides the expected critical role of customers, also universities assume a leading role in total product innovation. Competitors collaborate effectively although to a lower extent, while suppliers produce a negative impact. In the case of total process innovation instead, all types of collaboration support the innovation process, although it is suppliers and research centres that take the lead. The first one is expected, while the second is not, although it shows again the proactive role taken by research in the UK environment to respond to competitive business needs.

In relation to complex product and process innovation, STI collaborations are particularly important. Once again, the UK LME with its EIS makes a difference and shows how universities and research centres are close to businesses and interact with them to design new services and processes. Customers and competitors also matter for complex product innovation here because services represent a visible sector that operates in the high streets where everyone can learn from their neighbours and their new business practices (i.e. knowledge spill-overs). In relation to incremental product/service innovation instead there are no relevant collaborative practices. Time and resources devoted to effective collaborations distract energies and reduces this type of innovation that mostly depends on internal activities. In relation to incremental process innovation only suppliers and competitors promote it successfully.

These general findings support Hall and Soskice's view of how LMEs work. In UK EISs (in some regions more, e.g. Cambridgeshire and Bristol more than Cornwall), SMEs benefit from frequent and effective collaborations with STI agents. Industry variations are expected (Akkerman, Castaldi, and Los 2009), with the highest creativity and radical innovations produced within the well-developed sector of KIBS (i.e. financial services, digital media) that represents the UK economy of the past two decades.

6. Conclusions

6.1. Main findings

In this study, our main argument is that innovation takes place with distinctive patterns in different institutional frameworks (see also Parrilli, Balavac, and Radicic 2020). Here, we focus on the literature of varieties of capitalism and connect it with the literature on innovation systems. Within these, the UK LME is characterized as an EIS (Asheim and Gertler 2005; Cooke 2004) in which businesses and universities are acting in proactive and entrepreneurial terms (Breznitz 2011; Goddard and Vallance 2013). Our effort has been to combine this political-institutional framework with the strand of the literature on business innovation modes where firms can be led by STI collaborations, or alternatively on DUI collaborations. The richness of this effort is to identify the way firms act and reap the benefits of their investments within specific institutional environments, and what kind of actors intervene to help them innovating.

The main findings of this study indicate a quite strong drive to generate complex product and process innovations (27–28% of the innovative firms) and the leading role of science and technology organizations in the UK LME in the production of such innovations. Universities and research centres represent leading organizations in

promoting product and process innovation with three novelties vis-à-vis the case of CMEs where IISs often operate (e.g. European countries). The first is that such organizations contribute significantly to process innovation and not just to product innovation as they do in CMEs and their IISs (Parrilli and Radicic 2020; Tether and Tajar 2008; Trott and Simms 2017). Secondly, they take a leading role when the firms develop complex innovations, where the role of customers is also essential (Fitjar and Rodriguez-Pose 2013; Thomä 2017). Differently from CMEs (e.g. Norway in Fitjar and Rodriguez-Pose 2013), in the UK LME, competitors become quite a relevant agent in both product and process innovation, possibly because they target wider markets for which competition is not extremely fierce while collaboration becomes useful. This finding aligns well with Hall and Soskice's prediction about the role of competitors in market-driven economies. Suppliers have a more limited role, and usually matter when the focus is on incremental process innovation. Thirdly, there are significant variations between manufacturing and service industries. Customers and universities matter indistinctively in both, especially for complex product and process innovation, while suppliers tend to matter mostly for incremental process innovation. The difference comes with research centres and competitors. For manufacturing these agents do not matter, whilst they matter a lot for services. Since the UK is an open economy with an internationalized service sector (e.g. finance and education), competitors focus on the large international market and do not compete with one another, thus cooperate effectively. In the case of research centres, the existence of important research centres focused on services is much more developed than in the manufacturing sector that mostly depends on universities for complex innovations.

Overall, this study sheds light on the variations expected across industries (Akkerman, Castaldi, and Los 2009; Boschma and Capone 2015) and that seem to explain the peculiar drive of LMEs in innovation. In the UK, the new service industries are in the position to benefit from the EIS through the proactive role of research centres and universities. This interaction promotes complex/radical transformations that lead to disruptive changes and a growing competitiveness of the economy. Within a multi-scalar perspective, the literature on varieties of capitalism has identified nuances at the territorial and sectoral level. The way innovation systems and their institutions work can vary regionally (Ebner 2016; Zhang and Peck 2016) and sectorally (Akkerman, Castaldi, and Los 2009; Boschma and Capone 2015). This study did not focus on regional variations that often exist (Isaksen and Trippl 2017), but produced useful insights at the industry level. In evolutionary terms, it has shown that, in addition to high-technology industries, also the KIBS offer margins for radical/complex innovation.

