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To what extent do universities' formal and informal knowledge exchange activities interact: evidence from UK HE-BCI survey

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Abstract

Third Mission engagement has become a necessary vehicle to transfer science and knowledge from higher education institutions (HEIs) to society. An extensive body of research has mainly focused on the determinants of research commercialization, and the consequence of knowledge exchange activities largely carried out on an individual academic level. There is a lack of theoretical and empirical evidence on the link and interaction between formal (traditionally referred to as commercialization of university research, such as patent, licensing and spin-off) and informal knowledge exchange activities (usually denoted as university community engagement activities, such as collaborative research, consultancy, facilities and equipment, continuing professional development etc.). In this article we seek to fill this gap by viewing knowledge exchange activities as an enabler and supporter of commercial activities. Against this background, we intend to provide an analysis into the relationship between informal activities and formal activities using an unbalanced panel of UK universities for the period 2005–2020. Our results reveal that while provision of continuing professional development courses, facilities and equipment, and consultancy significantly impact commercial activities such as patenting and licensing, collaborative research appears to be a strong predictor for spin-offs generation. This study offers some general implications for HEIs' policy and Technology Transfer Offices.

Keywords Third mission · Commercialization · Knowledge exchange · Higher Education Institutions · Technology Transfer Offices

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1 Introduction

Third Mission (TM) engagement refers to the knowledge-related interactions between higher education institutions (HEIs) and non-academic organisations. TM engagement has been a subject of major policy interest as it is a necessary vehicle to channel science and technology to create impact to the wider society (Upton et al., 2014). It includes activities and the role of HEIs in transferring technology to industry via different mechanisms (Hsu et al., 2015; Rothaermel et al., 2007; Secundo et al., 2017). Amongst the various activities available for establishing these interactions, the commercialization of academic knowledge, relating to IP appropriation of inventions including academic entrepreneurship, has been a subject of attention both within the academic literature and the policy makers (O'Shea et al., 2008; Phan & Siegel, 2006; Rothaermel et al., 2007). Although commercialization clearly illustrates an important means for academic research to contribute to economy and society, there are various other ways in which knowledge can be exchanged (De Wit-de Vries et al., 2019; Salter & Martin, 2001). These interactions include formal activities such as patenting, licensing, or spin-off creation (Jensen & Thursby, 2001; Thursby & Thursby, 2002; Mowery & Sampat, 2005; O'Shea et al. 2004; Azoulay et al., 2009) as well as informal activities ranging from informal contacts to academic consulting, or joint teaching courses (Arvanitis et al., 2008).

Scholarly interest has closely tracked the relevance of the topic with a substantial increase in publications on TM (e.g. Compagnucci & Spigarelli, 2020; Zhou & Tang, 2020) and academic engagement (e.g. Abreu & Grinevich, 2017; Perkmann et al., 2021). Both terms are linked to knowledge transfer activities, though academic engagement is usually seen as the tool to achieve TM, which refers to "an extensive array of activities performed by HEIs which seek to transfer knowledge to society in general and to organizations, as well as to promote entrepreneurial skills, innovation, social welfare and the formation of human capital" (Compagnucci & Spigarelli, 2020, pp. 1). Academic engagement refers to "knowledge-related interactions by academic researchers with non-academic organisations, as distinct from teaching and commercialisation" (Perkmann et al., 2021, pp. 1). This article focuses on TM. An extensive body of research has mainly focused on the determinants of commercialization (e.g. Al-Tabbaa & Ankrah, 2016; Hsu et al., 2015) and the consequence of TM largely carried out on individual level (e.g. Bikard et al., 2019; Lawson, 2013). Additionally, previous literature tends to have a narrow focus on the transfer of science research and inventions to licences and start-ups, so called commercialization, especially with respect to formal IP (Siegel & Wright, 2015). Limited attention is observed in the full portfolio of knowledge exchange (KE) activities pursued by HEIs (Abreu et al., 2016; Hewitt-Dundas, 2012; Sengupta & Ray, 2017), such as teaching/education–third mission nexus informed by research. There's a call for studies to embrace a variety and mix of KE activities to reflect the extent and features of TM engagement (Siegel & Wright, 2015).

Among those studies that examine various KE activities pursued by HEIs, only a handful of them discussed the interaction and interplay between activities, especially between formal and informal activities (e.g. Dechenaux et al., 2011; D'Este & Patel, 2007; Perkmann et al., 2013; Schaeffer et al., 2020). In fact, the work by Perkmann et al., (2013) has underlined the gap in the knowledge about the relationship between KE activities and commercial outputs, whether these activities are complementary or contradictory (Fini et al., 2018). The existing literature fails to fine-slice the knowledge exchange channels and activities under TM engagement and test the interactions whether the informal forms of KE activities affect and contribute to the outcome of formal activities. Although existing studies provide valuable insights into the antecedents (e.g. Blind et al., 2018; Lawson et al., 2019) and consequences (e.g. Banal-Estañol et al., 2015; Bikard et al., 2019) of TM engagement by predominantly studying individual researchers, they do not help to understand what happens at the institutional level. Consequently, this has presented a gap in the research in terms of the range, combination and link between KE activities and commercial outputs at the institutional level. Against this background, the purpose of this study is, therefore, focusing at institutional level in order to examine the interaction between informal and formal KE activities. The UK has provided a context and landscape for this study because of the long-established interest of knowledge exchange and commercialisation activities within HEIs, encouraged by the UK government. Since 1991, the Higher Education Business and Community Interaction (HE-BCI) survey administered by the UK government has centrally collected financial and output data related to knowledge exchange from UK HEIs each academic year. In this study, we analysed the HE-BCI results for the period 2005–2020.

Our paper makes a number of contributions to the existing knowledge. Theoretically, it extends the knowledge on the TM activities and the interactions between formal and informal activities from an institutional perspective that can potentially impact the commercial outcomes. Practically, we argue that such interaction at macro/institutional level is important for HEIs as it will allow them to have a better understanding of the KE activities and their effect. In addition, this information can aid the development of KE policy and strategies including support programmes for transferring technology to enhance the commercialization outcomes.

The remaining sections of our paper is structured as follows. Section two offers detailed discussions on relevant literature. Section three provides an overview of our data and the adopted methodology. Section four presents our findings and discussion of the findings is offered in section five. Section six presents our concluding remarks.

2 Literature review

2.1 Entrepreneurial and commercial activities of HEIs

The role of HEIs has increasingly been transformed to take on economic contribution and development (e.g. Lazzeretti & Tavoletti, 2005; Lenger, 2008) especially through innovation (Benneworth & Hospers, 2007). In many countries around the world, there are growing efforts in government policy to encourage more commercialization of research outputs produced by HEIs. Government funding cuts and a decrease in number of students also have an implication towards HEIs in a sense that they have been driven to develop sources of income through TM engagement (Gibb et al. 2009). Hence, the conventional view of purposes and values of a HEI, which focusses on teaching, knowledge for its own sake or free-for-all knowledge (Audretsch, 2014; Behrens & Gray, 2001; Ranga & Etzkowitz, 2013), has now been challenged and broadened to include the economic contributions to the milieu where they are located (Gibb et al., 2009; Guerrero et al., 2015). Hence, the concept of "Entrepreneurial University" can be used to explain this phenomenon (Gibb et al., 2009). This means HEIs develop close connections through continually mutually beneficial knowledge exchange or TM activities, which in turn strengthen the Triple Helix model (Etzkowitz, 2003; Etzkowitz & Leydesdorff, 2000) emphasising the interaction between HEIs, government and business. Activities such as patenting, licensing of technology, as well as university spin-offs are regarded as the core of commercialization and TM activities.

An extensive body of the literature (e.g. Carayanniset al., 2016; Gulbranson & Audretsch, 2008; Slavtchev & Göktepe-Hultén, 2016) has attempted to understand the nature of entrepreneurial and commercial activities originating from HEIs, and has emphasised core TM activities, such as formation of university spin-offs, IP, and licensing of research outputs and inventions. However, it can be contested that there are broader aspects of TM and KE activities than just core commercialization activities of IP, licensing or spin-offs. Commercial and TM activities are intricate and can have different ranges at formal and informal levels (Murray, 2004). Similarly, Jain et al. (2009) identify entrepreneurial activities as any form of technology transfer which has some potential commercial benefits. These signify the broader scope of commercial/Third Mission activities. In addition, there is a view that other knowledge exchange activities such as contract research or consultancy often act as the pivotal first step leading to further academic and commercial outcomes (Franzoni & Lissoni, 2006). Generally, it is recognised that other means of commercialization activities are vital, pertinent and lay a foundation for contractual or formalised activities (Martinelli et al., 2008), despite being not as discernible as the former (Landry et al., 2006).

2.2 Categories of formal and informal KE activities

HEIs employ a wide range of KE activities (Abreu et al., 2016; D'Este & Patel, 2007; Perkmann et al., 2013). Various terms have been employed to give an explanation, for example Caldera and Debande (2010) roughly categorise them into 'soft' and 'hard'. According to Philpott et al. (2011), soft activities are in accord with conventional missions of HEI, such as public lectures and consulting. On the other hand, the 'hard' activities are usually related to the commercialization of research, knowledge or inventions, such as licensing or spin-off creation.

A number of studies and authors have proposed and employed the terms 'formal' and 'informal' activities (e.g., Berggren & Lindholm Dahlstrand, 2009; Kirchberger & Pohl, 2016; Wright et al., 2004). Nevertheless, there is a lack of agreement in relation to what activities are categorised as formal and what informal activities comprise of. Some activities are regarded as formal by some authors, but informal activities by the others. Schaeffer et al (2020) have addressed this disparity by suggesting two approaches; (i) contractual; (ii) interaction-based.

From the contractual approach perspective, formal activities are categories by a formal contract (Vedovello, 1997; D'Este & Patel, 2007; Landry et al., 2010; Grimpe and Hussinger 2013; Perkmann et al. 2013; Azagra-Caro et al., 2017). For instance, this may include licensing technology, or a consulting activity etc. On the contrary, informal activities thus comprise non-contractual mechanisms, e.g., conferences, joint research publications, etc. (Arvanitis et al., 2008; Boardman & Ponomariov, 2009; Cohen et al., 2002). The contractual approach has been the dominant view in literature since it offers a plain, clear and coherent way to categorise KE activities. However, the tacit as well as the interaction elements of KE activities have been overlooked. This means certain activities, which are considered formal, might envelope informal interactions and discussion prior to the drawing of a contract as such. Against this viewpoint, Schaeffer et al (2020) propose four categories adopting narrow and broad definition and based on contract and interactions: (i) *a purely* *formal activity based solely on contract,* such as licensing (patents, software), (ii) *a formal interactive activity encompassing interactions,* e.g. academic spin-off or contractual consultancy, (iii) *a purely informal activity based solely on interactions*, e.g. teaching activities, joint publications or academic conferences and workshops (iv) *an activity based on no contract and no interaction*, in this category, Schaeffer et al (2020) referred to the situation when knowledge is available in the public domain, such as academic reports or scientific publications that companies can utilise to develop products/services. Such knowledge is arguably not transferred via any contractual or interactive mechanism. Though, it is difficult to capture the activities and measure the outcomes of this category.

Similarly, the study by Abreu and Grinevich (2013) proposes three broad categories of KE activities, mainly based on the types of knowledge (i.e., explicit—can be IP protected or tacit) and the involvement by Technology Transfer Office (TTO). The first category, denoted '*formal commercial activities*', contains traditional activities related to academic entrepreneurship, such as licensing and spin-offs. These activities are focused around technological innovations that can be appropriated through IP, can be subsequently commercialized, and require high involvement from TTOs. The second category is based on more tacit knowledge and is unable to protect through IP mechanism. This '*informal commercial activities*' category includes activities, such as consultancy works, contract research, and joint research projects. TTO's involvement is not active. The third category involves '*non-commercial activities*', which are based on knowledge that is highly tacit and is not easy to protect through IP. These activities are often organised informally with little or without TTO's involvement. The examples are public lectures, informal advice to business, or publishing books or journal articles for the public's benefit. However, the activities under this category can lead to relationship building and commercial activities afterwards.

In this study, we focus on the interactions between KE activities by adopting categories of '*formal commercial activities*' proposed by Abreu and Grinevich (2013) based on IP appropriation and commercial outcomes, and '*informal activities*' based on a combination of '*informal commercial activities*' proposed by Abreu and Grinevich (2013) and *a formal interactive activity encompassing interactions* proposed by Schaeffer et al (2020). The combination of these categories and definitions is coherent with our objective, which is to examine the effect of informal activities towards the formal commercial activities and outputs (patents, licences and spinoffs). Table 1 provides a summary of the definition of formal and information activities. Formal activities denote IP appropriation and commercialization outcomes such as, spin-offs, patenting and licensing, whereas informal activities refer to the engagement and interactions with industry, but not necessarily and directly commercialize research outputs, for example, consultancy, contract research, collaborative research, training and facilities-related services.

2.3 The interconnections between formal and informal activities

The study of the formal and informal activities of knowledge transfer between university and industry has long been established in the field of Economics and Innovation (Mowery & Ziedonis, 2015). These studies have examined these separately and individually, for example, licensing of university patents as a formal activity (Grimaldi et al., 2011) or personal relationship between academic and industry researchers as an informal activity (Ramos-Vielba & Fernández-Esquinas, 2012). Even though there has been an acknowledgement of the existence of continuity and interaction among formal and informal