6.2. Policy implications and further research steps

The UK LME shows that the capacity of firms and STI agents to connect and work together for innovation is more advanced than in CMEs (Cooke 2004; Asheim and Gertler 2005). The tradition of world leading universities and their focus on professional practice has anticipated the similar effort made in other countries (Breznitz 2011; Goddard and Vallance 2013). The UK represents a reference in how the production system and the whole society appreciate the role of universities and science. In policy terms, this evidence implies the importance to keep promoting the research excellence

of UK universities and research centres and their interaction with firms through an explicit focus on professional practice. This needs to be developed according to institutional and policy adaptations in the evolution of territories and industry (Flanagan and Uyarra 2016). This could happen through the upgrading of successful university-industry collaboration programmes such as the 'Knowledge Transfer Partnership' (KTP). These could be extended beyond current one-to-one collaborations to involve initiatives that support the activity of industry clusters, thus building on critical mass in specific/regional territories. The 'Catapult' programme could be upgraded by more specific integration of universities and private research centres within this programme that currently works with selected operative innovation/technology centres. Simultaneously, new arrangements are necessary with the EU for the continued access to the EU research framework 'Horizon-Europe' facilities that can promote further learning across UK universities that engage with leading partners abroad.

Various steps for further research are suggested. Primarily, the possibility of strengthening this analysis through panel data could show the evolution of the EIS. This would help to understand whether such an effective system can be built up or it is eminently culture-specific. Moreover, the sectoral drive of innovation modes could be studied in more depth and entail the division between high and low-technology sectors, and traditional services vs KIBS that are likely to show different trends (Lee and Miozzo 2019). This would help to understand what types of collaboration matter within such different industries. Finally, the availability of regional data would permit the delivery of findings and policy recommendations for socially and economically bounded territories (e.g. regions or clusters).

Notes

1. The Small Business Survey (SBS) has been conducted since 2003. In 2015, for the first time, the survey was designed to have a longitudinal tracking element. However, survey questions on firms' cooperation for innovation were only included in the 2015 wave and omitted from subsequent surveys.
2. The SME definition is based on the headcount, whereby SMEs have less than 250 employees.
3. A dummy variable for medium-sized firms is a reference category.
4. We do not show summary statistics for 71 dummies, because this table would be too large. It is however available from authors upon request.

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Appendix

Table A1. Correlation coefficients.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)growth_decrease	1.000							
(2) growth_same	−0.336***	1.000						
(3) micro_firms	0.102***	0.069***	1.000					
(4) small_firms	−0.034***	−0.010	−0.606***	1.000				
(5) age_10	−0.043***	−0.056***	0.173***	−0.044***	1.000			
(6) age_more20	0.008	0.055***	−0.191***	0.029**	−0.658***	1.000		
(7) urban	0.009	0.015	−0.076***	0.026**	0.028**	0.000	1.000	
(8) exports	−0.016	−0.043***	−0.119***	0.050***	−0.051***	0.032***	0.004	1.000

Notes: ***$p < 0.01$; **$p < 0.05$.

Figure A1 shows the standardized mean difference and the variance ratio for our models. All criteria uniformly show that our matching estimator satisfies the matching quality in each model. The left panel shows plot of covariate-by-covariate standardized mean differences in the unmatched data (black dots) and in the matched data (grey dots). The standardized bias measures the difference in means between the treatment and control group (scaled by the standard deviation). Zero bias indicates identical means, dots to the right (left) of zero indicate a higher mean among the treatment (control) group. All standardized mean differences in matched data are equal to zero. The right panel shows the variance ratio for a covariate-by-covariate in the unmatched and in the matched data. All variance ratios in matched data are equal to one.
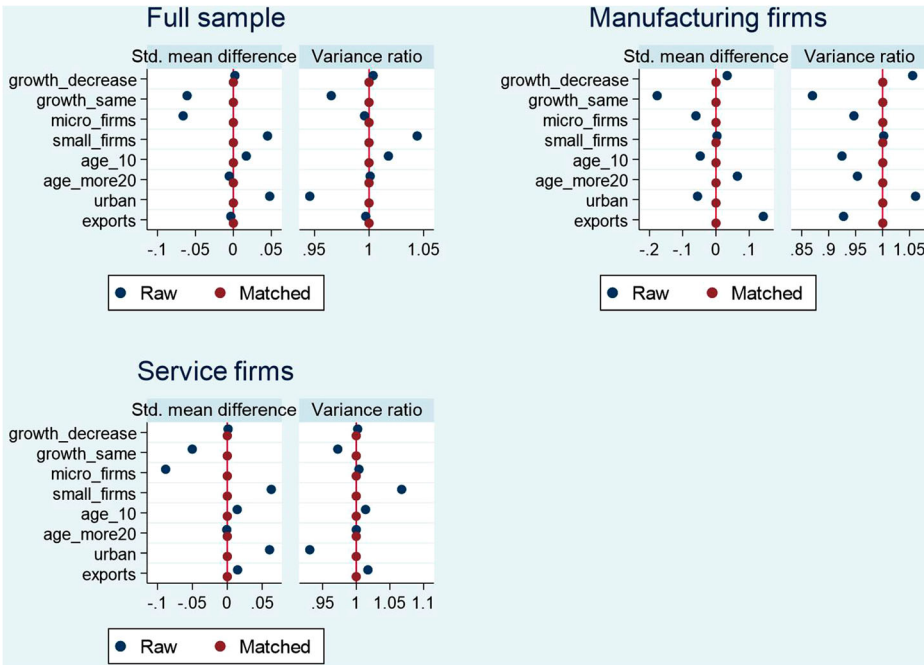

Figure A1. Matching quality – standardized mean difference and variance ratio.