Table 1 Definition of formal and informal KE activities

	Definition
Formal activities	
Patenting	The application of an exclusive right granted for an invention, which is a product or a process that provides a new way of doing something. Patenting traditionally plays an important role in commercializing university knowledge and scientific and technological discovery by protecting its intellectual property (IP) (Crespi et al., 2011). Though, Leydesdorff and Meyer (2010) note on a decline trend of this activity amongst universities since the start of twenty-first century. Universities can utilise patenting via vending it to firms in a form of licensing, in which universities earn revenue from royalty
Licensing	The settling of an agreement through which an organisation leases the rights to a legally protected piece of intellectual property from an HEI. In many academic studies, licensing (or licensing income) has also been employed as one of the measures of entrepreneurial university (Caldera & Debande, 2010; Powers & McDougall, 2005), or of university's knowledge transfer or economic contribution (Roessner et al., 2013; Caldera & Debande, 2010; Siegel et al., 2008)
University spin-offs	The creation of any newly established, small at the start, knowledge or technology intensive, in which the IP has originated from an academic institution or public research organisations. The university spin-offs are established to commercially exploit inventions or ideas originated within the university, based on academic research (Jones-Evans et al., 1998). A similar definition is given to the spin-offs as any newly established, small at the start, knowledge or technology intensive, in which the IP has originated from an academic institution or public research organisations (Lawton Smith & Ho, 2006). Spin-offs from universities offer many local and regional benefits (Rossi et al., 2021; Shane, 2004), such as jobs, innovation, investment, economic contributions. Studies on spin-offs have categorised different types of spin-off from various aspects, such as sponsored and unsponsored spin-offs (Bathelt et al., 2010), or orthodox, hybrid or technological (Nicolaou & Birley, 2003), or whether graduate or staff spin-offs (Åstebro et al., 2012)
Informal activities	
Continuing Professional Development (CPD) and CE	CPD and CE courses denote specific courses offered to executives, professionals and business partners by HEIs. This includes revenue generated by CPD and CE courses, defined as a range of short and long training programmes for learners already in work who are undertaking the course for purposes of professional development, upskilling or workforce development This is considered as another important strategy for HEIs to engage and achieve their TM as well as a source for income generation. The previous studies suggest that CPD is more evident among less research-intensive universities (e.g. Hewitt-Dundas, 2012; Zhou & Tang, 2020)
Facilities and Equipment	Facilities and equipment (FE) provided for businesses are one of the KE activities that allow HEIs to achieve their third mission as well as generate income (Etzkowitz, 2003). This includes the use and income associated with the use of the HE provider's physical academic resources by external parties, and captures provision which can be uniquely provided by a HE provider

Table 1 (continued)

	Definition
Consultancy	Consultancy, generally, involves application-oriented research and development activities and expert opinions offered by academics individually (Goel & Göktepe-Hultén, 2013). This includes contract numbers and income associated with consultancy, that is advice and work crucially dependent on a high degree of intellectual input from the HE provider to the client (commercial or non-commercial) without the creation of new knowledge. They provide specialist knowledge as well as act as sources of information for innovation activities for firms (Tether and Tajar, 2008) In some cases, consultancy agreement is established to provide service and assistance related to a particular technology; sometimes included as part of a licence agreement. (Nilsen and Anelli, 2016). This is considered by Perkmann and Walsh (2007) as a low-relational knowledge exchange activity and less restricted by distance. This means, academics and firms have limited interaction and mostly, academics, who provide consultancy have limited access to the technology base of the business (Perkmann & Walsh, 2008) Research intensity of HEIs has played a role in the scale of consultancy activity (Hewitt-Dundas, 2012). Compared with other KE activities such as licensing and contract research, consultancy is still less eminent among research-intensive HEIs (Zhou & Tang, 2020)
Contract research	Contract research refers to research that is directly commercially relevant to businesses and, often is commissioned by firms. The work and research outcomes are generally more practical than in collaborative research arrangements (Van Looy et al. 2004). This includes contract numbers and income identifiable by the HE provider as meeting the specific research needs of external partners, excluding any already returned in collaborative research involving public funding and excluding basic research council grants
Collaborative research	Collaborative research describes projects where a HEI and businesses collaborate and work together to solve shared and common problems (Martinelli et al., 2008; Boehm and Hogan, 2013). This includes research projects with public funding from at least one public body, and a material contribution from at least one external non-academic collaborator. According to the European Commission (2007), this can entail all forms of arrangements between HEIs and businesses by which they share a research commitment to a common aim by assembling resources from both parties, organising and co-ordinating their activities. This activity involves networks of multiple stakeholders, such as researchers, commercialization managers, TTO, business or industry partners and possibly government funding agents. Its purpose is to generate technological outcomes with a prospect for commercial exploitation (Nilsen and Anelli, 2016)

activities, less attention has been paid to the dynamic relationship among activities (Azagra-Caro et al., 2017).

The study by Schaeffer et al (2020) suggests that formal and informal activities are connected and mutually supporting (D'Este & Patel, 2007; Landry et al., 2010). Further, informal activities are likely to allow industries to access tacit knowledge including the formal knowledge transferred by HEIs and to aid the development of formal commercial activities, such as spin-offs or start-ups (Grimpe and Hussinger 2013). However, the interconnection between formal and informal activities is noted in a scattered manner, particularly when looking at specific informal activities. For example, when HEIs supply knowledge to industries through continuing professional development (CPD) courses (Lawton Smith, 2007) or training to firms' employees, this signals HEIs' expertise and research excellence. Hence, CPD activities provided to industry or business partners are believed to be able to build a foundation for further knowledge exchange and commercialization opportunities (Zhou & Tang, 2020). However, the research by Sengupta and Ray (2015) contend that CPD activities do not tend to form any special pathways for additional KE activities.

In the same way, facilities and equipment (FE) enhance knowledge sharing and exchanging, as shown in the case of Stanford University when equipment and workspace were offered to the inventors, with equal share of patent rights between the university and their inventor partners (Etzkowitz & Zhou, 2021). They also form a basis for licensing as well as future collaboration (Huffman & Quigley, 2002). In the same way, FE are noted conducive to patents as when firms access state-of-the-art facilities, equipment or laboratory provided by HEIs, they can also gain accessibility or exploit other research related opportunities (Owen-Smith & Powell, 2003). This engagement has enabled academics to discover new ideas and technologies and can lead to patent outputs (Galib et al., 2015).

As noted by Franzoni and Lissoni (2006), consultancy is deemed a vital step to further academic and commercial outcomes. In addition, through consultancy—medium relational KE activities, relationships with industrial partners can be formed including gaining deeper understanding of industry's problems and application of scientific knowledge to solve such problems (D'este & Perkmann, 2011). In addition, contract research can also strengthen relationships with industry (Prince 2007), support spin-off creation (Van Looy et al. 2011), or complement other knowledge exchange activities (Landry et al., 2010; Van Looy et al. 2011) However, the study by D'Este and Perkmann (2011) found that the individual motivation of academics towards contract research was research-driven as opposed to focussed on commercial outcomes.

Collaborative research creates knowledge spill-over in a sense that both parties not only build social capital through trust and relationship, but also open up a potential avenue for commercialization of the new knowledge and technology through licensing of IP (Boehm and Hogan, 2013). It also allows academic researchers to pool their expertise, resources, and perspectives to solve complex problems. This can lead to the development of new ideas, technologies, and approaches that would not have been possible otherwise. By leveraging different strengths, a collaborative research team has a better chance of creating something new and valuable. In addition, collaborative research projects are often subsidized significantly by public funds (Perkmann & Walsh, 2007). Despite this, there is less involvement from the industry. Most HEIs continue seeking industrial sponsorship, as they can access significant funding opportunities that can support research and development. This additional funding can enable research teams to develop prototypes, conduct pilot studies, and bring their ideas closer to commercialization. Furthermore, it enables HEIs to expand their networks beyond their local communities (Galib et al., 2015) through working with researchers from other institutions, industry experts, and other stakeholders. These connections are valuable social capitals that can lead to new ideas, partnerships, and opportunities for creating spin-offs (Guimón, 2013).

In summary, it is widely acknowledged within extant literature that these informal activities have contributed and linked to formal activities leading to commercial outcomes (through patenting, licensing and spin-offs). However, most of these studies acknowledge a dynamic interaction among informal and formal activities without providing more detail nor fine slicing on which informal activities exactly create such an influence towards commercialization outputs (i.e., patents, licensing and University spin-offs). Hence, in this study, we aim to address the research question: "Which informal KE activities interact and have an influence on formal commercial activities?".

3 Data and methodology

3.1 Data source

This paper draws data from the HE-BCI survey in the UK, which is administered by Higher Education Statistical Agency (HESA) annually to collect qualitative and quantitative data on the TM activities undertaken by UK universities. The survey consists of two parts. Part A of the survey returns qualitative data on six broad areas of TM activities: 'Strategy'; 'Infrastructure'; 'Intellectual Property' (IP); 'Social, Community and Cultural'; 'Regeneration'; 'Education and Continuing Professional Development' (CPD—courses for business and the community). Part B of the survey returns quantitative data on 'Research Related Activities' (collaborative research and contract research), 'Business and Community Services' (consultancy, CPD and FE), 'Regeneration and Development Programmes' (regeneration funding), 'Intellectual Property' (disclosures and patents, IP income/licences, and spin-off activity), and 'Social, Community, and Cultural Engagement' (designated public events). Drawing together the two parts of the survey, we argue that the TM activities can be classified into two categories: (1) informal KE activities, including consultancy, collaborative research, contract research, CPD, and FE; and (2) formal KE activities, including patenting, licensing, and creation of spin-offs. Employing the data, we examine the extent to which the informal forms of KE affect commercialization, as measured by income from: (1) patenting; (2) licensing; and (3) spin-off creation. The analysis of the paper relies on an unbalanced panel of 1599 observations covering the period 2005–2020.

3.2 Variables

3.2.1 Dependent variables

Table 2 lists all variables and their definition. Table 3 presents summary statistics for all continuous variables. To reiterate, three measures of commercialization are employed. The first dependent variable is measured in terms of number of granted patents received by HEIs. The second dependent variable is measured in terms of number of licences concluded by HEIs. The third dependent variable is measured in terms of number of spin-offs created by HEI staff, thus capturing number of start-ups, formal spinoffs, and spin-offs partially owned by an HEI. Spin-off has been recognised as a way of exploiting university research (Fuller et al., 2019). Spinoffs can provide many benefits to the economy, including jobs, investment, economic value, and impacts (Rossi et al., 2021).

3.2.2 Independent variables

The first independent variable is measured in terms of income (per HEI staff) generated by offering consultancy services to businesses and communities. According to HE-BCI statistics, SMEs are the main users of university consultancy services. Hewitt-Dundas (2012) found that high research-intensive HEIs tend to have a higher scale of consultancy activities than low research-intensive HEIs.

The second independent variable is measured in terms of income (per HEI staff) generated by delivering CPD and CE courses to businesses and members of the communities

Table 2 Variables and definition

Variables	Definition
Patent grants$_t$	Number of patent applications granted in year t
Licences$_t$	Number of licences concluded in year t
Spin-offs$_t$	Number of spin-offs created in year t
Consultancy$_{t-3}$	Income from consultancy service per HEI staff in year t − 3
CPD_CE$_{t-3}$	Income from courses for the business and community per HEI staff in year t − 3
FE$_{t-3}$	Income from facilities and equipment per HEI staff in year t − 3
Contract research$_{t-3}$	Income from contract research per HEI staff in year t − 3
Collaborative research$_{t-3}$	Income from collaborative research per HEI staff in year t − 3
Total academics$_{t-3}$	Number of academic staff employed in year t − 3 (log transformed)
Regional GVA$_{t-3}$	The value of goods and services produced in a region in year t − 3
Knowledge exchange funding$_{t-3}$	The amount of knowledge exchange funding received by HEI in year t − 3
Total research income$_{t-3}$	Total amount of research income received by HEI in year t − 3
Patent stock$_{t-3}$	Number of cumulated patent grants in year t − 3
KEF dummy	A categorical variable captures seven KEF clusters: Cluster E: Large universities with broad discipline portfolio across both STEM and non-STEM generating excellent research across all disciplines. Significant amount of research funded by government bodies/hospitals; 9.5% from industry. Large proportion of part-time undergraduate students. Small postgraduate population dominated by taught postgraduates Cluster J: Mid-sized universities with more of a teaching focus (although research is still in evidence). Academic activity across STEM and non-STEM disciplines including other health, computer sciences, architecture/planning, social sciences and business, humanities, arts and design. Research activity funded largely by government bodies/hospitals; 13.7% from industry Cluster M: Smaller universities, often with a teaching focus. Academic activity across disciplines, particularly in other health domains and non-STEM. More research activity funded by government bodies/hospitals; 14.7% from industry Cluster V: Very large, very high research intensive and broad-discipline universities undertaking significant amounts of excellent research. Research funded by range of sources including UKRI, other government bodies and charities; 10.2% from industry. Significant activity in clinical medicine and STEM. Student body includes significant numbers of taught and research postgraduates Cluster X: Large, high research intensive and broad-discipline universities undertaking a significant amount of excellent research. Much of research funded by UKRI and other government bodies; 8.5% from industry. Discipline portfolio balanced across STEM and non-STEM although less clinical medicine activity. Large proportion of taught postgraduates in student population Arts specialists: Specialist institutions covering arts, music and drama, as defined by a very high concentration of academic staff in these disciplines. A range of sizes of institutions, although many are relatively small and specialist Science, Technology Engineering and Maths specialists: Specialist institutions covering science, technology, engineering and mathematics (as defined by a very high concentration of academic staff in these disciplines). Often high amounts of excellent research, particularly in bioscience & veterinary and engineering

Table 2 (continued)

Variables	Definition
Year dummy	Time period 2005–2020

Table 3 Summary statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Patent grants	2631	6.882554	25.2332	0	459
Licences	2638	159.729	1664.512	0	58,466
Spin-offs	2715	1.091713	2.581335	0	32
CPD_CE	2626	0.9275573	0.6942018	0	5.553152
FE	2626	0.292553	0.4042868	0	5.303305
Consultancy	2626	0.5782358	0.5906825	0	4.418703
Contract research	2626	0.8038121	0.752867	0	3.639794
Collaborative research	2605	0.8210584	0.8165767	0	5.461355
Patent stock	2631	2.309821	2.330308	0	8.402007
Regional GVA	2670	195,197.4	124,832.7	28,977	482,863
Total academics	2645	6.326682	1.33371	0	8.978535
Total research income	2714	7.63244	3.27864	0	13.38987
Knowledge exchange funding	2052	11.50536	5.198169	0	15.381

who undertake them for professional development. CPD has been used for "facilitating the improvement of skills and human capital development" (PACEC, 2009, p. 6) and is widely subscribed to by SMEs (HESA, 2017).

The third independent variable is measured in terms of income (per HEI staff) generated by leasing HEI's physical resources—facilities and equipment (FE), for instance scientific instruments, lecture theatres, concert halls, and media suites, among others. Access to these facilities is often part of "a wider collaborative, contract, or consultancy project" (IP Pragmatics, 2016, p. 60). The leasings are also generally concluded with SMEs. In addition to obtaining financial benefits, HEIs can build relationships and expand their networks (social and business) from interaction with external users.

The fourth independent variable is measured in terms of income (per HEI staff) generated by delivering contracted research to businesses and members of the communities. The benefits of contract research include enhancing relationship with industry, assist spin-off creation, complement other KE activities, and benefit the local region.

The fifth independent variable is measured in terms of income (per HEI staff) generated by delivering collaborative research to businesses and members of the communities. D'Este and Patel (2007), and Gerbin and Drnovsek (2016) show that collaborative research can increase the variety and frequency of interactions.