Figure A2 shows density probability plots for the estimated propensity scores that are used to check for covariate balance after the estimation of the propensity score. When the distribution of a propensity score does not vary between the untreated and treated firms, the propensity score is said to be balanced. The figure shows the distribution of the propensity scores does not vary. Figure A3 in Appendix shows cumulative density probability plots. These plots also show that the distribution of the estimated propensity scores does not vary, which means that the scores are balanced.
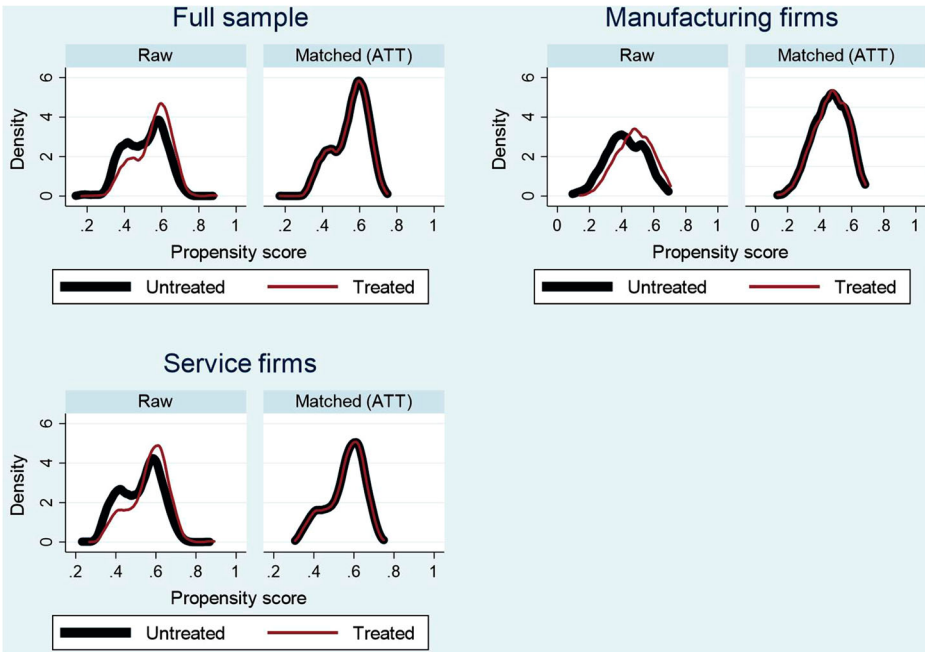
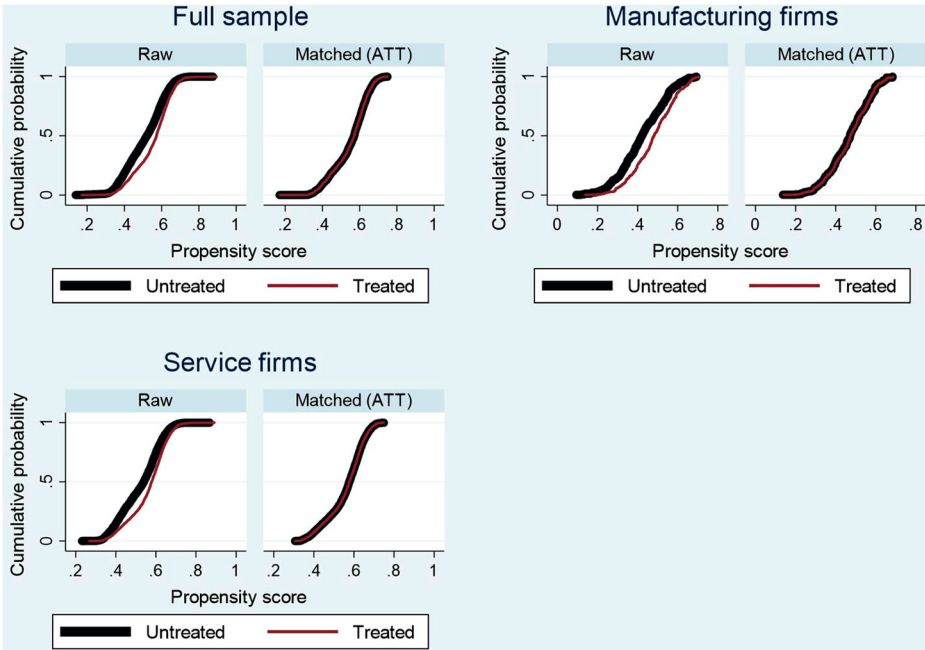**Figure A2.** Density probability plots for the estimated propensity scores.

Figure A3. Cumulative density probability plots for the estimated propensity scores.