3.2.3 Control variables

Patent stock. This variable is measured as number of cumulative patents held by an HEI. Patenting forms an important part of an entrepreneurial university, thus the number of cumulative patents can represent the amount of entrepreneurial knowledge of an HEI.

Knowledge exchange funding. The amount of KE funding an HEI received could affect how it allocates resources for KE activities. The data on KE funding is extracted from HEFCE (2015) website. In England, KE funding is distributed to HEIs by Research England through Higher Education Innovation Funding. The allocation of KE funding is calculated by adding together their main KE income indicators that are collected through HE-BCI survey and Knowledge Transfer Partnerships.[1]

Total gross value-added. The socio-economic environment where an HEI is located may affect its KE performance. It is likely that businesses and individuals use more KE services in productive regions than less productive ones. The productivity of the region an HEI is located in is controlled for, using total gross value-added published by the UK's Office for National Statistics.

KEF clustering. It is widely acknowledged that HEIs in the UK differ in resources, capabilities and research orientations, thus it is important to control for their KE characteristics. To control for heterogeneity of KE activities among HEIs, we adopt Knowledge Exchange Framework clustering (Research England, 2020), which groups HEIs into clusters that have similar capabilities and resources to engage in KE activities. There are seven clusters: (1) large universities with broad discipline portfolio across both STEM and non-STEM generating excellent research across all disciplines (2) Mid-sized universities with more of a teaching focus; (3) Smaller universities with a teaching focus; (4) Very large, very high research intensive and broad-discipline universities undertaking significant amounts of excellent research; (5) Large, high research intensive and broad-discipline universities undertaking a significant amount of excellent research; (6) Specialist institutions covering arts, music and drama; (7) Specialist institutions covering science, technology, engineering and mathematics.

Total research grant. We select total research grant as an input. The amount of research grant by HEIs signal their research capability, thus is important to be included in the model. This variable is measured as consolidated research grant captured by an HEI. In the UK, research grant can be captured by annual allocation based on quality-related formula, as well as applying to competitive funding initiatives.[2]

Total academic staff. Total academic staff represents the amount of human capital that is a crucial input for developing TM activities. This has been documented in the work of Daraio, et al. (2015), and Degl'Innocenti et al., (2019). This variable is measured as number of academic staff employed by an HEI.

3.3 Estimation strategy

We start with the classical Poisson regression which is based on the strong assumption of equi-dispersion, or more descriptively, that the conditional mean and variance are equal. Although this parametric model is popular due to its simplicity, it nevertheless comes with a cost stemming from the fact that it is not unusual for data to exhibit overdispersion (i.e. the conditional variance greater than the conditional mean) which is also the case with our data. Therefore, more efficient estimators are needed.

[1] This is based on the information provided by UKRI on https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/higher-education-innovation-fund/.

[2] This is also based on the information provided by UKRI on https://www.ukri.org/councils/research-england/our-funds-for-research-and-knowledge-exchange/.

The second, and more efficient, estimator is the Poisson quasi-generalized pseudo-maximum likelihood estimator with robust standard errors. This is designed to relax the equi-dispersion assumption, making it more appropriate for inference based on our data. Although it is a consistent and asymptotically normal estimator, it is likely to be less efficient than the maximum likelihood.

This brings us to two mixture regression models known as negative binomial models, both of which are estimated using the maximum likelihood method. The first one, which we denote NB, assumes a linear relationship between the variance and the mean (NB1); and the second one is based on a quadratic variance function (NB2).

Finally, it is worth noting that, in our case, the four approaches yield almost identical results at least in terms of the sign and significance of coefficients. This is particularly telling about the robustness of our analysis. Since observed variance in the dependent variables is higher than expected. i.e., over-dispersed, we employ the negative binomial approaches, which take into account the overdispersion of data by adding a parameter to fit variability of the observation. Moreover, since NB1 fits our data better, we decided to present the results of the NB1 approach.

Furthermore, we follow a lagged approach that enables us to partially to overcome the problem of endogeneity (Almeida & Phene, 2004). We recognise that while effects of some informal activities may be immediate, others may require a longer time frame to manifest on the formal, commercial activities. We aim to find a balance between these effects. Following previous literature (Black, 2004), we lag the independent and control variables by three years. The econometric model is written as:

$$Y_i = \alpha_1 + X_{1t-3}\alpha_2 + X_{2t-3}\alpha_3 + \epsilon_i$$

where Y_i denotes the dependent variable (i.e. number of patent granted/licences concluded/spinoffs created by an HEI), X_{1t-3} represents a vector of the independent variables, X_{2t-3} represents a vector of the control variables, α*'s* are the estimable parameters (α_1 a constant, α_2 and α_3 estimable coefficients) and ϵ_i is the error term.

4 Findings

At the outset, it is worth noting that with the non-linear models employed, it is more straightforward to interpret the average marginal effects (AME) than the estimated model coefficients. Unsurprisingly, this is also the customary practice in the existing literature (Gambardella et al., 2007; Rosell & Agrawal, 2009) and for that reason, we report the AME—which are obtained first by aggregating all individual responses and then calculating the average response.

Table 4 presents the Pearson's correlation matrix for all the continuous variables. In general, the correlation between most informal KE activities and formal KT activities are positive and significant at 1% level (the exceptions are FE and licences, and consultancy and licences).

With regards to the effect of informal KE activities on the likelihood of patenting grants, Table 5 shows that the incomes on CPD (with β value of 2.71), Facilities and Equipment (with β value of 1.68), and consultancy (with β value of 1) are positively associated with number of patents granted to HEIs. This means that low research-intensive KE activities are linked to patenting of HEIs, which is a type of knowledge exploitation activity (Schaeffer et al., 2020). Specifically, the result shows that 1 unit increase in CPD income is

Table 4 Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Patent grants	1												
2. Licences	0.1381*	1											
3. Spin-offs	0.4656*	0.0682*	1										
4. CPD_CE	−0.0212	0.0284	−0.0524*	1									
5. FE	0.0904*	0.03	0.0561*	0.0512*	1								
6. Consultancy	0.1007*	0.0042	0.1053*	0.2337*	0.1751*	1							
7. Contract research	0.3930*	0.0989*	0.3447*	0.0229	0.2399*	0.4034*	1						
8. Collaborative research	0.2546*	0.0970*	0.3279*	0.0315	0.2172*	0.3592*	0.6364*	1					
9. Patent stock	0.4626*	0.1111*	0.4295*	−0.0495*	0.1944*	0.2682*	0.7112*	0.6260*	1				
10. Regional GVA	0.0543*	−0.0473*	−0.0555*	0.1456*	0.1127*	−0.0517*	−0.0896*	−0.1386*	−0.1499*	1			
11. Total academics	0.3374*	0.0753*	0.3366*	0.0198	0.0775*	0.2074*	0.5114*	0.4543*	0.6953*	−0.2221*	1		
12. Total research income	0.3350*	0.0909*	0.3448*	0.1203*	0.1438*	0.3362*	0.7242*	0.6627*	0.7569*	−0.1780*	0.7904*	1	
13. Knowledge exchange funding	0.1530*	0.1129*	0.1905*	0.1379*	0.1442*	0.2675*	0.3977*	0.3573*	0.4673*	−0.0408	0.5894*	0.5519*	1

*denotes a correlation coefficient significant at 5% level or better

Table 5 Patent grant

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
CPD_CE_{t-3}		2.71*** (0.50)					2.64*** (0.52)
FE_{t-3}			1.68** (0.72)				0.86 (0.76)
$Consultancy_{t-3}$				1.00** (0.49)			0.98** (0.46)
Contract $research_{t-3}$					0.84 (0.61)		1.12* (0.58)
Collaborative $research_{t-3}$						−0.44 (0.45)	−0.12 (0.42)
Patent $stock_{t-3}$	4.59*** (0.42)	4.87*** (0.40)	4.62*** (0.43)	4.57*** (0.43)	4.55*** (0.40)	4.55*** (0.41)	4.83*** (0.39)
Regional GVA_{t-3}	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	−0.00 (0.00)	−0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Total $academics_{t-3}$	2.38*** (0.85)	1.57* (0.82)	2.71*** (0.87)	2.74*** (0.85)	2.83*** (0.90)	2.24*** (0.85)	2.68*** (0.93)
Total research $income_{t-3}$	3.47*** (0.69)	3.32*** (0.66)	3.35*** (0.69)	3.46*** (0.68)	3.07*** (0.72)	3.64*** (0.73)	2.72*** (0.74)
Knowledge exchange $funding_{t-3}$	−0.23* (0.14)	−0.24* (0.13)	−0.23* (0.14)	−0.24* (0.13)	−0.25* (0.14)	−0.23 (0.14)	−0.29** (0.13)
KEF clustering							
Cluster J	6.07* (3.60)	4.59* (2.78)	6.15* (3.68)	6.54* (3.80)	5.83 (3.57)	5.88* (3.49)	4.55 (2.91)
Cluster M	−9.62*** (3.36)	−7.96*** (2.77)	−9.83*** (3.55)	−9.74*** (3.72)	−10.10*** (3.31)	−9.58*** (3.30)	−8.70*** (2.98)
Cluster V	−6.39*** (2.42)	−3.65* (1.99)	−6.93*** (2.48)	−7.14*** (2.56)	−6.76*** (2.49)	−6.25*** (2.35)	−4.80** (2.16)
Cluster X	−3.60** (1.79)	−1.72 (1.50)	−4.23** (1.89)	−3.94** (1.88)	−3.60** (1.82)	−3.60** (1.76)	−2.18 (1.66)

Table 5 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Arts specialists	−1.97	−2.53	−2.25	−1.54	−2.09	−1.72	−2.56
	(4.86)	(3.71)	(4.94)	(5.30)	(4.96)	(4.92)	(4.11)
STEM specialists	−8.16***	−6.85***	−8.04***	−8.23***	−8.21***	−8.13***	−7.12***
	(2.53)	(1.99)	(2.62)	(2.68)	(2.58)	(2.49)	(2.18)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1599	1599	1599	1599	1599	1599	1599

Standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

associated with 2.71 units increase in patent grants of a HEI; 1 unit increase in FE income is associated with 1.68 units increase in patent grants of a HEI; 1 unit increase in consultancy income is associated with 1 unit increase in patent grants of a HEI. We did not find a significant effect of contract research and collaborative research on the patent grant of HEIs. Model 7 shows that CPD and consultancy consistently demonstrate a positive effect on the likelihood of HEI being granted a patent; the positive effect of FE diminished. In summary, results for the independent variables are largely consistent across models 1–7. All the control variables show consistent effects throughout the models, with knowledge stock, research grant, and total academic staff showing significant and positive impact on the likelihood of patent grants, while KE funding shows a negative but weak effect on the likelihood of patent grants of a HEI. As for KEF clustering, Cluster J is the only one that is positively associated with the likelihood of patent grant; Clusters M, V, X, and STEM specialists are negative and significantly associated with the likelihood of patent grant.

With regards to the effect of informal KE activities on the performance of licensing activities, Table 6 shows that CPD (with β value of 16.63), FE (with β value of 16.98) and consultancy (with β value of 32.95) are positively related to licences concluded by HEIs. The result demonstrates that low research-intensive KE activities are also good predictors of licensing performance of HEIs. Specifically, the finding suggests that 1 unit increase in CPD income is associated with 16.63 units increase in the number of licence of HEIs; 1 unit increase in FE income is associated with 16.98 units increase in the number of licence of HEIs; 1 unit increase in consultancy income is associated with 32.95 units increase in the number of licence of HEIs respectively. The finding also shows that 1 unit increase in contract research is associated with 36.73 units decrease in the number of licences of HEIs. We did not find a significant effect of collaborative research towards licence numbers. Model 14 shows that FE and consultancy are consistently and positively associated with the number of licences concluded by HEI; contract research, on the other hand, shows a negative and significant effect on licensing activities; the level of significance for CPD reduces, but remains positive. In summary, results for the independent variables are largely consistent across models 8–14. All the control variables show consistent effects throughout the models, with knowledge stock, total academic staff, research grant, and knowledge exchange funding showing positive effect on licences, while economic development of the region shows negative effect. As for KEF clustering, while Clusters M and V are negatively associated with licensing performance, the Arts and STEM specialist clusters are positively linked to licensing performance.

With regards to the effect of informal KE activities towards the creation of spin-offs, Table 7 shows that collaborative research (with β value of 0.16) is positively but weakly associated with creation of spin-offs. This means, for every 1 unit increase in collaborative research income, there is a 0.16 unit increase in the number of spin-offs created by a HEI. We did not find any significant effect of other informal KE activities on the creation of spin-offs. Model 21 shows that the sign and significance for collaborative research remain largely the same as in Model 20. In summary, results for the independent variables are consistent across models 15–21. All the control variables show consistent effects throughout the models, with knowledge stock and research grant showing positive and significant effects on creation of spin-offs, while the level of regional economic development negatively affects the creation of spin-offs. As for KEF clustering, only the Arts specialists cluster shows a positive effect on spinoff creation; Clusters V, X, and STEM specialists have a negative and significant effect on spinoff creation.

Overall, the findings suggest that low research-intensive engagement informal activities (i.e. CPD, FE, and consultancy) are positively linked to knowledge exploitation activities

Table 6 Licences

Variables	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
CPD_CE_{t-3}		16.63***					11.49*
		(6.03)					(6.70)
FE_{t-3}			16.98*				20.22*
			(10.28)				(12.08)
$Consultancy_{t-3}$				32.95***			31.09***
				(7.28)			(7.27)
Contract $research_{t-3}$					−36.73**		−42.97**
					(14.53)		(16.70)
Collaborative $research_{t-3}$						7.49	1.55
						(7.29)	(8.44)
Patent $stock_{t-3}$	28.79***	30.07***	28.64***	29.31***	30.25***	29.01***	31.56***
	(4.14)	(4.22)	(4.15)	(4.13)	(4.32)	(4.19)	(4.42)
Regional GVA_{t-3}	−0.00***	−0.00***	−0.00***	−0.00***	−0.00***	−0.00***	−0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Total $academics_{t-3}$	106.57***	104.01***	110.14***	117.63***	99.00***	107.77***	110.22***
	(17.12)	(16.72)	(17.78)	(18.03)	(15.57)	(17.41)	(16.58)
Total research $income_{t-3}$	32.60***	32.63***	32.11***	28.79***	44.64***	30.46***	42.24***
	(8.35)	(8.34)	(8.27)	(8.04)	(11.73)	(8.26)	(12.74)
Knowledge exchange $funding_{t-3}$	3.46***	3.26**	3.37***	2.77**	3.93***	3.51***	3.01**
	(1.31)	(1.31)	(1.29)	(1.22)	(1.41)	(1.32)	(1.29)
KEF clustering							
Cluster J	−14.66	−10.94	−16.26	−18.33	−6.33	−12.75	−7.85
	(21.57)	(21.04)	(22.09)	(21.64)	(21.27)	(22.07)	(21.22)
Cluster M	−174.50***	−167.18***	−178.43***	−176.98***	−155.80***	−175.66***	−154.08***
	(28.51)	(27.25)	(30.05)	(29.26)	(25.21)	(28.89)	(26.28)
Cluster V	−93.66***	−84.51***	−98.92***	−99.30***	−70.89***	−95.39***	−71.99***
	(25.62)	(24.27)	(27.38)	(26.18)	(22.87)	(26.05)	(23.87)
Cluster X	2.93	10.21	−3.03	7.35	8.31	2.44	12.10
	(18.76)	(18.08)	(20.11)	(19.35)	(17.70)	(18.79)	(18.75)

Table 6 (continued)

Variables	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
Arts specialists	402.40**	415.24**	415.53**	436.31**	436.99**	396.13**	493.98**
	(189.43)	(186.73)	(198.14)	(199.53)	(198.03)	(188.99)	(219.32)
STEM specialists	101.11**	88.05**	113.07**	101.86**	122.85**	98.43**	131.06**
	(47.20)	(42.43)	(51.32)	(48.89)	(50.04)	(47.30)	(55.16)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1599	1599	1599	1599	1599	1599	1599

Standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 7 Spin-offs

Variables	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21
CPD_CE_{t-3}		−0.13 (0.10)					−0.11 (0.11)
FE_{t-3}			0.03 (0.13)				−0.01 (0.13)
$Consultancy_{t-3}$				0.01 (0.09)			0.03 (0.09)
Contract $research_{t-3}$					0.12 (0.11)		0.16 (0.12)
Collaborative $research_{t-3}$						0.16* (0.10)	0.18* (0.10)
Patent $stock_{t-3}$	0.16*** (0.06)	0.15** (0.06)	0.16*** (0.06)	0.16*** (0.06)	0.16*** (0.06)	0.16*** (0.06)	0.15** (0.06)
Regional GVA_{t-3}	−0.00** (0.00)	−0.00** (0.00)	−0.00** (0.00)	−0.00** (0.00)	−0.00** (0.00)	−0.00* (0.00)	−0.00** (0.00)
Total $academics_{t-3}$	−0.10 (0.12)	−0.09 (0.12)	−0.10 (0.12)	−0.10 (0.12)	−0.07 (0.12)	−0.08 (0.12)	−0.01 (0.12)
Total research $income_{t-3}$	0.80*** (0.12)	0.82*** (0.12)	0.80*** (0.12)	0.80*** (0.12)	0.77*** (0.12)	0.75*** (0.12)	0.71*** (0.13)
Knowledge exchange $funding_{t-3}$	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)
KEF clustering							
Cluster J	0.67 (0.64)	0.69 (0.68)	0.67 (0.65)	0.67 (0.65)	0.67 (0.66)	0.71 (0.66)	0.74 (0.73)
Cluster M	0.91 (1.34)	0.96 (1.42)	0.92 (1.34)	0.93 (1.35)	0.87 (1.35)	0.94 (1.36)	0.96 (1.49)
Cluster V	−1.51*** (0.47)	−1.65*** (0.52)	−1.53*** (0.48)	−1.52*** (0.48)	−1.63*** (0.49)	−1.56*** (0.47)	−1.85*** (0.54)
Cluster X	−1.34*** (0.40)	−1.46*** (0.44)	−1.36*** (0.40)	−1.34*** (0.40)	−1.42*** (0.42)	−1.37*** (0.40)	−1.59*** (0.47)

Table 7 (continued)

Variables	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21
Arts specialists	13.29*	13.88*	13.34*	13.39*	14.12*	13.08*	14.84*
	(7.29)	(7.73)	(7.32)	(7.48)	(7.80)	(6.99)	(8.13)
STEM specialists	−1.69***	−1.79***	−1.70***	−1.70***	−1.79***	−1.75***	−1.99***
	(0.49)	(0.53)	(0.49)	(0.49)	(0.50)	(0.49)	(0.55)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1599	1599	1599	1599	1599	1599	1599

Standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

(i.e. licensing and patenting), while high research intensive activities (i.e. collaborative research) are positively associated with staff entrepreneurship (i.e. creation of spin-offs). In particular, low research-intensive engagement activities show a much more positive and significant effect on licensing than on patenting activities. Our findings are consistent with those of Degl'Innocenti et al. (2019), highlighting that efficiency in generating university-industry income is positively linked to research performance of HEIs.

5 Discussion

5.1 Patents

Our empirical evidence suggests that there is no conflict between pursuing informal KE activities and certain types of formal KE activities. Furthermore, engaging in CPD, FE, and consultancy lead to more patents appropriation. This finding complements current research (e.g. Crespi et al., 2011) on the relationship between academic patenting and informal KE activities. The engagement activities can facilitate the creation of patents through several ways. Our findings agree with the extant studies that through KE activities, such as CPD and consultancy, HEIs form relationships with industries and signal research excellence (D'este & Perkmann, 2011). This has the propensity to the development of innovations and technologies enabling patents creation. Besides, the findings support the studies by Owen-Smith and Powell (2003) that when providing facilities or equipment to firms, this has opened doors to many other research related opportunities and can extend to discover technologies and to patent outputs subsequently (Galib et al., 2015). To our surprise, collaborative research, which is categorized as high relational KE activities (Hewitt-Dundas, 2012), has observed negative effect on patent outputs. The explanation can be given that undertaking collaborative research with industry is governed by learning motivation of academics, hence leading more to academic outputs, such as research publications rather than commercial outputs, i.e., patents (D'este & Perkmann, 2011). Additionally, there is a possibility that patents may be assigned to companies instead of universities in these collaborations (van Burg et al., 2021).

5.2 Licensing

Our findings reveal that some informal KE activities (i.e. CPD, FE, and consultancy) can promote licensing activities of HEIs. There are a number of possible reasons. First, as academics engage in consultancy work, for example, they may develop innovative solutions to real-world problems that have the potential to be protected through intellectual property. These intellectual property assets can then be licensed to firms for commercial use, generating revenue for HEIs. Secondly, through informal KE activities, academics can build relationships with industry partners, who may be interested in licensing the HEI's IP or collaborating on research projects. These relationships can help establish the HEI as a trusted source of innovation and expertise, making it easier to attract potential licensees. Thirdly, by engaging in informal KE activities, academics can raise the profile of the HEI and demonstrate its expertise in a particular field. This can increase the likelihood of licensing opportunities, as firms may be more likely to acquire knowledge from a reputable HEI (Hewitt-Dundas, 2012).

Yet again, we have found that contract research negatively impacts licensing activities. There are a number of possible explanations. Firstly, contract research agreements often include provisions that give ownership of any resulting intellectual property to the company sponsoring the research. This can limit the university's ability to licence or commercialise the intellectual property for its own benefit (Bercovitz & Feldman, 2006). Secondly, contract research agreements may require HEIs to keep the results of the research confidential (Mirowski & Van Horn, 2005), which can limit HEIs' ability to disclose the results and generate interest from potential licensees. Thirdly, contract research agreements are often focused on meeting specific, short-term goals for the sponsoring company. Contract research tends to focus on one-off acquisition of specialist expertise (Hewitt-Dundas, 2012). This can lead to a lack of emphasis on the long-term research and development needed to create valuable IP for licensing.

Additionally, collaborative research of HEIs does not show a significant effect on their licensing activities. We argue that IP ownership, publication requirements, and limited value capturing can hinder the positive influence on licensing activities. Firstly, in collaborative research, the ownership of IP may be shared among multiple parties, which can create complexities in licensing agreements. It may also be difficult to determine who has the right to license the IP, and this can delay or hinder licensing activities. Secondly, many funding agencies require that research findings be disseminated widely, such as through publications or open access repositories. This can make it difficult to protect the IP through licensing agreements. In addition, contrary to common understanding, licensing can be quite limited in capturing value (Teece, 2018). For collaborative research that involves higher commercial potential than that of other informal KE activities, technology licensing may not be the best option to capture value.

5.3 Spin-offs

Our results show that collaborative research is positively linked to the creation of spin-offs. Collaborative research is more common among high research-intensive HEIs, because it tends to focus on blue-skies or generic research (Agrawal & Henderson, 2002; Polt et al., 2001). The findings have supported extant studies that collaborative research allows the research team to develop new ideas and technologies as well as to create valuable social capitals necessary for spin-offs creation (Guimón, 2013). In addition, other informal KE activities such as CPD, FE, consultancy, and contract research show an insignificant effect on the creation of spin-offs. There are a number of possible explanations. Firstly, while these activities can provide valuable experience and knowledge, they may not necessarily equip academics with the entrepreneurial and business skills needed to start and grow a new business (Stephan & Black, 1999). Entrepreneurship requires a different set of skills, such as risk-taking, creativity, networking (Rank & Strenge, 2018; Sebora et al., 2009), entrepreneurial mind-set (Wang et al., 2021) that may not be developed through these activities alone.

Secondly, academics engaging in these activities may not have the same level of economic incentives or motivations to engage in commercial activities generally or to create a spin-off. Prior research has indicated that many academic scientists, for example, struggle to create spin-offs because they can face different incentives to engage in commercial activity. The studies by Cohen et al. (2020) have highlighted the different individual motives as well as incentives in commercial works engagement across different scientific fields. For instance, for academics in life sciences, social impact is considered a strong motive to undertake commercial activities, whereas in engineering, the motivations are related to challenge and advancement. The study by Hossinger et al. (2021) has also noted that publishing research in international peer-reviewed journals is traditionally perceived as the pathway to success and recognition within academic/scientific communities. Similarly, as noted by Wang et al. (2021), when academic scientists possess strong scientific identity centrality, they prefer to publish their work in academic journals instead of engage in commercialization activities, particularly spin-offs creation. Hence, they may be more motivated to gain access to research funding, laboratory equipment, and support from the HEI's TTO for production of research outputs (D'este & Perkmann, 2011).

Lastly, the results for KEF clustering show that these clusters are differed in their commercial performance. In general, mid-sized universities (Cluster J) and the Arts and STEM clusters are more effective in IP transfer and spin-off activities than larger, high research-intensive universities (Clusters V and X). The latter has a different approach in the exploitation of their knowledge, focusing less on licensing activities (Siegel et al., 2008). In contrast, the Arts and STEM clusters has a strong commercial motive, which is linked to traditional channels of engagement (D'Este & Perkmann, 2011).

6 Conclusion

In this paper, we have addressed the research question "*Which informal KE activities interact and have an influence on formal commercial activities?*" by analysing the HE-BCI survey in the UK. We defined '*formal commercial activities*' based on IP appropriation and commercial outcomes, and '*informal activities*' based on a combination of '*informal commercial activities*' proposed by Abreu and Grinevich (2013) and *a formal interactive activity encompassing interactions* proposed by Schaeffer et al. (2020). Our empirical analysis reveals that there is an interaction between informal and formal commercial KE activities and our findings show the complementarities between them.

Our study contributes to the literature in the discipline of TM activities and knowledge exchange activities of HEIs by shedding light on the effect of informal knowledge exchange activities towards formal commercial activities. The extant literature has denoted the relationship between these activities, though in a vague manner. Our study also fine slices and goes beyond the discussions over particular departmentalised KE and HEIs' commercial activities and enables us to investigate the effects and interaction between them. Moreover, our research informs the decision-making of HEIs' TM and commercialisation policy on how to make use of particular informal KE activities to effectively maximise the commercial outcomes. Our analysis reveals, for instance, CPD, FE and consultancy have significant impact on formal commercial activities, such as patents and licensing, while collaborative research is positively linked to the creation of spin-offs. Certain informal KE activities, such as collaborative research and contract research, link more towards research publications (D'este & Perkmann, 2011) and depend more on previous experience of HEIs in dealing with such activities (Schartinger et al., 2001). Hence, more focused policy approaches are needed. It is vital for HEIs' policy makers to acknowledge that different informal KE and formal commercial activities may require different support structures and incentive mechanisms (Perkmann et al., 2013). Rather than generically promote KE activities, policy and support mechanisms should be more targeted to encourage and motivate specific commercial outcomes. For example, HEIs can consider devise a business partnership policy to specifically support academics and scientists in building relationships with business partners when engaging in KE activities, such as contract research or collaborative research. In the same way, commercialisation policy administered by TTO can promote and support activities, such as patenting, licensing or spin-offs creation.

In practice, the conventional organisational structure and role played by TTO that provides support centrally and universally to TM, KE and commercial activities could be more focused and selective based on the targeted commercial goals intended by HEIs. As noted by Hewitt-Dundas (2012), TTOs generally are providing one-size-fit-all services across HEIs in the UK regardless of their research intensity or strategic priorities. Hence, policy for infrastructure and staffing to support KE activities needs to consider the institutional and organisational resources of HEIs together with their strategic objectives (de la Torre et al., 2019). For example, HEIs with strategic objectives to maximise commercial outcomes through development and exploitation of IP and licensing, resources and TTO's supports should be allocated not only on the process of IP appropriation or licensing, but also on other KE activities, such as CPD, FE or consultancy.

It is undeniable that faculty members, academics and researchers tend to play a central role in HEI's commercial and KE activities (Abreu et al., 2016). Hence, they need to develop the entrepreneurial and commercial capabilities in order to engage in informal KE activities and realise the potential outcomes of these activities. Even though HEIs' policy to encourage and support KE and commercial opportunities, is regarded as important, making sure that the provision of the entrepreneurial and management capabilities to develop opportunities is comparatively crucial (Rasmussen & Wright, 2015). When HEIs regard TM or KE activities a strategic objective, setting a policy in supporting the entrepreneurial skills is vital (Hofer & Potter, 2010). Providing training or externally sourcing entrepreneurial and commercial capabilities may be one of the critical roles of TTOs (Baines & Lawton Smith, 2020).

The scope of this study is the institutional-level examination of the interaction and impact of informal KE towards formal commercial activities in the UK HEIs. Even though this presents a unique and useful perspective to approach the issue and concept, limitations can be noted on the methodology and point of reverse causality. In this research, we have investigated solely on the impact of informal KE towards commercial activities and outcomes. Further research needs to be undertaken to test the possibility of the effect of commercial activities on informal KE activities.

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